

Study on the Decoupling Effect of Economic Growth and Carbon Emission in Zhejiang Province

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Abstract

In the context of the "double carbon" target and digital economy, it is of great significance to study the decoupling effect of carbon emissions and the mechanism of digital development on carbon decoupling. Based on the Tapio decoupling elasticity index and catching-up decoupling index to measure the decoupling effect of carbon emissions and the degree of catching-up decoupling of 11 cities in Zhejiang Province from 2005 to 2017, and using the mediation effect model to analyze the driving mechanism of the decoupling effect of carbon emissions by digital development, the following conclusions are drawn: (1) In 2005, all prefectural-level cities in Zhejiang Province were in the stage of expansion relative to the negative decoupling or the expansion of the linkage stage, and their economic development was more relaxed, while in 2017, all the cities were in the stage of expansion relative to negative decoupling or expansion linkage. And in 2017, all cities were in the stage of strong absolute decoupling of expansion or weak absolute decoupling of expansion, and economic growth and carbon emissions have been absolutely decoupled, and the economy has entered a low-carbon development mode. (2) From 2005 to 2017, the carbon emission intensity of the 11 cities in Zhejiang Province showed a continuous downward trend, with an overall decrease of 51.3%; the total carbon emissions and per capita carbon emissions reached the peak in 2012 and then showed a downward spiral trend. Taking Hangzhou as a benchmark city, Huzhou and Quzhou have the best performance in their catch-up journey, while the rest of the cities have insufficient power to catch up and decouple, with more room for progress. (3) Digital development promotes the decoupling of economic growth and carbon emissions through enhanced industrial upgrading and technological innovation. As the degree of decoupling deepens, the greater the impact of digitalization on the decoupling of economic growth and carbon emissions.

Keywords

Carbon Emissions; Decoupling Effect; Catch-up Decoupling Level; Digitisation; Driving Mechanisms.

1. Introduction

since the 18th CPC National Congress, China's economy has shifted from a stage of high-speed growth to a stage of high-quality development, however, problems such as increased ecological and environmental pollution and sloppy resource exploitation and utilisation are still seriously constraining China's comprehensive modernisation process[1]. China's carbon emissions in 2020 will be as high as 9.899 billion tonnes, accounting for 30.92 percent of the global total, making it the world's largest carbon emitter. Zhejiang Province is the birthplace of the concept

of green mountains is golden mountains, but also given the historical mission of building a high-quality common wealth demonstration area, "dual-carbon" work is not only to practice the "two mountains" concept of an important task, but also to achieve the common wealth of the topic. With the rapid development of information technology such as big data, artificial intelligence, cloud computing, blockchain, Internet of Things, digital technology from the new concept, new business, new mode and other aspects of the impact of the people's production and life, widely used in the field of low carbon. The absolute decoupling of carbon emissions and economic growth is the basis and premise for the realisation of the "dual-carbon" goal, and it is of great significance to measure the correlation between economic growth and carbon emissions, assess the decoupling status, and analyse the driving mechanism of the decoupling effect of digital development on carbon emissions for high-quality and low-carbon development in Zhejiang. This paper focuses on the strategic objectives of carbon peak and carbon neutrality, constructs carbon decoupling and catching-up decoupling indices, empirically measures the decoupling situation in various cities of Zhejiang Province, studies and compares the degree of catching-up decoupling in various cities, and analyses the mechanism of the effect of digital development on carbon emissions, so as to provide useful references for the realisation of the "dual-carbon" goal in Zhejiang Province.

