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Elasticity of Substitution, Technological Progress Bias and Labor Income Share: Evidence From China

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Abstract: Long-time low-level stagnation of labor income share (LIS) could lead to continuous deterioration of national income distribution status and increase the uncertainty of national development trend. A deep analysis into the root of long-time low-level stagnation of LIS is crucial to rectifying the structural disequilibrium of national income distribution and key to promoting sustainable economic growth. In view of this, this paper selects the province-level panel data of China during 2000 – 2017 for analysis. The research results show that elasticity of factor substitution (EFS) and technological progress bias (TPB) are key factors influencing LIS. With the rise of EFS, technological progress tends to be gradually biased towards capital factors and cause LIS to reduce. Meanwhile, the presence of TPB would in turn boost EFS, further causing LIS to reduce, forming a vicious circle, and leading the national economic structure to become even unbalanced. The above conclusion remains valid through the robustness test. Therefore, the government should design a series of reasonable institutions to promote the structural transformation of the national economy, rationalize the factor endowment during the production process, and make technological progress gradually biased towards labor factors, so as to improve the factor income distribution (FID) pattern.

Keywords: Elasticity of Factor Substitution; Technological Progress Bias; Labor Income Share

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1.Introduction

China's economic aggregate has realized high growth over the past 40 years, but labor income share (LIS) has been stagnating at a low level for a long time instead of climbing with the increase of economic aggregate. This characteristic may lead China's economic growth to become lacking in strength and innovation ability to become limited, even to the point of falling into the "middle-income trap"[1].

Low-level LIS has multifaceted impacts on society, mainly embodied in the following aspects. First, low-level LIS could limit the society-wide distributable total wealth and fall short of the demand for secondary distribution, thereby posing a challenge to the fairness of income distribution. Next, low-level LIS could lead to a weakness in society-wide consumptive power. In view of the fact that the pillar of economy of most households stems mainly from labor income at present, a low level of LIS will directly reduce the total social consumption, decrease the economic growth rate, increase the employment difficulty, and create adverse impacts on industrial upgrading. Lastly, a long-time low level of LIS will accelerate the rise of the aggregate saving of the economy. As most of the saving transforms into investment expenditures of enterprises, a possible consequence is excessive growth of investment, which goes against the upgrading of the economic structure and long-term sound development in economy.

In response to this, it is imperative to raise LIS. To do so with effectiveness, it is necessary to make deep analysis into the decisive factors behind LIS, among which technological progress and elasticity of substitution (ES) are two most important aspects[2-4]. Technological progress refers to the process of boosting production efficiency and product performance and quality through innovation and application of new knowledge, skills, methods, techniques or equipment. Such a revolution not only changes the demands in the labor market but also directly affects LIS.

On the one hand, technological progress, as the core engine driving economic and social development, is typically tendentious towards capital-augmenting paths, which means the marginal output brought about with technological progress is more manifested in capitals than in labors. Specifically, with the widening application of automatic production lines, artificial intelligence, and other advanced technologies, while production efficiency has boosted significantly, these technologies have also reduced the dependence on manpower labors, leading to a decrease in LIS[5]. On the other hand, the development in emerging industries, digital economy, and innovative fields have provided more job opportunities for labor forces, thus increasing demands in the labor market and leading to an increase in LIS[6]. Furthermore, the development of new technologies typically favors high-skilled labor forces, which further intensifies the phenomenon of inequality in the labor market. High-skilled labor forces earn higher skill premium for their scarcity and irreplaceability, while low-skilled laborers' relative income is squeezed, leading the income gap to widen further. The rapid development of information technology and digital technology are cases in point of this phenomenon: they have not only widened the income gap between high-skilled and low-skilled laborers but also accelerated the polarizing trend of the labor market.

The variation of ES, as an index measuring the difficulty degree of substitution between production factors, profoundly influences LIS and income distribution pattern. Specifically, when capital factors are relatively low-cost, the increase in ES will make enterprises more inclined to increase capital input and reduce labor dependence, thereby lowering LIS and intensifying income inequality. Further, the variation of ES could also trigger a profound transition of industrial structure. With technological progress and EFS adjustment, the labor demand structure also changes. Take the manufacturing-oriented service industry as an example. LIS in finance, technology, and other fields is typically higher than in the traditional manufacturing industry. Such a transformation not only changes the distribution pattern of the labor market but also significantly affects LIS. However, the skill mismatching, territorial restriction, and other issues existing in this process further amplify the phenomenon of income inequality. To make things more complicated, there exists a cycle mechanism with interaction between ES and LIS. The variation of LIS could in turn affect ES by changing the supply and demand of factors, thereby increasing the complexity of the income distribution problem.

Besides, technological progress and ES jointly influence LIS. The influence of technological progress on LIS is mainly embodied in the interaction between the "price effect" and the "market size effect", whose relative importances are determined by ES. When ES > 1, the market size effect dominates, so enterprises are more inclined to use resource-rich production factors. If labor factors are rich, technological progress would increase demands for labor factors and raise LIS; if the production technology efficiency of capitals is higher, technological progress would likely be biased towards capitals, decrease demands for labor factors, and reduce LIS. When ES of capitals and labors is smaller than 1, the price effect dominates, so enterprises are more inclined to use resource-scarce production factors. If labor factors are scarce, technological progress would decrease demands for labor factors and reduce LIS. Conversely, if the production technology efficiency of labor factors is higher, technological progress would likely increase demands for labor factors and raise LIS.

In view of the above analysis, the substitution effect of production factors and the influence of technological progress on LIS are uncertain. Therefore, to effectively narrow the huge economic gap across China, mitigate the long-time low-level stagnation of LIS, and realize common prosperity, it is necessary to further analyze the relationships between elasticity of production factor substitution and technological progress and LIS in China's current stage and find out the influence rule therein. Only this way can well-targeted measures be taken to raise LIS.

2.Domestic and overseas research status

2.1 Related studies on EFS and LIS

The concept of elasticity of factor substitution (EFS) was first put forward by Hicks, with one of its objectives being to analyze the change of factor income distribution (FID) pattern. The initial estimation method was the CD production function, which relied on the fundamental assumption that EFS = 1 and LIS was stable in a long term, which was questioned by many scholars[7-8]. With the progressive expansion of observed data, the fundamental assumption of the CD production function could not be satisfied completely across different countries and industries[9]. Therefore, scholars represented by Blanchard et al.[10] employed an inverse method to explore the relationship between EFS and LIS. On that basis, scholars found that when ES was greater than 1, capital-output ratio bore a negative correlation to LIS; when ES was equal to 1, capital-output ratio was uncorrelated to LIS; when ES was smaller than 1, capital-output ratio bore a positive correlation to LIS[11-12]. With the continuous improvement in calculating methods, scholars utilized concrete production functions to probe into the relationship between EFS and LIS. Studies have found that, on the one hand, the increase of EFS could accelerate the rise of capital income share and the drop of LIS[13]; on the other hand, some external factors could bring down LIS via affecting EFS[14-15]. An exploration into the reason has revealed that the industry-wide allocation mechanism of factors and resources and the dynamic change of their mobility would cause ES across factors to vary. This variation of ES further gives rise to fluctuations in internal LIS across different industries[16-18]. Eventually, the LIS variations at these industrial levels add up to wield a significant influence on LIS of the entire region[19]. On the contrary, Scholar Acemoglu[20] found that there was no significant correlation between LIS variation and ES in a short term, when analyzing the relationship between FID and ES.

