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Empirical Research on the Investment Performance of Information and Communication Technology in China

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Abstract

The continuous development of the new-generation Information and Communication Technology (ICT) has drawn increased focus and investment from China. However, will China's investment in the ICT bring a long-term positive impact on China's economic growth? Will such impact be changed by any external factors? These questions bear strong significance for the academic cycle and require urgent solutions. Given such concerns, the paper introduced a partial dynamic adjustment model and selected the panel data of China from 2001 to 2016 to study how China's investment in ICT affected its economic performance. The study found that such investment has significantly promoted the economic growth of China with gradually shortened gap between physical capital and the ICT investment, while human capital still played a vital role in economic growth; there is a mutual and harmonious influence between macrovariable and the speed of adjustment, and only their effective combination can improve economic performance to the maximum extent.

Keywords: Information and Communication Technology (ICT), total factor productivity (TFP), productivity paradox, partial dynamic adjustment model

1. Introduction

Since Premier Li Keqiang first proposed "Internet+" in March 2015, the new-generation information technology has moved a step closer to finding a way out of its traditional pattern, remodeling a new business format and realizing the overall transformation and upgrading of the industry. The Report to the 19th CPC National Congress clarified further commitment to deepening supply-side structural reform and developing a new generation ICT infrastructure network, while actively promoting in-depth integration of the Internet, big data and artificial intelligence with the real economy. General Secretary of CPC Central Committee Xi Jinping noted in his Letter of Congratulation to the 5th World Internet Conference in November 2018 that: "As modern information technologies such as Internet, big data and artificial intelligence are making continuous breakthroughs with the thriving of digital economy, the interests of all countries have been more closely connected. To foster new growth drivers for the world economy, it is an urgent need for us to accelerate the development of digital economy and promote a fairer and more equitable global Internet governance system."

So far, China's economy has shifted from a stage of rapid growth to that of high-quality development, and has reached a critical juncture for transforming its growth model, optimizing economic structure and fostering new drivers of growth (Note 1). The key to the future high-quality development is to raise the total factor productivity (Fang, 2018). However, will Information and Communication Technology (ICT) raise China's productivity and become a major driver to promote high-quality economic development.

The contribution of Information and Communication Technology (ICT) investment to economic growth has been a major concern for domestic and foreign scholars, who have conducted extensive studies and discussions on whether such investment can have long-term positive impact on economic growth. However, divergence still exists. Currently, the academic circle features two schools of thoughts: one is "Pro-Effectiveness", represented by Brynjolfsson and Jorgenson et al., who believe that the ICT investment has effectively improved the TFP and economic growth; and the other is "Pro-Insufficiency", represented by Solow, who believes that despite a large amount of resources input, the ICT investment has made little contribution to the growth of TFP.

The researches on the contribution of Information and Communication Technology (ICT) to economic growth fall into two categories by research method: growth accounting and econometric methods. Growth accounting is mostly based on the premise of perfectly competitive market and constant returns to scale. The accuracy of results will be affected if the premise cannot be satisfied. However, econometric method relies little on perfectly competitive market and constant returns to scale. At present, linear model is often used in academia to study the contribution of Information and Communication Technology (ICT) to economic growth.

Overall, divergence still exists in the research on the contribution of ICT investment to economic growth. The reason lies in the presumption of most existing literatures that the contribution of ICT investment to economic growth demonstrates a linear relation, and the study with traditional linear model is a static impact analysis in most cases, which fails to reflect the dynamic change on the contribution of ICT investment to economic growth. Economic phenomena are actually complicated and changeful, with many non-linear relations among variables, and it is not reasonable to simply presume it as a linear relation. In addition, most of the empirical literatures lay emphasis on the direct impact of Information and Communication Technology (ICT) on economic growth while neglect the indirect factors, resulting in failure to comprehensively depict the contribution of ICT investment to economic growth.

Given such factors, the paper intends to take an overall consideration on Lin & Kao's model research method, select the data of China from the period of Internet bubble to new industrial revolution (2001~2016) for a comprehensive analysis based on partial dynamic adjustment model, and study on the impact of China's ICT investment on economic performance in different periods as well as the specific factors affecting the full potential of Information and Communication Technology (ICT) by comparing the level of economic performance before and after the introduction of ICT, so as to judge whether there is a productivity paradox in China. The conclusion is based on the empirical results.

2. Literature Review

2.1 Contribution of ICT Investment to Economic Growth in China

Researches on the contribution of ICT investment to economic growth were first conducted in the USA. From mid-1980s to 1990s, the mainstream thoughts in the academic circle represented by Solow widely believed that the ICT investment had little contribution to the TFP and economic growth. Since the "productivity paradox" was proposed, many scholars began to interpret its rationality from an empirical perspective. Based on what Solow has proposed, the study conducted by Berndt and Morrison (1992) found that every dollar invested in Information and Communication Technology (ICT) could generate a marginal value of merely 80 cents from 1968 to 1986, and the ICT industry was under excessive investment. Oliner and Sichel (1994) found by applying economic growth accounting theory that, since the ICT capital accounted for a small portion in entire social capital stock, it had limited contribution to economic growth.

