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How Can Information Technology Use Improve Construction Labor Productivity? An Empirical Analysis from China

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Abstract: Labor productivity is a significant indicator to measure the sustainable development potential and competitiveness of the construction industry. Under the background of the integration of global construction industry and information and communication technology (ICT), the pursuit of the growth of construction labor productivity (CLP) requires deepened understanding of how these technological advancements characterized by ICT take effect in the change of CLP as well as what the key factors are that led to the variation of CLP at this stage. The paper aims to investigate the effect of ICT progress on CLP and examine the key factors influencing CPL. Based on the data of 31 regions from the China Construction Industry Statistical Yearbook and the Local Statistical Yearbook during the period 2000–2018, this study proposed new methodology (Cobb–Douglas production function, growth rate model, and Malmquist Data Envelopment Analysis) for measuring the technology progress contribution and identified the key factors affecting the change of CLP. The analysis results illustrate that the information technology progress has a significant contribution to CLP growth, but the contribution rate is decreasing with the growing degree of development of the regional construction industry. Three main factors affecting the further improvement of CLP have been identified: human resources, research and development (R&D) investment, and ICT level. The findings can provide the decision-making reference and the general methodology for the local and international industry practitioners to improve the labor productivity performance of the construction sector.

Keywords: construction labor productivity; information and communication technology; technology progress contribution; influencing factors



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1. Introduction

Labor productivity (LP) is a significant indicator to measure the sustainable development potential and competitiveness of specific industry, and has always been the spotlight in the economic field [1]. As a labor-intensive industry and major sources of employment in most countries, the construction industry has been regarded as a typical example of low LP with minimum technological innovations [2]. In 2003, Pearce published a report on the social and economic value of construction [3]. Since then, LP in the construction sector has become one of the most frequently focused research topics. Studying the dynamic characteristics and influencing factors of construction labor productivity (CLP) will help managers to adjust policies in time, and then raise profits and earnings in the sector. For instance, it is estimated that per 10% increase of CLP in UK is equivalent to save £1.5 billion

for clients [4]. However, the study of CLP is still in its infancy [5,6], and there is particularly a lack of literature on China. In the past two decades, under the background of the integration of global construction industry and information and communication technology (ICT), China's construction sector puts ICT use as the main direction of reform. A large number of ICT such as building information modeling (BIM), management information system (MIS), artificial intelligence (AI) and internet of things (IOT) were adopted by the construction enterprises, which has led to great changes in the way of production and working of the industry.

The purpose of this paper is to investigate the contribution of information technology progress to CLP growth and identify influencing factors of CLP variation from the recent data in China. Accordingly, this paper aims to answer the two research questions: (1) How do these ICT advancements take effect in the change of CLP? and (2) What are the key factors impacting the variation of CLP at this stage? In the course of China's construction digitization, if some factors impacting CLP become more advantageous, while others may serve as barriers, it is necessary to propose a theoretical explanation that emphasizes how these factors are distinguished from each other at the industry level. However, previous studies have not developed methods to measure and investigate the contribution of information technologies to improve CLP. Therefore, in order to answer these questions, this paper will investigate the contribution of ICT progress to CLP growth and influencing factors of CLP variation in recent years. Particularly, this study will systemically develop a new methodology by combining the Cobb–Douglas production function, the Data Envelopment Analysis (DEA) technology and the Malmquist decomposition index to measure the contribution.

The remainder of this paper will first present a literature review relevant to measurement methods and indicators, and will then put forward the research design, use the data to test the above questions, and finally discuss the results of the analysis, concluding with recommendations.

2. Literature Review

LP is a technical concept of output-input ratio. It is related to the proportion of the labor outcomes created by workers in a certain time period to the corresponding labor consumption [7]. As a typical labor-intensive industry, construction labor costs account for 30% to 50% of the total project cost [8]. Moreover, CLP is as an important indicator to measure the performance of the construction sector and is officially counted by governments based on output quantity/labor hours.