2.2 Studies on EFS and TPB

In the research of the economic field, Hicks[21] first introduced the concept of EFS in his work Theory of Wages, elaborated on the role it assumes in measuring the degree of influence of relative price variation of factors on factor input ratio, and stressed on the role of price variation as the driving force of technological progress. Follow-up scholars conducted preliminary studies on the relationship between ES and technological progress bias (TPB)[22]. However, it was not until the research by Acemoglu[20, 23] that this relationship was interpreted more concretely and deeply, providing a solid theoretical groundwork for follow-up academic research. On this basis, researchers compared different estimation techniques by Monte Carlo simulation method, finding that the standardized supply-side system approach delivered the most reliable estimation results in estimating EFS and TPB[24]. The empirical analysis with the use of the CES production function indicates that technological progress is biased towards capital factors and that EFS is generally smaller than 1 in most years[25]. A synthetic analysis of ES and TPB estimation methods discloses a significant difference across different documents in the estimation of EFS value and TPB index of developed economies[26]. These research outcomes not only exhibit the complexity and multidimensionality of the relationship between EFS and TPB but attach vital significance to deeply understanding the dynamic changes of economic growth and income distribution[27].

2.3 Related studies on TPB and LIS

In his work Theory of Wages Hicks[19] first elaborated on the concept of technological progress and expressly pointed out that the relative price variation of factors could stimulate enterprises to innovate technologically, thereby wielding a far-reaching influence on FID. On this basis, follow-up scholars made in-depth exploration into the concrete mechanism of action of technological progress on LIS[28]. Their research findings suggest that TPB has significance influence on LIS: when technological progress is biased towards labors, LIS presents an uptrend; when technological progress is biased towards capitals, LIS presents a downtrend[29-30]. This finding has inspired extensive research interests in the relationship between TPB and LIS throughout the academia, so that numerous scholars have conducted in-depth exploration from distinct perspectives and models[31-32]. By analyzing the export data of OECD countries, some studies found that, under the condition of factor price converging, the consistence between production technology innovation direction and the country's relatively rich capital factors is conducive to optimizing the country's FID structure[33]. Additionally, there are still some other studies focusing on the TPB due to foreign direct investment as well as its potential influence on FID[34-35]. These studies have revealed the complex effect of TPB on FID in multiple dimensions, providing a crucial theoretical basis and policy enlightenment for understanding and improving FID.

2.4 Related studies on EFS, TPB and LIS

Since the 1960s, the academia of economics started to turn its attention to the influences of EFS and TPB on LIS. By comparing statistics of developed and underdeveloped economies, researchers found that labor factors are relatively scarce in developed economies so that the increase in ES tends to lower LIS, while a reverse trend of this relationship was observed in underdeveloped economies[36]. This hypothesis was further verified in follow-up studies, which disclosed the effects of EFS and TPB on LIS[37]. The substitutional relationship of capital factors and high-skilled labors for simple labors and capital-augmenting technological progress are the main causes of the deterioration of LIS[38]. Furthermore, the variation of EFS could trigger changes in TPB, thus influencing LIS and FID[39]. The latest endogenous growth theory has lent stronger theoretical support to this argument, stressing that EFS plays a vital role in the process of moderating TPB and LIS[40]. These research outcomes have not only deepened our understanding of the LIS variation mechanism but also provided scientific basis and strategic guide for decision-makers to make policies for fairer income distribution.

2.5 Literature review

Relevant studies by domestic and overseas scholars have achieved highly valuable research conclusions, including the following points. First, the directivity of innovation progress of production technology affects LIS; second, the direction of technological progress during the production process is subject to EFS; third, other external factors influence LIS via EFS and TPB.

By combing the above related research documents, it is found that there remain a few deficiencies in the existing research literatures. This paper innovates in the following two aspects. First, most of the existing studies, starting with the CES production function and taking the standardized supply-side system approach of estimation with EFS as a fixed parameter, explain the influences of technological progress, capital deepening, relative asset price variation, and other single factors on LIS. However, they overlook the possible circumstance that the variation of EFS itself could influence LIS. As a result, their analysis of the labor market is incomprehensive, and their explanation of LIS variation might be overstated or underrated. Second, a few of the existing studies utilize the VES production function or transcendental logarithmic function or other methods to solve for EFS and explore the influence of EFS variation on LIS. However, they overlook the possible circumstance that EFS may influence LIS via the mediating factor TPB, which could lead to incomprehensive and inaccurate analysis of labor market, thereby affecting the reliability of relevant conclusions on LIS and the validity of policy suggestions. Third, despite the fact that some scholars have included all the three factors in their framework, they failed to comb the theoretical relationship among the three systematically and conduct any empirical analysis on it[40].

From the perspective of TPB condition, therefore, this paper explores the joint action of EFS and TPB on LIS, constructs a theoretical mechanism of influence of EFS on LIS with the presence of TPB, and conducts an empirical analysis.

3.Theoretical mechanism analysis

To explore the theoretical model of influence of EFS and TPB on LIS, this paper begins by exploring the theoretical model of influence of EFS on TPB, then the one of TPB on LIS, and finally the one of EFS on LIS with the presence of TPB.

3.1 Theoretical analysis of the influence of EFS on TPB

Assume an enterprise produces some product, a process that brings forth technological innovation. The enterprise pursues profit maximization. Labor factors are an exogenous variable, and capital factors are accumulated as fixed exogenous savings. Referring to the methods of scholars Casellif et al.[41] and Zheng Meng[42], this paper sets the production function in the following form:

$$Y = [(A_K K)^{\frac{\sigma-1}{\sigma}} + (B_L L)^{\frac{\sigma-1}{\sigma}}] \tag{1}$$

where $(A_K)^\gamma + (B_L)^\gamma = F$, Y denotes the output of the product, σ denotes EFS, K and L denote the inputs of capital and labor factors, respectively, A_K and B_L denote the technological progress efficiencies of capital and labor factors, respectively, different combinations (A_K, B_L) represent different TPBs, and F denotes the current technological frontier of the enterprise.