As the global climate is getting warmer and warmer, the issue of carbon emission reduction is getting more and more attention from the international community[2], and how to balance the economic development and the growth of carbon emissions has become a research issue of great importance to the academic community at home and abroad[3]. The Organisation for Economic Co-operation and Development (OECD) introduced the decoupling model in physics into the study of agricultural policy development in 2002, defining it as "material energy consumption increases with economic growth in the early stage of industrial development, and then changes in the opposite direction after a certain stage, achieving economic growth and decreasing material energy consumption". Subsequently, the decoupling model has been gradually integrated into the research field of environmental economy, becoming a tool for analysing the fit between economic growth and environmental protection, and has been widely practiced and innovated in terms of research scales and research objects. It has been proved that the Tapio elasticity index method solves the problem of over-sensitive base period selection in the OECD decoupling model and improves the classification scheme of decoupling types into eight types according to the size of the decoupling index[4]. The improvement of decoupling model by the Tapio elasticity index method has made decoupling model become the most commonly used tool to analyse the interrelationships between economic growth and environmental pressures[5]. Carbon emissions accompanying China's rapid economic growth are threatening the environment on which people depend, and scholars have carried out extensive research on the decoupling relationship between economic growth and carbon emissions in order to achieve a harmonious development. In the study of the decoupling relationship between economic growth and carbon emissions, the application of decoupling models has gradually matured. For example, Wang Jie et al., Sun Yaohua et al. and Zhang Huaming et al. have studied the decoupling relationship between economic growth and carbon emissions at the country[6], provincial[7] and municipal[8] scales, respectively, and the regional scales of the decoupling model research have shown a gradual trend of narrowing. With the depth of the study, the research object also expands from a single subject to multiple subjects between regions. On the basis of analysing the decoupling relationship between economic growth and carbon emissions in 29 provinces in China, Zhang Cheng et al[9]. constructed a catching-up decoupling model to cross-sectionally examine the trend of the decoupling status gap among multiple research subjects. The decoupling model moves from examining the static decoupling status of a single subject to the dynamic catching up of multiple subjects. At present, the application of decoupling models in the study of the relationship

between economic growth and carbon emissions is relatively mature, but the comprehensive study of the decoupling effect of economic growth and carbon emissions in time and space dimensions at the urban scale is still to be improved.

In recent years, digital development, centred on a new generation of information technology, is upgrading and reshaping society and the economy in multiple dimensions. Current research in the field of digital development mainly focuses on the role of digital development in economic and social development. For example, digital development can play a positive role in economic growth[10], industrial upgrading[11], innovation[12] and high-quality development[13]. Digitalisation continues to integrate with society and the economy, empowering social and economic development. The economic effects of digital development have been discussed extensively by scholars, but the environmental effects of digital development are still in the exploratory stage. Deng Rongrong et al.[14] based on the panel data of 285 cities in China from 2011-2018, confirmed that digital economic development is effective in reducing industrial sulfur dioxide emissions, as well as industrial wastewater, industrial soot emissions and PM2.5 concentrations. Guo Bingnan et al.[15] also confirmed that digital economic development has a significant effect on the improvement of urban air quality, and the emission reduction effect is characterised by thick and thin, and found that the effect of digital economic development to improve urban air quality has a spatial spillover effect. As one of the important factors causing environmental problems, some scholars have explored the impact of digitalisation on carbon emissions. For example, Xie Yunfei[16] used inter-provincial panel data from 2011-2018 to confirm that the digital economy significantly reduces regional carbon emission intensity and is more obvious in regions with high carbon emission intensity. Miao Lujun et al.[17] found that the impact of digital economic development on carbon emissions shows an inverted U-shaped non-linear relationship. Due to the fact that there are fewer studies on the impact of digitalisation on carbon emissions, and no literature has been found that focuses specifically on the systematic examination of the impact of digitalisation on the decoupling of economic growth and carbon emissions, how to make effective use of digitalisation to promote the decoupling of economic growth and carbon emissions has become an urgent issue.