The existing literature mainly focused on the measurement of labor productivity and the analysis of its influencing factors at the project level, such as project management model, worker skill, equipment [8], the implementation of building information modeling [9], and worker characteristics [10]. However, there is little literature on productivity at the industry level. Moreover, with the step-by-step opening of EU KLEMS data, many studies have begun to discuss the relationship between the construction productivity and technological advancements from industry level. Mohamed and Abdel found that the contribution that technological innovation has provided to productivity growth had been declining year by year in the United States, Britain, Japan, Germany, and France, and even exhibiting negative effects [1]. Similarly, Sveikauskas et al. also reached a similar conclusion [5]. More importantly, the current mature and widely exercised method is Geweke's linear feedback technique [11], stochastic frontier production function [12], Malmquist index [13], Solow residual [14], and Cobb–Douglas function [15]. Accordingly, based on this stream of study, the heterogeneous impacts of different technological advancements on CLP have been identified in different countries.

The factors causing the change of CLP are not only technological advancements, but also many non-technological progress factors which often limit the impact of technological progress on CLP. In general, the non-technological factors are related to the following categories in existing studies: operation management, financing, labor, government man-

agement, contracts, and owner characteristics [16]. In early studies, the factors proposed were more related to economics. For instance, Dacy [17] systematically discussed the factors that affect CLP growth, including capital-labor ratio, output composition, labor quality, economic level, and union proportion factors. Denison's factors are related to the variables of economic level, resource transformation level, and knowledge improvement [18]. Rojas and Aramvareekul have measured and compared the CLP of the US construction industry from 1979 to 1998 [19]. In recent years, CLP in construction sector has attracted more attention than before. Zhi et al. found that the factors such as labor quality, material quality, economic level, government management, industry cycle, related industries, and accidents were influential on Singapore CLP [20]. In the United States, many more detailed factors such as construction equipment, building materials, tools, engineering drawings, and consumables had been identified by scholars [21]. Yi and Chen adopt a systematic review to analyze factors affecting CLP from different perspectives [16]. Therefore, study on the factors influencing CLP has become increasingly detailed along with the availability of data collected.

Certain limitations still exist in the extant research conclusions, that is, they are greatly limited by timeliness and territoriality. Meanwhile, the analysis methods of technology progress contribution and influencing factors of CLP are different in different countries. In order to provide decision-making reference and identify the efficient factors for improving CLP for practitioners, this study will improve the methodology and select the internationally accepted statistical data. The outcome can provide decision-making reference and general methodology for the local and international industry practitioners to improve the LP performance of the construction sector.

3. Research Design

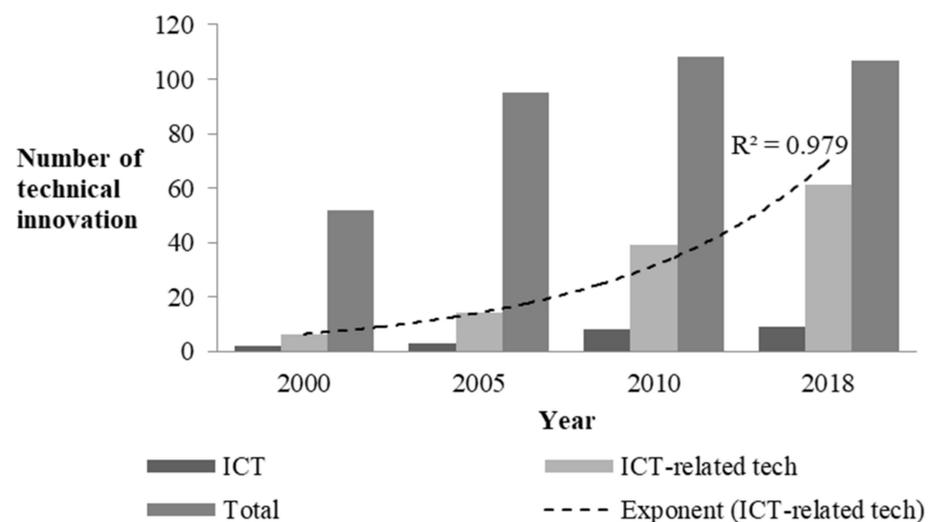
3.1. Industry Background of a Digitization Perspective

