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The Impact of ICT Capital Services on Economic Growth and Energy Efficiency in China

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Abstract: This study aims to investigate the impact of ICT capital services on economic growth and energy efficiency in China at both national and industrial levels during the period 2000–2020. To achieve this aim, this study introduces a measurement method for capital services, explores ICT's contributions to economic growth, and analyzes the impact of ICT on energy efficiency. The empirical results of this study indicate that although the ICT capital services scale is relatively small, accounting for only 8.87% of the total in 2020, its growth rate is faster than that of non-ICT capital services, and the distribution of ICT capital services varies widely among different industries. Additionally, based on the economic growth decomposition framework, this study finds that the contribution of ICT capital services to economic growth is 6.95% on average. It is significantly higher in certain industries, such as Financial industry; Information transmission, software and information technology services; Construction; and Manufacturing compared to others. The total factor energy efficiency (*TFEE*) reveals that industries with higher energy consumption have lower energy efficiency, while the panel regression model illustrates that the development of ICT has a positive impact on improving energy efficiency, with variability across industries. Overall, the findings of this study provide crucial scientific evidence and policy implications for promoting the development of ICT and integrating it with various industries, which can significantly contribute to boosting economic growth and energy efficiency.

Keywords: ICT capital services; economic growth decomposition framework; energy efficiency; panel regression

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1. Introduction

The development of information and communication technology (ICT) has promoted the modernization and transformation of industrial development. It has driven the development of big data, artificial intelligence, the Internet, Internet of Things, cloud computing and other modern new industries to inject new vitality into economic growth, and has become an important support for high-quality economic development [1]. ICT has characteristics of a general-purpose technology and, through its extensive integration and penetration with traditional industries, has improved production efficiency and increased output. Especially with the accelerated replacement of ICT-related equipment and decreasing prices of ICT, the substitution of ICT for traditional capital and labor is enhanced, and ICT provides more efficient production and services [2]. The continuous accumulation of ICT capital has gradually become an important factor for supporting economic growth.

In 2015, all member states of the United Nations adopted "the 2030 Agenda for Sustainable Development", which outlines 17 Sustainable Development Goals (SDGs) [3]. SDG 7 aims to double global energy efficiency by 2030, while SDG 12 emphasizes the importance of sustainable management and efficient use of natural resources. Improving energy efficiency is crucial to achieving sustainable development. The development of ICT not only contributes to improving economic quantity, but also to enhancing economic quality. In the context of sustainable development strategy, achieving green production and solving environmental problems are the main tasks, and China's "carbon peaking and carbon neutrality" strategic goal requires reducing energy consumption and improving energy efficiency, in which the development of ICT can empower the industry to opt for clean production, energy saving and recycling [4–6]. Improving energy efficiency is an important way to resolve energy shortages and environmental pollution. The widespread application of ICT on one hand accelerates the construction of information infrastructure, while on the other hand, through scientific and technological innovation, it helps to explore the development path of digitalization and greening, and boosts energy saving and emission reduction [7].

As the world's second largest economy, although China has tremendous economic potential, there is still a lot of effort to be made in terms of energy conservation and emission reduction. In 2020, China's primary energy consumption increased by 2.1%, down from an average annual growth rate of 3.8% over the previous decade, while global primary energy consumption decreased by 4.5%, which was the largest and the first-ever decrease recorded. Over the past decade, the proportion of China in primary energy consumption has been increasing slightly, constituting 26% in 2020, ranking it first globally [8]. Figure 1 shows the primary energy consumption of China and the world, and China's proportion during the period 2010–2020, and it is evident that China has a high energy consumption level. It is to be noted that high energy consumption leads to high carbon emissions. The average annual growth rate of China's carbon dioxide emissions is 1.97% during the period 2010–2020, significantly higher than the world average annual growth rate of 0.31%, and its proportion of world carbon dioxide emissions shows a slight upward trend, comprising 31% in 2020, ranking first globally, as shown in Figure 2 [8]. China is currently facing a serious global challenge in terms of energy conservation and carbon emission reduction. Therefore, it has become increasingly urgent to implement various measures to improve energy efficiency.

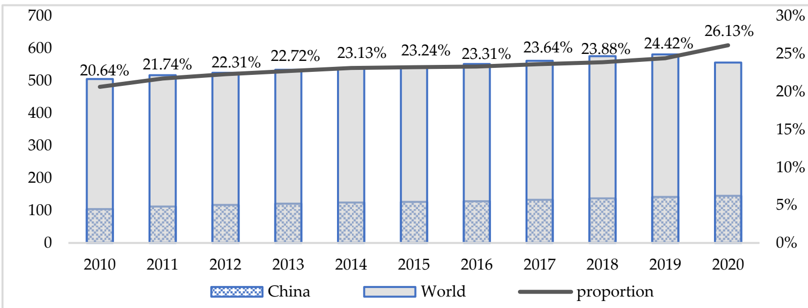

Figure 1. The primary energy consumption of China and the world, and China's proportion during the period 2010–2020 (EJ, %).

In September 2021, the "Opinions on Complete and Accurate Implementation of the New Development Concept to Do a Good Job of Carbon Peaking and Carbon Neutral Work" was issued by the Central Committee of the Communist Party of China and the State Council [9]. The document outlines several goals, including the improvement of energy efficiency in information technology infrastructure, such as data centers and new communications, acceleration of the development of new generation of information technology, and promotion of deep integration of emerging technologies such as the Internet, big data, artificial intelligence, and fifth-generation mobile communications (5G) with green and low-carbon industries. This highlights the vital role of ICT development in achieving energy conservation and emission reduction targets, providing a policy basis for this study to investigate the impact of ICT development on energy efficiency.

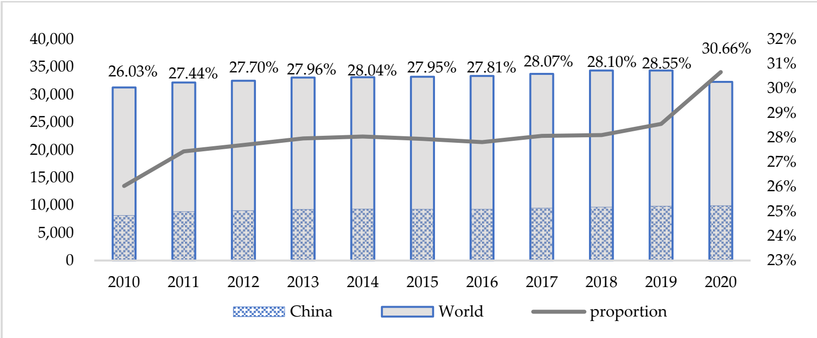

Figure 2. The carbon dioxide emissions of China and the world, and China's proportion during the period 2010–2020 (million tons, %).

To promote sustained economic growth and tackle pressing issues, such as energy conservation and emission reduction, this study aims to achieve the following objectives: (1) Measure the scale of ICT capital services in China and their distribution across industries as capital investment continues to grow. (2) Estimate the contribution of ICT capital services to China's economic growth and analyze differences in their contribution among 19 industries. (3) Investigate the impact of ICT capital services on energy efficiency, specifically examining whether they lead to improvements in energy efficiency.

The main contributions of this study are as follows: (1) Capital input in previous studies mostly is expressed as capital stock, whereas, referring to the Measuring Capital-OECD Manual 2009, this study measures capital services in China and 19 industries under the GDP accounting framework and takes it as capital input, which is in line with international accounting norms. (2) The impact of ICT capital services on energy efficiency in major energy-consuming industries is analyzed, and while this is mainly analyzed at the national level in previous studies, the industry level study is more specific. (3) Industry differences relating to the impact of ICT capital services on economic growth and energy efficiency are analyzed, which is conducive to understanding and addressing ICT development issues at an industry level.