Referring to the study by Lin Yifu[43], this paper sets the level of frontier technology to be $F=1, \gamma=1$. Then for the externally given capital factor price (capital interest rate) r and labor factor price (wage) w, and the capital-to-labor factor quantity ratio input in each production technology, we have:

$$\frac{K}{L}=(\frac{A_K}{B_L})^{\sigma-1}(\frac{w}{r})^{\sigma} \tag{2}$$

This paper further assumes that there are N identical enterprises producing homogeneous products in a perfectly competitive market, with consistent capital and labor inputs selected during the production process, and each of the enterprises would select the technological combination that delivers the maximum production efficiency and profit. Meanwhile, due to the "learning-by-doing" effect, this research refers to the practices of Lin Yifu[43] and Romer[44] and assumes that the enterprise cost is 0 during the technological transformation process. Hence

$$Max\{(A_K\frac{K}{N})^{\frac{\sigma-1}{\sigma}}+[(1-A_K)\frac{L}{N}]^{\frac{\sigma-1}{\sigma}}\}^{\frac{\sigma}{\sigma-1}} \tag{3}$$

Further solving from formula (3) gives

$$\frac{B_L}{A_K}=(\frac{K}{L})^{1-\sigma} \tag{4}$$

From formula (4), TPB and factor endowment are correlated. To further study their relationship, this paper refers to the study by Zheng Meng[45] and introduces TPB into the VES production function to give

$$Y=\theta[(A_K K)^{\frac{1}{c}}(B_L L)+(\frac{b}{1+c})(A_K K)^{\frac{1+c}{c}}]^{\frac{ac}{1+c}} \tag{5}$$

where Y, A_K, B_L, K, and L have the same connotations as in formula (1), θ denotes neutral (unbiased) technological progress, and a is a returns-to-scale parameter; $a=1$ means the returns to scale remain unchanged. From formula (5) the marginal output of capital factors can be obtained.

$$MP_K=\theta\frac{acA_K}{1+c}[(A_K K)^{\frac{1}{c}}(B_L L)+(\frac{b}{1+c})(A_K K)^{\frac{1+c}{c}}]^{\frac{ac-1-c}{1+c}} \\ [\frac{1}{c}(A_K K)^{\frac{1-c}{c}}(B_L L)+\frac{b}{c}(A_K K)^{\frac{1}{c}}] \tag{6}$$

Marginal output of labor factors:

$$MP_L=\theta\frac{acB_L}{1+c}[(A_K K)^{\frac{1}{c}}(B_L L)+(\frac{b}{1+c})(A_K K)^{\frac{1}{c}} \tag{7}$$

EFS σ can be expressed as

$$\sigma=\frac{d\ln(\frac{L}{K})}{d\ln(TRS_{KL})}=1+b\frac{A_K}{B_L}\frac{K}{L} \tag{8}$$

Substitute formula (8) into (2) to get formula (9).

$$\frac{B_L}{A_K}=(\frac{\sigma-1}{b})^{\frac{1}{\sigma}-1} \tag{9}$$

From formula (9), TPB depends on ES. Combining the relationship between ES and b given by formula (8), we can get the following three change relations: As b tends towards 0, ES σ tends towards 1; when $b>1$, ES $\sigma\rightarrow+\infty$; when $-1<b<0$, ES $\sigma\rightarrow 0$. Hence, we get formula (10).

$$\begin{cases} \lim\limits_{\sigma\to 0}=\lim\limits_{\sigma\to 0}\frac{B_L}{A_K}=\lim\limits_{\sigma\to 0}(\frac{\sigma-1}{b})^{\frac{1}{\sigma}-1}=+\infty \\ \lim\limits_{\sigma\to 1}=\lim\limits_{\sigma\to 1}\frac{B_L}{A_K}=\lim\limits_{\sigma\to 1}(\frac{\sigma-1}{b})^{\frac{1}{\sigma}-1}=1 \\ \lim\limits_{\sigma\to +\infty}=\lim\limits_{\sigma\to +\infty}\frac{B_L}{A_K}=\lim\limits_{\sigma\to +\infty}(\frac{\sigma-1}{b})^{\frac{1}{\sigma}-1}=0 \end{cases} \tag{10}$$

From formula (10), the relationship between EFS and TPB can be derived. As $\sigma \to 0$, the direction of technological progress is increasingly biased towards labor factors; as $\sigma \to 1$, technological progress becomes neutral; as $\sigma \to +\infty$, the direction of technological progress is increasingly biased towards capital factors. Based on this, this research concludes Hypothesis 1: elasticity of factor substitution can influence the direction of production technology innovation progress. The greater the value of σ, the more biased the innovational direction of technological progress towards capital factors; conversely, the more biased the direction of technological progress towards labor factors. When σ=1, production technology progress is neutral.

3.2 Theoretical analysis of the influence of TPB on LIS

Based on the neoclassical theory of economic growth, over the economic growth process increasing the mere input ratio of relevant factors can only yield short-term economic returns, while the long-term impetus for economic growth needs to rely on technological progress. Referring to Chen Yong et al.[46] and many other scholars, this paper sets the TPB related production function as below.

$$Y_t = \left[(1-\alpha)(A_t L_t)^{\frac{\sigma-1}{\sigma}} + \alpha(B_t K_t)^{\frac{\sigma-1}{\sigma}}\right]^{\frac{\sigma}{\sigma-1}} \quad (0<\alpha<1) \tag{11}$$

where Y_t, A_t, B_t, σ, L_t, and K_t have the same connotations as in the foregoing passage, and α is a parameter of distribution between capital and labor factors. Enterprises pursue profit maximization, then the enterprise profit maximizing production function is expressed as formula (12), where r_t and w_t denote the prices of capital and labor factors, respectively.

$$Y_t - w_t L_t - r_t K_t \tag{12}$$

In a perfectly competitive market, differentiate the enterprise profit maximizing production function in formula (12) and substitute into formula (11) to find the enterprise labor reward, as shown in formula (13).

$$w_t = (1-\alpha)\left(\frac{Y_t}{L_t}\right)^{\frac{1}{\sigma}} (A_t)^{\frac{\sigma-1}{\sigma}} \tag{13}$$

According to the relevant definition of labor income share, LIS is calculated by formula (14).

$$LS_t = \frac{w_t L_t}{Y_t} \tag{14}$$

Substitute formula (13) into (14) to get formula (15).

$$LS_t = \left[1 + \left(\frac{\alpha}{1-\alpha}\right)\left(\frac{B_t}{A_t}\right)^{\frac{\sigma-1}{\sigma}} \left(\frac{K_t}{L_t}\right)^{\frac{\sigma-1}{\sigma}}\right] - 1 \tag{15}$$

When technological progress accelerates the increase of the marginal output of capitals relative to the marginal output of labors, technological progress is considered to be biased towards capitals, otherwise towards labors. Accordingly, if , then technological progress (neutral) results in an increase of the marginal output of factors by the same proportion, and LIS is unchanged; when , if technological progress is biased towards capitals, then LIS would decrease gradually, otherwise increase; when , if technological progress is biased towards labors, then LIS would increase, otherwise decrease. On the above, Hypothesis 2 of this paper can be concluded: when technological progress is biased towards capital factors labor income share would fall; else when technological progress is biased towards labor factors labor income share would rise.

