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Understanding the Nonlinear Impact of Information and Communication Technology on Carbon Emissions in the Logistics Industry of China

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Abstract: Information and communication technology (ICT) has broken the boundaries of traditional geographical space, and thus substantially promoted the development of the logistics industry. However, the effect of ICT on the carbon emissions of the logistics industry (CELI) has not been systematically explained. With Chinese provincial data from 2000 to 2018, this paper uses static and dynamic panel models and three robustness test methods to unveil the nonlinear impact of ICT (taking Internet usage as a proxy) on CELI. Some significant findings are concluded in this paper. (1) The relationship between Internet usage and CELI is inverted U-shaped, with the curve's inflection point emerging in 2015. (2) The formation of the inverted U-shaped relationship is determined by the different roles of total factor productivity (TFP) and the express delivery business of the logistics industry. Specifically, Internet usage plays a positive role in TFP, which reduces carbon emissions but simultaneously increases carbon emissions by promoting the development of express delivery business. (3) The relationship between Internet usage and CELI is an inverted U-shape in the eastern and western regions, while in the central region, the relationship is linear. According to the findings, some policies at country, region and enterprise levels are highlighted in order for policymakers to utilize ICT to achieve reductions in carbon emissions.

Keywords: carbon emissions; logistics industry; information and communication technology; internet penetration rate; inverted U-shaped relationship

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1. Introduction

With the advent of the digital era, the wide application of information and communication technology (ICT) in industries has deeply changed development modes, methods of value creation, competitive patterns [1], and production organization models [2], and has also improved productivity [3]. According to China Internet Development Report 2021, the integration of ICT into the real economy has promoted the digital economy on a scale of up to CNY 39.2 trillion, with China ranking second in the world at the end of 2020. As an important channel through which ICT affects industries, Internet usage has been an important foundation for the digital transformation of the Internet economy. It is worth noting that China has 989 million Internet users, the Internet penetration rate has reached 70.4%, and the total number of mobile Internet users has exceeded 1.6 billion. As we know, the logistics industry (according to the classification standard of National Economic Industries of China (GB/T4754-2017, [4]), the logistics industry consisting of transportation, storage, and post and telecommunication industries, as referred to in this paper) is the main support for the offline business of digital economy. However, the logistics industry has become one of the largest and most important contributors to energy consumption and carbon emissions in the Chinese energy structure, with the rapid development of digital economy [5]. In 2020, the largest-ever decline in global emissions occurred due to the COVID-19 pandemic, but the annual carbon emissions of China still increased. In response to the rising pressure to reduce carbon emissions, China has committed to achieving a carbon peak by 2030, and carbon neutrality by 2060 [6]. At present, the Chinese logistics industry not only bears the service pressure caused by the rapid development of the digital economy, but also faces the strict constraints of carbon emissions targets [7]. Therefore, it is vital to discuss the mechanisms of the impact of ICT's application on the carbon emissions of the logistics industry (CELI), and to provide policies targeted at reducing carbon emissions.

There are many factors affecting carbon emissions at industry level or country level, such as economic growth, FDI and energy intensity [8], real output and renewable energy consumption [9], corruption [10], digital economy [11], and technological innovation [12,13]. In particular, the rapid growth of ICT, as the most important impetus of economic growth [14], is believed to have a significant impact on energy conservation and the reduction of carbon emissions [15]. However, due to the different characteristics of various industries, the application of ICT has a heterogeneous effect on carbon emissions at the industrial level. For example, Shabani and Shahnazi found that ICT increases the carbon emissions of the agricultural and industrial sectors, while reducing them in the transport and service sectors [16]. Many studies on the relationship between ICT and carbon emissions pay more attention to the manufacturing industry or countries. For the logistics industry, the efficient development of modern logistics closely depends on the media and platform provided by the Internet. In addition, the logistics industry is less energy-intensive than the traditional manufacturing industry. Therefore, the application of ICT in the logistics industry may have a vital and distinct influence on carbon emissions, which may also be very different from other industries. On the one hand, the Internet's development is conducive to strengthening the deep integration of ICT and the logistics industry, which may reduce total carbon emissions by improving the technical efficiency and energy utilization efficiency of the logistics industry. On the other hand, ICT can promote the growth of express delivery businesses (express delivery is an important component of logistics, and the variation in express delivery businesses is a good representative of the development of the logistics industry), which should increase carbon emissions by increasing energy consumption. Therefore, the impact of ICT on CELI is theoretically uncertain. This judgment is similar to the viewpoint of Raheem et al., who consider ICT a double-edged sword that can harm and benefit the environment [17].

This paper aims to investigate the potential connection between ICT and CELI for useful and timely policies targeting the goal of reducing carbon emissions in China. Prior research on the impact factor of CELI has discussed the role of the digital economy [11] or technological innovation [12,13]. Nevertheless, our research examines the relationship between ICT and CELI from the more micro perspective of Internet usage, which is distinct from other macro perspectives, such as the digital economy. The domain of the digital economy is broad and vague, and thus it is difficult for conclusions about the impact of the digital economy on CELI to provide clear and specific implications for policy makers. Additionally, compared with the ICT index with multiple dimensions (e.g., Ahmed et al. [18]), this paper takes an indicator, the Internet penetration rate, as the measure of the development of ICT. Internet users are the end customers of the Internet economy, and Internet usage is the final reflection of the application of ICT; thus, we argue that the Internet penetration rate can act as a measure of the development of ICT in the logistics industry. As shown in Figure 1, the growth of Chinese Internet users is positively related to the trend in CELI. Therefore, the Internet penetration rate, as an important reflection of the application of ICT in logistics, may have a vital impact on CELI. Second, we identify the nonlinear impact of Internet usage on CELI, and accurately estimate the inflection point of the inverted U-shaped relationship between Internet usage and carbon emissions in different regions of China. Third, we explain the impact mechanism of Internet usage on CELI, and try to deepen our understanding of the internal logic of the impact of Internet usage on carbon emissions. Specifically, we find that Internet usage can affect carbon emissions by promoting the development of express delivery business and improving the technical efficiency of the logistics industry. Considering the regional differences in industrial distribution and resource endowment, we further find that the impact of Internet usage on CELI varies in different regions. Our conclusions are of great practical importance for China to reduce carbon emissions while maintaining economic growth and realizing the coordinated development of the economy and environment.

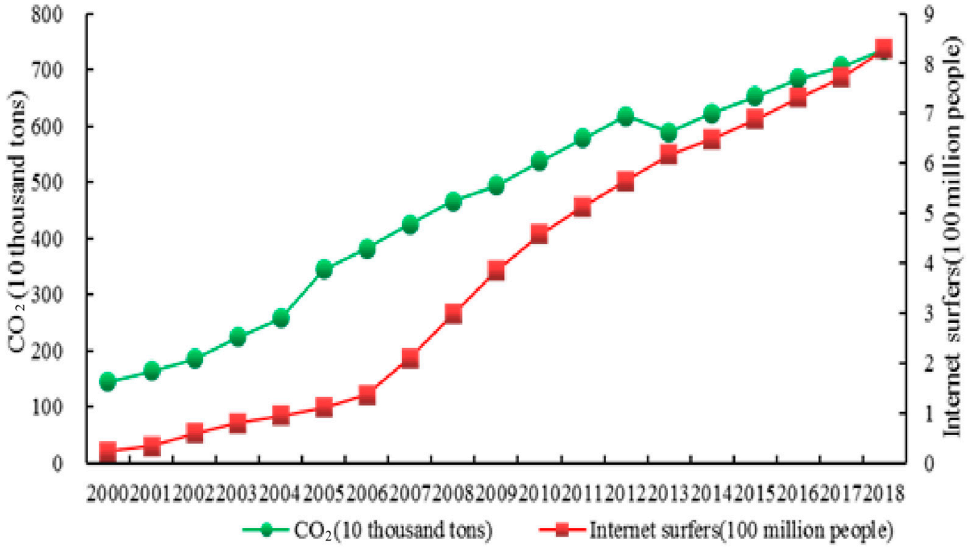

Figure 1. The relationship between Internet users and CELI (the data are from Statistical Reports on Internet Development in China and the China Statistical Yearbook on Environment. The units of CO_2 and Internet surfers are 10 thousand tons and 100 million people, respectively).