To effectively address the objectives of this study, the rest of this paper is arranged as follows. Section 2 provides an overview of existing literature on the relationship between ICT and economic growth, as well as the relationship between ICT and energy efficiency. Section 3 describes the methods used to measure capital services, the contribution of ICT to economic growth, and energy efficiency. It also describes the panel regression model that is used to evaluate the impact of ICT on energy efficiency, and provides information on our samples and data sources. Section 4 presents empirical results, including the scale of capital services, the contribution of ICT capital services to economic growth, and the impact of ICT capital services on energy efficiency. Section 5 delves into the discussion of findings, and Section 6 concludes the paper with final remarks.

2. Literature Review

2.1. ICT and Economic Growth

The reasons for economic growth can be attributed to factor inputs and total factor productivity, and the significant contribution of ICT capital as an important component of capital input factors in economic growth has been confirmed in many studies. In the framework of economic growth accounting, Oliner and Sichel [10] divided capital into IT capital (hardware, software, and communication equipment) and other capital, and concluded that the contribution of IT capital to non-agricultural economic growth in the U.S. increased during the period 1974–1999, and its average contribution grew to 22.82% during the period 1996–1999. Jorgenson [11] showed that declining prices for IT products contributed to the post-1995 recovery in the U.S. economy, with the average contribution of IT capital to GDP at 29.85% during the period 1995–1999, which is significantly higher than the contribution in the earlier period. Jorgenson and Vu [12] decomposed the economic growth of the world's major economies, and the results showed that for the economic recovery period from 1995 to 2003, nearly half of the economic growth originated from the accumulation and efficient allocation of capital; and that the rapid growth of investment in IT capital equipment and software was the main driving force, leading to almost doubling its contribution to economic growth compared to the previous period. Vu [13] showed that the contribution of ICT capital to Singapore's GDP increased during the period 1990–2008, while in the period 2002–2008, its contribution to the growth was 33.30%.

Shahiduzzaman and Alam [14] constructed a linear production function model of IT capital affecting value-added, and the coefficients were 0.001, 0.08, and 0.07, respectively in the regressions over three time periods from 1975–2011; the contribution of IT declined slightly in the last period, but the contribution of IT capital to labor productivity and technological progress was continuously significant in Australia. Appiah-Otoo and Song [15] constructed an ICT development index from mobile, internet, and fixed broadband, divided 123 countries into rich countries and poor countries, and using regression analysis found that ICT contributed significantly more to GDP in poor countries compared to rich countries. Tsachtsiris et al. [16] used the Cobb–Douglas production function to estimate the output elasticity of ICT capital to GDP for the EU-27 countries, for the period 1996–2016, and concluded that for every 10% increase in ICT capital, GDP would increase by 0.92%; the result within the range of elasticities estimated by other studies and collated by Cardona et al. [17] exhibits a significant growth-promoting effect. Díaz-Roldán and Ramos-Herrera [18] applied panel data regression on the EU-27 countries during the period 2008–2018 and concluded that ICT promoted per capital economic growth in the European countries.

The impact of the development of ICT on China's economic growth has been addressed by some previous studies. Representative results and findings can be summarized as follows. The growth rate of gross products for China's information industries was 29.07% during the period 1991–2001, which was higher than that of the three traditional industries. The information abundance coefficient, which represents the development of ICT, had a strong and positive contribution to the growth of GDP [19]. Wang and Yu [20] calculated China's informatization index and found it had a greater driving effect on the value-added of secondary industry than primary and tertiary industries during the period 1990–2002. Sun et al. [21] studied the economic growth contribution of ICT in 33 industries during the period 1994–2005, and the results showed that the contribution of ICT to China's economic growth originated from increased ICT capital and TFP improvement in ICT industries; the improvement effect of ICT on TFP in other industries was not significant. Yang and He [22] analyzed the contribution of ICT capital to economic output and TFP in China over the period 1991–2013 using the economic growth accounting framework, and showed that the growth of hardware investment greatly influenced the contribution of ICT to the output growth and TFP, but lagged behind global levels. Liu and Zhang [23] measured the development of ICT from the internet penetration rate, total employment in the urban communication industry, mobile phone penetration, fixed broadband penetration rate, and constructed regression analysis with GDP using provincial data during the period 2008–2013. The conclusion was that ICT development plays a significant role in enhancing China's economic growth. The average contribution rate of the substitution effect of ICT capital to economic growth was 9.84% during the period 2010–2012 [24]; in the study of Cai and Niu [2], the average contribution was 7.65% during the period 2015–2018; and in the study of Zhou [25], the average contribution was 7.05% during the period 2016–2020. With the development of the digital economy, ICT is also regarded as digital technologies, which promote the development of China's digital economy through substitution and synergy effects [26].

From the review of existing studies, methods to analyze the impact of ICT on economic growth mainly include: (1) constructing an economic growth decomposition framework to decompose the contribution of ICT capital; (2) constructing a composite index of ICT development and conducting econometric regression; and (3) estimating the factor output elasticity of ICT capital on output. Furthermore, studies have mainly focused on the national level, but there are a few focused on the industry level. The impact of ICT on economic growth changes in different periods, with some studies indicating a weak impact in the early period, a strong boost in the middle period, and a slight turn to weakness in the late period. The measures of ICT capital invested to production differ between capital stock and capital services. Most studies measure the direct impact of ICT on economic growth, while some studies measure it indirectly in terms of promoting total factor productivity.

2.2. ICT and Energy Efficiency

The development of ICT is closely related to energy consumption and energy efficiency. Ishida [27] estimated the relationship between ICT and energy consumption in Japan and concluded ICT investment could contribute to a moderate reduction in energy consumption over the period 1980–2010. Schulte et al. [28] studied 27 industries in 10 OECD countries during the period 1995–2007 and showed that the development of ICT reduced non-electric energy demand, but it had no correlation with electric energy demand, and overall, significantly associated with the reduction in total energy demand. May et al. [29] analyzed research literature on energy management and showed that the application of ICT in process automation, production control, monitoring and decision making, and integration of processes and information flows improved energy efficiency. Khuntia et al. [30] found that green IT investment reduced energy consumption and was associated with a higher profit impact. The study by Zhang and Wei [31] showed that every time the standard deviation of the application of ICT in Chinese manufacturing enterprise production increased by one unit, the energy intensity would decrease by 0.23 units.

There are also studies indicating that ICT can increase energy consumption. Zhou et al. [32] found that ICT contributed to a 4.54% increase in energy intensity, but ICT input substitution was conducive to reducing energy use in production during the period from 2002 to 2012. Sun et al. [33] showed that the application of infrastructure, such as ICT, increased energy consumption in BRICS countries during the period 1990–2018. Meanwhile, Tzeremes et al. [34] thought that the development of ICT was beneficial to energy transition and solving environmental problems in BRICS countries. Wang et al. [35] constructed an ICT maturity index to study the impact of China's ICT development on energy consumption in different stages during the period 2001–2030, and concluded that although the development of ICT could slow down the continuous growth of energy consumption by improving energy efficiency, the use of ICT increased energy consumption; this was in line with the findings of Lange et al. [36]. Popkova et al. [37] concluded that the use of ICT in e-government could improve energy efficiency and reduce environmental pollution, and that there were differences in the effects between developed and developing countries. Bildirici et al. [38] studied the G7 countries during the period 1990–2020 and showed that in the short term, the development of ICT increased energy consumption and environmental pollution, but in the long term, it improved energy efficiency, promoted economic growth, and reduced environmental pollution. Hao et al. [39], and Gao et al. [40] constructed a comprehensive ICT development index for China's cities and provinces, and both studies concluded that the development of ICT promoted green total factor energy efficiency.