However, in the mid and late 1990s, discussions on the "productivity paradox" have been reversed, as mainstream opinions admitted that the ICT investment could effectively promote economic growth. The research on "productivity paradox" in this period laid more emphasis on its possible causes. American economic historian David (1990) believed that, affected by the time-lag effect, the ICT's promotion to economic growth would become more pronounced after a certain period. On that basis, Sharp (1999) found that the external factors might impede the impact of ICT and prolonged the lagged time. Besides, Brynjolfsson and Hitt (1993) believed that "errors in measurement" was another major cause of paradox. Most of the benefits brought by the ICT capital were apt to be neglected by traditional accounting method so that the productivity was underestimated systematically.

However, in the beginning of the 21st century, the academic circle began to reexamine the value of ICT, and most scholars in this period studied at industrial and enterprise levels. Miaojun, Weiying et al. (2006, 2007) studied the impact of ICT on enterprise performance from the perspective of enterprise, and found that the ICT investment promoted the enterprise production performance, competitiveness and innovation ability, and the efficiency of ICT capital was much higher than non-ICT capital. Bin and Dongyun (2004) analyzed the impact of ICT investment on the productivity of different industries from an industry level and found that, affected by both internal and external factors, ICT's role in driving industry growth was not synchronously played, with significant differences among different industries.

Since 2008, the new-generation ICT represented by Internet of Things (IoT), cloud computing, big data, AI and 5G has triggered a new round of worldwide industrial revolution. Research on the contribution of ICT investment to economic growth was again widely discussed in all sectors of society. Foreign scholars were no long confined to the analysis at micro level, but started to turn the research perspective to macroscope and study the differences of ICT's economic effect and value among countries (Lin, 2009). Developing countries, rather than developed countries, have become the object of study. Studies conducted by Dedrick and Kraemer (2013) on the contribution of ICT input to economic growth in different countries found that the long-term positive impact of ICT on economic growth has extended from developed countries to developing countries.

Currently, study on the contribution of ICT investment to economic growth is still at an initial stage in China. According to the academic research of Li Zhitang (2009), 34 academic papers were themed on "Information and Communication Technology (ICT) investment" from 2000 to 2008 in China, including six reviews (17.6%), 15 theoretical analyses (44.1%), 4 empirical studies (11.8%) and 9 general descriptive papers (26.5%). Liping (2012), Fei andLiping (2013), et al. studied the growth of economy and productivity from 1978 to 2009 in China and found that the contribution of informatization was subject to historical evolvement. Productivity paradox was prevalent over the first decade at the initial stage of reform and opening-up, and informatization had negative contribution to TFP and economic growth. However, with the popularization and development of Information and Communication Technology (ICT), productivity paradox disappeared. Jiatang et al. (2016) and Xianfeng et al. (2019) conducted an empirical analysis on the panel data at provincial level in China and found that the conclusion on productivity paradox did not conform to the actual development of China, and that Information and Communication Technology (ICT) has significantly promoted the increase of TFP.

2.2 Research Methods on Contribution of ICT Investment to Economic Growth

How to properly measure the contribution of ICT to economic growth is another key issue in academic research. At present, the mainstream research methods fall into two categories: the growth accounting method and the econometric method. For the growth accounting method, the Organization for Economic Co-operation and Development (OECD) (2003) proposed the growth accounting framework. Linlin et al. (2012) and Yuezhou et al. (2015) applied this method to measure the changes of different factor inputs and their contributions to economic growth. However, the method is mostly based on the premise of perfectly competitive market and constant returns to scale. The accuracy of the results will be affected if the premise cannot be satisfied.

However, the econometric method relaxes the assumption of perfectly competitive market, constant returns to scale, etc. At present, linear model is often used in academia to study the contribution of ICT to economic growth. Dewan (2000), Lee (2005), Zifeng et al. (2016), studied the economic returns of ICT investment to measure the contribution of non- ICT investment and ICT investment to economic growth. However, in the process of linear regression, there is the possibility that the unobservable error is related to the predictive variable, which brings error to the result of estimated coefficient. On the basis of previous academic research, W. T. Lin et al. introduced local adjustment model to measure the impact of ICT investment to economic performance.

Reviewing the literatures of the above-mentioned scholars, the paper summarizes that the current researches have the following shortcomings: First, from the perspective of research, most existing literatures assume that the contribution of ICT investment to economic growth is linear, and the static linear model is adopted for research. However, Granger (1988) indicated that "the world is almost made up of non-linear relationships". Ignoring the non-linear relationship between variables, while adopting the static linear method to study the contribution of ICT investment to economic growth, will inevitably lead to errors in the estimation results. Second, from the perspective of mechanism, current researches mainly directly analyze the contribution of ICT to economic growth, while ignoring the indirect factors that influence the role of ICT. Even if indirect factors are taken into account, they are mostly static and cannot reflect the dynamic changes brought by indirect factors to ICT investment.