The current research results on the theoretical connotation and measurement method of decoupling economic growth and carbon emissions are very fruitful, but there is still a lot of room for excavation in terms of horizontal comparison between research objects, longitudinal analysis in time, and the choice of paths for decoupling carbon emissions. Although digital empowerment of carbon emission reduction is widely recognised in practice, there is relatively little literature on the correlation between digitalisation and carbon emission reduction, and there is a lack of research results on the mechanism and effect of digital development on the decoupling of economic growth and carbon emissions. To this end, the contributions of this paper are as follows: (1) to assess the decoupling effect of carbon emissions using 11 cities in Zhejiang Province, a modernisation-first and digitisation-first province, as a research sample, and to test the driving mechanism of digital development on the decoupling of economic growth and carbon emissions, which will provide a reference for the implementation of the carbon peaking and carbon neutrality policy in other provinces in China; (2) to synthesise the carbon decoupling index and the catching-up decoupling index, and to compare the decoupling effect and carbon reduction potential of carbon emissions in the temporal and spatial dimensions. decoupling effect and carbon reduction potential in time and space. (3) The mechanism of digital development on the decoupling effect of carbon emissions is revealed from the dimensions of industrial structure and scientific and technological innovation.

2. Methods and Data

2.1. Analysis of Theoretical Mechanisms

2.1.1. Digitalisation, Industrial Upgrading, and Carbon Reduction

Upgrading an industrial structure involves elevating it from a lower to a higher level, evident in the transition and enhancement of the industrial structure from a state of low to high value addition. Yuan Liao et al.[18] take the provincial data of China from 2005 to 2017 as an example and conclude that the improvement of the rationalisation level of industrial structure has a suppressing effect on carbon emission. Wang Xiangjin et al. study the development trend of service and high-end manufacturing in China and find that the service of manufacturing can promote the upgrading of industrial structure and significantly reduce the level of carbon emissions in the industry. Under the background of the rapid development of digital technology, traditional industries have fully integrated digital technology to carry out digital transformation and promote the digitalisation, automation and intelligence of traditional industries. Specific path: digital technology mainly promotes industrial structure upgrading by improving resource mismatch and stimulating enterprise innovation. Numerous scholars have adopted various methods to prove that industrial upgrading can effectively achieve carbon emission reduction. Overall, digitalisation promotes industrial structure to leap to advanced level by promoting resource allocation and innovation, eliminating backward production capacity and supporting emerging industries, and more advanced industrial structure has higher productivity, which ultimately achieves the utility of energy saving and emission reduction. Based on this, this paper proposes:

Hypothesis 1: Digital development can contribute to decoupling economic growth from carbon emissions by improving industrial structure.

2.1.2. Digitalisation, STI and Carbon Reduction

Digitalisation influences carbon emissions through scientific and technological innovation in two main ways: on the one hand, digitalisation empowers traditional industries. Digital technology can deeply integrate with traditional key carbon emission industries, innovate in energy allocation, cost, risk and decision-making control, etc., and overall promote the traditional industries to save energy, reduce costs, increase efficiency and improve quality, and help carbon emission reduction to achieve. Chen Xiaohong et al.[19] believe that digital technology represented by big data, digital twin, artificial intelligence, blockchain, etc. can not only technically help the energy industry to optimise energy allocation, energy saving and emission reduction, and efficient decision-making, but also achieve efficient and accurate carbon emission prediction and planning, and help achieve carbon peak and carbon neutrality. On the other hand. Digital technology gives rise to new industries and new business forms. Wu Yilin et al.[20] argued that the digital economy has emerged as the central driver of the scientific and technological transformation and industrial evolution, and that digital economic activities should be regarded as a new industrial category different from traditional industries. This type of economic activity is different from industrial digitalisation. As an independent subject, it enhances inter-subjective connections and generates empowerment through collaboration and knowledge sharing among innovative subjects[21]. Digital industry can effectively promote the flow of resources between industries and regions, facilitate the exchange of excess resources and lack of resources, and improve the efficiency of resource utilisation, thereby reducing carbon emissions. In addition, not all technological innovations have a positive impact on carbon emission reduction, and digital technological innovations represented by digital currencies can, to a certain extent, cause a large amount of energy consumption and increase additional carbon emissions. However, on the whole, the benefits of technological innovation

spawned by digital development outweigh the disadvantages. Based on this, this paper proposes:

Hypothesis 2: Digital development can contribute to the decoupling of economic growth from carbon emissions by promoting scientific and technological innovation.