From the above studies, it can be seen that there are differences in findings as to whether ICT development increases or decreases energy consumption, mainly due to differences in the stage of the research and the research objectives. However, the results of previous studies have reached a consensus that ICT can promote energy efficiency. In addition, most existing research mainly focus on national level analysis.

In summary, most existing studies on the relationship between ICT and economic growth have neither reached a consistent conclusion nor provided a credible measurement of ICT capital services. Similarly, prior analyses on the relationship between ICT and energy efficiency have primarily focused on China's national level. In contrast, this study aims to measure the impact of ICT capital services on economic growth and energy efficiency at both national and industry levels. First, capital services in China and 19 industries are measured according to the Measuring Capital-OECD Manual 2009. Second, the direct contribution of ICT capital services on economic growth is decomposed using the economic growth decomposition framework and analyzed at national and industry levels; the industry differences are also discussed. Third, the energy efficiency of major energy-consuming industries is measured, and the impact of ICT capital services on energy efficiency and industry differences are analyzed by constructing a panel regression model.

3. Methods

3.1. Measurement of Capital Services

Capital input is an essential factor for economic growth. Measuring Capital-OECD Manual 2009 [41] points out that capital services are the flow of productive services from capital assets to production, which are suitable for production and productivity analysis. This study computes the total value of capital services as capital input and measures the scale of ICT capital input to analyze its impact on economic activities. This study divides capital into ICT capital and non-ICT capital based on the type of fixed asset investment. ICT capital is further divided into ICT hardware and ICT software, and non-ICT capital is further divided into three types: construction and installation works, equipment and apparatus purchase, and other costs. The capital input of each type of asset is measured using the following steps. (1) Collect the investment series of each type of asset, i.e., gross fixed capital formation. (2) Choose the appropriate retirement profile of asset. The retirement profile represents the random distribution process of asset retirement with the same age around the expected service life. Assets with the same type and age have the same expected service life, but in practice, assets with the same age exit the production process before or after reaching the expected service life. (3) Set a suitable age-efficiency profile, which shows an asset's loss in productive efficiency as it ages. (4) Compute productive stock of each type of asset using the perpetual inventory method. The quantity of capital services is derived from the productive stock. This study takes productive stock as the quantity of capital services, referring to Cai and Zhang [24]. (5) Estimate the price of capital services (the user costs) of each asset. The total value of capital services of each asset is obtained by multiplying the quantity of capital services by its corresponding price. The process can be described as shown in Figure 3.

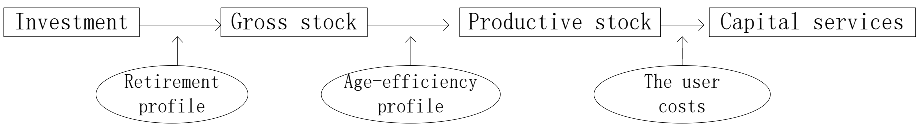

Figure 3. The measurement of capital input in the form of capital services.

3.1.1. Capital Investment Series—Gross Fixed Capital Formation

Gross fixed capital formation is used as the capital investment series and divided into five capital types: ICT hardware, ICT software, construction and installation works, equipment and apparatus purchase, and other costs. The explanation and acquisition process of the data are as follows.

(1) The gross fixed capital formation of the Computer, communication, and other electronic equipment manufacturing industry is used as the capital investment of ICT hardware.

(2) The gross fixed capital formation of the Information transmission, software, and information technology services industry is used as the capital investment of ICT software.

(3) The annual national data of gross fixed capital formation is obtained as a part of the GDP accounted via the expenditure method, and we adjust it to correspond to the GDP accounted via the production method.

(4) The gross fixed capital formation of ICT hardware is calculated using the national gross fixed capital formation from process (3) multiplying the proportion of gross fixed capital formation of computer, communication and other electronic equipment manufacturing in input–output tables.

(5) The gross fixed capital formation of ICT software is calculated by the national gross fixed capital formation from process (3) multiplying the proportion of gross fixed capital formation of Information transmission, software, and information technology services in input–output tables.

The missing data of the proportion (in process (4) and (5)) in the input–output tables are estimated according to the same structure of the adjacent years.

(6) We subtract the gross fixed capital formation of ICT software from the gross fixed capital formation of nation, and decompose the remaining value according to the proportion of construction and installation works, equipment and apparatus acquisition, and other costs in the fixed asset investment, and then subtract the gross fixed capital formation of ICT hardware from the equipment and apparatus acquisition.

Through the above process, the gross fixed capital formation of five asset types will be obtained at the national level.

(7) The gross fixed capital formation of ICT hardware and ICT software of 19 industries is estimated by decomposing the corresponding total according to intermediate inputs proportion of the computer, communication, and other electronic equipment manufacturing industry and information transmission, software, and information technology services industry to other industries from the input–output tables.

(8) The gross fixed capital formation of the other three type assets of 19 industries is obtained by decomposing the corresponding total according to the proportion of fixed asset investment of construction and installation works, equipment and apparatus acquisition, and other costs.

Through the processes (7) and (8), the gross fixed capital formation of five types of assets across 19 industries will be obtained.

To obtain the constant price investment series, the price index of each asset is estimated. The ICT hardware price index is estimated by the industrial ex-factory price index;l the ICT software price index is estimated by the consumer price index for communication services; and the price indices for construction and installation work, equipment and apparatus acquisition, and other costs are estimated by the respective investment price indices.

3.1.2. Retirement Profile

Referring to the Measuring Capital-OECD Manual 2009 [41], the retirement profile is set in the form of a lognormal distribution that is in common use, and the lognormal frequency distribution is shown in the following equation:

$$f(\tau) = \frac{1}{\tau\sigma\sqrt{2\pi}} e^{\frac{-(\ln\tau-\mu)^2}{2\sigma^2}} \quad (1)$$

where, σ is the standard deviation of the lognormal distribution, μ is the mean of the lognormal distribution and τ is the number of years since the asset is installed.

Where,

$$\sigma = \sqrt{\ln(1+(m/s)^{-2})}, \text{ and } \mu = \ln m - 0.5\sigma^2 \quad (2)$$

where, m and s are the mean and standard deviation of the normal distribution corresponding to the logarithmic normal distribution, respectively. m and s are estimated as half of the asset service life and $m/2$ respectively [24].

3.1.3. Age-Efficiency Profile

Referring to the Measuring Capital-OECD Manual 2009 [41], the hyperbolic age-efficiency profile is used to express efficiency declines over time for each type of asset, with the following expression:

$$E_\tau = \frac{E_0 * (T-(\tau-1))}{T-\beta(\tau-1)} (E_0 = 1, \tau = 1, \ldots, T) \quad (3)$$

where, T is the service life of the asset in years. Parameter β is the slope-coefficient, determining the rate of efficiency decline of asset. Referring to the Measuring Capital-OECD Manual 2009 [41], the parameter of construction and installation works takes a value of 0.75, and other assets take a value of 0.5. Referring to the study of Wang and Wang [42], the service life of construction and installation works, equipment and apparatus acquisition, and other costs assets have the values of 38 years, 16 years, and 20 years, respectively, and the service life of ICT hardware and ICT software assets both have the value of 8 years.