China is the largest developing country in the world. The percentage of added value of the construction industry reached 6.01%, and the number of employees was nearly 45 million in 2018 [22]. Since the mid-1990s, the Chinese government has taken ICT usage as a significant national strategy to develop information resources, improve information exchange and knowledge sharing, enhance quality of economic growth, and promote economic and social transformation [23]. In general, the construction sector has experienced a process of ICT innovation and application in the past 20 years [24]. The main goal of enterprises is to use ICT to support work flow, improve organizational processes, and transform organizational model and business strategy [25]. As shown in Table 1, this process is divided into three stages based on the past industry practice [26]. From the early stage of computer-aided design, to the second stage of the integration of ICT and management, then to the third stage of the comprehensive application of ICT [26], a large amount of construction ICT has brought great changes to the way of production and working within the sector [27]. Therefore, the ICT innovation and progress can be noted in the Chinese construction industry.

Figure 1 displays the trend and changes of ICT innovation and application in the Chinese construction industry during 2000–2018. Among the major technological innovations in the Chinese construction industry, ICT-related innovations grew exponentially. As Goodrum pointed out, the technological renewal is a significant reason for the change of CLP [28]. Therefore, this study inferred that since 2000, great changes have taken place in the Chinese construction sector's level of production, operation, and management, which is different from any other period in the past. It is necessary to recalculate the contribution of technological progress to CLP, and the phased characteristics of ICT use should be treated as a key variable to explore factors impacting CLP change.

Table 1. ICT practice in the Chinese construction industry.

Phase	Features	Applications
Info. 1.0 (Late 1980s—Early 21st Cent.)	Computer-aided design; single system or software; within the department; orientation of work efficiency	CAD, engineering calculation software, and office automation, etc.
Info. 2.0 (Early 21st Cent.—2010)	ICT supported management; multi-system integration; interdepartmental cooperation within the organization; orientation of process and management control	Construction automation, MIS, and database, etc.
Info. 3.0 (2010—Up to now)	Comprehensive and integrated applications of ICT; inter-organizational coordination; data analysis and utilization; business and service innovation	BIM, mobile computing, IOT, AI, big data, e-commerce, and wireless tech, etc.

**Figure 1.** Statistics on top ten technological innovations in the Chinese construction industry.

3.2. Measurement Model for Technological Progress Contribution

In the industry level, technological progress refers to the sum of all the factors that cause output growth, excluding the increase of labor and capital input. Although the contribution of technological progress to LP growth can be measured by many methods [16], the Cobb–Douglas (C–D) production function is widely used in the existing literature. Except for labor and capital input, the C–D function provides a basis for comparing the results of this study with those of other similar studies. This study will use mathematical derivation to obtain the equation of the technological progress contribution to CLP growth. The derivation process is as follows.

The Cobb–Douglas production function is presented in Equation (1):

$$Y = AL^{\alpha}K^{\beta} \quad (1)$$

where Y = industrial output; A = average production technology level; L = labor input; K = capital input; α = elasticity coefficient of labor output and β = elasticity coefficient of

capital output. Then, introducing a time variable into Equation (1), the function can be changed as Equation (2):

$$Y = AL^\alpha K^\beta \quad (2)$$

Assuming that under the condition of complete competition, then both L and K take marginal products as rewards, and the two can replace each other. When the scale of productive returns maintains constant, the technological progress is Hicks neutral. The technical level would determine the output. Therefore, when $\alpha + \beta = 1$, and the Equation (2) is divided by L , the equation can be transformed into Equation (3):

$$\frac{Y_t}{L_t} = A_t \left(\frac{K}{L} \right)_t^\beta \quad (3)$$

where Y/L represents the labor productivity of the industry, and is written as LP . By substituting and taking the logarithm and derivatives on both sides, the equation of LP growth rate can be drawn as Equation (4):

$$\frac{\Delta LP}{LP} = \frac{\Delta A}{A} + \beta \left(\frac{\Delta C}{C} \right) \quad (4)$$

where $\Delta LP/LP$ = growth rate of construction LP ; $\Delta A/A$ = growth rate of technological level; C = per capita capital (L/K); $\Delta C/C$ = growth rate of capital possession per capita. Obviously, the growth rate of technological progress and the growth rate of capital per capita determine the growth rate of construction LP . Therefore, the contribution (E) that the technological progress made to construction LP growth can be presented as Equation (5):