3.3 Theoretical analysis of the influence of EFS on LIS with the presence of TPB

Referring to the studies by scholars Acemoglu[208, 47] and Zheng Meng[42], etc., this section sets the production function in CES form of technological progress and ES as below.

$$Y = \left\{\left[A_K(\beta)K\right]^{\rho} + \left[B_L(\beta)L\right]^{\rho}\right\}^{\frac{1}{\rho}} \quad 0<\rho<1 \tag{16}$$

where Y, A_K, B_L, L, K, and σ have consistent connotations with the foregoing passage, β represents exogenous technological progress level, and it is assumed that the technological efficiency of capital factors and the technological efficiency of labor factors would increase with the increase of total technological efficiency, namely satisfying $\frac{dA_K(\beta)}{d\beta} > 0$ and $\frac{dB_L(\beta)}{d\beta} > 0$. Each enterprise pursues profit maximization. When the production process meets the optimization condition, capital factor and labor factor rewards can be calculated as:

$$\begin{cases} w=\left[B_L(\beta)L\right]^{\rho}L^{\rho-1}\left\{\left[A_K(\beta)K\right]^{\rho}+\left[B_L(\beta)L\right]^{\rho}\right\}^{\frac{1}{\rho}-1} \\ r=\left[A_K(\beta)K\right]^{\rho}K^{\rho-1}\left\{\left[A_K(\beta)K\right]^{\rho}+\left[B_L(\beta)L\right]^{\rho}\right\}^{\frac{1}{\rho}-1} \end{cases} \tag{17}$$

From formula (17), the ratio of relative prices of capital factors to labor factors in logarithmic form can be derived as formula (18).

$$\ln(\frac{r}{w})=\rho \ln\left[\frac{A_K(\beta)}{B_L(\beta)}\right]+(\rho-1)\ln(\frac{K}{L}) \tag{18}$$

Find the partial derivative of formula (18) with respect to to get formula (19).

$$\frac{d\ln(\frac{r}{w})}{d\beta}=\rho\frac{B_L(\beta)}{A_K(\beta)}\frac{d\left[\frac{A_K(\beta)}{B_L(\beta)}\right]}{d\beta}+(\rho-1)\frac{d(\frac{r}{w})}{d\beta}\left[\frac{\frac{dK}{d(r/w)}}{K}-\frac{\frac{dL}{d(r/w)}}{L}\right] \tag{19}$$

Rearrange formula (19) into formula (20).

$$\frac{d(\frac{r}{w})}{d\left[\frac{A_K(\beta)}{B_L(\beta)}\right]}=\rho KL\frac{B_L(\beta)}{A_K(\beta)}\left[\frac{KLw}{r}-(\rho-1)L\frac{dk}{d(\frac{r}{w})}+(\rho-1)K\frac{dL}{d(\frac{r}{w})}\right] \tag{20}$$

In formula (20), the inputs *K* and *L* in capital and labor factors, respectively, the capital factor and labor factor rewards *r* and *w*, respectively, the technological efficiency levels $A_K(\beta)$ and $B_L(\beta)$, and ρ are all greater than 0. Therefore, formula (20) is positive. From formula (17), $0<\rho<1$, and as the capital-to-labor relative price rises, capital factor supply increases whereas labor factor supply decreases. Hence, in formula (20), ρ-1<0, $\frac{dK}{d(\frac{r}{w})}>0$, and $\frac{dL}{d(\frac{r}{w})}<0$, and further the terms $(\rho-1)L\frac{dK}{d(\frac{r}{w})}$ and $(\rho-1)K\frac{dL}{d(\frac{r}{w})}$ in the square brackets of the right side of formula (20) are both positive. Concerning the influences of TPB on the relative supply between capital and labor factors, this study differentiates the relative technological progress efficiency level $A_K(\beta)/B_L(\beta)$ via the relative supply K/L.

$$\frac{d(\frac{K}{L})}{d\left[\frac{A_K(\beta)}{B_L(\beta)}\right]}=\frac{\frac{dK}{d(\frac{r}{w})}\frac{d(\frac{r}{w})}{d\left[\frac{A_K(\beta)}{B_L(\beta)}\right]}L-K\frac{dL}{d(\frac{r}{w})}\frac{d(\frac{r}{w})}{d[\frac{A_K(\beta)}{B_L(\beta)}]}}{L^2} \tag{21}$$

Through the foregoing analysis on basic factors and technological efficiency levels in formula (20), it can be known that formula (21) is overall positive.

Associating formulae (20) and (21) gives formula (22).

$$\frac{d(\frac{rK}{wL})}{d\left[\frac{A_K(\beta)}{B_L(\beta)}\right]}=\frac{d(\frac{r}{w})}{d\left[\frac{A_K(\beta)}{B_L(\beta)}\right]}(\frac{K}{L})+\frac{r}{w}\frac{d(\frac{K}{L})}{d\left[\frac{A_K(\beta)}{B_L(\beta)}\right]}>0 \tag{22}$$

A synthesis of formulae (20), (21) and (23) reveals that due to the presence of TPB in economic production process, as TPB augments gradually, it will lead to an increase in the ratio of capital input to labor input, thereby to a widening income gap between capitals and labors. On the above, this paper concludes Hypothesis 3: with the presence of technological progress bias, the increase of elasticity of factor substitution would result in the gradual decrease of labor income share.

From the foregoing theories, the variation in the relative price of factors during the production process could stimulate enterprises to innovate technologically. The marginal output growth caused by such an innovation is out of pace, thereby leading to changes in LIS. The influence of TPB on LIS depends on EFS. Below is the specific process. First, when EFS > 1, there is a substitutional relationship between capitals and labors. If the production technology efficiency of labor factors is higher than that of capital factors, then the manufacturer is more inclined to increase the input in labor factors and decrease the input in capital factors. At this time technological progress would be gradually biased towards labor factors, otherwise towards capital factors. Second, when EFS < 1, there is a complementary relationship between production factors. If the production technology efficiency of labor factors is higher than that of capital factors, then the manufacturer is more inclined to increase the input in labor factors. Nevertheless, since the capital-labor relationship is complementary, this measure would trigger the manufacturer's excess demand for capital factors such that technological progress becomes gradually biased towards capital factors, otherwise towards labor factors. Third, when EFS = 1, technological progress is neutral.

On the above, both EFS and TPB are key factors influencing LIS, but to some extent it is via TPB that EFS influences LIS. Therefore, this paper suggests that EFS is a deeper-seated key factor influencing LIS, with TPB acting as the bridge connecting both. Next, this paper will move on to verify the above conclusion through empirical study.

4.Empirical test

4.1 Model setup

The theoretical analysis indicates that EFS could affect the direction of technological progress, the presence of TPB could affect LIS, and with the presence of biased technological progress changes in EFS could also lead to changes in LIS. Based on this, this paper sets up the following empirical models.

$$LS_t = \rho_0 + \rho_1\sigma_{it} + \sum_n \rho_n Z_{ii}^n + \delta_{it} \tag{23}$$

$$Tech_{it} = \beta_0 + \beta_1\sigma_{it} + \sum_{ik} \beta_k X_{it}^k + \varepsilon_{it} \tag{24}$$

$$LS_{it} = \alpha_0 + \alpha_1 Tech_{it} + \sum_n \alpha_n Z_{it}^n + \mu_{it} \tag{25}$$

where the variable LS_{it} denotes the LIS of year t; the variable $Tech_{it}$ denotes TPB; the variable σ_{it} denotes the ES between capital and labor factors of year t ; β, α, and ρ are coefficients of influence of the explanatory variables and other control variables upon the explained variables in the three models; ε_{it}, μ_{it}, and δ_{it} are random error terms of the three models; X_{it}^k and Z_{it}^n are control variables having influences upon the dependent variable in the three models.

4.2 Declaration of main variables

4.2.1 Estimation of LIS

The variable LS_{it} denotes the LIS of year t. For the calculation of LIS, this paper starts with its definition and expresses it in terms of the ratio of laborers' reward to GDP.