3.1.4. Productive Stock

Referring to the Measuring Capital-OECD Manual 2009 [41] and according to the perpetual inventory method (PIM), the formula for the productive stock of capital i in year τ is as follows:

$$K_{i,\tau} = \sum_{\tau=0}^{T} E_{i,\tau} S_{i,\tau} I_{i,\tau} \tag{4}$$

where,

$$S_{i,\tau} = 1 - F_i(\tau) = 1 - \int_0^{\tau} \frac{1}{\tau\sigma\sqrt{2\pi}} e^{\frac{-(\ln\tau-\mu_i)^2}{2\sigma^2}} d\tau \tag{5}$$

Equation (5) denotes the survival function of capital i in year τ, and $I_{i,\tau}$ denotes the constant price capital investment of i asset. The initial productive stock of each asset is measured using the growth rate method [42], which can be expressed as follows:

$$I_0 = A_0(1 + g_I)/(g_I + \delta) \tag{6}$$

where, A_0 is the capital investment in the initial year, g_I is estimated by the average annual growth rate of investment in various assets for five consecutive years since the initial year, and δ is the depreciation rate of asset.

3.1.5. The Price of Capital Services

Drawing on the equation for estimating the price of capital services from Jorgenson [11]:

$$C_{j,i,t} = r_{j,i,t} P_{j,i,t-1} + \delta_j P_{j,i,t} \tag{7}$$

where, $C_{j,i,t}$ is the price of capital services(the user cost) of j asset in the industry i in year t, $r_{j,i,t}$ is the actual return rate of j asset in the industry i in year t, $P_{j,i,t}$ is the price of j asset in the industry i in year t (the value of j asset in its year of purchase), and δ_j is the depreciation rate of j asset. Referring to Wang and Wang [42], the depreciation rate of ICT hardware and ICT software is all taken as 31.5%, and the depreciation rates of building and installation work, equipment and apparatus purchase, and other costs are taken as 8%, 18%, and 15%, respectively. The price of each asset $P_{j,i,t}$ is estimated by price indices, and the actual return rate of each asset is estimated by the capital compensation from the input–output tables according to the following process.

The value-added data in input–output tables are firstly adjusted corresponding to GDP accounted via the production method, and the missing value-added data in the input–output tables are estimated using the RAS method [43]. The value-added is allocated between labor and capital factors, and the net production tax is shared proportionally between capital and labor factors. Capital compensation can be expressed as:

Capital compensation = (depreciation of fixed assets) + (operating surplus) + (net production taxes) $*$ [((depreciation of fixed assets) + (operating surplus))/ ((labor compensation) + (depreciation of fixed assets) + (operating surplus))].

Combined with Equation (7), capital compensation can be expressed as:

$$\sum_j C_{j,i,t} K_{j,i,t} = \sum_j (r_{j,i,t} P_{j,i,t-1} + \delta_j P_{j,i,t}) * K_{j,i,t} \tag{8}$$

The left side of the equal sign is the capital compensation, $K_{j,i,t}$ is the productive stock, and the actual return rate on capital $r_{j,i,t}$ is calculated according to Equation (8), which is then taken into Equation (7) to obtain $C_{j,i,t}$. It is also assumed that the actual return rate for each type of asset does not differ among industries.

The above-mentioned data are for the period 2000–2020, derived from the China Statistical Yearbook and the China Input–output Table, deflated taking 2000 as the base year, and the data in the following text are also from these resources [44].

3.2. Measurement of ICT's Contribution to Economic Growth

Economic growth is decomposed as the contributions of capital, labor, total factor productivity and other factors, and abundant research have been conducted in this field. Based on existing studies, where the contribution of ICT to economic growth is mainly in the form of direct and indirect contributions, with the direct contribution derived from the intervention of ICT capital and its substitution of traditional capital, and indirect contribution derived from the improvement of total factor productivity by ICT capital [2], this study analyzes the direct contribution of ICT to economic growth. According to Jorgenson and Griliches [45], Hulten [46], and Cai and Zhang [24], the economic growth decomposition framework can be expressed as:

$$\frac{\dot{Y}_i}{Y_i} = \frac{\dot{A}_i}{A_i} + v_{iL}\frac{\dot{L}_i}{L_i} + \sum_a v_{iK_{a,ICT}}\frac{(\dot{K}_{a,ICT})_i}{(K_{a,ICT})_i} + \sum_b v_{iK_{b,NICT}}\frac{(\dot{K}_{b,NICT})_i}{(K_{b,NICT})_i} \quad (9)$$

($\frac{\dot{Y}}{Y}$ represents the growth rate of the output variable, v represents the share of each factor's output in total output, $K_{a,ICT}$ represents ICT capital of a, $K_{b,NICT}$ represents non-ICT capital of b, and i represents industry or country).

In this study, the output is GDP, the total value of capital services of the five assets calculated above are used for capital inputs, and urban employment is the labor input. The share of each factor's output in total output v is calculated by the value-added data from the input–output tables. Labor share is estimated by the share of labor compensation in value-added, and the shares of each type of capital are estimated by multiplying the share of capital compensation in value-added by the capital proportion of each asset.

The contribution of ICT capital input to the economic growth is expressed as:

$$ICT_i^{con} = (\sum_a v_{iK_{a,ICT}}\frac{(\dot{K}_{a,ICT})_i}{(K_{a,ICT})_i})/(\frac{\dot{Y}_i}{Y_i}) \quad (10)$$

The contributions of other factors are similar. They will be calculated separately for China and 19 industries.

3.3. Measurement of Energy Efficiency and the Regression Model of ICT and Energy Efficiency

Hu and Wang [47] proposed the concept of total factor energy efficiency (*TFEE*) to measure energy efficiency. Compared to single-factor energy efficiency, such as energy intensity, *TFEE* is more consistent with the actual production and efficiency definition [48]. *TFEE* is expressed as the ratio of the obtained target energy input to the actual energy input. The *TFEE* of the decision unit i in year t is expressed as:

$$TFEE(t,i) = \frac{Target\ Energy\ Input(t,i)}{\text{Actual}\ Energy\ Input(t,i)} \quad (11)$$

The value of *TFEE* ranges from 0 to 1. The lower the target energy input of the decision unit, the more redundant the energy input and the smaller the value of *TFEE*, the lower the energy efficiency. We introduce the SBM (slack-based measure) model of the DEA (data envelopment analysis) approach to measure efficiency [49], which is set as the input-oriented and constant return to scale. The amount of target energy input is obtained from the above model. The output variable is the sum of GDP and energy consumption expenditure, and input variables are energy consumption, labor employment, and the value of capital services measured above. Due to the limited availability of industrial energy consumption data, this study measures energy efficiency in the following seven industry sectors: Agriculture, forestry, animal husbandry, and fishery; Mining; Manufacturing; Electricity, heat, gas, and water production and supply; Construction; Transportation, storage, and postal services; and Wholesale, retail, hotels, and catering services; these industries account for about 84% of total energy consumption on average. The data is for the period 2000–2020, and data are deflated taking 2000 as the base year.

To analyze the impact of ICT development on energy efficiency, the following panel regression model is constructed.

$$TFEE_{it} = \beta_0 + \beta_1 lnICT_{it} + \sum \beta_j X_{it}^{j} + \mu_i + \lambda_t + \varepsilon_{it} X_{it} = [lnGDP_{it}, lnNICT, lnR\&D] \quad (12)$$

The explained variable is $TFEE$ in the industry i in year t. $lnICT$ is the logarithm of ICT capital services (the sum of ICT hardware and ICT software) in the industry i in year t. X includes the logarithm of industry GDP, non-ICT capital services and R&D expenditures. μ_i denotes the individual effect, λ_t denotes the time effect, and ε_{it} is the random perturbation term.