$$E = \frac{\Delta A}{A} / \frac{\Delta LP}{LP} \times 100\% \quad (5)$$

In order to calculate $\Delta A/A$, this study introduced the technological progress index TP . According to the change of t , $\Delta A/A$ is presented as Equation (6):

$$\frac{\Delta A}{A} = (TP_{t+1} - TP_t) / TP_t \times 100\% \quad (6)$$

The technological progress index TP is calculated by the Malmquist DEA method [29]. Consider a set of regions $\tilde{R} = \{1, 2, \dots, R\}$, R is the last region; a set of time duration $\tilde{T} = \{1, 2, \dots, T\}$, T is the final time duration; a set of production factors $\tilde{I} = \{1, 2, \dots, I\}$, I is the last production factor; a set of outputs $\tilde{J} = \{1, 2, \dots, J\}$, J is the last output. The inputs and outputs of the r th region in the t period then are recorded as $x_{r,i}^t$ and $y_{r,j}^t$ respectively. Under the premise of free disposal of input factors (S) and constant return of scale (C), the technology level of t period is defined as Equation (7):

$$L^t(y^t|S, C) = \left\{ (x_1^t, x_2^t, \dots, x_r^t) : \sum_{r=1}^R V_r^t y_{r,j}^t \geq y_{r,j}^t, \sum_{r=1}^R V_r^t x_{r,i}^t \leq x_{r,i}^t, V_r^t \geq 0 \right\} \quad (7)$$

$$r \in R, t \in T, i \in I, j \in J$$

where V_r^t = weight of the r -th decision-making unit in the t period. For each region, the input-output distance function during the t period can be defined as Equation (8):

$$D_r^t(x_r^t, y_r^t) = \min \theta^r, \text{ s.t. } \sum_{r=1}^R V_r^t y_{r,j}^t \leq y_{r,j}^t, \sum_{r=1}^R V_r^t x_{r,i}^t \leq \theta^r x_{r,i}^t, V_r^t \geq 0 \quad (8)$$

Similarly, the input-output distance function of the $t + 1$ period can be defined as Equation (9):

$$D_r^t(x_r^{t+1}, y_r^{t+1}) = \min \theta^r, \text{ s.t. } \sum_{j=1}^R V_r^t y_{r,j}^{t+1} \leq y_{r,j}^{t+1}, \sum_{i=1}^R V_r^t x_{r,i}^t \leq \theta^r x_{r,i}^{t+1}, V_r^t \geq 0 \quad (9)$$

According to what Balk and Caves et al. proposed [30,31], from the t period to the $t + 1$ period, the input-based total factor productivity can be replaced and represented by the Malmquist index. Therefore, for the region r , the Malmquist index of the technology L^t of the t period and the technology L^{t+1} of the $t + 1$ period can be written as Equation (10):

$$\begin{cases} M_r^t(x_r^t, y_r^t, x_r^{t+1}, y_r^{t+1}) = D_r^t(x_r^{t+1}, y_r^{t+1}) / D_r^t(x_r^t, y_r^t) \\ M_r^{t+1}(x_r^t, y_r^t, x_r^{t+1}, y_r^{t+1}) = D_r^{t+1}(x_r^{t+1}, y_r^{t+1}) / D_r^{t+1}(x_r^t, y_r^t) \end{cases} \quad (10)$$

Based on Fisher's proposed ideal index method, Caves et al. combined the above two indices and used the geometric mean as the Malmquist index from t period to $t + 1$ period, so the following exponential equation can be brought in as Equation (11):

$$M_r^{t+1}(x_r^t, y_r^t, x_r^{t+1}, y_r^{t+1}) = \left[\frac{D_r^t(x_r^{t+1}, y_r^{t+1})}{D_r^t(x_r^t, y_r^t)} \times \frac{D_r^{t+1}(x_r^{t+1}, y_r^{t+1})}{D_r^{t+1}(x_r^t, y_r^t)} \right]^{1/2} \quad (11)$$