4.2.2 Estimation of TPB

The variable $Tech_{it}$ denotes the TPB of year t. For the research of the TPB index, this paper refers to the practices of Acemoglu[20, 47], Zheng Meng[42], and many other scholars and sets the CES production function:

$$Y_t = C[\alpha(A_t K_t)^{\frac{\sigma-1}{\sigma}} + (1-\alpha)(B_t L_t)^{\frac{\sigma-1}{\sigma}}]^{\frac{\sigma}{\sigma-1}} \tag{26}$$

where C is an efficiency parameter that remains time-invariant; the parameters Y_t, K_t, L_t, α, and σ have consistent connotations with the foregoing passage; A_t and B_t denote the technological levels of capital and labor factors, respectively, both growing exponentially, i.e.

$$A_t = A_0 e^{\gamma_{Kt}}, B_t = B_0 e^{\gamma_{Lt}} \tag{27}$$

$$\hat{A} = \gamma_{Kt}, \hat{B}_t = \gamma_{Lt} \tag{28}$$

In formulae (27) and (28), A_0 and B_0 are initial values of technological progress terms of capital and labor factors, respectively; γ_K and γ_L are growth rates of technological progress terms of capital and labor factors, respectively. When $\gamma_K > \gamma_L$, the technological progress of the economic subject is embodied as net capital augmenting technological progress; otherwise, when $\gamma_K < \gamma_L$, it is embodied as net labor augmenting technological progress.

Referring to the related study by Zhu Lin[47], this research constructs the TPB index as follows.

$$Tech_t = \frac{\sigma - 1}{\sigma}(\hat{A} - \hat{B}) \tag{29}$$

When the TPB index $Tech > 0$, technological progress is biased towards capital factors; when the TPB index $Tech < 0$, technological progress is biased towards labor factors. From formula (29), additionally, the precondition of determining the direction of technological progress is to analyze the total ES σ between capital and labor factors and related growth rates of technological progress, $\hat{A}_t$ and $\hat{B}_t$. In solving for ES σ, referring to the related study by Askar et al.[46], this research assumes market factors are perfectly competitive, then factor price is equal to the marginal output:

$$\frac{w_t}{r_t} = \frac{\partial Y / \partial L}{\partial Y / \partial K} = \frac{\alpha}{1-\alpha}(\frac{K}{L})^{\frac{1}{\sigma}}(\frac{A_t}{B_t})^{\frac{\sigma-1}{\sigma}} \tag{30}$$

Taking the logarithm on both sides gives:

$$\ln(K/L) = \beta_{w/r}\ln(w/r) + \beta_t t + \beta_0 + \varepsilon \tag{31}$$

From formula (31), the capital-labor ES $\sigma = \beta_{w/r}$, with the parameter $\alpha = (1 + e^{\beta_0/\beta_{w/r}})^{-1}$. Substitute the data into it to get the capital-labor ES.

In solving for the growth rates of technological progress, $\hat{A}_t$ and $\hat{B}_t$, referring to the related studies by scholars Acemoglu[20,47] and Askar et al.[49], this research sets up formula (32) for the ratio of capital reward to labor reward.

$$S_t = \frac{r_t K_t}{w_t L_t} = \frac{\partial Y / \partial L}{\partial Y / \partial K}\frac{K_t}{L_t} = \frac{\alpha}{1-\alpha}(\frac{A_t K_t}{B_t L_t})^{\frac{\sigma-1}{\sigma}} \tag{32}$$

From formula (32),

$$\begin{cases} (A_t K_t)^{\rho} = S_t \dfrac{1-\alpha}{\alpha}(A_t L_t)^{\frac{\sigma-1}{\sigma}} \\ (B_t L_t)^{\rho} = S_t \dfrac{\alpha}{1-\alpha}(B_t K_t)^{\frac{\sigma-1}{\sigma}} \end{cases} \tag{33}$$

Substituting the two equations in formula (33) into formula (32) gives the expression for technological progress of factors.

$$\begin{cases} \dfrac{A_t}{C} = \dfrac{Y_t}{K_t}\alpha^{\frac{\sigma}{1-\sigma}}(1 + \dfrac{1}{S_t})^{\frac{\sigma-1}{\sigma}} \\ \dfrac{B_t}{C} = \dfrac{Y_t}{L_t}(1-\alpha)^{\frac{\sigma}{1-\sigma}}(1 + S_t)^{\frac{\sigma-1}{\sigma}} \end{cases} \tag{34}$$

From the foregoing passages, the values of total ES σ, parameter α, total output Y_t, and inputs in capital factor K_t and labor factor L_t can be determined. Substituting them into formula (34) gives the technological progress terms of capital and labor factors. Further calculation gives the growth rates of technological progress, $\hat{A}_t$ and $\hat{B}_t$ of capital and labor factors, respectively, and substituting them into formula (29) gives the result of the TPB index.

4.2.3 Estimation of EFS

The variable σ_{it} is the EFS index of year t. Considering the relationship between EFS and LIS, this paper utilizes the VES production function set as below to solve for the EFS index.

$$Y = AK^{\frac{a}{1+c}}[L + (\frac{b}{1+c})K]^{\frac{ac}{1+c}} \tag{35}$$

where A is an exogenous parameter of technological progress, and a is an exogenous parameter of returns to scale. When a = 1, the returns to scale remain unchanged. The marginal outputs of capital and labor factors can be expressed as

$$\begin{cases} MP_K = \dfrac{a(L+bK)}{(1+c)L+bK} \bullet \dfrac{Y}{K} \\ MP_L = \dfrac{acY}{(1+c)L+bK} \end{cases} \tag{36}$$

The capital-labor marginal rate of technological substitution TRS can be expressed as

$$TRS_{KL} = -\frac{MP_K}{MP_L} = -\frac{b+\dfrac{L}{K}}{c} \tag{37}$$

EFS σ can be expressed as

$$\sigma_{KL} = \frac{d\ln\dfrac{L}{K}}{d\ln TRS_{KL}} = 1 + b\frac{K}{L} \tag{38}$$

Taking the logarithm of the VES production function in formula (35) gives

$$\ln Y = \ln A + \frac{a}{1+c}\ln K + \frac{ac}{1+c}\ln[L + (\frac{b}{1+c})K] \tag{39}$$

Performing Talyor expansion of the above formula gives

$$\ln Y = \ln A + \alpha\ln K + \beta\ln L + \gamma\frac{K}{L} + \varepsilon \tag{40}$$

where:

$$\alpha = \frac{a}{1+c},\quad \beta = \frac{ac}{1+c},\quad \gamma = \frac{abc}{(1+c)^2} \tag{41}$$

From the above formula (41),

$$a = \alpha + \beta,\quad b = \frac{\gamma(\alpha+\beta)}{\alpha\beta},\quad c = \frac{\beta}{\alpha} \tag{42}$$

Solve formula (42) to get the values of a, b, and c and figure out EFS and other indexes.

4.2.4 Selection of other control variable indexes

In the model formula (24), X_{it}^{k} is a control variable. Referring to the studies by scholars Acemoglu et al.[47] and Bergholt et al.[50], this paper selects the control variables including: (1) foreign direct investment Fdi and opening-up factor open, the former calculated in terms of the proportion of practically utilized foreign direct investment over GDP of China, and the latter measured in terms of the ratio of total imports and exports of cargoes inbound and outbound to GDP; (2) educational factor edu, measured in terms of the proportion of education expenditures of all provinces over GDP; (3) labor factor labor, measured in terms of unemployment rate; (4) government regulation factor gov, measured in terms of the ratio of government fiscal revenue to GDP.