Therefore, the paper introduces the local dynamic adjustment model to analyze the contribution of ICT investment to economic growth, analyze and summarize the performance status of ICT investment in China, and provide some references for effectively promoting the implementation of "Internet Plus" action plan in China and accelerating the construction of modern China under the new normal.

3. Theoretical Model and Research Design

3.1 Local Adjustment Model and Its Improvement

In real life, due to the influence of external factors such as technologies and systems, the explained variable often fails to achieve the expected effect immediately. There is a certain time delay, that is, the actual change of the explained variable is only a part of the expected variable. Considering the above, Nerlove proposed the theory of local adjustment to analyze the relationship between explanatory variables and explained variables under the influence of external factors and conditions. The theory was first used to explain the distributed lag of demand for agriculture and other commodities. Later on, the theory was widely used in macroeconomic and microeconomic research. W. T. Lin et al. applied the local adjustment model to measure the impact of ICT investment on the level of economic performance. Considering the impact of ICT investment to economic performance, a time-delay adjustment speed is set. The specific formula is as follows:

$$Y_{jt} = \delta_j Y_{jt}^* + (1-\delta) Y_{j,t-1} \tag{1}$$

$$Y_{jt} - Y_{j,t-1} = \delta_j (Y_{jt}^* - Y_{j,t-1}) \tag{2}$$

$$0 < \delta_j < 1 \quad j = 1,2,...,m \ , \ t = 1,2,...,n$$

Wherein, Y_{jt} is the actual output of country j at time t; Y_{jt}^* is the expected output of country j at time t; $Y_{j,t-1}$ is the actual output of country j at time t-1; and δ_j is the constant speed of local adjustment in country j. If $\delta_j = 1$, $Y_{jt} = Y_{jt}^*$; if $\delta_j = 0$, $Y_{jt} = Y_{j,t-1}$. However, restricted by external technical conditions, Y_{jt} cannot achieve the expected level of economic growth in the same period. Therefore, follow the hypothesis of local adjustment theory, $0 < \delta_j < 1$.

Add random error u_{jt} in formula (2), and u_{jt} follows $N(0, \sigma_u^2)$, and then formula (2) is:

$$Y_{jt} - Y_{j,t-1} = \delta_j Y_{jt}^* - \delta_j Y_{j,t-1} + u_{jt} \tag{3}$$

$$j = 1,2,...,m \ , \ t = 1,2,...,n$$

It can be seen from formula (3) that the local adjustment speed δ_j is the ratio of the actual adjustment quantity $(Y_{jt} - Y_{j,t-1})$ and the expected adjustment quantity $(Y_{jt}^* - Y_{j,t-1})$.

According to W. T. Lin et al. Y_{jt}^* cannot be directly observed, but it can be quantified by production functions. However, there is the possibility that unobservable error is related to the predictive variable of Cobb-Douglas (C-D) production function, which easily causes error to the result of estimated coefficient. Box-Tidwell production function can reduce the correlation between unobservable error and predictive variable to some extent. Based on such, Box-Tidwell production function is selected for analysis in this paper.

Based on the local adjustment model, two factors and three factors are respectively considered. The followings are the mathematical expressions of two production functions under two factors and three factors:

Two-factor production function model (excluding ICT):

$$\frac{Y_{jt}^{\lambda} - 1}{\lambda} = \beta_{j0} + \beta_{j1} \frac{K_{jt}^{\theta} - 1}{\theta} + \beta_{j2} \frac{L_{jt}^{\theta} - 1}{\theta} \tag{4}$$

λ and θ meet the maximization of following formula:

Wherein, Y_{jt} is the actual output, which is expressed by the GDP of a country. K_{jt} is physical capital, and the gross capital value of a country in the current year is used to subtract the ICT investment of current year. L_{jt} is human capital, and the total labor cost of a country in the current year is used to subtract the manpower expenditure of ICT in the current year. *N* is the number of countries. *M* is the statistical year.

Three-factor production function model (including ICT):

$$\frac{Y_{jt}^{\lambda} - 1}{\lambda} = \beta_{j0} + \beta_{j1} \frac{K_{jt}^{\theta} - 1}{\theta} + \beta_{j2} \frac{L_{jt}^{\theta} - 1}{\theta} + \beta_{j3} \frac{I_{jt}^{\theta} - 1}{\theta} \tag{5}$$

Wherein, λ and θ meet the maximization of following formula:

$$L_{\max}(\lambda, \theta) = -(\frac{NM}{2}) \ln(\frac{SSE}{M}) + (\lambda - 1) \sum_{j,t} \ln(Y_{jt}) + (\theta - 1) \sum_{j,t} \ln(Y_{jt})$$

Wherein, the ICT capital investment (I_{jt}) is composed of ICT capital input and manpower expenditure. Where, the ICT capital investment includes investment in software, hardware and other equipment; ICT manpower expenditure includes services and internal expenditure of ICT.