By transforming the above formulation, the following one could be obtained as Equation (12):

$$M_r^{t+1}(x_r^t, y_r^t, x_r^{t+1}, y_r^{t+1}) = EC \times TP = \frac{D_r^{t+1}(x_r^{t+1}, y_r^{t+1})}{D_r^t(x_r^t, y_r^t)} \times \left[\frac{D_r^t(x_r^{t+1}, y_r^{t+1})}{D_r^{t+1}(x_r^{t+1}, y_r^{t+1})} \times \frac{D_r^t(x_r^t, y_r^t)}{D_r^{t+1}(x_r^t, y_r^t)} \right]^{1/2} \quad (12)$$

In the Equation (12), the left side indicates the Malmquist index, which can also be called the comprehensive efficiency index; the right side is decomposed into the technological efficiency change index (EC) and the technological progress change index (TP). EC indicates the gap between the output of construction sector in the r -th region and the maximum possible output, which reflects the change of technology efficiency. TP represents the change of technological progress in the r -th region. By taking the TP values into Equations (6) and (5) sequentially, the contribution rate of technological progress to the growth of construction LP can be calculated.

3.3. Measuring Variables of Technological Progress Index

This study first used Equation (12) to calculate the technological progress index (TP), which is based on the input-oriented distance function, and then got the contribution rate of technological progress to construction LP based on the Equations (5) and (6). Therefore, the first step is to determine the input and output variables for the calculation model of Equation (12).

In representative studies [1,24,28,32,33], input variables often adopt capital, technical equipment, labor (labor quantity or payment), and energy consumption. In the selection of output variables, many studies have used the total output value or added value of the construction sector as the output indicators, while a few studies have considered the industry profit and construction acreage. This study, by means of adverse choice, selected the key factors that affect construction LP from the representative literature. After the cluster analysis, the selected input-output variables were shown in Table 2.

Table 2. Main input and output variables and their details.

Types	Variables	Details
Input	Capital input	Total fixed assets and circulating assets of enterprises (10,000 yuan)
	Labor input	Number of employees (person)
	Technical equipment	Technical equipment rate (yuan/person)
Output	Industrial output	Gross output value of construction industry (10,000 yuan)
	Enterprises profits	Total profits of enterprises (10,000 yuan)

3.4. Analysis Variables of Factors Impacting Labor Productivity

Many studies explored the factors that influence construction LP from the project level. Representative research, such as what Heizer and Render conducted, classified the factors into labor characteristics, project characteristics, and non-productive activities [34]. From the industry level, through the survey of construction enterprises, Rojas and Aramvareekul pointed out that management level, policies and regulations, and human resources have greater impacts on the construction sector's LP [32]. Grau and Caldas et al. analyzed 82 factors in Turkey, and pointed out that the adoption of new technologies is the most effective factor to improve the construction LP [35]. Allen illustrated that market demand, average number of employees per enterprise, labor capital ratio, and high-quality human resources (age of workers) are the key factors affecting the variation of CLP [36]. Grounded on the systematic analysis of the factors impacting the competitiveness of the construction industry by Flanagan et al. [37], this study selected the following 12 variables as potential factors impacting construction LP: regional economic environment, R&D investment, capital investment, human resources, material investment, technical equipment, key auxiliary industries, market demand, market openness, market structure, market concentration, and industrial development. In addition, according to the background of ICT implementation concerning the Chinese construction industry shown in Table 1, this study divided the years during 2000–2018 into three periods (Stage 1: 2001–2005, Stage 2: 2006–2010, and Stage 3: 2012–2018), and set the ICT level as the 13th variable. All variables and their descriptions are shown in Table 3.

Table 3. Potential influencing factors of labor productivity.

Categories	Descriptions
Economic condition (F1)	Regional Gross Domestic Product (GDP) (100 million yuan)
R&D investment (F2)	Patent authorization amount (piece)
Capital investment (F3)	Construction enterprises' liquid assets (10,000 yuan)
Human resources (F4)	Construction workers' average wage (yuan)
Material investment (F5)	Building materials consumption (steel/ton)
Technical equipment (F6)	Total power of mechanical equipment (10,000 kW)
Auxiliary industry (F7)	Employees of survey and design enterprises (person)
Market demand (F8)	China's fixed asset investment (100 million yuan)
Market openness (F9)	Asset proportion of foreign construction enterprises
Market structure (F10)	Asset proportion of state-owned enterprises
Market concentration (F11)	Ratio of output value of special and first-class general contracting enterprises
Industrial development (F12)	Construction industry output as a percentage of GDP
ICT level (F13)	2001–2005 (1), 2006–2010 (2), and 2012–2018 (3)
Labor productivity (LP)	Labor productivity calculated by added value of construction industry (yuan/person)