In the model formulae (23) and (25), Z_i^n is another control variable. Referring to the studies by Cao Zhanglong[51] and Yang Yang[52], this paper selects the control variables: (1) tax burden tax, measured in terms of the ratio of total taxes over GDP of China; (2) capital deepening structure ln(K/L), measured in the logarithm of per capita capital, namely the logarithm of the ratio of capital stock value to employment population; the other control variables are selected the same way as formula (23).

4.3 Declaration of relevant data

Since regional statistical yearbooks stopped updating relevant data on GDP of regional income law in 2017, this paper selects the panel data of 31 province-level administrative regions of inland China during 2000 – 2017 as samples. The data of laborers' reward, net amount of production taxes, depreciation of fixed assets, and operating surplus needed for the calculation of LIS stem from the China Statistical Yearbook of all provinces. The total output and labor input data needed for EFS and TPB stem from China Statistical Yearbook, China Labor Statistical Yearbook, and China National Bureau of Statistics, whereas the capital input data stem from www.macrodatas.cn. The price factor has been rejected from laborers' reward, net amount of production taxes, depreciation of fixed assets, operating surplus, and capital stocks. The data of tax, Fdi, open, and other control variable indexes all stem from the China Statistical Yearbook of all provinces and national statistics websites. Among them, the data of Fdi is converted at the CNY-to-USD currency rate in each year. After outliers are rejected, the descriptive statistics of indexes are shown in Table 1.

Table 1. Descriptive statistics of variables

Variable Name	Variable Symbol	Mean	Standard Deviation	Minimum	Maximum	Sample Size
Labor income share	LS	0.493	0.061	0.333	0.647	536
Elasticity of factor substitution	σ	0.707	0.222	0.012	0.97	536
Technological Progress Bias	*Tech*	0.121	0.882	-0.675	8.94	536
Tax burden	*tax*	0.075	0.026	0.034	0.026	536
Educational factor	*edu*	0.039	0.021	0.0028	0.173	536
Capital deepening structure	$\ln(K/L)$	1.912	0.848	-0.087	3.448	536
Labor factor	*labor*	0.0355	0.007	0.007	0.065	536
Government regulation	*gov*	0.09	0.045	0.041	0.0308	536
Foreign direct investment	*Fdi*	0.0233	0.023	0.00004	0.146	536
Opening-up factor	*open*	0.429	0.101	0.032	0.022	536

5.Empirical analysis of influences of ES and TPB on LIS

5.1 Empirical test on the benchmark regression models

The benchmark models in formulae (23) – (25) are regressed to examine the research conclusions of influences of EFS and TPB on LIS. With a hybrid pool regression model for benchmark regression, this paper obtains the regression coefficients in Table 2.

Table 2. Benchmark model regression

Variable	(1)	(2)	(3)
Intercept	0.698*** (21.658)	0.727* (1.959)	0.555*** (32.171)
σ	-0.139*** (-5.627)	0.694*** (2.965)	-0.008*** (-3.420)
labor	-0.978*** (-3.160)	-20.719*** (-3.506)	-1.396*** (-4.385)
edu	1.241*** (11.439)	-3.674* (-1.786)	1.106*** (10.123)
gov	0.535** (2.406)	-2.186 (-1.152)	0.325 (1.449)
open	-0.028*** (-3.124)	0.048 (0.365)	-0.037*** (-4.051)
Fdi	-0.019 (-0.180)	-1.470 (-0.741)	-0.153 (-1.441)
tax	-0.757*** (-2.925)		-0.361 (-1.415)
$\ln(K/L)$	-0.053*** (-7.425)		-0.021*** (-5.365)
R^2	0.451	0.055	0.430
Sample size	536	536	536

Notes: ***, **, and * denote the significance levels of 1%, 5%, and 10%, respectively.

From Table 2, it can be known that EFS bears a negative correlation to LIS; meanwhile, EFS bears a positive correlation to TPB; besides, TPB and LIS also exhibit a negative correlation. The regression results of all the three models are significant at the significance level of 1%, which coincides with the theoretical expectation of this paper.

5.2 Robustness test

5.2.1 Robustness test on EFS and LIS

Formula (23) verifies the influence of EFS on LIS. This section conducts a robustness test on its regression results and obtains the regression coefficients in Table 3.

Table 3. Robustness test on EFS-LIS regression

Variable	(1)	(2)	(3)	(4)
Intercept	0.636*** (23.269)	0.668*** (17.965)	0.744*** (22.148)	0.670*** (9.678)
σ	-0.143*** (-6.929)	-0.069*** (-3.023)	-0.117*** (-4.538)	-0.117* (-1.939)
labor	0.508 (1.411)	1.281*** (3.138)	-0.95*** (-2.943)	-1.083 (-1.380)
edu	0.593*** (2.742)	-0.655** (-2.093)	1.090*** (9.632)	1.240*** (7.346)
gov	0.496** (2.311)	-0.138 (-0.490)	0.908*** (3.917)	0.386 (0.988)
open	-0.048*** (-3.852)	-0.012 (-0.779)	-0.029*** (-3.099)	-0.033 (-1.393)
Fdi	0.073 (0.606)	0.286** (2.204)	-0.103 (-0.922)	-0.049 (-0.143)
tax	-0.369 (-1.454)	0.038 (0.118)	-0.808*** (-2.995)	-0.586 (-1.018)
$\ln(K/L)$	-0.046*** (-7.661)	-0.072*** (-7.695)	-0.058*** (-7.796)	-0.043*** (-2.937)
R^2	0.362	0.655	0.437	0.432
Sample size	536	536	536	489

Notes: ***, **, and * denote the significance levels of 1%, 5%, and 10%, respectively.

Columns (1)-(4) of Table 3 represent the robustness test on the benchmark regression. Column (1) corresponds to the robustness test on the fixed effect model; column (20) corresponds to the robustness test with the VES production function changed into the SFA method for the calculation of EFS; column (3) corresponds to the robustness test on the fixed effect model with the VES production function changed into the EFS calculated by SFA method; column (4) corresponds to the robustness test after 5% truncation treatment of the core variables. Their regression results have all passed the robustness test.

From the above, either the benchmark regression or the robustness test indicates a negative correlation between EFS and LIS. Despite some changes in the regression coefficients, the direction and significance of the correlation remain unchanged. This shows that with the gradual increase in capital-labor ES, LIS tends to drop gradually, which agrees with the outcome of Hypothesis 3 of the theoretical analysis in this paper.

5.2.2 Robustness test on EFS and TPB

Formula (24) examines the influence of EFS on TPB. This section conducts a robustness test on its regression results and obtains the regression coefficients in Table 4.

Table 4. Robustness test on EFS-TPB regression

Variable	(1)	(2)	(3)	(4)
Intercept	0.979** (2.103)	0.716* (1.916)	0.962** (2.054)	0.429 (1.588)
σ	1.044** (2.451)	0.706*** (2.965)	1.062** (2.451)	0.285*** (2.586)
labor	-31.195*** (-3.744)	-20.719*** (-3.506)	-31.195*** (-3.744)	-9.963 (-1.559)
edu	12.888** (2.011)	-3.674* (-1.786)	12.888** (2.011)	-1.748 (-1.475)
gov	-9.047*** (-2.927)	-2.186 (-1.152)	-9.047*** (-2.927)	-1.974*** (-2.681)
open	-0.525* (-1.776)	0.048 (0.365)	-0.525* (-1.776)	0.090 (0.456)
Fdi	-0.400 (-0.162)	-1.470 (-0.741)	-0.400 (-0.162)	-0.000363 (-0.000140)
R^2	0.159	0.055	0.159	0.027
Sample size	536	536	536	489

Notes: ***, **, and * denote the significance levels of 1%, 5%, and 10%, respectively.