According to formula (3) of local adjustment model, it is assumed in the model that local adjustment speed δ_j is the ratio of actual adjustment quantity $(Y_{jt} - Y_{j,t-1})$ and the expected adjustment quantity $(Y_{jt}^* - Y_{j,t-1})$. It is assumed that the local adjustment speed δ_j is fixed. But in real life, the adjustment speed is not fixed. Therefore, simply setting a constant adjustment speed for empirical analysis will bring certain deviations to the research results, leading to deviation of the analysis results. Based on such, this paper adopts the method of W. T. Lin et al. (2014) to convert the constant speed δ_j into dynamic adjustment speed δ_{jt} for analysis, and $\delta_{jt} = g(Z_{jt}, \pi_j)$. Formula (3) is changed into:

$$Y_{jt} - Y_{j,t-1} = \delta_{jt} f(X_{jt}, \beta_j) - \delta_{jt} Y_{j,t-1} + u_{jt} \tag{5}$$

$$\delta_{jt} = g(Z_{jt}, \pi_j),\ 0 < \delta_{jt} < 1,\ j = 1,2,...,m,\ t = 1,2,...,n$$

Wherein, $f(X_{jt}, \beta_j)$ represents the production function. X_{jt} represents the production factor. Specifically including; physical capital K_{jt}, human capital L_{jt} and ICT capital investment I_{jt}; K_{jt} is the parameters to be estimated for the production function; π_j represents the parameter to be estimated δ_{jt}, and Z_{jt} is the control variable.

In terms of the selection of control variable Z_{jt}, through previous literature reviews, Phelps (1969), Lin (1986), Lin (1998, 2000 and 2002), Hackbarth et al. (2004), Kunrong and Jian (2000) et al. believed that real interest rates had a particularly significant impact on economic growth. Therefore, this paper selects the real interest rate R_{jt} as the control variable Z_{jt} to study. In addition, with the continuous development of ICT, government expenditures of all countries on ICT have also been increased. Is it reasonable to spend a lot of government expenditure? Does it really work? Ram (1986), Aschauer (1989), Devarajan et al. (1993), Mingxi and Zhiyong (2005) et al. believed that government expenditure plays an important role in economic growth and has a positive promoting effect. However, Grier and Tullock (1987), Barro (1990), Wenlin, Kunrong et al. (2006) argued that government expenditure is negatively correlated with economic growth. Besides, Choi and Devereux (2005), Youcai and Ninhui (2009), as well as Qiang and Shushu (2017) argued that there is a non-linear relationship between government expenditure and economic growth. Based on such, this paper takes government expenditure as one of the control variable Z_{jt} to study its impact on dynamic adjustment speed and economic performance.

Different from previous studies, this paper processes the expectation of control variable, and adopts the expectation form of control variable. That is, expected interest rate R^*_{jt} and expected government expenditure GE^*_{jt} are used to analyze the influence of control variable Z_{jt} on dynamic adjustment speed and economic performance.

The expectation form of a variable is actually an autoregressive process. At present, the autoregressive process includes one-step autoregressive process, two-step autoregressive process, three-step autoregressive process and four-step autoregressive process, in which the three-step autoregressive process is widely recognized by academia. Hence, this paper applies the three-step autoregressive process to deal with the expectation of macroeconomic variable, as follows:

$$R^*_{jt} = \frac{1}{2} R_{j,t-1} + \frac{1}{3} R_{j,t-2} + \frac{1}{6} R_{j,t-3} \tag{7}$$

$$GE^*_{jt} = \frac{1}{2} GE_{j,t-1} + \frac{1}{3} GE_{j,t-2} + \frac{1}{6} GE_{j,t-3} \tag{8}$$

3.2 Model Building

Based on the local adjustment model (2) and the improved local adjustment model (3), eight regression models under the two conditions of two factors and three factors are established by considering the expected interest rate R^*_{jt} and expected government expenditure GE^*_{jt} and combining the Box-Tidwell production function:

Local adjustment model of two-factor production function (excluding ICT), with constant adjustment speed):

Model 1: based on Box-Tidwell production function, and considering UR_{jt} and UG_{jt}:

$$\frac{Y_{jt}^{\lambda}-1}{\lambda}-\frac{Y_{j,t-1}^{\lambda}-1}{\lambda}=\delta_j f(X_{jt};\beta_j)-\delta_j \frac{Y_{j,t-1}^{\lambda}-1}{\lambda}+u_{jt}$$

$$f(X_{jt};\beta_j)=\beta_{j0}+\beta_{j1}\frac{K_{jt}^{\theta}-1}{\theta}+\beta_{j2}\frac{L_{jt}^{\theta}-1}{\theta} \tag{9}$$

Regression model of local dynamic adjustment to two-factor production function (excluding ICT):