The rest of this paper is organized as follows. The literature is reviewed in Section 2. Section 3 is a simple theoretical analysis and Section 4 provides a detailed description of the empirical methods and data sources. The results of empirical analysis and mechanism discussion are presented in Section 5, and Section 6 presents the conclusions and policy implications.

2. Literature Review

To promote low-carbon development, the impact of ICT on energy conservation and carbon emissions' reduction has always been emphasized [19,20]. However, although many studies have tested the impact of ICT on carbon emissions, the results are still inconclusive; ICT may harm, benefit, or have no impact on the environment. The study of Shabani and Shahnazi shows that ICT has an inhibitory effect on carbon emissions in the transport and service sector of the Iranian economy [16]. Danish examined the impact of ICT on carbon emissions in 59 countries, and found that ICT reduces carbon emissions in high- and middle-income countries [21]. Likewise, ICT can reduce carbon emissions in different provinces of China [22,23]. Additionally, the results from ASEAN-6 countries indicate that ICT contributes to the improvement of environmental quality by mitigating carbon emissions [24]. For Latin American and Caribbean countries, Ahmed et al. revealed that ICT contributes to reducing carbon emissions [18], and Haldar and Sethi also discovered that ICT can reduce carbon emissions directly and indirectly in 16 emerging countries [25].

Some studies have discovered that ICT can increase carbon emissions. In some emerging economies, Danish et al. investigated the ICT–emissions nexus and discovered that ICT adds to carbon emissions [26]. Regarding the agricultural and industrial sector in Iran, Shabani and Shahnazi found that ICT had a promotional effect on carbon emissions. Danish found that ICT increases carbon emissions in low-income countries [21]. Zhou et al. argue that ICT is far from being environmentally friendly across all sectors in China [27]. Using data from thirteen G-20 countries, Nguyen et al. explored the influence of ICT on carbon emissions, and revealed that ICT (taking exported and imported ICT goods as a proxy) increases carbon emissions [28]. Apart from these studies, Raheem et al. [17], Ulucak et al. [29], and Alataş [30] also reported that ICT enhances carbon emissions in G7 countries, BRICS countries, and 93 countries selected by Alataş, respectively.

In addition, several studies have not reported any meaningful impact of ICT on carbon emissions. For instance, Salahuddin et al. found that there is no causality between ICT and the environment in OECD countries [31]. ICT also has no meaningful effect on carbon emissions in sub-Saharan African countries [32]. These results are similar to the findings of Amri et al., who analyzed the impact of ICT on carbon emissions in Tunisia and discovered that the former does not significantly affect the latter [33].

In summary, the above conclusions on the effects of ICT on carbon emissions are mixed for different countries and different industries. Recently, a few studies have discovered that the impact of ICT on carbon emissions varies over time at the country level. For instance, Higón et al. analyzed the ICT–emissions nexus in 142 countries and disclosed that ICT initially increases carbon emissions, but that a high level of ICT application can mitigate emissions [34], which means that the relationship between them may be nonlinear. Furthermore, Faisal et al. found an inverted U-shaped relationship between ICT and carbon emissions for rapidly emerging economies [35]. The development of the digital economy has both a significant inhibitory and evolutionary effect on CELI in China, and thus leads to a U-shaped correlation between them [11].

However, the nonlinear effect of ICT on CELI has not received interest from a more micro perspective. Therefore, we initiated this study to investigate the nonlinear effect of the micro application of ICT, i.e., the Internet penetration rate, on carbon emissions, and to investigate the impact mechanism of the former on the latter for the logistics industry in China. The findings herein may provide new insight and understanding of the role of ICT in environmental sustainability, and reveal how ICT affects carbon emissions at the industrial level.

3. The Effects of ICT on CELI

Figure 2 illustrates the relationship between the growth rate of Internet users and the growth rate of CELI from 2000 to 2018. Before 2005, carbon emissions increased rapidly with the growth of Internet users; we found that the growth rate of Internet users started increasing rapidly in 2005, while the growth rate of carbon emissions started decreasing. Furthermore, the growth rate of Internet users shows a decreasing trend after 2007, and the growth rate of carbon emissions consistently decreased after 2005. Comparing the growth rate of Internet users and carbon emissions, we find that the former is always larger than the latter. The relationship between the growth rate of Internet usage and CELI implies that Internet usage might have a nonlinear effect on CELI.

We argue that there are two different channels through which Internet usage might have effects on CELI. First, the popularity of the Internet is conducive to promoting the development of express delivery businesses, resulting in an increase in carbon emissions. As an emerging shopping mode in the Internet era, e-commerce has gradually become the mainstream method of consumption, and the shift from traditional offline consumption to online consumption has occurred. In addition, the popularization of the Internet may lead to the development of e-commerce by significantly reducing coordination costs [36], search costs in trade [37–39], production costs [40], information matching and exchange costs [41], transportation costs [42], management costs [43], and communication costs between the buyer and the seller [44]. The shift in shopping modes and the development of e-commerce caused by Internet usage will induce the growth of express delivery businesses, which are an important source of CELI.

Second, Internet usage can enhance the production efficiency and energy efficiency of the logistics industry, resulting in the inhibition of carbon emissions. The correlation effect and interaction effect of Internet usage and logistics technology are beneficial for enhancing production efficiency by optimizing the cross-regional transportation route. As a carrier of information transmission and value recreation, the application of ICT can also improve decision-making efficiency by reducing transaction costs and optimizing resource allocation to drive technical innovation and promote the upgrading of the industrial structure of the logistics industry. In addition, Internet thinking can promote the formation of information, sharing ideas, knowledge, technology and capital, which should improve energy efficiency through capital accumulation and R&D cooperation, and through the technology spillover of logistics enterprises. Particularly in the context of carbon emissions' reduction, the formation of energy-saving and low-carbon behaviors is conducive to improving the awareness of the systematic and networked management of the whole energy process of logistics enterprises, and to promoting the efficient management of energy. As important parts of technical efficiency, the improvement of production efficiency and energy efficiency will reduce CELI. Since ICT has obvious characteristics of the network externality, the size of the network will directly affect the role of the application of ICT [45–47]. When the size of the application of ICT is very small, it is difficult for ICT to enhance the technical efficiency of the logistics industry. However, if it is sufficient to enhance technical efficiency, Internet usage should greatly reduce CELI.

Figure 2. The relationship between Internet users and CELI from the perspective of growth rate (the data are from Statistical Reports on Internet Development in China and the China Statistical Yearbook on Environment).

The promotion effect and the inhibition effect described above make the influence of Internet usage on CELI uncertain. Combining stylized facts and theoretical analysis, we argue that there is a nonlinear relationship between Internet usage and CELI. Specifically, Internet usage should increase carbon emissions at the early stage because of its positive impact on the development of express delivery businesses. Nevertheless, carbon emissions will decrease with the improved technical efficiency resulting from the wide application of ICT.