3.5. Analysis Procedure

The analysis procedure consists of three parts: data selection, calculation of technological progress contribution rate, and regression analysis of factors impacting construction

LP. Firstly, 527 objective data from 31 regions were taken from the China Construction Industry Statistical Yearbook and the Local Statistical Yearbook. The time range is from 2000 to 2018. Taking into account the comparability of the data, the data of the 1999 year were selected as reference, and the data were standardized according to the Chinese price index. Secondly, adopting the TP formulation of the Malmquist index (Equation (12)) and the construction LP growth rate formulation (Equations (5) and (6)) to calculate the contribution rate of technological progress to construction LP. Thirdly, the method of multivariate step-wise regression was used to analyze factors impacting construction LP, and compared the current heterogeneous effects of technical and non-technical progress factors on construction LP. In order to avoid missing potential influencing factors, this study selected 13 independent variables. This requires a higher estimation accuracy of the analysis method. The multivariate step-wise regression can effectively reduce the impact of incomplete independence between the variables on the analytical results. In addition, there are some missing values in the data (e.g., F9 values in some regions). The study used the median values of two years before and after the data to replace it.

4. Analysis Results

4.1. Technology Progress Contribution to Labor Productivity

According to the Formulation (5), (6) and (12), 527 data from 31 regions were analyzed by the calculation tools of DEAP 2.1 and SPSS 21.0. The regions were classified by China's geographic standards, but excluding Hong Kong, Macao, and Taiwan. For instance, East China includes Shanghai, Jiangsu, and Zhejiang, etc., provinces. The results were shown in Table 4.

Table 4. Technology progress contribution to labor productivity.

China's Regions	Average Growth Rate of LP	Means of Technological Progress Contribution Rate (ETP)	Stage 1: Technology Progress Contribution Rate (ETP1)	Stage 2: Technology Progress Contribution Rate (ETP2)	Stage 3: Technology Progress Contribution Rate (ETP3)
Northeast	9.77%	0.2156	0.4734	1.5925	−1.1898
North	10.01%	0.4176	0.1051	0.7638	0.4416
East	10.38%	−0.5399	−1.339	0.2775	−0.4221
Central	11.38%	0.0978	0.3344	0.3213	−0.0842
South	16.82%	0.0305	−0.5716	−0.2383	0.8566
Southwest	13.84%	−0.0153	0.3183	−0.1178	−0.2635
Northwest	13.09%	0.27954	0.4837	0.0412	0.2740
Means	12.18%	0.0694	−0.0949	0.3772	−0.0553

Table 4 shows that, during 2000–2018, the LP within China's construction sector showed an overall growth trend with an average annual growth rate of 12.18%. However, the contribution that technological progress has offered to construction LP is different. In the first phase (ETP1: 2001–2005), except for the two regions with developed construction sector in East China and South China, the technological progress in the remaining regions all had a positive impact on the LP growth. The contribution rate of technological progress on the LP in Northwest region is the highest, reaching 48.4%. In the second stage (ETP2: 2006–2010), the contribution rate has been greatly improved compared with the previous stage. The average of each region is as high as 37.7%. In Northeast China, it even reached 1.5 times. In the third stage (ETP3: 2012–2018), the overall trend of the technological progress contribution is negative, indicating that the promotion role which the technological progress has made to construction LP is on its decline.

Moreover, as shown in Figure 2, the impact of technological progress on construction LP is consistent with the change cycle of ICT level in China. However, the more developed the regional construction industry is, the smaller the contribution of the technological

progress has made to LP is. Based on these analysis results, the study inferred that the level of ICT implementation may be a significant factor impacting China's construction LP change. The next part of this study will compare the impact roles of ICT and non-ICT factors on construction LP through empirical analysis.