Model 2: $$\frac{Y_{jt}^{\lambda}-1}{\lambda}-\frac{Y_{j,t-1}^{\lambda}-1}{\lambda}=g(Z_{jt},\pi_j)f(X_{jt},\beta_j)-g(Z_{jt},\pi_j)\frac{Y_{j,t-1}^{\lambda}-1}{\lambda}+u_{jt} \tag{10}$$

$$f(X_{jt},\beta_j)=\beta_{j0}+\beta_{j1}\frac{K_{jt}^{\theta}-1}{\theta}+\beta_{j2}\frac{L_{jt}^{\theta}-1}{\theta}$$

$$g(Z_{jt},\pi_j)=\pi_{0j}+\pi_{1j}\ln R_{jt}^{*}$$

Model 3: $$\frac{Y_{jt}^{\lambda}-1}{\lambda}-\frac{Y_{j,t-1}^{\lambda}-1}{\lambda}=g(Z_{jt},\pi_j)f(X_{jt},\beta_j)-g(Z_{jt},\pi_j)\frac{Y_{j,t-1}^{\lambda}-1}{\lambda}+u_{jt} \tag{11}$$

$$f(X_{jt},\beta_j)=\beta_{j0}+\beta_{j1}\frac{K_{jt}^{\theta}-1}{\theta}+\beta_{j2}\frac{L_{jt}^{\theta}-1}{\theta}$$

$$g(Z_{jt},\pi_j)=\pi_{0j}+\pi_{2j}\ln GE_{jt}^{*}$$

Model 4: $$\frac{Y_{jt}^{\lambda}-1}{\lambda}-\frac{Y_{j,t-1}^{\lambda}-1}{\lambda}=g(Z_{jt},\pi_j)f(X_{jt},\beta_j)-g(Z_{jt},\pi_j)\frac{Y_{j,t-1}^{\lambda}-1}{\lambda}+u_{jt} \tag{12}$$

$$f(X_{jt},\beta_j)=\beta_{j0}+\beta_{j1}\frac{K_{jt}^{\theta}-1}{\theta}+\beta_{j2}\frac{L_{jt}^{\theta}-1}{\theta}$$

$$g(Z_{jt},\pi_j)=\pi_{0j}+\pi_{1j}\ln R_{jt}^{*}+\pi_{2j}\ln GE_{jt}^{*}$$

Local adjustment model of three-factor production function (including ICT), with constant adjustment speed):

Model 5: based on Box-Tidwell production function, and considering UR_{jt} and UG_{jt}:

$$\frac{Y_{jt}^{\lambda}-1}{\lambda}-\frac{Y_{j,t-1}^{\lambda}-1}{\lambda}=\delta_j f(X_{jt};\beta_j)-\delta_j \frac{Y_{j,t-1}^{\lambda}-1}{\lambda}+u_{jt}$$

$$f(X_{jt};\beta_j)=\beta_{j0}+\beta_{j1}\frac{K_{jt}^{\theta}-1}{\theta}+\beta_{j2}\frac{L_{jt}^{\theta}-1}{\theta}+\beta_{j2}\frac{I_{jt}^{\theta}-1}{\theta} \tag{13}$$

Regression model of local dynamic adjustment to three-factor production function (including ICT):

Model 6: $$\frac{Y_{jt}^{\lambda}-1}{\lambda}-\frac{Y_{j,t-1}^{\lambda}-1}{\lambda}=g(Z_{jt},\pi_j)f(X_{jt},\beta_j)-g(Z_{jt},\pi_j)\frac{Y_{j,t-1}^{\lambda}-1}{\lambda}+u_{jt} \tag{14}$$

$$f(X_{jt},\beta_j)=\beta_{j0}+\beta_{j1}\frac{K_{jt}^{\theta}-1}{\theta}+\beta_{j2}\frac{L_{jt}^{\theta}-1}{\theta}+\beta_{j2}\frac{I_{jt}^{\theta}-1}{\theta}$$

$$g(Z_{jt},\pi_j)=\pi_{0j}+\pi_{1j}\ln R_{jt}^{*}$$

Model 7: $$\frac{Y_{jt}^{\lambda}-1}{\lambda} - \frac{Y_{j,t-1}^{\lambda}-1}{\lambda} = g(Z_{jt},\pi_j)\, f(X_{jt};\beta_j) - g(Z_{jt},\pi_j)\frac{Y_{j,t-1}^{\lambda}-1}{\lambda} + u_{jt} \tag{15}$$

$$f(X_{jt},\beta_j) = \beta_{j0} + \beta_{j1}\frac{K_{jt}^{\theta}-1}{\theta} + \beta_{j2}\frac{L_{jt}^{\theta}-1}{\theta} + \beta_{j2}\frac{I_{jt}^{\theta}-1}{\theta}$$

$$g(Z_{jt},\pi_j) = \pi_{0j} + \pi_{2j}\ln GE_{jt}^{*}$$

Model 8: $$\frac{Y_{jt}^{\lambda}-1}{\lambda} - \frac{Y_{j,t-1}^{\lambda}-1}{\lambda} = g(Z_{jt},\pi_j)\, f(X_{jt},\beta_j) - g(Z_{jt},\pi_j)\frac{Y_{j,t-1}^{\lambda}-1}{\lambda} + u_{jt} \tag{16}$$

$$f(X_{jt},\beta_j) = \beta_{j0} + \beta_{j1}\frac{K_{jt}^{\theta}-1}{\theta} + \beta_{j2}\frac{L_{jt}^{\theta}-1}{\theta} + \beta_{j2}\frac{I_{jt}^{\theta}-1}{\theta}$$

$$g(Z_{jt},\pi_j) = \pi_{0j} + \pi_{1j}\ln R_{jt}^{*} + \pi_{2j}\ln GE_{jt}^{*}$$