Columns (1)-(4) of Table 4 represent the robustness test on the benchmark regression. Column (1) corresponds to the robustness test with the random effect model changed; column (2) corresponds to the robustness test with the fixed effect model changed; column (3) corresponds to the robustness test on the fixed effect model with the VES production function changed into the EFS calculated by SFA method; column (4) corresponds to the robustness test after 5% truncation treatment of the core variables. Their results have all passed the robustness test.

From the above, either the benchmark regression or the robustness test indicates a positive correlation between EFS and TPB. Despite some changes in the regression coefficients, the direction and significance of the correlation remain unchanged. This shows that with the increase in ES between capital and labor production factors, the direction of production technology progress is more and more biased towards capital factors, which agrees with Hypothesis 1 of the theoretical analysis in this paper.

5.2.3 Robustness test on TPB and LIS

Formula (25) examines the influence of EFS on TPB. This section conducts a robustness test on its regression results and obtains the regression coefficients in Table 5.

Table 5. Robustness test on TPB-LIS regression

Variable	(1)	(2)	(3)	(4)
Intercept	0.531*** (24.121)	0.630*** (19.959)	0.626*** (35.172)	0.532*** (10.729)
Tech	-0.005** (-3.067)	-0.012*** (-5.689)	-0.0082*** (-3.392)	-0.011*** (-4.359)
labor	-0.616 (-1.577)	0.798** (1.984)	-1.339*** (-4.073)	-1.221* (-1.651)
edu	0.272 (1.248)	-0.765*** (-2.631)	0.972*** (8.613)	1.125*** (7.557)

Variable	(1)	(2)	(3)	(4)
gov	0.394* (1.777)	-0.151 (-0.546)	0.726*** (3.136)	0.216 (0.594)
open	-0.076*** (-6.171)	-0.023 (-1.640)	-0.036*** (-3.877)	-0.041* (-1.86)
Fdi	-0.104 (-0.847)	0.187 (1.514)	-0.214* (-1.955)	-0.101 (-0.357)
tax	-0.048 (-0.188)	0.011 (0.035)	-0.469* (-1.777)	-0.242 (-0.482)
$\ln(K/L)$	-0.017*** (-4.165)	-0.0614** (-7.251)	-0.031*** (-7.751)	-0.014* (-1.707)
R^2	0.335	0.689	0.427	0.423
Sample size	536	536	536	489

Notes: ***, **, and * denote the significance levels of 1%, 5%, and 10%, respectively.

Columns (1) – (4) of Table 5 represent the robustness test on the benchmark regression. Column (1) corresponds to the robustness test with the random effect model changed; column (2) corresponds to the robustness test with the fixed effect model changed; column (3) corresponds to the robustness test on the fixed effect model with the VES production function changed into the EFS calculated by SFA method; column (4) corresponds to the robustness test after 5% truncation treatment of the core variables. Their results have all passed the robustness test.

From the above, either the benchmark regression or the robustness test indicates a negative correlation between TPB and LIS. Despite some changes in the regression coefficients, the direction and significance of the correlation remain unchanged. This shows that as the direction of production technology progress is progressively biased towards capital factors, LIS becomes lower and lower, which agrees with theoretical Hypothesis 2 in this paper.

5.3 Regional heterogeneity test analysis

Since the indexes of LIS, production factors, and production technology are closely related to the region and population, this section divides the provinces into eastern, central, and western regions by national standard[1] to examine the heterogeneous effect of regional factors on the relationship among the three.

5.3.1 Regional heterogeneity analysis of EFS and LIS

The influence of EFS upon LIS may differ significantly across regions. The concrete heterogeneity analysis is shown in Table 6 below, in which columns (1) – (3) report the regression results of the benchmark models corresponding to the eastern, central, and western regions, respectively.

Table 6. Regional heterogeneity test on the influence of EFS upon LIS

Variable	(1)	(2)	(3)
Intercept	0.423*** (7.27)	0.728*** (12.18)	0.599*** (15.768)
σ	0.624 (1.634)	-0.08* (-1.853)	-0.203*** (-6.16)

[1] Beijing, Tianjin, Hebei, Shanghai, Liaoning, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong, and Hainan (3 municipalities and 8 provinces) are divided as the eastern region; Shanxi, Jilin, Heilongjiang, Anhui, Jiangxi, Hunan, Hubei, and Guangxi (7 provinces and 1 autonomous region) are divided as the central region; Chongqing, Sichuan, Guizhou, Yunnan, Shaanxi, Gansu, Ningxia, Xinjiang, and Xizang (1 municipality, 5 provinces, and 3 autonomous regions) are divided as the western region.

Variable	(1)	(2)	(3)
labor	-1.144*** (-2.639)	-1.14 (-1.438)	2.367*** (4.08)
edu	0.600 (0.884)	2.81*** (3.069)	1.578*** (16.424)
gov	1.047* (1.884)	0.706 (1.326)	0.287 (1.236)
open	-0.049*** (-3.66)	-0.263** (-2.212)	-0.038 (-0.959)
Fdi	-0.092 (0.065)	-2.63*** (-2.268)	-0.205 (-0.562)
tax	-0.496 (-0.934)	-2.275*** (-3.539)	-0.468 (-1.556)
$\ln(K/L)$	-0.007 (-0.521)	-0.044*** (-3.214)	-0.0529*** (-6.002)
R^2	0.247	0.276	0.736
Sample size	195	180	155

Notes: ***, **, and * denote the significance levels of 1%, 5%, and 10%, respectively.

5.3.2 Regional heterogeneity analysis of EFS and TPB

The influence of EFS upon TPB may differ significantly across regions. The concrete heterogeneity analysis is shown in Table 7 below, in which columns (1) – (3) report the regression results of the benchmark models corresponding to the eastern, central, and western regions, respectively.

Table 7. Regional heterogeneity test on the influence of EFS upon TPB

Variable	(1)	(2)	(3)
Constant term	0.345 (0.672)	2.107** (2.001)	1.775*** (1.756)
σ	0.819* (1.847)	0.456*** (4.006)	1.009* (1.66)
labor	-9.08 (-867)	-39.500*** (-2.55)	-52.158* (-1.73)
edu	-13.541 (-0.755)	-25.654*** (-2.145)	-4.279* (-1.889)
gov	1.760 (0.496)	-1.185 (-0.365)	-3.024 (-1.56)
open	-0.190 (-0.785)	1.027 (0.601)	0.862* (1.801)
Fdi	-1.254 (-0.300)	-3.283 (-0.476)	-4.010 (-0.423)
R^2	0.037	0.156	0.177
Sample size	195	180	155

Notes: ***, **, and * denote the significance levels of 1%, 5%, and 10%, respectively.