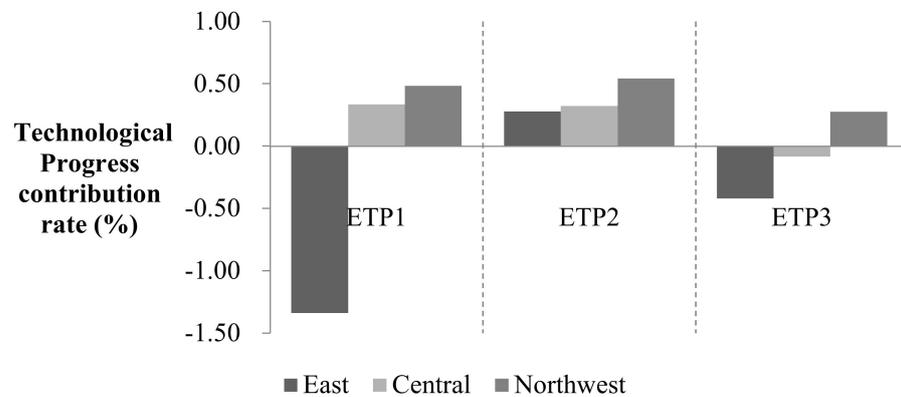


Figure 2. Periodic changes of technological contribution rate in different regions.

4.2. Multiple Step-Wise Regression Analysis of Factors Influencing Labor Productivity

In order to further testify the potential factors (F1–F13) influencing the construction LP in China, this study first used SPSS 21.0 to perform the ordinary least squares regression analysis. The D-W test result was 1.697, close to 2, indicating that the independent variable and the residual are independent of each other. The variance inflation factors for the regression model ranged from 1.038 to 4.217 and were much lower than the recommended criterion of 10 [33], indicating that there is no autocorrelation and multicollinearity problem, and the regression analysis is desired. Second, in the interest to avoid the multicollinearity problem of 13 observed variables even more, all variables are standardized by way of SPSS 21.0. Finally, via using the backward step-wise regression analysis method, the variables that meet the model requirements were filtered out and the variables that are not suitable for entering the model were gradually removed from the full-variables model. The remaining 8 models are omitted due to the layout limitations. The results of the analysis were shown in Table 5.

Table 5. Analysis results of factors impacting labor productivity.

Model	Variables	Coefficient B	Standard Error	t	Sig.
	(Constant quantity)	1.005×10^{-13}	0.029	0.000	1.000
Model-9	F2	0.157	0.057	2.732	0.007
	F3	−0.268	0.076	−3.509	0.000
	F4	0.453	0.062	7.336	0.000
	F8	0.096	0.054	1.785	0.075
	F13	0.372	0.057	6.546	0.000

Note: The probability of F-to-enter ≤ 0.05 , F-to-remove ≥ 0.10 .

After 9 times of backward regression, the 8 variables of regional GDP (F1), material investment (F5), technical equipment (F6), auxiliary industry (F7), market openness (F9), market structure (F10), market concentration (F11), and industrial development degree (F12) did not meet the judgment standards, and were eliminated out of the model. The remaining 5 variables were consistent with expectations. According to the results, the regression coefficients of R&D investment (F2), human resources (F4), and ICT level (F13) are positive and significant at 0.01. They were thus considered to be the main variables affecting the construction LP. However, the regression coefficient of capital investment (F3) is negative and significant at 0.05, indicating an increase of 1 unit in the capital

investment, and the construction LP will change by 0.268 units in the opposite direction. In particular, though the regression coefficient of market demand (F8) is positive, it is not statistically significant. This implicated that the correlation relationship between the market demand and the construction LP is not significant. When the regression analysis was done individually, F8's coefficient is positive at 0.05; that is, an increase of 1 unit in the market demand, the construction LP will increase by 1.427 units. From a realistic point of view, the market demand is indeed an important variable in impacting the LP. When the national fixed assets investment increases, enterprises will certainly invest more manpower, material, and property for technological reformation and business expansion. Therefore, the finally obtained construction LP impacting the factors model is as follows.

$$\text{Construction LP} = 0.157 F2 - 0.268 F3 + 0.453 F4 + 0.096 F8 + 0.372 F13 + 1.005$$