2.2. Model Construction and Data Description

2.2.1. Decoupling Models

In researching the link between economic expansion and carbon emissions, the OECD and Tapio decoupling models are extensively employed, and the Tapio elasticity index is not affected by the selected base period, so the results are more accurate and stable. Therefore, this paper adopts the decoupling elasticity index constructed with reference to Tapio's research to measure the decoupling situation of prefecture-level cities in Zhejiang Province. As shown in equation (1):

$$e_{i,t}^s = \frac{\% \Delta C}{\% \Delta Y} = \frac{\Delta C}{C_{i,t-1}} / \frac{\Delta Y}{Y_{i,t-1}} = \frac{[(C_{i,t} - C_{i,t-1}) / C_{i,t-1}]}{[(Y_{i,t} - Y_{i,t-1}) / Y_{i,t-1}]} \quad (1)$$

where $e_{i,t}^s$ denotes the decoupling elasticity index between economic growth and carbon emissions for the i th city in year t . $C_{i,t}$ and $Y_{i,t}$ denote the amount of carbon emissions, total GDP of the i th city in year t , respectively; ΔC , $\% \Delta C$ denote the amount and rate of change of carbon emissions in year t relative to year $t-1$ for city i , respectively; ΔY , $\% \Delta Y$ denote the amount and rate of change of total GDP in year t for city i relative to year $t-1$, respectively. Tapio based on $\% \Delta C$, the $\% \Delta Y$ direction of change and the size of the decoupling elasticity index, it is divided into eight categories: expansionary negative decoupling, strong negative decoupling, weak negative decoupling, weak decoupling, strong decoupling, recessionary decoupling, and expansionary link. To comprehensively examine the issues of relative and absolute decoupling, this document cites the methodology employed by Zhang Cheng et al.[9] further elaborates on the transition from strong decoupling to both weak absolute and strong absolute decoupling, and from strong negative decoupling to weak absolute negative decoupling and then to strong absolute negative decoupling and the weak decoupling is replaced by the relative decoupling. Based on the $\% \Delta P$ symbol will be added to the classification of expansion and decline classification mark eight types of decoupling state division expanded to ten categories, as shown in Table 1:

Table 1. Division of decoupling elasticity index

out of touch		$\% \Delta C$	$\% \Delta Y$	$e_{i,t}^s$
negative decoupling	Expansion relative to negative decoupling	+	+	$(1.2, +\infty)$
	Recessionary strong absolute negative decoupling	+	-	$(-\infty, -0.5)$
	Recessionary weak absolute negative decoupling	+	-	$[-0.5, 0)$
	Recessionary relative negative decoupling	-	-	$[0, 0.8)$
cut ties	Relative decoupling of expansion	+	+	$[0, 0.8)$
	Weak absolute decoupling of expansion	-	+	$[-0.5, 0)$
	Expansion of strong absolute decoupling	-	+	$(-\infty, -0.5)$
	Recession relative decoupling	-	-	$(1.2, +\infty)$
links	expansionist link	+	+	$[0.8, 1.2]$
	recession link	-	-	$[0.8, 1.2]$

where absolute decoupling is defined as $\% \Delta C$, $\% \Delta Y$ changes in opposite directions, i.e., economic growth with a decrease in carbon intensity, or economic recession with an increase in carbon intensity, showing two distinct economic conditions, expansion and recession. $e_{it}^s < 0$ This is confirmed by the fact that $\% \Delta C$, $\% \Delta Y$ move in opposite directions; $e_{it}^s < -0.5$ The same $-0.5 \leq e_{it}^s < 0$ difference is that the former achieves a higher decline in carbon emissions growth rate when both obtain the same GDP growth rate, hence the stronger decoupling of the former and the weaker decoupling of the latter. Relative decoupling means that $\% \Delta C$, $\% \Delta Y$ change in the same direction, i.e. economic growth with a rise in carbon intensity, or economic recession with a fall in carbon intensity, again showing two very different economic conditions, expansion and recession. $e_{it}^s \geq 0$ This is confirmed by the fact that $\% \Delta C$, $\% \Delta Y$ move in the same direction; $e_{it}^s > 1.2$ The difference between $\%$ and $0 \leq e_{it}^s < 0.8$ The difference is that the growth rate of carbon emissions exceeds the growth rate of the economy in the former case and is slightly less than the growth rate of the economy in the latter case. The similarity between linkage and relative decoupling means that $\% \Delta C$, $\% \Delta Y$ move in the same direction, the difference is the difference in the decoupling index. $0.8 \leq e_{it}^s < 1.2$ The difference is the difference in the decoupling index, which implies that the growth rate of the carbon emission rate is comparable to the growth rate of the economy.