4. Measurement and Empirical Results

4.1. Capital Services

4.1.1. Capital Services of China

According to the above process in Section 3.1, the total value of capital services of each type of asset are derived, as shown in Table 1. The scale of construction and installation works is the largest, followed by equipment and apparatus purchase, and other costs; and the scale of ICT software is greater than ICT hardware from 2013, while the scale of ICT hardware is greater than ICT software in previous years. During the period 2000–2020, the growth rate of capital services for ICT software is the highest, at 34.97%, followed by ICT hardware, at 14.48%. The growth rate of capital services of construction and installation, equipment and apparatus purchase, and other costs are 11.90%, 13.80% and 12.11%, respectively.

Table 1. The total value of capital services of five types of assets during the period 2000 to 2020 (100 million).

Year	ICT Hardware	ICT Software	Construction and Installation Works	Equipment and Apparatus Purchase	Other Costs
2000	3327.60	261.82	128,682.05	24,396.39	16,667.42
2001	4794.21	406.31	161,613.06	32,228.90	23,067.11
2002	6679.86	633.52	194,149.23	38,125.79	30,104.31
2003	8662.19	853.89	217,043.52	43,654.20	36,778.68
2004	11,504.57	1124.18	251,817.92	52,329.30	44,365.69
2005	16,282.11	2004.93	347,364.43	60,728.70	62,877.71
2006	18,860.63	2984.23	387,069.09	74,441.31	64,906.15
2007	19,474.08	4110.20	432,306.52	89,922.25	74,118.67
2008	20,383.76	5666.07	481,997.17	104,439.60	81,383.23
2009	20,167.84	7109.75	496,996.03	109,431.78	80,186.69
2010	25,227.29	11,393.32	548,504.43	135,217.25	99,008.01

Table 1. *Cont.*

Year	ICT Hardware	ICT Software	Construction and Installation Works	Equipment and Apparatus Purchase	Other Costs
2011	23,780.54	15,055.13	477,057.59	141,153.11	95,916.42
2012	23,340.97	22,317.14	532,809.84	158,908.68	102,152.74
2013	23,991.86	31,698.74	597,654.42	188,275.82	113,366.54
2014	23,460.03	41,317.54	675,187.19	213,405.15	120,367.52
2015	22,865.66	52,447.16	768,932.43	241,479.77	125,277.41
2016	25,403.04	65,399.36	854,405.67	262,374.41	131,617.61
2017	30,480.66	78,061.51	956,344.22	273,993.63	136,369.61
2018	36,100.56	83,616.41	1,068,870.17	281,548.20	138,661.55
2019	42,180.37	92,838.19	1,162,303.63	302,936.77	149,665.00
2020	48,099.31	101,680.79	1,220,375.01	323,538.40	163,995.13
Average growth rate	14.29%	34.73%	11.90%	13.80%	12.11%

4.1.2. ICT Capital Services of Industries

The total value of ICT capital services of each industry is the sum of the value of ICT hardware and ICT software. The value of 19 industry sectors and of Computer, communication and other electronic equipment manufacturing industry for selected years are shown in Table 2. From the measured results, it can be seen that the use of ICT capital in each industry varies significantly. Taking the results of the year 2020 as an example, industries with more intensive ICT capital are Financial industry; Information transmission, software, and information technology services; Construction; and Computer, communication, and other electronic equipment manufacturing. The capital services proportion of ICT to the whole country is 8.87% in 2020 and there are 10 industries below 8.87%. The ICT capital services used in Water, environment, and public facilities management; Real estate; Mining; and Agriculture, forestry, animal husbandry and fishery is less than 1%.

4.2. The Contribution of Capital Services to Economic Growth

4.2.1. The Contribution of Capital Services to Economic Growth in China

The contribution of capital services to the overall economic growth of China is carried out by employing Equation (9). The results are presented in Tables 3 and 4. During the period 2000–2020, the contribution of non-ICT capital services to economic growth is 47.26%, making it the main supporting factor of economic growth, followed by TFP with 34.93%, and the contribution of labor and ICT capital services is 10.86% and 6.95%, respectively. The contribution of ICT hardware and ICT software is 2.27% and 4.68%, respectively. In terms of the trends, the contribution of ICT hardware decreases initially and then increases, and the contribution of ICT software continues to increase, which is consistent with the aforementioned trend of capital services of ICT hardware and ICT software. The results indicate that the role of ICT software in economic development is gradually increasing. The contribution of labor to economic growth initially shows an increase, followed by a decrease, which correlates with the decreasing trend of employment from 2015.

Table 2. The ICT capital services of industries for selected years (100 million).

Industry Classification	2010	2012	2014	2016	2018	2020	ICT Proportion in 2020 (%)
Agriculture, forestry, animal husbandry and fishery	322.09	320.11	355.54	419.28	479.51	572.18	0.94
Mining	147.18	242.71	393.45	511.75	339.68	306.28	0.82
Manufacturing	25,957.38	24,475.15	25,987.42	30,431.77	41,206.36	53,613.20	8.87
Computer, communications and other electronic equipment manufacturing	18,784.51	17,147.83	17,194.04	19,330.25	28,484.68	38,116.75	52.29
Electricity, heat, gas and water production and supply industry	396.40	478.54	801.96	1204.20	1128.25	1210.29	1.48
Construction	2197.61	3563.86	6747.97	10,425.91	10,140.62	11,112.72	52.41
Wholesale and retail	669.58	753.48	1111.39	1708.11	2273.56	2832.48	6.68
Transportation, storage and postal industry	619.72	1180.56	2120.87	3485.03	5294.02	6764.58	4.12
Hotels and catering industry	106.25	198.84	323.96	471.81	726.39	928.31	5.01
Information transmission, software and information technology services	1630.86	5741.87	11,976.72	19,998.59	28,316.53	35,558.17	64.74
Financial industry	1237.18	2969.40	5298.53	7619.26	9510.54	11,449.81	77.38
Real estate	192.68	370.63	666.73	1042.83	1370.84	1680.17	0.42
Leasing and business services	1042.32	1069.72	1568.39	2349.74	3068.97	3802.16	10.25
Scientific research and technical services	376.90	737.34	1116.90	1676.42	2930.59	3927.92	19.96
Water, environment and public facilities management industry	86.08	139.80	250.14	384.09	408.42	473.63	0.25
Residential services, repairs and other services	264.21	382.82	528.39	680.88	857.30	1084.97	14.31
Education	265.58	580.33	1013.20	1402.77	1712.78	2047.88	6.43
Health and social work	238.01	520.03	950.76	1464.57	1861.66	2279.64	10.92
Culture, sports and entertainment	87.28	167.48	305.77	462.45	594.72	723.10	2.95
Public administration, social security and social organizations	783.32	1765.43	3259.50	5062.93	7496.22	9412.61	29.27

Table 3. The sources of economic growth in different stages during the period 2000–2020 (%).

Stages	GDP	ICT Capital	ICT Hardware	ICT Software	Non-ICT Capital	Construction and Installation Works	Equipment and Apparatus Purchase	Other costs	Labor	TFP
2000–2005	8.47	0.49	0.43	0.06	4.64	2.72	1.23	0.68	0.64	2.70
2006–2010	9.63	0.41	0.21	0.20	4.54	3.01	1.11	0.42	1.38	3.30
2011–2015	7.65	0.49	−0.02	0.51	3.40	2.09	1.06	0.25	1.29	2.47
2016–2020	4.73	0.48	0.16	0.33	2.36	1.66	0.48	0.22	0.45	1.44
2000–2020	7.96	0.55	0.18	0.37	3.76	2.42	0.98	0.37	0.86	2.78

Note: The geometric mean is calculated at different stages.