4. Methodology and Data Sources

4.1. Benchmark Model

We used the following static panel model (1) as a benchmark model to test the nonlinear impact of Internet usage on CELI.

$$LnCO_{2_{i,t}} = \alpha_0 + \beta_1 Intpera_{i,t} + \beta_2 Intpera^2_{i,t} + \beta_j X^c_{i,t} + year_t + province_i + \varepsilon_{it} \quad (1)$$

where $LnCO_2$ refers to the natural logarithm of total carbon dioxide, *Intpera* refers to the Internet penetration rate, and *XC* refers to the vector of control variables. To control for time and individual effects, the variables of year and province are included in the model. If the coefficient of $Intpera^2$ is negative, then we can conclude that there is an inverted U-shaped relationship between Internet usage and CELI.

Considering the dynamic continuity of carbon emissions, we also used a dynamic panel model (2) to perform the empirical analysis.

$$LnCO_{2_{i,t}} = \phi_0 + \theta LnCO_{2i,t-1} + \omega_1 Intpera_{i,t} + \omega_2 Intpera^2_{i,t} + \omega_j X^c_{i,t} + year_t + province_i + \mu_{it} \quad (2)$$

Compared with model (1), model (2) includes the lag of $LnCO_2$ to show that carbon emissions are a dynamic process, and to control for other uncontrollable factors affecting carbon emissions. Model (2) may thus be more reasonable than model (1). For the judgment of an inverted U-shaped relationship, the criteria with the sign and significance of the coefficient of $Intpera^2$ are invalid when the true relationship is convex and monotonic [48]. Therefore, we used the appropriate test method provided by Lind and Mehlum [48] to ensure that the inverted U-shaped relationship is true.

4.2. Models for Handling Possible Endogeneity

CELI increases with the development of the logistics industry induced by the application of ICT, and conversely the popularity of the Internet is also influenced by the dramatic growth of the logistics industry. Therefore, there may be a reverse causal relationship between Internet usage and CELI. Additionally, there may be missing variables in model (1), other than the control variables involved.

We used three methods to handle the possible endogeneity of the Internet penetration rate. First, the divorce rate is taken as an instrumental variable for the Internet penetration rate to perform 2SLS estimation. Cheng and Zhang argue that more divorcees seek spiritual sustenance, emotional support, and entertainment online (with an increase in the divorce rate), which may change the Internet user ratio [49]. This judgment means that there is a certain correlation between the divorce rate and the Internet's development, i.e., the divorce rate satisfies the correlation condition of the instrumental variable. Furthermore, CELI does not affect the divorce rate, so it also satisfies the exclusivity requirement.

Second, we used the following model for a robustness test in view of the possible endogeneity of the Internet penetration rate.

$$LnCO_{2_{i,t}} = \phi_0 + \theta' LnCO_{2i,t-1} + \omega_1{}' Intpera_{i,t-1} + \omega_2{}' Intpera^2_{i,t-1} + \omega_j{}' X^c_{i,t} + year_t + province_i + \mu_{it} \quad (3)$$

In model (3), we replaced *Intpera* and $Intpera^2$ with their first-order lag terms. Theoretically, there is only a one-way causal relationship between the current CELI and the early Internet penetration rate. Thus, if the coefficients of $Intpera_{\mathrm{i,t-1}}$ and $Intpera^2{}_{\mathrm{i,t-1}}$ in model (3) are consistent with the coefficients of *Intpera* and $Intpera^2$ in model (2), respectively, then the regression results of model (2) are robust.

Finally, we used simultaneous equation models (4) and (5) to test whether there is a two-way causal relationship between *Intpera* and $LNCO_2$ by using 2SLS based on the Hausman simultaneous test.

$$LnCO_{2_{i,t}} = \alpha_0 + \alpha_1 Intpera_{i,t} + \sum_j \alpha_j X^c_{i,t} + year_t + province_i + \varepsilon_{it} \quad (4)$$

$$Intpera_{i,t} = \lambda_0 + \lambda_1 LnCO2_{i,t} + \sum_j \lambda_j X^c_{i,t} + year_t + province_i + \varepsilon''_{i,t} \quad (5)$$

If α_1 = 0 and λ_1 = 0 statistically, then there is a two-way causal relationship between *Intpera* and $LNCO_2$. $\alpha_1 \neq 0$ and λ_1 = 0 statistically mean that only *Intpera* affects $LNCO_2$, while α_1 = 0 and $\lambda_1 \neq 0$ statistically mean that only $LNCO_2$ affects *Intpera*.

4.3. Variables

4.3.1. Dependent Variable

As the dependent variable, CELI is calculated using Equation (6):

$$CO_2 = \sum_{i=1}^{8} E_i \times NCV_i \times CEC_i \tag{6}$$

where E refers to the amount of energy consumption from different fuel types (emission factors), and is replaced by the energy consumption of the transportation, storage and postal sectors, as published in the China Energy Statistical Yearbook. NCV refers to the net calorific value of different fuel types, and CEC refers to the carbon emissions coefficient. We use the specific information of NCV and CEC in Table 1 for Equation (6). This approach has been adopted by many studies to measure CELI [12,50].

Table 1. Fuel types, net calorific value and carbon emissions coefficient.

Fuel Types	Coal	Coke	Crude Oil	Gasoline	Kerosene	Diesel Oil	Fuel Oil	Natural Gas
NCV [kj/kg(m^3)]	20,908	283,435	41,816	43,070	43,070	46,252	41,816	38,931
CEC [kg·CO_2/TJ]	95,333	107,000	73,300	70,000	71,500	74,100	77,400	56,100

Notes: The *NCV* data are from the China Energy Statistical Yearbook and the *CEC* data are from the 2006 IPCC (Intergovernmental Panel on Climate Change) Guidelines for National Greenhouse Gas Inventories.

4.3.2. Independent Variable

The internet penetration rate (*Intpera*)—the ratio of the number of Internet users to the resident population—is used as a proxy for the application of ICT in the logistics industry, i.e., the independent variable.

4.3.3. Control Variables

In addition, to control the impacts of other variables on CELI, X^C consists of economic development vitality (*Edv*), industrial structure (*Indst*), financial agglomeration (*Finag*), logistics industry agglomeration (*Logia*), foreign capital dependence (*Forcd*), consumption capacity (*Consca*), energy structure (*Enerst*), environmental regulation (*Envre*), and population size (*Popusi*). All variables are defined in Table 2.

(1) Economic development vitality (*Edv*). Economic development is an important determinant of carbon emissions [51]. The more frequent economic activities there are, the more carbon emissions there will be.

(2) Industrial structure (*Indst*). Reasonable industrial restructuring can improve resource utilization efficiency [52] and reduce carbon emissions [53]. Many studies have discussed how to adjust the industrial structure to reduce carbon emissions. For example, an increase in the proportion of the tertiary industry in GDP can mitigate carbon emissions [54].

(3) Financial agglomeration (*Finag*). Financial development can reduce carbon emissions through the improvement of resource utilization caused by the increase in investment in R&D [55]. However, financial development makes it easier to finance expansion of the production scale, and therefore increases carbon emissions [56,57].

(4) Logistics industry agglomeration (*Logia*). According to the theory of industrial agglomeration, enterprises gathering in specific regions can generate an "external economy", thus reducing production costs [58]. The scale effect, technological innovation effect, information spillover effect, and industrial structure adjustment brought about by industrial agglomeration are all conducive to reducing energy consumption and carbon emissions [59].

(5) Foreign capital dependence (*Forcd*). The pollution haven hypothesis [60] and the pollution halo effect [61] focus on the relationship between trade and the environment. The former theorizes that foreign trade can increase the carbon emissions of the host country,

while the latter theorizes that it can reduce carbon emissions through the technology spillover effect.