2.2.2. Catch-up Decoupling Modelling

The Tapio decoupling elasticity index reflects an individual's own low-carbon development status and cannot be used for cross-sectional comparisons between individuals. In order to compensate for the potential shortcomings of the Tapio decoupling elasticity index, Zhang Cheng et al.[9], in their study of the decoupling relationship between economic growth and carbon emissions, selected a benchmark province, compared other provinces with the benchmark province, and made a horizontal comparison of the development status of each research object by constructing a catching-up decoupling model. This paper also adopts this method to construct a catch-up decoupling model as shown in equation (2):

$$e_{i,t}^r = \frac{\% \Delta CI}{\% \Delta PY} = \frac{-\Delta CI_{i,t}/(CI_{t-1}^* - CI_{i,t-1})}{-\Delta PY_{i,t}/(PY_{t-1}^* - PY_{i,t-1})} = \frac{-[(CI_{t-1}^* - CI_{i,t}) - (CI_{t-1}^* - CI_{i,t-1})]/(CI_{t-1}^* - CI_{i,t-1})}{-[(PY_{t-1}^* - PY_{i,t}) - (PY_{t-1}^* - PY_{i,t-1})]/(PY_{t-1}^* - PY_{i,t-1})} \quad (2)$$

where $e_{i,t}^r$ denotes the catch-up decoupling elasticity index for the i th city in year t . The catch-up decoupling elasticity indices are shown in the following table; $CI_{i,t}$, and $PY_{i,t}$ denote the carbon intensity, GDP per capita of city i in year t , respectively. CI_t^* and PY_t^* denote the carbon intensity, GDP per capita of the benchmark city in year t , respectively; $\Delta CI_{i,t}$ and $\% \Delta CI_{i,t}$ denotes the amount and rate of change of the carbon intensity gap between the i th ordinary city and the benchmark city in year t , $\Delta PY_{i,t}$, and $\% \Delta PY_{i,t}$ denote the amount and rate of change of the gap between the GDP per capita of the i th city and the benchmark city in year t , respectively. In the selection of benchmark cities, the cities with leading green development level within the same economic development stage can be taken as benchmark cities, and other cities can be taken as ordinary cities[22]. In terms of the classification of the status of catching up and decoupling, the same classification criteria as decoupling are adopted, based on $\% \Delta CI$ The same classification criteria as for decoupling will be adopted, based on the following criteria $\% \Delta PY$ direction of change and the size of the elasticity index of catching up and decoupling, it is classified into ten categories of catching up and decoupling states. When $\% \Delta CI > 0$ when, it means that the gap between the carbon emission intensity of an ordinary city and that of a benchmark city is gradually narrowing, and the city is not consuming a lot of fossil energy in the process of catching up; on the contrary, the gap is gradually widening, and the city is consuming a lot of fossil energy in the process of catching up. When $\% \Delta PY > 0$ time, it means that the GDP per

capita of the ordinary city and the benchmark city is gradually shrinking, and the economic development gap is decreasing; on the contrary, the gap is gradually widening, and the economic gap is also increasing. Among them, the strong absolute decoupling is the most ideal catching-up mode, indicating that the gap between the catching-up city and the benchmark city in terms of GDP per capita and carbon emission intensity is shrinking at the same time, and the proportion of the latter shrinking is larger, and the economic growth and carbon emission are absolutely decoupled; the strong negative decoupling in terms of recession is the most undesirable catching-up mode, in which the gap between the catching-up city and the benchmark city in terms of GDP per capita and carbon emission intensity are shrinking at the same time and the proportion of the latter expanding is larger. Economic growth and carbon emissions are not decoupled.