Table 4. The contribution of different factors to economic growth in different stages during the period 2000–2020 (%).

Stages	GDP	ICT Capital	ICT Hardware	ICT Software	Non-ICT Capital	Construction and Installation Works	Equipment and Apparatus Purchase	Other Costs	Labor	TFP
2000–2005	100	5.82	5.13	0.69	54.71	32.12	14.55	8.04	7.58	31.89
2006–2010	100	4.26	2.14	2.11	47.14	31.26	11.53	4.36	14.33	34.27
2011–2015	100	6.39	−0.27	6.67	44.46	27.34	13.83	3.30	16.80	32.34
2016–2020	100	10.22	3.32	6.91	49.88	35.19	10.06	4.62	9.46	30.44
2000–2020	100	6.95	2.27	4.68	47.26	30.35	12.30	4.61	10.86	34.93

4.2.2. The Contribution of ICT Capital Services to Economic Growth in Different Industries

The contribution of ICT capital services to economic growth in industries for the selected years are shown in Table 5. Differences in ICT capital services of different industries lead to different contributions to the economic growth. The industries with higher contributions are Financial industry; Information transmission, software, and information technology services; and Construction. The industries with lower contributions are Agriculture, forestry, animal husbandry and fishery; Mining; Electricity, heat, gas and water production and supply; and Water, environment, and public facilities management. From the above analysis, it can be seen that the ICT capital services of each industry are increasing over the years, but do not show a significant upward trend of contribution to economic growth in the industry as a whole, and most industries show fluctuations. Due to the impact of COVID-19, economic growth is weak in 2020, with some industries showing negative growth rates, and the contribution of ICT capital services also indicates a negative effect. The development of ICT and its integration effect can drive efficient development of traditional industries and help with digital transformation and upgradation of industry development [2]. Currently, significant difference in ICT investment across industries is one of the main reasons for differences in their levels of development. Increasing the penetration effect of ICT on traditional industries will be an important direction to take to narrow the industry development gap, and accelerate high-quality development in each industry sector.

4.3. Energy Efficiency and the Impact of ICT on Energy Efficiency

4.3.1. Energy Efficiency

The average energy efficiency of seven high energy consuming industries is shown in Table 6. The results show that in the comparison of the seven industries, Agriculture, forestry, animal husbandry and fishery has the highest energy efficiency with an average level of 0.99, followed by Wholesale, retail, hotels and catering with an average level of 0.954; Construction has an average level of 0.892, while the remaining industries have lower energy efficiency levels between 0.3 and 0.6, which are significantly lower when compared with the top three. The lowest energy efficiency level is in Electricity, heat, gas and water production and supply, with an average level of 0.368. As seen from Figure 4, the energy efficiency of Construction, and Wholesale, retail, hotels and catering fluctuates significantly, and except for Agriculture, forestry, animal husbandry and fishery, the remaining industries show a slightly upward trend. The energy efficiency in the seven industries as a whole shows an upward trend, but the overall level is not high; the average level is 0.697 during the period 2016–2020, which indicates that energy consumption redundancy is 30.3%. The cumulative redundant emission of CO_2 during the period 2016–2020 is calculated to be 13,611.858 (Mt) based on the proportion of energy consumption shown in Table 6. This figure highlights the potential for reducing CO_2 emissions by 13,611.858 (Mt) if we can save 30.3% of energy. Given the current push for energy conservation and emission reduction, improving energy efficiency has become an essential and inevitable trend.

Table 5. Contribution of ICT capital services to economic growth in industries for selected years (%).

Industry	2001	2006	2008	2010	2012	2014	2016	2018	2020
Agriculture, forestry, animal husbandry and fishery	1.85	3.51	0.50	0.83	0.13	0.46	0.96	0.09	0.09
Mining	1.10	0.62	0.07	0.43	1.09	−1.00	0.21	2.05	0.72
Manufacturing	33.42	13.79	16.12	13.71	12.46	12.31	34.14	20.03	28.66
Electricity, heat, gas and water production and supply industry	0.31	0.58	0.42	0.70	0.70	4.94	5.05	0.38	0.56
Construction	17.71	9.86	10.18	24.83	42.53	39.42	39.03	36.31	−18.91
Wholesale and retail	4.27	2.84	0.35	3.90	2.33	5.50	9.70	3.76	−2.63
Transportation, storage and postal industry	0.30	0.98	1.56	1.81	6.59	4.64	7.33	5.87	−3.25
Hotels and catering industry	3.33	3.35	1.45	3.03	3.89	2.45	2.76	5.83	−1.42
Information transmission, software and information technology services	14.74	23.27	22.80	42.23	32.15	36.28	39.20	27.40	39.01
Financial industry	48.44	36.49	42.32	39.05	28.37	30.48	36.81	41.89	43.98
Real estate	0.03	0.06	1.95	0.31	1.14	1.81	0.50	0.31	2.96
Leasing and business services	18.34	−4.01	8.84	6.10	6.94	11.51	7.07	1.41	−4.26
Scientific research and technical services	5.79	−2.08	5.59	6.93	18.67	13.91	24.51	14.96	11.13
Water, environment and public facilities management industry	0.03	0.21	0.16	0.18	0.21	0.32	1.06	−0.10	0.09
Residential services, repairs and other services	4.33	34.43	13.38	6.07	28.31	4.77	3.55	3.31	2.62
Education	0.06	0.47	0.25	0.20	3.47	2.34	2.28	1.24	1.84
Health and social work	0.55	5.85	2.99	2.36	4.13	3.47	3.48	1.01	4.18
Culture, sports and entertainment	0.58	1.68	0.29	0.76	5.41	4.58	3.63	1.75	1.26
Public administration, social security and social organizations	0.10	0.23	0.20	4.07	9.45	9.87	2.96	8.35	9.61

Note: When calculating the contribution of ICT capital services of each industry, some data appear as outliers with extremely large or small values, because the ICT growth rate is much bigger than the GDP growth rate. To reduce abnormal fluctuations in the data, the average level of the adjacent year is used instead.

Table 6. Average energy efficiency and cumulative redundant emissions of CO_2 of different industries at different stages.

Industries	2000–2005	2006–2010	2011–2015	2016–2020	AVERAGE
Agriculture, forestry, animal husbandry and fishery (AFAF)	0.998	1.000	0.982	0.981	0.990
Mining (MIN)	0.434	0.521	0.513	0.523	0.498
Manufacturing (MAN)	0.475	0.451	0.536	0.569	0.508
Electricity, heat, gas and water production and supply (EHGW)	0.365	0.363	0.370	0.373	0.368
Construction (CON)	0.812	0.901	0.933	0.921	0.892
Transportation, storage, and postal industry (TSP)	0.465	0.486	0.469	0.511	0.483
Wholesale, retail, hotels, and catering (WRHC)	0.931	0.942	0.943	0.999	0.954
AVERAGE	0.640	0.666	0.678	0.697	——
CO2 Cumulative Redundant Emissions (MT)	7961.734	10,857.814	13,994.132	13,611.858	——