(6) Consumption capacity (*Consca*). With the continuous enhancement of living standards, high carbon consumption will become an important factor driving the growth of carbon emissions [62]. Therefore, it is necessary to include consumption capacity in the set of control variables.

(7) Energy structure (*Enerst*). Energy structure is a main factor affecting carbon emissions [63]. In particular, fossil fuels produce more carbon than renewable energy [64].

(8) Environmental regulation (*Envre*). Every government should make policies and implement mandatory means to reduce the external diseconomies caused by pollutant emissions [65]. Therefore, the environmental regulation implemented by the government also plays a positive role in the reduction of carbon emissions [66].

(9) Population size (*Popusi*). Obviously, regions with a large population undertake more frequent economic activities, which result in more carbon emissions [67].

Table 2. Definition of the variables.

Variables	Definition
$LnCO_2$	The natural logarithm of carbon dioxide calculated by Equation (3).
Intpera	The ratio of the number of Internet users to resident population.
Edv	The growth rate of private enterprise.
Indst	The ratio of the added value of tertiary industry to GDP.
Finag	The level of financial agglomeration of *i* province equals $\frac{FAV_i/TIAV_i}{FAV/TIAV}$, where FAV_i and $TIAV_i$ are the added value of financial industry and the added value of the tertiary industry of *i* province, respectively, and *FAV* and *TIAV* are the added value of the financial industry and the added value of the tertiary industry of the whole country, respectively.
Logia	The level of logistics industry agglomeration in *i* province equals $\frac{TSPC_i/TIAV_i}{TSPC/TIAV}$, where $TSPC_i$ and $TIAV_i$ are the added value of the logistics industry and the added value of the tertiary industry of *i* province, respectively, and *TSPC* and *TIAV* are the added value of the logistics industry and the added value of the tertiary industry of the whole country, respectively.
Forcd	The ratio of total imports and exports to GDP.
Consca	The ratio of the total retail sales of social consumer goods to GDP.
Enerst	The ratio of coal consumption to total energy consumption.
Envre	The ratio of the government investment in environmental governance to GDP.
Popusi	The natural logarithm of resident population.

4.4. Data Sources

Due to the lack of data, Macau, Hong Kong, Taiwan, and Tibet are excluded from the sample. Therefore, the other 30 provinces of China are taken as the units for analysis. All data in this paper are from the China Statistical Yearbook, Statistical Reports on Internet Development in China, China Statistical Yearbook on Environment, China Energy Statistical Yearbook, China Statistical Yearbook on Science and Technology, National Bureau of Statistics, and Statistical Yearbook and Bulletin of each province. Since the outbreak of the COVID-19 pandemic at the end of 2019 resulted in poor quality data on the logistics industry, we set the sample period from 2000 to 2018 to avoid the impact of such a "black swan event" on the conclusions of this study.

5. Results

5.1. A Scatter Fitting Analysis

Figure 3 illustrates the scatter fitting relationship between the Internet penetration rate and CELI of various regions from 2000 to 2018, in which the dotted line represents the fitting curve of the linear relationship, and the solid line represents the fitting curve of the quadratic relationship. We found that the linear relationship at the national level (Figure 3A), in the eastern region (Figure 3B), and in the western region (Figure 3D) is not obvious (according to the economic region division method adopted by the State Council of China in 1986, the central region includes Shanxi, Inner Mongolia, Jilin, Heilongjiang, Anhui, Jiangxi, Henan, Hubei and Hunan, the eastern region includes Beijing, Tianjin, Hebei, Liaoning, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong, Guangxi and Hainan, and the western region includes Chongqing, Sichuan, Guizhou, Yunnan, Shaanxi, Gansu, Qinghai, Ningxia and Xinjiang), and the linear curve only accounts for 15.48%, 4.86%, and 26.17% of the three samples, respectively. However, the quadratic curve can account for the relationship between the Internet penetration rate and carbon emissions with 21.29%, 8.16%, and 31.35% for the three samples, respectively. For the central region (Figure 3C), the quadratic curve and linear curve almost coincide, which implies that the relationship between the Internet penetration rate and carbon emissions might be linear.

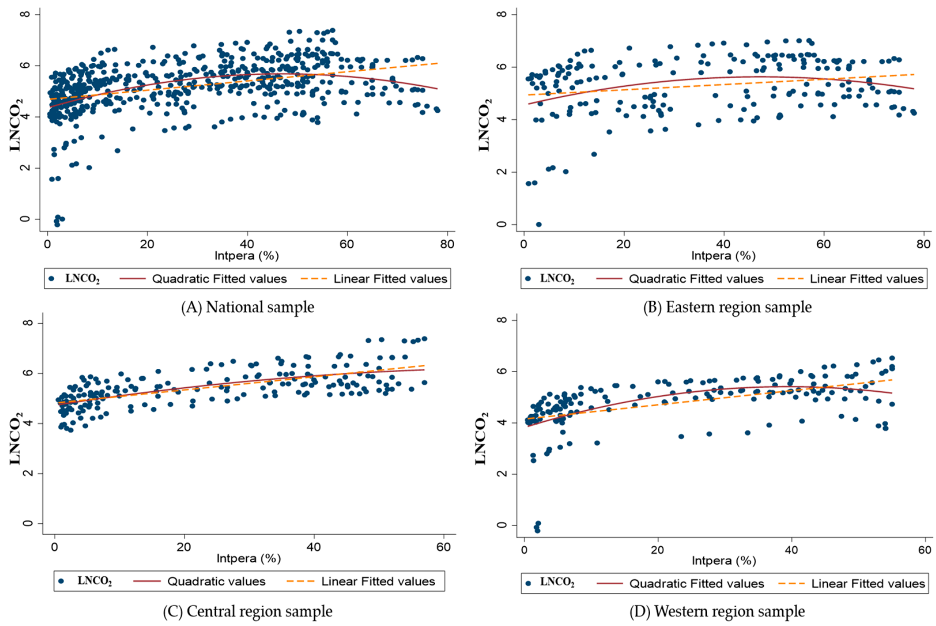

Figure 3. Scatter diagrams of different samples.

5.2. The Results with National Sample

Table 3 reports the results of static panel and dynamic panel regression with the national sample, in which dynamic panel regression is estimated by the system's generalized method of moments (sys-GMM). According to the AIC judgment criterion, the first-order lag of $LnCO_2$ is included in the dynamic panel model. The regression residual correlation test results of GMM estimation indicate that there is no first-order sequence correlation in the residual terms of model (2). In model (1), the inverted U-shaped relationship test results prove that there is an inverted U-shaped relationship between Internet usage and CELI, regardless of whether the control variables are included. Similarly, the inverted U-shaped relationship is proven by the one-step sys-GMM and two-step sys-GMM estimation [68] in model (2). Therefore, the relationship between the Internet penetration rate and CELI is inverted and U-shaped at the national level.

Table 3. Regression results with the national sample.