According to the definition of economic performance by W. T. Lin et al. (2016), the contribution of various production factors to economic growth is analyzed by taking $PM_{jt} = \delta_{jt} f(X_{jt},\beta_j) = g(Z_{jt},\pi_j)$ as the economic performance of a country. Wherein, PV_{jt} is the estimation of economic performance PM_{jt}, indicated in the following formula:

$$PV_{jt} = \hat{\delta}_{jt} f(X_{jt},\hat{\beta}_j) = g(Z_{jt},\hat{\pi}_j)\, f(X_{jt},\hat{\beta}_j) \tag{17}$$

Wherein, $\hat{\delta}_{jt}$ and $\hat{\beta}_j$ respectively represent the estimators of δ_{jt} and δ_{jt}.

For the convenience of observation, the index PV_{jt} of economic performance is obtained by dividing economic performance Y_{jt}^{Δ} by actual output PR_{jt}:

$$PR_{jt} = PV_{jt} / Y_{jt}^{\Delta} \tag{18}$$

Wherein, Box-Tidwell production function $Y_{jt}^{\Delta} = (Y_{jt}^{\lambda} - 1)/\lambda$; average economic performance index $APR_j = \sum_{t-1}^{n} PR_{jt}/n$, and $j = 1,2,...,m$.

It can be seen from formula (17) that economic performance of a country is affected by the dynamic adjustment speed and the production function. On the one hand, the optimal combination of production factors affects the level of economic performance; on the other hand, the dynamic adjustment speed affects the effect of various factors on economic growth.

4. Research Methods and Data Sources

4.1 Research Methods

In the study of panel data, nonlinear least square method is adopted for regression analysis. In terms of data time range: for GDP, K_{jt}, L_{jt} and I_{jt}: select data from 2001 to 2016, and for R_{jt} and GE_{jt}: select data from 1998 to 2016. All quantitative analyses in this paper are completed by Stata15, and statistical analyses are completed by Excel.

4.2 Date Sources

1) For GDP, physical capital (K_{jt}) and human capital (L_{jt}): from the database of the World Bank and OECD

database (data from 2001 to 2016), the monetary unit is USD 1 million, and all monetary units have been converted into constant price of dollar in 2000.

2) For ICT capital investment (I_{jt}) and ICT manpower expenditures: from the Chinese statistics website (data from 2001 to 2016). The monetary unit is USD 1 million, and all monetary units have been converted into constant price of dollar in 2000.

3) For actual interest rate R_{jt} and government expenditure GE_{jt}: from the database of the World Bank, OECD database and Chinese statistics website (data from 1998 to 2016). The monetary unit is USD 1 million, and all monetary units have been converted into constant price of dollar in 2000.

5. Empirical Research

5.1 Descriptive Statistics

Firstly, a descriptive statistical analysis on the sample data is conducted. Table 1 shows the descriptive statistics of panel data of China from 2001 to 2016. The maximum and minimum GDPs are USD 11,500,000 million and USD 1,711,542 million, respectively, indicating that Chinese economy has undergone tremendous changes from 2001 to 2016; the mean and median of physical capital (K_{jt}) are USD 2,529,991 million and USD 2,181,303 million, respectively; the mean and median of human capital (L_{jt}) are USD 2,222,322 million and USD 1,891,222 million, respectively; while the mean of Information and Communication Technology (ICT) investment (I_{jt}) is only USD 255,849.2 million, which is less than 1/9 of physical capital (K_{jt}) and human capital (L_{jt}); and in terms of control variable, the difference between the mean and the median of the expected interest rate R^*_{jt} is relatively small; while there is a significant difference in the expected government expenditure GE^*_{jt}.

Table1. Descriptive statistics of each variable

	Mean	Min.	Max.	Q1	Median	Q3
GDP	5782518	1711542	11500000	2707173	5152455	8753475
K_{jt}	2529991	487838.1	5023456	892462.6	2181303	4298091
L_{jt}	2222322	792581.7	4574292	1108315	1891222	3269015
I_{jt}	255849.2	84867.7	375415.8	150960	298023.4	328224.2
GE^*_{jt}	802118.9	278807.9	1680444	380699.9	689243.9	1196875
R^*_{jt}	2.311806	1.0222	3.3245	2.03405	2.19	2.79595

5.2 Contribution of Production Factors to Economic Growth

The empirical results in Tables 2 and 3 indicate that without considering the ICT investment factors, the elastic coefficients of physical capital and human capital (two production factors) are positive, and the elastic coefficient of human capital is higher than that of physical capital, indicating that both investment in physical capital and human capital plays a positive role in promoting economic growth, and human capital investment contributes more to economic growth in China than physical capital investment.