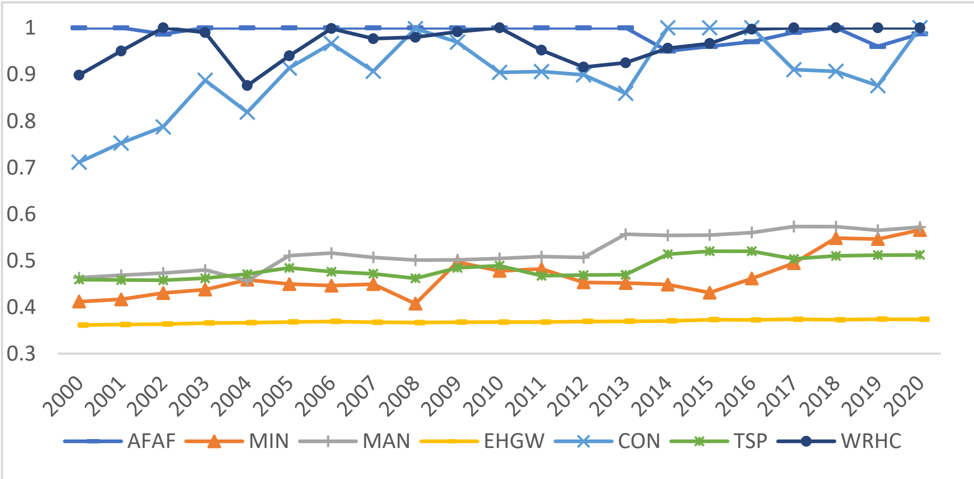

Figure 4. Changing trend of energy efficiency from 2000 to 2020.

4.3.2. The Impact of ICT on Energy Efficiency

Based on the literature review above, it can be seen that existing studies have tested if ICT can improve energy efficiency using national level data and different methods. This study aims to test the impact of ICT on energy efficiency from industry level panel data by calculating ICT capital services, which differs from the previous calculation of capital stock and national level analysis.

1. Unit root test and multicollinearity test

To avoid pseudo-regression and ensure the validity of the estimation results, the data are first tested for stationarity. The results obtained using the common panel unit root test are shown in Table 7, which demonstrates that the original data are stationary.

Table 7. Unit root test of variables.

Variables	Testing Method				Identify
	LLC	**IPS**	**ADF-Fisher**	**PP-Fisher**	
TFEE	−2.5841 *** (0.0049)	−2.4828 *** (0.0065)	−4.0813 *** (0.000)	−1.9324 ** (0.0267)	Stationary
lnICT	−6.4011 *** (0.000)	−2.3993 *** (0.0082)	−3.8205 *** (0.0001)	−4.2745 *** (0.000)	Stationary
lnNICT	−8.9370 *** (0.000)	0.8082 (0.7905)	−4.8534 *** (0.000)	−10.7403 *** (0.000)	Stationary
lnGDP	−3.7475 *** (0.0001)	−0.8231 (0.2052)	−4.5479 *** (0.000)	−1.9387 ** (0.0263)	Stationary
lnR&D	−1.4799 * (0.0694)	−1.5649 * (0.0588)	−3.8393 *** (0.0001)	−0.5818 (0.2803)	Stationary

Note: ***, **, * indicate significance at 1%, 5%, and 10% significance levels, respectively, and p values are in parentheses.

The result of the multicollinearity test is shown in Table 8. All the values of variance inflation factor (VIF) are less than 10, therefore, the multicollinearity problem can be ignored.

Table 8. Multicollinearity Test.

Variables	VIF	1/VIF
lnICT	2.88	0.3476
lnNICT	1.98	0.5058
lnGDP	1.84	0.5449
lnR&D	1.14	0.8777
Mean VIF	1.96	

2. Panel regression results

The random effect model is selected based on the Hausman test, and the feasible generalized least squares (FGLS) method is used to estimate the regression model (Equation (12)). To test the robustness of the regression model, the energy intensity of each industry is used as a proxy variable for energy efficiency and then regressed.

$$\text{Energy intensity (EI)} = (\text{energy consumption})/\text{GDP} \tag{13}$$

Regression results are shown in Table 9. In the basic regression result (1) of the two variables, the coefficient of the effect of ICT on *TFEE* is 0.0117, which is significantly positive, and after adding other control variables, the coefficient decreases to 0.0039, which indicates that the introduction of other variables dilutes the positive effect of ICT on energy efficiency, e.g., the coefficient of GDP on *TFEE* is 0.2041, which is significantly greater than that of ICT, and means GDP has a significant promoting effect on energy efficiency. In the robustness test with energy intensity (EI) as the substitution, the positive effect of ICT on *TFEE* remains significant. The panel regression results indicate that development of ICT promotes energy efficiency to some extent, which provides an experiential basis for strengthening ICT development in each industry.

Table 9. Regression coefficients of ICT and other variables on energy efficiency.

IV \ DV	(1) *TFEE*	(2) *TFEE*	(3) EI	(4) EI
lnICT	0.0117 * (0.051)	0.0039 ** (0.0436)	0.1279 ** (0.032)	0.0202 * (0.0658)
lnGDP	— —	0.2041 *** (0.001)	— —	0.5969 *** (0.0001)
lnNICT	— —	0.0174 (0.603)	— —	0.3002 *** (0.000)
lnR&D	— —	−0.0165 ** (0.014)	— —	0.0014 * (0.0911)
β_0	0.6391 *** (0.000)	1.1815 * (0.083)	0.7391 *** (0.01)	1.9555 * (0.089)

Note: ***, **, * indicate significance at 1%, 5%, and 10% significance levels, respectively, and p values are in parentheses. The sample observation value is 147.

In our panel data, the length of the time series is longer than the number of sections. In order to observe the different effects of ICT on energy efficiency in each industry, the variable coefficient model is introduced to estimate different slopes. The same panel data is analyzed using the random coefficient model, which is also estimated using FGLS. The main results (the coefficients of ICT on energy efficiency) are presented in Table 10. It can be seen that the positive effect of ICT on energy efficiency is significant and robust in industries such as Agriculture, forestry, livestock and fishery (AFAF), Mining (MIN), Manufacturing (MAN),and Wholesale, retail, hotels and catering (WRHC). The magnitude of the coefficients can be used to compare the different effect of ICT on *TFEE* in different industries. For Result (1) with *TFEE* as the explanatory variable, the largest ICT positive effect is in the Mining industry (MIN), and for Result (2) with energy intensity (EI) as the explanatory variable, the largest ICT positive effect is in the Manufacturing (MAN), so it is inferred that the positive impact of ICT development on these two industries is larger. The impact on Transportation, storage and postal (TSP) is negative in Result (1) and is not significant in Result (2), from which it is inferred that ICT capital is not the main driving force in achieving energy efficiency improvement in Transportation, storage, and postal industry (TSP). The coefficients for Electricity, heat, gas and water production and supply (EHGW), and Construction (CON) change from insignificant to significant from Result (1) to Result (2), and the positive impact of ICT shows instability. The regression coefficients of different industries indicate significant differences in the effect of ICT on energy efficiency, but the regression result of all samples including seven industries show that, overall, the development of ICT has a positive effect on the improvement of energy efficiency.

Table 10. Regression coefficients of random coefficient model of ICT on the energy efficiency of different industries.

Industries	AFAF	MIN	MAN	EHGW	CON	TSP	WRHC
(1) *TFEE*	0.03075 ** (0.04)	0.0324 ** (0.013)	0.0008 * (0.0947)	−0.00194 (0.799)	0.0105 (0.44)	−0.0024 ** (0.033)	0.0277 * (0.076)
(2) EI	0.0249 * (0.0629)	0.044 *** (0.007)	0.2318 *** (0.000)	0.1284 *** (0.000)	0.0118 ** (0.032)	0.01417 (0.548)	0.0963 ** (0.031)

Note: ***, **, * indicate significance at 1%, 5%, and 10% significance levels, respectively, and *p*. values are in parentheses. Regression coefficients for non-core variables are omitted.