Variables	Model (1)		Model (2)	
	Random Effect	Fixed Effect	One-Step Sys-GMM	Two-Step Sys-GMM
Intpera	0.029 *** (0.007)	0.039 *** (0.012)	0.009 *** (0.003)	0.010 *** (0.003)
$Intpera^2$	−0.034 *** (0.005)	−0.047 *** (0.017)	−0.012 *** (0.004)	−0.011 *** (0.003)
Edv		0.066 (0.060)	−0.062 (0.038)	−0.044 *** (0.011)
Indst		−2.140 (1.492)	−0.314 (0.438)	−0.607 (0.650)
Finag		−0.619 (0.949)	−0.791 (0.215)	−1.243 (0.775)
Logia		−1.215 *** (0.428)	−0.063 ** (0.027)	−0.305 ** (0.125)
Forcd		−0.393 ** (0.184)	0.168 * (0.091)	0.232 *** (0.079)
Consca		0.707 (0.441)	−0.271 (0.275)	−0.283 (0.246)
Enerst		1.270 *** (0.338)	0.543 *** (0.088)	0.430 *** (0.139)
Envre		−0.152 * (0.086)	0.016 (0.039)	0.016 (0.012)
Popusi		2.551 * (1.291)	0.177 * (0.097)	0.191 *** (0.053)
$L.LnCO_2$			0.653 *** (0.069)	0.609 (0.041)
Constant	4.213 *** (0.165)	−16.15 (10.183)	0.403 (0.763)	−0.398 (1.917)
Year fixed effect	Yes	Yes	Yes	Yes
Province fixed effect	Yes	Yes	Yes	Yes
Inverted U-shaped relationship test	4.39 *** [0.000]	2.49 *** [0.009]	2.54 *** [0.007]	4.28 *** [0.000]
Hausman	0.10 [0.992]	54.50 *** [0.000]		
AR(1)			1.239 [0.216]	−0.838 [0.402]
AR(2)			1.350 [0.177]	0.114 [0.909]
AR(3)			0.971 [0.332]	0.703 [0.482]
Sargan			135.814 [0.971]	26.019 [1.000]
R^2	0.247	0.572		
F		652.42 *** [0.000]		
Wald test	1048.34 *** [0.000]		3720.78 *** [0.000]	1451.23 *** [0.000]
Observations	570	570	540	540

Notes: The standard errors are reported in parentheses, the numbers in square brackets are *p* values of the F test, and *, **, *** indicate significance at the 10%, 5%, and 1% levels, respectively. The selection of random effect or fixed effect is made according to the Hausman test. $L.LnCO_2$ is the first-order lag of $LnCO_2$. In addition, the null hypothesis of the inverted U-shaped relationship test is monotone or U-shaped. All regressions control the fixed effect of time and individual.

Alataş also used the Internet penetration rate (individuals using the Internet) as a proxy for ICT, and discovered that information technology has a statistically significant and positive impact on carbon emissions [30]. This finding is the same as ours, but Alataş did not further analyze the nonlinear effect of ICT on carbon emissions. The inverted U-shaped relationship we detected means that an improvement in the Internet penetration rate should increase CELI at the early stage, but reduce carbon emissions at the later stage. This conclusion is consistent with the findings of Higón et al. [34] and Faisal et al. [35], who discovered that the effect of ICT changes with the variation in its application level at the national level. Internet development has promoted the rapid growth of Chinese e-commerce, and further inevitably increased CELI by increasing energy consumption in the express delivery industry. However, with the increase in the Internet penetration rate, Internet usage will reduce carbon emissions by promoting technological innovation and energy efficiency. Besides, the combination of ICT with the logistics industry can enhance the productivity of the logistics industry by promoting the personalization and accuracy of the traditional service industry [69], and can then reduce carbon emissions. Li and Wang also found a U-shaped relationship between digital economy and the carbon emissions of China's logistics industry [11]. As a more micro indicator than digital economy, the Internet penetration rate—proven to have a nonlinear impact on CELI by this study—indicates that the U-shaped relationship between the application of ICT and CELI is not affected by the specific measurement of ICT. Additionally, it is worth noting that the Internet penetration rate is 48.56% (it equals $-0.0103416/(2 \times -0.0106475) \times 100\%$) at the inflection point of the inverted U-shaped curve, according to the results of the two-step sys-GMM estimation. According to the China Internet Development Report, the Internet penetration rate was 47.9% in 2014 and 48.8% in 2015, which implies that the inflection point emerged in 2015. In the same year, "The Guiding Opinions on Actively Promoting the 'Internet Plus' Action" was issued by the Chinese government. Our findings prove that the implementation of the Internet plus policy has optimized energy emissions' efficiency and achieved the goals of energy conservation and emissions' reduction.

5.3. Robustness Tests

Because the Internet penetration rate is also affected by the development of the logistics industry, there may be a reverse causal relationship between Internet usage and CELI. Therefore, the endogeneity problem may reside in the empirical analyses above. The first and second columns of Table 4 report the endogenous test results estimated by 2SLS, in which *Divor* represents the divorce rate (*Divor* = (Number of registered divorces/Population aged 15–64) $\times$ 1000) and serves as an instrumental variable. The estimation results of the first stage show that the coefficient of *Divor* is significantly positive, and that the value of the Cragg-Donald Wald F is also significant. These findings mean that *Divor* is an efficient instrumental variable [70]. The estimation results with the instrumental variable in the second column also present an inverted U-shaped relationship between the Internet penetration rate and CELI. In addition, the third, fourth and fifth columns report the results of models (3), (4) and (5), respectively. The third column shows that the coefficients of $Intpera_{i,t-1}$ and $Intpera^2{}_{i,t-1}$ are consistent with the coefficients of *Intpera* and $Intpera^2$ in Table 3, respectively. The results of the simultaneous equation model in columns 4 and 5 indicate that there is only one-way causality (of *Intpera* on $LnCO_2$). These findings also imply that the results in Table 3 are robust.

Table 4. Results of the endogenous test.

Variables	2SLS		Reverse Causality Test		
	First Stage	Second Stage	$LNCO_2$	$LNCO_2$	*Intpera*
	1	2	3	4	5
Divor	0.028 *** (0.007)				
Intpera		0.365 *** (0.166)		0.017 *** (0.002)	

Table 4. *Cont.*

Variables	2SLS		Reverse Causality Test		
	First Stage	Second Stage	$LNCO_2$	$LNCO_2$	*Intpera*
	1	2	3	4	5
$LNCO_2$					0.661 (0.587)
$Intpera^2$		−0.235 ** (0.120)			
L.Intpera			0.021 *** (0.007)		
$L.Intpera^2$			−0.036 *** (0.007)		
Ports					
$Ports^2$					
Control variables	Yes	Yes	Yes	Yes	Yes
Constant	−308.961 *** (28.136)	−2.265 (1.504)	−12.043 *** (3.400)	−4.509 * (2.691)	−271.639 *** (55.242)
Year fixed effect	Yes	Yes	Yes	Yes	Yes
Province fixed effect	Yes	Yes	Yes	Yes	Yes
R^2	0.2221	0.1624	0.5963	0.6668	0.2888
F	¥ 634.52 *** [0.000]	765.86 [0.000]	53.53 *** [0.000]	122.79 *** [0.000]	2223.82 *** [0.0000]
Observations	570	570	540	570	570

Notes: The standard errors are reported in parentheses, the numbers in square brackets are *p* values of the F test, and *, **, *** indicate significance at the 10%, 5%, and 1% levels, respectively. L represents the first-order lag and ¥ represents the Cragg–Donald Wald *F* statistic. For simplicity, the regression results of control variables are not reported. All regressions control the fixed effect of time and individual.