When the ICT investment is put into the production process, the degree of fitting of model is improved. The elastic coefficient of the ICT investment is positive, showing a positive effect on economic growth. From the perspective of overall contribution, the gap between the contribution of the investment of physical capital and ICT has gradually narrowed. However, the contribution of human capital to economic growth still dominates.

Table 2. Non-linear estimation of two factors based on Box-Tidwell production function

	Model 1	Model 2	Model 3	Model 4
π_{0j}	1.012***	1.008***	1.1897***	1.1859***
π_{1j}	—	0.0015***	—	0.0004***
π_{2j}	—	—	-0.0126***	-0.0127**
β_{0j}	-0.2516**	-8.3817*	3.8906**	5.2476***
β_{1j}	0.3863***	0.5613***	0.5462***	0.5044***
β_{2j}	0.4789***	0.6465***	0. 6591***	0.6929***
R^2	0.9573	0.968	0.9608	0.9662

Note. *** means 1% significance level; ** means 5% significance level; and * means 10% significance level.

Table 3. Non-linear estimation of three factors based on Box-Tidwell production function

	Model 5	Model 6	Model 7	Model 8
π_{0j}	0.999***	1.0014***	1.0386***	1.0071***
π_{1j}	—	-0.0012**	—	-0.0005*
π_{2j}	—	—	-0.0027***	-0.0004***
β_{0j}	-0.1787***	-8.3635**	-4.4839***	-4.322**
β_{1j}	0.2802***	0.2873***	0.2819***	0.2874***
β_{2j}	0.4903***	0.8741***	0.8083***	0.8624***
β_{3j}	0.2096***	0.2153***	0.2042***	0.2144***
R^2	0.9731	0.9738	0.9745	0.9727

Note. *** means 1% significance level; ** means 5% significance level; and * means 10% significance level.

In the models of two production factors (physical capital & human capital) (without considering the ICT investment), the expected interest rate R_{jt}^* has a significant impact on economic growth. Comparing Model 2 and Model 6, before the ICT investment is put into the production process, the impact speed of the expected interest rate R_{jt}^* on economic growth is positive. However, after introduction of the ICT investment, the direction of the impact speed has changed: from the increase of dynamic adjustment speed by 0.0015 once 1% increase of the two production factors, to the decrease by 0.0012, indicating that after the introduction of the ICT investment, the expected interest rate R_{jt}^* did not have a good impact, but it hindered the promotion of the ICT investment to economic growth.

The expected government expenditure GE_{jt}^* has a negative impact on economic growth with a negative effect. Comparing Model 3 and Model 7, after the ICT investment is put into the production process, for the expected government expenditure GE_{jt}^*, the following change occurred: from the decrease of dynamic adjustment speed by 0.0126 led by every additional USD 1 million in expenditure, to the decrease by 0.0027, indicating that after introduction of the ICT investment, the adjustment speed of the expected government expenditure GE_{jt}^* to economic growth has been adjusted.

After considering the effects of expected interest rate R_{jt}^* and expected government expenditure GE_{jt}^* and comparing Model 4 and Model 8, it is found that after introduction of the ICT investment, the negative effects of expected government expenditures GE_{jt}^* on economic growth have been reduced, but the expected interest rate R_{jt}^* has changed from positive to negative on economic growth, indicating that the impact of macro variables on the adjustment speed is a process of mutual and harmonious influence.

Based on contrastive analysis of constant speed, and comprehensive comparison of Model 1 and Model 5, it is found that regardless of whether the ICT investment is considered, the constant speed is positive. However, the introduction of the ICT investment has reduced the increase in the adjustment speed to a certain extent, from 1.012 to 0.999.

Taken together, the role of ICT investment has not been fully exerted. On the one hand, there is a mutual and harmonious influence relationship between macroeconomic factors and ICT. Only effective combination of the two can maximize the level of economic performance; on the other hand, different from the model of "promoting economic growth with ICT" in developed countries, China adopts the model of "promoting ICT with economic growth", forming an anti-driving mechanism. This has also caused the rapid development of ICT to deviate from the imperfect infrastructure construction, which led to the failure of ICT to fully play its role.

5.3 Contribution of ICT Investment to Economic Growth

Table 4 indicates that after ICT is put into the production function, under different models, economic performance (APR) increases to different degrees. Comparing Model 1 with Model 5, it is found that introduction of the ICT investment has increased APR from 0.6982 to 0.7619, an increase of 0.0637, indicating that ICT has promoted economic performance, and China no longer has or has got rid of the "productivity paradox".