2.2.3. Modelling

In order to study the impact of digital development on carbon decoupling effect, the mediating effect model is constructed according to hypothesis 1 and hypothesis 2 in the theoretical analysis part, and scientific and technological innovation and industrial upgrading are added into the model as mediating variables to test the mediating effect. The first stage tests the impact of digital development on carbon decoupling effect, constructing the benchmark model as shown in equation (3):

$$DC_{it} = \alpha_0 + \alpha_1 DE_{it} + \alpha_c Z_{it} + \lambda_t + \mu_i + \varepsilon_{it} \quad (3)$$

The second and third stages test the effects of digital development on the mediating variable, digital development and the mediating variable on the decoupling effect of carbon emissions, respectively, and construct the second and third stage models as shown in equation (4)(5):

$$m_{it} = \beta_0 + \beta_1 DE_{it} + \beta_c Z_{it} + \lambda_t + \mu_i + \varepsilon_{it} \quad (4)$$

$$DC_{it} = \gamma_0 + \gamma_1 DE_{it} + \gamma_2 m_{it} + \gamma_c Z_{it} + \lambda_t + \mu_i + \varepsilon_{it} \quad (5)$$

where DC_{it} and DE_{it} denote the decoupling of economic growth from carbon emissions and the digital development of the i th city in year t , respectively; m_{it} denotes the mediating variable; Z_{it} denotes the group of control variables; λ_t and μ_i denote the time effect and the individual effect, respectively; ε_{it} is the error term; and the existence of the mediating effect is proved if α_1 is significantly negative, and β_1 , γ_1 , and γ_2 are also significantly in line with the expectation.

2.2.4. Sample Selection

Zhejiang Province, as one of the strongest economic provinces in the eastern coastal region of China, is of great significance in taking the lead in achieving carbon peak and carbon neutrality. In January 2022, the international environmental organisation Greenpeace released a briefing note entitled "Tracking Carbon Emissions in China's 30 Provinces (Municipalities), Who Will Lead the "First Echelon"? According to the briefing, apart from the municipalities of Beijing and Shanghai, Zhejiang Province's total carbon emissions have remained stable for many years in a row, and the effectiveness of low-carbon transformation is at the forefront. In December 2021, Zhejiang Province released the "Implementation Opinions on Complete and Accurate Implementation of the New Development Idea of Doing a Good Job in Carbon Peak and Carbon Neutral Work", which also makes it clear that carbon control is achieved by digital means. Therefore, in the study of the correlation between digital development and the decoupling of

economic growth and carbon emissions, the selection of Zhejiang Province as a research sample is consistent with the actual needs of the country and Zhejiang Province, as well as the advanced needs of the relevant theoretical research.

2.3. Selection of Indicators

2.3.1. Explained Variables

The explanatory variable in this paper is the carbon decoupling index. The decoupling of economic growth and carbon emissions is used to describe the correlation between economic growth and changes in CO₂ emissions, and economic growth and carbon emissions are considered to be decoupled when economic growth is achieved while the growth rate of CO₂ emissions is smaller than the economic growth rate or the growth rate of CO₂ emissions is negative. Existing research on the decoupling of economic growth and carbon emissions is mainly measured by two methods: the OECD decoupling index method and the Tapio elasticity index method. Given that the OECD decoupling index method has a sensitivity problem in the selection of the base period, and in order to ensure the accuracy and stability of the decoupling index, this paper draws on the Tapio elasticity index method, and quantifies the decoupling of economic growth and carbon emissions through the ratio of the rate of change of regional carbon emissions to the rate of change of GDP. This paper draws on the Tapio elasticity index method to quantify the decoupling of economic growth and carbon emissions by measuring the ratio of regional carbon emission change rate to GDP change rate.