5.4. The Formation Mechanism of the Inverted U-Shaped Relationship

Many studies have analyzed the indirect environmental effects of ICT at the regional level from the perspective of the external environment, including globalization [24], human capital [18], urbanization [30], renewable energy, innovation, trade, and financial development [25]. At the industrial level, we argue that it is more reasonable to discuss the formation mechanism of the inverted U-shaped relationship between Internet usage and CELI from the internal factors of the logistics industry. As mentioned earlier, Internet usage can reduce carbon emissions by improving the technical efficiency of the logistics industry while increasing carbon emissions by promoting the development of express business. Therefore, we analyze this inverted U-shaped relationship by discussing the effects of TFP and express delivery business in the logistics industry on the relationship between Internet usage and carbon emissions. In Table 5, *LnExpdel* represents the natural logarithm of the number of express delivery business, and *TFP* represents the total factor productivity of the logistics industry, which is measured with the three-stage DEA (data envelopment analysis) model (for the measurement of the TFP of the logistics industry, we use the number of employees, total investment in fixed assets, railway operating mileage, highway mileage, inland waterway mileage and energy consumption of the logistics industry as input indicators, and use the added value of the logistics industry as output indicator). The coefficients of *Intpera* in columns 1 and 2 indicate that Internet usage can promote the development of express delivery business and the total factor productivity of the logistics industry. The results of columns 3 and 4 indicate that *LnExpdel* promotes carbon emissions, while *TFP* reduces carbon emissions. Additionally, the interaction effects between express delivery business, *TFP*, and Internet usage in columns 5 and 6 show that *LnExpdel* plays a positive role, while *TFP* has a negative role in the relationship between Internet usage and carbon emissions.

Table 5. Results of the formation mechanism.

	1	2	3	4	5	6
Variables	***TFP***	***LnExpdel***	***LnCO$_2$***	***LnCO$_2$***	***LnCO$_2$***	***LnCO$_2$***
Intpera	0.175 *** (0.038)	0.651 *** (0.072)			0.052 *** (0.007)	−0.015 *** (0.005)
LnExpdel			0.097 *** (0.028)		0.350 *** (0.073)	
TFP				−0.131 *** (0.049)		−0.155 (0.103)
Intpera × *LnExpdel*					0.006 *** (0.001)	
Intpera × *TFP*						−0.011 *** (0.003)
Control variables	Yes	Yes	Yes	Yes	Yes	Yes
Constant	0.279 (1.191)	−4.515 * (2.242)	−4.225 * (2.478)	−3.464 (2.422)	−11.380 *** (2.547)	−3.964 (2.625)
Year fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Province fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
R^2	0.718	0.897	0.654	0.700	0.622	0.692
F	149.06 *** [0.000]	965.16 *** [0.000]	860.41 *** [0.000]	236.56 *** [0.000]	61.68 *** [0.000]	51.92 *** [0.000]
Observations	570	570	570	570	570	570

Notes: The standard errors are reported in parentheses, the numbers in square brackets are *p* values of the F test, and *, *** indicate significance at the 10% and 1% levels, respectively. For simplicity, the regression results of the control variables are not reported. All regressions control the fixed effect of time and individual.

Regarding the formation mechanism at regional level, Table 6 indicates that it is the same as the national sample for the eastern and western regions. However, Internet usage does not have a significant impact on TFP, and the negative interactive effect between them on CELI is also not significant for the central region. Therefore, we can conclude that the positive impact of Internet usage on carbon emissions—by promoting the development of express delivery businesses—leads to a monotonic linear relationship between Internet usage and CELI in the central region.

According to the findings of the formation mechanism analysis, the development of express delivery businesses has a promotion effect on CELI, while the TFP of the logistics industry has an inhibition effect on carbon emissions. At the early stage, Internet usage increases CELI by promoting the development of express delivery businesses. With the saturation of the express delivery industry and the deep integration of ICT in the logistics industry, the enhancement of TFP will then reduce carbon emissions. The overlap of the dual effects forms the inverted U-shaped relationship between Internet usage and CELI, similar to the illustration in Figure 4.

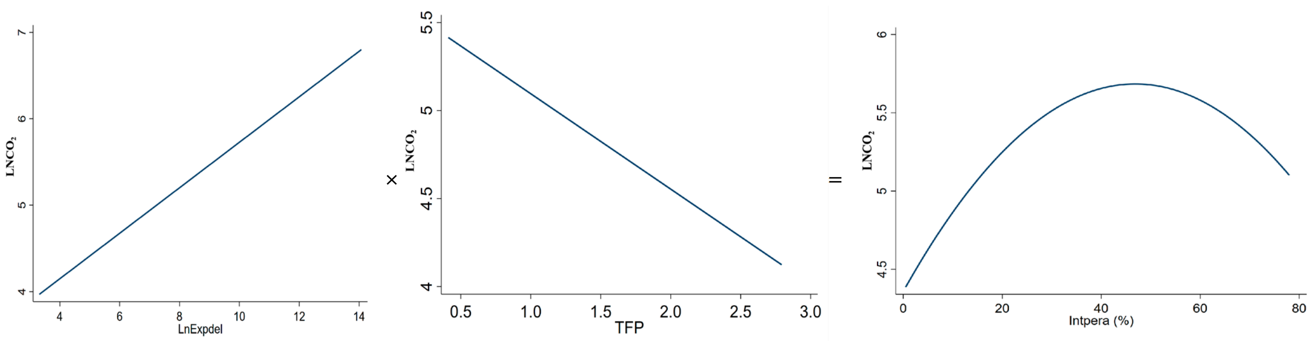

Figure 4. The formation mechanism of the inverted U-shaped relationship.

Table 6. The results of the formation mechanism analysis of each region.

Variables	Eastern Region						Central Region					
	TFP	***LnExpdel***	***$LNCO_2$***				***TFP***	***LnExpdel***	***$LNCO_2$***			
Intpera	0.157 *** (0.052)	1.005 *** (0.109)			−0.009 (0.007)	0.047 *** (0.012)	0.034 (0.021)	1.690 *** (0.096)			−0.014 (0.010)	0.052 *** (0.018)
TFP			−0.357 ** (0.149)		0.280 (0.205)				−0.424 ** (0.179)		−0.744 *** (0.217)	
Expdel				0.056 ** (0.028)		0.282 *** (0.099)				0.196 *** (0.023)		0.269 ** (0.134)
Intpera × *TFP*					−0.047 ** (0.019)						−0.030 (0.021)	
Intpera × *LnExpdel*						0.005 *** (0.001)						0.003 *** (0.001)
Control variables	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Constant	1.478 (1.796)	0.514 (3.759)	2.727 (3.589)	−3.772 (3.321)	−3.894 (3.595)	−5.516 (3.754)	3.030 (2.943)	6.918 (13.258)	−17.347 *** (6.428)	−9.942 ** (6.426)	−12.123 * (6.470)	−17.762 *** (6.612)
Year fixed effect	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Province fixed effect	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
R^2	0.243	0.873	0.272	0.669	0.695	0.819	0.163	0.821	0.076	0.107	0.122	0.073
F	9.22 *** [0.000]	529.05 *** [0.000]	24.40 *** [0.000]	55.57 *** [0.000]	48.19 *** [0.000]	26.68 *** [0.000]	8.37 *** [0.000]	351.47 *** [0.000]	50.39 *** [0.000]	117.22 *** [0.000]	50.35 *** [0.000]	47.77 *** [0.000]
Observations	209	209	209	209	209	209	190	190	190	190	190	190

Variables	Western Region					
	TFP	***LnExpdel***	***$LNCO_2$***			
Intpera	0.080 * (0.045)	1.626 ** (0.095)			−0.032 (0.021)	0.041 * (0.024)
TFP			−0.417 *** (0.131)		−0.308 (0.227)	
Expdel				0.374 *** (0.058)		0.313 (0.195)
Intpera × *TFP*					−0.020 ** (0.009)	
Intpera × *LnExpdel*						0.006 *** (0.002)
Control variables	YES	YES	YES	YES	YES	YES
Constant	13.874 *** (3.670)	2.586 (7.757)	−22.698 ** (10.026)	−6.602 (8.994)	−18.051 (11.196)	−14.484 (11.060)
Year fixed effect	YES	YES	YES	YES	YES	YES
Province fixed effect	YES	YES	YES	YES	YES	YES
R^2	0.539	0.772	0.400	0.523	0.489	0.524
F	9.28 *** [0.000]	345.10 *** [0.000]	27.76 *** [0.000]	38.47 *** [0.000]	16.45 *** [0.000]	16.46 *** [0.000]
Observations	171	171	171	171	171	171

Notes: The standard errors are reported in parentheses, the numbers in square brackets are *p* values of the F test, and *, **, *** indicate significance at the 10%, 5%, and 1% levels, respectively. For simplicity, the regression results of the control variables are not reported. All regressions control the fixed effect of time and individual.