5. Discussions

From the contribution of technology progress to construction LP, the role of technological innovations is declining year by year in the United States, Britain, Japan, Germany, and France [1]. Unexpectedly, this is happening in developing countries like China. The analysis results show that the technological advancements characterized by the popularization of computer and internet contribute greatly to the construction LP in underdeveloped regions, but as the level of ICT implementation enhances, the contribution rate of technological progress is decreasing year by year in all regions (Table 1 and Figure 2). From 2012 to 2018, with the large-scale comprehensive application of ICT such as BIM, prefabricated buildings, cloud computing, and IoT, the role of technological progress in China's construction LP did not increase, but decreased. There are two possible explanations. One is that the ICT implementation in the construction industry is still in its infancy and has not yet been fully recognized and implemented [38]; the other is that the effects of other factors impacting the construction LP are becoming more and more significant. Further, the analysis of this study found that R&D investment, human resources, and ICT level have significant impacts on the construction LP, yet are negatively affected by capital investment. This is contrary to the conclusions of earlier studies which emphasized the capital investment and economic development level [39,40].

The findings show that under the background of integration of ICT and the global construction industry, building production has entered a new stage of fine management. The pattern of LP growth that relied on market expansion and capital investment in the past has become unsustainable. Practitioners should not hesitate to learn from the advanced industries such as manufacturing, and put more resources into R&D, human resources, and ICT implementation. Meanwhile, policy makers should pay attention to the imbalance of the contribution of technological progress to construction LP in different regions. The results in Figure 2 have shown that the over-emphasis on ICT innovations in China's developed regions (East China) has not led to a contribution in the construction LP, and the LP growth brought about by technological progress in underdeveloped regions (Northwest China) has become very small. Technological progress is not always beneficial, and sometimes it is a waste of social resources. These findings indicated that solely relying on technological innovation, but without improving enterprises' management level and ability to transform and absorb knowledge, may not lead to construction LP growth. Practitioners should focus on the training and re-education of employees and on the improvement of their cultural and technical attainments, especially the ability to adapt to the ICT-based work environment. The findings are particularly important for those developing countries in the transformation period of the construction industry [25].

6. Conclusions

By collecting the objective data of 31 regions in China from the year 2000 to 2018 as a sample and adopting the analysis methods of Malmquist DEA, growth rate equation, and multiple backward step-wise regression, this study explored the technology progress contribution and influencing factors of construction LP. The analysis results illustrate that

the technological advancements characterized by ICT have a significant contribution to construction LP growth, but the contribution rate decreases with the increase of the degree of development of the regional construction industry. R&D investment, human resources, and ICT level are the main factors affecting the further improvement of construction LP. The influential roles of the factors to construction LP from high to low are as follows: human resources, ICT level, R&D investment, and market demand.

Overall, this paper proposed a new methodology for measuring the contribution of technological progress to construction LP and identified the factors impacting LP. The findings can provide the decision-making reference and the general methodology for the local and international industry practitioners to improve the LP performance of the construction sector. With regard to the limitations of this study, one possible question is that the data all come from China, which may be responsible for the explanatory power of research findings. A natural extension of the study would be to compare how the technology progress contribution and influencing factors of construction LP under the background of ICT implementation reveal themselves in different cultures and market environments, and thus help to further understand which stimuli are the core factors to promote the further improvement of LP in the construction sector and how they work.

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Abbreviations

The following symbols are used in this study:

<i>LP</i>	labor productivity;
<i>Y</i>	industrial output;
<i>A</i>	average production technology level;
<i>L</i>	labor input;
<i>K</i>	capital input;
α	elasticity coefficient of labor output;
β	elasticity coefficient of capital output;
<i>C</i>	per capita capital;
<i>E</i>	technological progress contribution rate;
<i>TP</i>	technological progress index;
<i>R</i>	last region;
\hat{R}	set of regions;
<i>T</i>	final time period;
\hat{T}	set of time periods;
<i>I</i>	last production factor;
\hat{I}	set of production factors;
<i>J</i>	last output;
\hat{J}	set of outputs;
<i>V</i>	weight of decision-making unit;
<i>M</i>	Malmquist index

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