Table4. China's economic performance levels from 2001 to 2016 under different influencing factors

China	Model 2-PR	Model 6-PR	Model 7-PR	Model 8-PR	Model 10-PR	Model 14-PR	Model 15-PR	Model 16-PR
2001	0.6981	0.4839	0.5491	0.5732	0.7630	0.5989	0.7689	0.8326
2002	0.6980	0.4872	0.5475	0.5709	0.7634	0.6028	0.7707	0.8346
2003	0.6984	0.4926	0.5483	0.5707	0.7652	0.6083	0.7737	0.8376
2004	0.6980	0.4983	0.5467	0.5680	0.7630	0.6108	0.7735	0.8371
2005	0.6962	0.5013	0.5421	0.5626	0.7627	0.6151	0.7749	0.8387
2006	0.6950	0.5054	0.5392	0.5587	0.7645	0.6214	0.7783	0.8422
2007	0.6949	0.5126	0.5365	0.5548	0.7627	0.6258	0.7791	0.8429
2008	0.6971	0.5215	0.5371	0.5541	0.7630	0.6310	0.7815	0.8454
2009	0.6989	0.5265	0.5376	0.5537	0.7637	0.6354	0.7836	0.8479
2010	0.6989	0.5322	0.5352	0.5505	0.7616	0.6376	0.7835	0.8476
2011	0.7000	0.5398	0.5322	0.5465	0.7613	0.6424	0.7859	0.8499
2012	0.7001	0.5432	0.5296	0.5433	0.7604	0.6452	0.7867	0.8508
2013	0.7002	0.5467	0.5277	0.5409	0.7597	0.6473	0.7873	0.8514
2014	0.7004	0.5493	0.5257	0.5384	0.7595	0.6501	0.7885	0.8529
2015	0.6993	0.5498	0.5218	0.5341	0.7583	0.6517	0.7885	0.8531
2016	0.6983	0.5502	0.5174	0.5295	0.7577	0.6535	0.7891	0.8539
APR	**0.6982**	**0.5213**	**0.5359**	**0.5531**	**0.7619**	**0.6298**	**0.7809**	**0.8449**

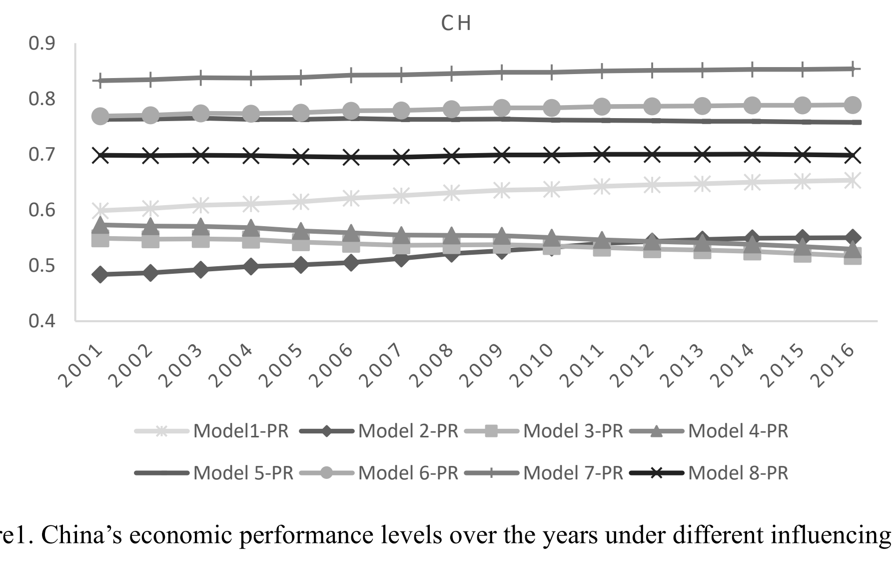

Figure1. China's economic performance levels over the years under different influencing factors

In order to more intuitively understand the trend of economic performance from 2000 to 2016, Figure 1 shows China's economic performance levels over the years under different factors.

It can be seen from Figure 1 that the ICT investment is not put into the production function model. From 2009 to 2016, China's economic performance showed a downward trend. However, after the ICT investment was put into the production function, China's economic performance showed a slow upward trend, which confirmed to a certain extent that the ICT investment had a significant role in promoting economic growth.

5.4 Robustness Test

In order to ensure the robustness of the empirical results, this paper analyzes the robustness of the above regression results from different perspectives such as replacing the explanatory variable (gross national income (GNI)) and Box-Cox production function. Due to limited space available, the robustness test is not repeated here.

6. Conclusions

This paper starts from the current academic limitations on the role of Information and Communication Technology (ICT) in economic growth and the objective economic world reality. From the empirical perspective, this paper adopts the local dynamic adjustment model for analysis, producing the following conclusions:

1) The ICT investment has contributed significantly to economic growth. By comparing the ICT investment before and after being put into the production function, it is found that 2009 was a key "inflection point" for China's economic development. Without considering the ICT investment, China's economic performance showed a downward trend. However, after increasing the ICT investment, the results indicate that China's economic performance shows a steady rise, indicating that in recent years, the ICT investment has contributed significantly to economic growth.

2) However, due to external conditions, the effect of ICT on economic performance has not been fully exerted. Macroeconomic factors and ICT have not been fully and effectively combined. According to the research performed by Zhiguang (2012), there is a complementary relationship between macroeconomic factors and ICT. Only the effective combination of both can maximize the level of economic performance.

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Note

Note 1. Report to the 19th CPC National Congress.