5.5. Regional Heterogeneity

From a global perspective across different regions, the findings of Danish indicate that ICT can mitigate carbon emissions in high- and middle-income countries, whereas ICT can increase carbon emissions in low-income countries [21]. For China, there are great regional differences in resource endowment, economic development, industrial structure and informatization degree. Therefore, this paper further tries to analyze the regional differences in the effects of Internet usage on CELI, including the eastern, central and western regions. Since the sys-GMM estimation with dynamic panel data is only suitable for a large sample, the three regional samples are analyzed by model (1). The results of regional heterogeneity in Table 7 show that the inverted U-shaped relationship between Internet usage and CELI only applies in the eastern and western regions, and it is not proven in the central region. This finding implies that Internet penetration in the central region has not yet reached the inflection point, and it is urgent that emphasis is placed upon employing ICT in the logistics industry with the aim of reducing carbon emissions.

Table 7. The results of regional heterogeneity.

Variables	Eastern Region	Central Region	Western Region
	Fixed Effect	Fixed Effect	Fixed Effect
Intpera	0.029 ** (0.012)	0.014 ** (0.006)	0.059 * (0.030)
$Intpera^2$	−0.032 *** (0.011)	−0.017 (0.018)	−0.076 *** (0.023)
Edv	−0.008 (0.046)	−0.066 (0.100)	0.505 *** (0.174)
Indst	−0.215 (1.154)	−2.359 ** (0.987)	−5.398 ** (2.101)
Finag	0.761 (0.578)	0.611 (0.474)	−3.531 *** (1.275)
Logia	−2.381 *** (0.509)	−0.804 * (0.425)	−1.724 (1.054)
Forcd	−0.089 (0.168)	−1.406 ** (0.652)	−1.519 (0.937)
Consca	1.782 ** (0.684)	1.435 *** (0.366)	−1.438 (2.133)
Enerst	0.951 *** (0.263)	0.647 *** (0.152)	1.249 *** (0.264)
Envre	−0.166 (0.106)	−0.210 ** (0.087)	−0.111 (0.253)
Popusi	1.750 *** (0.633)	2.450 *** (0.783)	3.636 ** (1.410)
Constant	−9.986 * (5.119)	−15.853 ** (6.898)	−21.479 * (11.631)
Year fixed effect	Yes	Yes	Yes
Province fixed effect	Yes	Yes	Yes
Inverted U-shaped relationship test	2.52 *** [0.007]	0.62 [0.269]	2.34 *** [0.010]
Hausman	82.81 *** [0.000]	89.83 *** [0.000]	81.22 *** [0.000]
R^2	0.826	0.163	0.469
F	20.28 *** [0.000]	46.52 *** [0.000]	16.51 *** [0.000]
Observations	209	190	171

Notes: The standard errors are reported in parentheses, the numbers in square brackets are *p* values of the F test, and *, **, *** indicate significance at the 10%, 5%, and 1% levels, respectively. The selection of random effect or fixed effect is performed according to the Hausman test. The null hypothesis of the inverted U-shaped relationship test is monotone or U-shaped. All regressions control the fixed effect of time and individual.

5.6. A Dynamic Analysis

We used a time trend method to analyze the dynamic characteristics of the impact of Internet usage on CELI. Specifically, the quadratic term of the Internet penetration rate is excluded from model (1), and then the interaction term of the Internet penetration rate and time is included. As shown in Table 8, the absolute values of the coefficients of the interaction term in 2014 and 2015 for the national sample are equal to the coefficient in 2000 (base period), which means that Internet penetration has had an inhibiting effect on CELI since 2014. This finding is consistent with the analysis of the inflection point for the national sample. Similarly, the inhibiting effect has emerged in the western region since 2009 and in the western region since 2012, but it did not emerge in the central region until 2018. These findings are also consistent with the results of regional heterogeneity.

Table 8. The dynamic characteristics of the impact of Internet usage on CELI.

Variables	National Sample	Eastern Region	Central Region	Western Region
Intpera	0.071 *** (0.020)	0.045 ** (0.017)	0.668 *** (0.171)	1.021 ** (0.414)
Intpera × year2001	−0.012 (0.021)	−0.010 (0.019)	−0.015 (0.213)	0.992 * (0.532)
Intpera × year2002	−0.014 (0.020)	0.0003 (0.018)	−0.502 *** (0.174)	1.458 *** (0.435)
Intpera × year2003	−0.034 (0.021)	−0.019 (0.019)	−0.510 *** (0.175)	0.998 ** (0.427)
Intpera × year2004	−0.036 * (0.021)	−0.020 (0.019)	−0.557 *** (0.174)	1.013 ** (0.427)
Intpera × year2005	−0.042 ** (0.020)	−0.018 (0.019)	−0.610 *** (0.173)	−1.019 ** (0.423)
Intpera × year2006	−0.052 *** (0.020)	−0.035 * (0.020)	−0.626 *** (0.172)	−0.996 ** (0.419)
Intpera × year2007	−0.062 *** (0.019)	−0.046 *** (0.017)	−0.674 *** (0.172)	−1.014 ** (0.411)
Intpera × year2008	−0.065 *** (0.019)	−0.045 *** (0.017)	−0.617 *** (0.171)	−1.014 ** (0.412)
Intpera × year2009	−0.066 *** (0.019)	−0.048 *** (0.017)	−0.634 *** (0.171)	−1.010 ** (0.411)
Intpera × year2010	−0.067 *** (0.019)	−0.049 *** (0.018)	−0.662 *** (0.171)	−1.007 ** (0.411)
Intpera × year2011	−0.069 *** (0.019)	−0.051 *** (0.017)	−0.655 *** (0.171)	−1.019 ** (0.411)
Intpera × year2012	−0.069 *** (0.019)	−0.052 *** (0.018)	−0.628 *** (0.171)	−1.032 ** (0.411)
Intpera × year2013	−0.069 *** (0.019)	−0.053 *** (0.018)	−0.615 *** (0.171)	−1.034 ** (0.411)
Intpera × year2014	−0.071 *** (0.019)	−0.060 *** (0.018)	−0.618 *** (0.171)	−1.034 ** (0.411)
Intpera × year2015	−0.071 *** (0.019)	−0.058 *** (0.018)	−0.618 *** (0.171)	−1.030 ** (0.412)
Intpera × year2016	−0.072 *** (0.019)	−0.062 *** (0.018)	−0.607 *** (0.171)	−1.044 ** (0.411)
Intpera × year2017	−0.072 *** (0.019)	−0.061 *** (0.018)	−0.601 *** (0.171)	−1.050 ** (0.411)
Intpera × year2018	−0.074 *** (0.019)	−0.062 *** (0.019)	−0.613 *** (0.171)	−1.051 ** (0.412)
Control variables	Yes	Yes	Yes	Yes

Table 8. *Cont.*

Variables	National Sample	Eastern Region	Central Region	Western Region
Constant	6.197 *** (0.515)	5.586 *** (0.419)	22.946 *** (4.710)	23.911 ** (11.375)
R^2	0.880	0.947	0.944	0.794
Year fixed effect	Yes	Yes	Yes	Yes
Province fixed effect	Yes	Yes	Yes	Yes
F	28.65 *** [0.000]	11.93 *** [0.000]	32.68 *** [0.000]	6.60 *** [0.000]
Observations	570	209	190	171

Notes: The standard errors are reported in parentheses, the numbers in square brackets are p values of the F test, and *, **, *** indicate significance at the 10%, 5%, and 1% levels, respectively. For simplicity, the regression results of the control variables are not reported. All regressions control the fixed effect of time and individual.