5.3.3 Regional heterogeneity analysis of TPB and LIS

The influence of TPB upon LIS may differ significantly across regions. The concrete heterogeneity analysis is shown in Table 8 below, in which columns (1) – (3) report the regression results of the benchmark models corresponding to the eastern, central, and western regions, respectively.

Table 8. Regional heterogeneity test on the influence of TPB upon LIS

Variable	(1)	(2)	(3)
Intercept	0.513*** (16.815)	0.680*** (15.755)	0.431*** (7.227)
Tech	-0.004 (-1.593)	-0.013*** (-2.77)	0.0013 (0.243)
labor	-1.33*** (-3.058)	-1.866** (-2.346)	1.186*** (1.065)
edu	0.955 (1.462)	2.326** (2.536)	1.416*** (11.140)
gov	0.686* (1.342)	0.447 (0.877)	1.146 (0.421)
open	-0.045*** (-3.96)	-0.326*** (-3.016)	-0.069 (-0.789)
Fdi	0.081 (0.566)	-1.278*** (-3.478)	-0.750 (-1.688)
tax	-0.271 (-0.526)	-1.797*** (-2.969)	-0.285 (-0.469)
$\ln(K / L)$	-0.025** (-2.38)	-0.0025*** (-3.541)	-0.0093 (-0.810)
R^2	0.249	0.293	0.667
Sample size	195	180	155

Notes: ***, **, and * denote the significance levels of 1%, 5%, and 10%, respectively.

On the above, according to the data analyses in Tables 6, 7, and 8, the influence path of EFS on LIS via TPB is significant in the central region and insignificant in the eastern and western regions. The reason may fall into the following points.

First, the difference in industrial structure: The eastern region may be more dependent on high-tech and service industries, in which technological progress has little influence on labor demands. By comparison, the central region may be more dependent on the traditional manufacturing industry, where technological progress has great influence on labor demands. Besides, the western region is mainly dependent on traditional industries such as agriculture and mining, in which technological progress is relatively slow-paced, hence with limited influence on LIS.

Second, the difference in technological level: Some cities in the eastern region are situated in the frontier of technological development, where many advanced technologies have been applied, hence less influenced by technological progress. The central region may feature a relatively backward technological level and is more susceptible to technological progress. The western region has the most backward technological level among the three regions, with limited application of advanced technologies, so the influence of technological progress on LIS is minor.

Third, the difference in the quality of labor forces: The labor force in the eastern region may have a higher skill level and can adapt to new technologies more quickly. By comparison, the labor force in the central region may have lower quality and are more likely to be impacted by technological progress. The labor force in the western region has a lower skill level and limited adaptability to new technologies and equipment, which also weakens the influence of technological progress on LIS.

Fourth, the difference in EFS: The eastern and western regions may feature smaller EFS, which impedes technological progress from being biased towards capitals and therefore has little influence on LIS. By contrast, the central region may feature larger EFS, which is conducive to technological progress being biased towards capitals.

Fifth, the difference in opening-up to the outside: The eastern region features a higher degree of opening-up to the outside and may attract more foreign capitals and technologies, hence less affected by technological progress. By comparison, the central region features a low degree of opening-up to the outside, hence relatively largely affected by technological progress. The western region introduces foreign capitals and technologies to a limited degree due to geographical disadvantages, which also restricts the influence of technological progress on LIS.

Sixth, the difference in developmental stage: The eastern region is likely situated in a more developed stage and thus less affected by technological progress. By contrast, the central region may be situated in a middle developmental stage and thus relatively largely affected by technological progress. The western region may remain in a middle developmental stage, where the potential of technological progress has not been fully unleashed, hence a minor influence on LIS.

The above factors may result in the creation of the influence path of EFS on LIS via TPB in the central region rather than in the eastern and western regions.

6.Conclusions and suggestions

While China's economy is developing rapidly, economic income misdistribution and disequilibrium have appeared behind the rapid development, so that China's LIS has not only failed to increase with economic growth but been descending and fluctuating at a low level for a long time. This is related to a series of factors including demographic structure change, industrial structural transformation, degree of China's opening-up, policy system design, and technological progress condition. This paper has further explored and found that all these factors influencing LIS have intrinsic connections with the ES between capital and labor factors, among which the connection between biased technological progress and EFS is closest. Against this research background, this paper has selected China's province-level panel data during 2000 – 2017 as the research samples, and two factors – EFS which can represent the factor input proportion structure in production process and TPB which can influence the production factor input structure and the marginal production output of factors – and explored their comprehensive influencing mechanism on FID. The results suggest the following conclusions. First, with the increase of capital-labor ES, the production process becomes increasingly dependent on capital factors while decreasing the demands for labor forces, thereby leading LIS to decline. The empirical results have also verified the negative correlation between EFS and LIS. Second, technological progress tends to raise the marginal output of capital factors and decrease demands for labor factors, leading LIS to decline, when biased towards capital factors. Conversely, technological progress tends to raise the marginal output of labor factors and increase demands for labor factors, thereby raising LIS, when biased towards labor factors. The empirical results have confirmed the negative correlation between TPB and LIS. Third, increase of EFS will promote technological progress to be biased towards capitals, which will in turn accelerate the increase of EFS, forming a vicious circle. Such a circular effect will lead to continuous decline of LIS. Fourth, there exists a regional difference: the influence path of EFS on LIS via TPB can be created in the central region but neither in the eastern region nor in the western region. This is probably because the eastern and western regions are more dependent on high-tech and traditional industries, respectively, while the central region falls in between. Besides, the eastern region features a higher technological level and higher degree of opening-up to the outside, while the western region features a lower technological level and lower degree of opening-up to the outside. These differences can also affect the influence path of EFS on LIS via TPB.

Based on the above research conclusions, this paper proposes the below suggestions. First, the government should make policies aiming at raising LIS, such as regulating the tax policy, to provide more preferential tax credits for labor-intensive industries; it should encourage labor-intensive industries to develop via industrial policies, create more employment opportunities, and stimulate enterprises to add training investments in laborers by means of financial subsidies to promote laborers' skill level. Second, promotion in structural transformation of the economy: The government can advance transformation and upgrading of the economic structure positively, especially by strengthening the support for service, manufacturing, and other labor-intensive industries, and create more high-quality job openings to increase laborers' income shares. Meanwhile, it should encourage enterprises to augment inputs in technological reconstruction of labor-intensive industries and raise labor productivity to create more employment opportunities. Third, the government can augment inputs in technological reconstruction of labor-intensive industries, especially in the realms of information technology and automatics, to raise labor productivity and create more employment opportunities. Additionally, the government can encourage enterprises to enhance skill training on employees and boost employees' skill level to adapt them to the development of new technologies. Fourth, the government can strengthen coordination of regional development, especially the support for development in the central and western regions, to minimize the regional development gap, facilitate technological progress to be more tilted towards labor factors, and raise LIS. Fifth, the government can augment inputs in education and training, especially in vocational education and skill training, to improve laborers' skill level and enhance laborers' employment competitiveness and adaptability to new technologies. Sixth, security of labor rights and interests: The government can further consummate the security system of labor rights and interests and reinforce protection for laborers' legal rights and interests, particularly the supervision over enterprises' abiding by labor laws and regulations, to ensure laborers can get due incomes. Meanwhile, the government can safeguard laborers' legal rights and interests by perfecting the labor dispute settlement mechanism.

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