5. Discussion

This study measures capital services as capital input, calculates the direct contribution of ICT capital input to economic growth, and tests the impact of ICT capital on energy efficiency.

(1) The capital is classified as ICT capital and non-ICT capital, which are measured as capital services at the national level for 19 industries. From the measurement results, the proportion of ICT capital services to the total is low, and the average proportion for the last five years is 7.50%. This indicates that although the trend of the proportion of ICT capital services tends to increase year on year and shows good development momentum, ICT capital investment is low in China.

According to the results of existing studies, the proportion of ICT capital services during the period 1994–2014 was between 5–8% [42], it was 6.75% in 2002 and 12.62% in 2020 [25]. In our study, however, from 2000 to 2014, it is between 2–6%, 3.5% in 2002, and 8.06% in 2020. The differences in results are mainly due to different calculation methods and base periods. In references [25,42], the authors use a geometric age-efficiency profile. In that model, the service provided by assets decreases significantly in the first year and gradually decreases thereafter. In contrast, the hyperbolic age-efficiency profile used in this study shows a slower decrease in the initial period and a quicker decrease in the later periods. The latter is more in line with the characteristics of asset provision services. Additionally, they apply simultaneous exit retirement profile, which assumes that all assets are retired from the capital stock when they reach the average service life for the type of asset concerned. This approach has a certain degree of "suddenness", as regardless of whether the asset still has production capacity, it is assumed to exit production. Therefore, the simultaneous exit retirement profile is not suitable for actual production. This study introduces lognormal distribution, which indicates that the retirement probability of an asset gradually increases with time, and then gradually decreases when reaching the maximum retirement probability near the average service life; this process is more in line with the reality.

The Financial and Construction industries hold a leading position in the proportion of ICT capital services compared to other industries. Popelo et al. [50] conclude that information technologies play an important role in the rapidly evolving modern digitalization processes, and promote financial innovations that contribute more to the economic development of countries. In particular, the technological innovation of payment methods in China has stimulated the development of the Financial industry and accelerated the process of industrial evolution [51]. Lu et al. [52] believe that in the past two decades, under the background of the integration of the global Construction industry and ICT, the Construction industry in China has regarded ICT application as the primary reform direction, and has adopted a large number of ICT tools, such as artificial intelligence, building information modeling, and management information system, which have brought significant changes in the way of working and production. The proportion of ICT capital services in Agriculture, forestry, animal husbandry, fishery; Mining; Real estate; and Water conservancy, environment, and public facilities management industry is less than 1% in 2020, highlighting that the development of ICT varies significantly among industries. Currently, with the rapid development of digitization, industries need to strengthen the introduction of ICT to meet the needs of the times, especially those industries mentioned above with low ICT capital input.

(2) The contribution of ICT capital services to economic growth is measured, and at the national level, the direct contribution of ICT capital services is about 6.95% during the period 2000–2020, which is significantly lower than the 47.26% contribution from non-ICT capital services, thus indicating that the contribution generated by the direct substitution effect of ICT capital to traditional factors is at a low level. With the continuous development of ICT and its integration into production activities, there is still much room for future improvement.

The size of the contribution of ICT capital services to economic growth is basically in line with the size of ICT capital proportion in each industry, i.e., a high ICT capital proportion in an industry is associated with a higher contribution to economic growth, and vice versa. The direct contribution of ICT capital services to economic growth is 7.65% during the period 2015–2018 as estimated by Cai and Niu [2], and it is 14.14% during the period 2016–2020 according to Zhou [25]. In this study, we estimate the contribution to be 10.22% during the period 2016–2020. The main reason for the difference is the inconsistency in the capital service measurement methods mentioned above. It is worth noting that this estimate may have been affected by the COVID-19 pandemic in 2020, which has lowered the overall economic growth level. Nevertheless, upon comparing the results, we believe that the difference in different studies falls within an acceptable range.

(3) The energy efficiencies of seven industries with high energy consumption are measured. Agriculture, forestry, animal husbandry and fishery; Wholesale, retail, hotels and catering; and Construction industries show significant high energy efficiency, i.e., the industries with relatively low energy consumption show higher energy efficiency, and industries with more energy consumption have more room for energy saving and consumption reduction.

The Electricity, heat, gas and water production and supply industry has the lowest energy efficiency. Among them, coal-based thermal power generation has long been the main source of power generation in China, and has high energy consumption and carbon emissions. Although the coal-fired power industry is more mature than other energy industries, the expansion of thermal power generation is not appropriate if energy and CO_2 emissions are to be reduced [53]. According to the study by Zuo et al. [54], freight energy consumption will reach its peak value of 145 million tonnes of standard coal in 2029, so the Transportation, storage, and postal industry, with low energy efficiency, faces an acute task of reducing energy consumption. The results from the panel regression analysis on the relationship between ICT capital services and energy efficiency suggest that, on the whole, the development of ICT has a positive impact on promoting energy efficiency, which is in line with the findings from previous studies [38–40]. However, the effect varies across different industries, with some showing instability or insignificant results. Improving energy efficiency is an inevitable requirement for the development of all industries and enhancing the application of ICT to achieve greater energy efficiency gains is also an effective path. However, attention needs to be paid to the rebound effect when improving energy efficiency to save energy [55,56]. Some collaborative policies, such as energy price reform, carbon tax, and energy tax, should be implemented together with energy efficiency policies to address this issue.

6. Conclusions

This study calculates the capital services of 19 industries in China by asset types during the period 2000–2020, and analyzes the current situation of ICT investment in different industries. Some branches of the economy, such as Financial industry; Information transmission, software and information technology services; Computer, communications and other electronic equipment manufacturing; and Construction industry use more ICT capital. Varied retirement and age-efficiency profiles is one of the reasons for the differences in capital services between different research. Capital investment has always been a key driving force for China's economic growth, and with the development of the digital economy, ICT capital will play an increasingly important role in future economic growth. Improving energy efficiency is also an important factor for sustainable development, which requires not only the assistance of ICT capital, but also many supportive policies to jointly promote energy conservation and emission reduction. In conclusion, this study highlights the significance of ICT development and reveals that China needs to increase investment in ICT capital and bridge the gap across different industry sectors.

This study can shed light on policy design and implementation in several areas. With the rapid development of ICT, enterprises must prioritize fully developing ICT and utilize digital technology to promote green development, particularly in industries with high energy consumption and low energy efficiency, such as Electricity, heat, gas and water production and supply; Transportation, storage and postal; and Mining. Intelligent supervision and monitoring through big data, cloud computing, and Internet of Things can help to reduce energy consumption and emissions while balancing supply and demand. Additionally, enterprises can accelerate the integration of ICT with production, which is crucial to drive economic growth and narrow the development gap. Finally, strengthening science and technology innovations through advanced information development can help to achieve the goal of energy saving and "double carbon" reduction by realizing the application of CCUS (Carbon Capture, Utilization and Storage).

However, this study has some limitations that require further investigation. Firstly, while it measures the direct contribution of ICT to economic growth, it does not consider the indirect contribution of ICT to economic growth through efficiency improvement. To address this limitation, one potential solution is to refine the underlying algorithm used in this study to capture the impact of ICT on energy efficiency improvement. Secondly, due to limited availability of industry data, this study only examines the impact of ICT on energy efficiency over a limited time span. To expand the scope of the study, collecting more industry data and observing how the impact of ICT on energy efficiency changes over a longer time period and across different stages of development may be necessary.

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