5.7. Discussion of Results

This paper analyzes the nonlinear relationship between Internet usage and CELI. The findings show that there is an inverted U-shaped relationship between them because of the different effects of express delivery businesses and the TFP of the logistics industry on carbon emissions. A possible explanation is that the enhancement of TFP has a time-cumulative effect, while there is not the same effect in the development of express delivery business. Therefore, the promotion effect of the rapid development of express delivery business is far greater than the inhibition effect of TFP on CELI at the early stage of Internet usage. According to the data of the China Statistics Bureau, the added value, energy consumption, and CELI from 2000 to 2018 present a synchronous growth trend. However, the energy consumption intensity (the energy consumption intensity is measured using the ratio of energy consumption to the added value of the logistics industry, and its unit is ton of standard coal per CNY 10,000) decreases from 1858 to 1081, with an average annual growth rate of −2.96%, and the carbon emissions intensity (the carbon emissions intensity is measured using the ratio of carbon emissions to the added value of the logistics industry, and its unit is ton per CNY 10,000) also decreases from 3322 to 1843, with an average annual growth rate of −3.22%. We can then conclude that the continuous reduction in energy consumption results in a decline in carbon emissions, which implies that the application of ICT in the logistics industry weakens the industry's dependence on energy and alleviates environmental pollution.

For the three regions, the relationship between Internet usage and carbon emissions in the eastern and western regions is an inverted U-shape, but a linear relationship is present in the central region. According to the empirical results, we found that the Internet penetration rate has no significant impact on the TFP of the logistics industry, and it affects carbon emissions only by promoting the development of express delivery business in the central region. The endowments of the central region are generally better than those of the western region in China. However, the central region has not crossed the inflection point, which is somewhat irreconcilable with the economic and geographical background and intuition. Nevertheless, we believe that this finding is reasonable for China. It is worth noting that the Chinese government successively launched the "Western Development Strategy" and the "Central Rise Strategy" to narrow regional differences. The western region has always been supported by national policies, and its economic development speed is faster than that of the central region. However, the "central rise" has become a "central collapse" because of the siphon effect of the eastern region. According to the circular causal mechanism of new geographic economics, the endogenous force of the economic system will eventually lead to regional evolution differentiation, and then industrial agglomeration will create an extreme "core–edge" structure. The market demand of core areas is far greater than that of edge areas, and becomes an important source to further absorb industries and population, accumulate capital, and innovate. In the process of industrial agglomeration in the eastern region, the outflow of production factors to the adjacent area (i.e., the central region) is greater than that in the western region, which would cause the industries of the central region to suffer a greater negative impact, and eventually a “central collapse”.

6. Conclusions and Policy Implications

6.1. Conclusions

This study examined the nonlinear influence of ICT on the CELI of China over the period of the years 2000 to 2018, considering the roles of total factor productivity and the development of express delivery businesses. Taking Internet usage as a proxy for the application of ICT in the logistics industry, we used a static and dynamic panel model analysis to study the nonlinear relationship between Internet usage and CELI, and found that the inverted U-shaped characteristic is only present nationwide and in the eastern and western regions. The three methods used to handle the endogeneity problem confirm that the inverted U-shaped relationship does exist. The findings prove that the application of ICT in the logistics industry has a promotion effect on carbon emissions at the early stage, but an inhibition effect at the later stage. The formation mechanism analysis proves that the inverted U-shaped relationship is formed by the different roles of TFP and the development of express delivery business. Specifically, Internet usage plays a positive role in TFP and then reduces carbon emissions, but increases carbon emissions by promoting the development of express delivery business.

6.2. Policy Implications

Our findings are very beneficial for policy makers.

First, the findings indicate that at present, China is on the right side of the inflection point of the inverted U-shaped curve; that is, Internet usage has an inhibitory effect on CELI. Therefore, the Chinese government should develop network infrastructure to promote the application of ICT by implementing the “Internet plus” strategy, industrial Internet, and the new generation “cloud end”. Specifically, it is vital to reasonably lay out the basic network system to support the development of the “Internet plus” strategy and make the industrial Internet the key to promoting the deep integration of the digital economy and the real economy. In addition, the government should strengthen international cooperation in the fields of network infrastructure, cloud computing and e-commerce, and then make more Chinese programs international standards through the development of the digital economy and international trade. Finally, the coverage of wireless networks, optical cable lines and cable TV networks should be improved for the service quality of communication networks.

Second, differentiated support policies should be implemented to enhance the TFP of the logistics industry in the central region. We can improve the TFP of the logistics industry in the central region through the agglomeration effect. For example, a comprehensive logistics base integrating commodity storage, cargo transportation, circulation processing and other supporting services should be established by introducing foreign investment and providing preferential policies. Through the guidance and policy support of the local government, the logistics base may attract many relevant service enterprises and logistics enterprises to make the operation, management and service of the logistics industry develop from decentralization and simplification to integration and diversification. In addition, it is very important to integrate various functions, such as raw material supply, product sales, after-sales service and resource sharing, into the supply chain to improve the operation efficiency of enterprises and achieve the interaction and coordinated development of logistics and trade. It is also necessary to conduct scientific research and effectively integrate the logistics and trade resources owned by provinces in the central region. In particular, the modernization of logistics infrastructure for enterprises with development potential, the integration of operation modes and management processes of enterprises with international standards, and the construction of exchange and coordination mechanisms among enterprises should be strengthened.

Third, as the main bodies of energy conservation and carbon emissions' reduction in the logistics industry, enterprises should improve operation efficiency, promote business model innovation, and then enhance TFP. In particular, enterprises need to increase investment in information technology and promote the deep integration of Internet technology and traditional technology. For information construction, financing channels should be actively broadened to ensure the source of funds. Additionally, it is very important to smooth the reverse transmission path of consumer demand to provide more accurate product information for upstream manufacturers, and to shift from transmitting demand quantity information to transmitting all aspects of information, including product quality and consumer experience. Finally, enterprises should promote the application of cloud computing, big data and other digital technologies within e-commerce platforms, and improve the intelligence and flexibility of the supply chain through C2B reverse customization to realize the matching of supply with demand.

This study unveils how the application of ICT affects CELI in China, but has some limitations. First, the measurement of the applications of ICT within the logistics industry is simple, and the impact of 5G and other Internet technology changes has not been considered. Second, the present analysis of the formation mechanism of the nonlinear relationship does not probe technological innovation in the logistics industry. Considering the limitations, studying the relationship between digital technology and CELI and their internal mechanism from the perspective of industrial technology innovation will be useful for deeply understanding the association between ICT and CELI. Additionally, because of the different practical backgrounds of other countries' ICT, carbon emissions, and other industries from China and the logistics industry, it is vital that we understand this nonlinear relationship in other industries or countries, in order to direct sustainable development policies.

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