2.3.2. Core Explanatory Variables

The core explanatory variable of this paper is digital development. Digitalisation is primarily the use of digital technologies to reduce costs and increase efficiency in individual businesses and to empower and reshape the entire system of an organisation. Recently, not only the digital industry is booming, but also the traditional industry is undergoing a large number of digital transformation, the goal of which is to adopt digital technology to upgrade and transform the production process in order to improve production efficiency. Currently, research on digitalisation is in its infancy, in which the concept and quantification of digital development have not yet formed a unified standard. Combined with the fact that digital development is highly dependent on digital technology and the comprehensive nature of development, it has become a consensus to quantify the state of digital development using multiple indicators. Therefore, in view of the fact that there are fewer studies on digitalisation from a municipal perspective and the availability of relevant data is poor, we draw on the principal component analysis method of Fang Huli et al.[11] to quantify the digital development status, and use the Internet penetration rate, the mobile phone penetration rate and the total amount of telecommunication services per capita to measure the development of communication technology; and use the proportion of the number of people employed in the information transmission, computer services and software industry (10,000) to the number of people employed in the urban units to measure the development status of information technology and related technologies. The proportion of employees in the information transmission, computer services and software industry (10,000 people) in urban units was used to measure the development of information technology and related services; and the entropy weight method was used to obtain a comprehensive index of digital development. At the same time, indicators such as the number of Internet users per capita (households), the number of mobile phone users per capita at the end of the year (households), the total amount of telecommunication services per capita (yuan), and the number of people employed in the information transmission, computer services and software industry (10,000) as a proportion of the number of people employed in urban establishments were used to form the substitution variables for the digital development index.

2.3.3. Endogeneity and Instrumental Variables

Digital development is a technological innovation, and the digital development index may be internally consistent with the mediating variable (technological innovation). Therefore, the model may have endogeneity problems. Drawing on the methodology of Huang Qunhui et al.[23], this paper takes the number of fixed-line telephones per million people in cities across Zhejiang Province in 1984 as the working variable. Given that the selected data are interface data and cannot be analysed in a panel, this paper refers to Nunn N. and Qian N[24] to use the interaction term formed by the number of Internet users in the country in the previous year and the number of fixed telephones per million people in 1984 as an instrumental variable.

2.3.4. Mediating Variables

Two mediating variables, scientific and technological innovation (TECH) and industrial upgrading (IU), were selected to test the mediating effect.

STI is an important concept for measuring original scientific research and technological innovation, and the perfect measurement of STI capability requires the establishment of a multi-variable comprehensive rating system, which needs to include a number of evaluation indexes for STI input capability, STI output capability, STI environmental support capability and STI capability for sustainable development, etc. Currently, there does not exist a set of perfect indicators system for evaluating STI capability. There is currently no perfect indicator system for evaluating S&T innovation capability[25]. The number of patents can actually be seen as a specific and comprehensive reflection of S&T innovation capability. Wang Shuan et al.[26] also confirmed that the number of patents can comprehensively show the enterprise's innovation investment capacity, research and development capacity, innovation production capacity and management innovation capacity by establishing Poisson log-linear model. Compared with the complex evaluation system, the number of patents can not only comprehensively show the scientific and technological innovation ability but also has the natural advantage of accurate data. Therefore, the number of patents granted by the region in the current year is used to indicate scientific and technological innovation.

Industrial upgrading is essentially a manifestation of the upgrading and transfer of industrial structure from low value-added to high value-added. At present, there are three main methods to measure industrial upgrading: firstly, measuring the proportion of secondary and tertiary industries in GDP[27]; secondly, measuring the ratio between tertiary and secondary industries[28]; and thirdly, weighting the output value of the three industries[29]. Combining the essence of industrial upgrading and the current economic development, the most significant feature of industrial upgrading is the shrinking of the proportion of output value of primary industry with low added value and the expansion of the proportion of output value of secondary and tertiary industries with higher added value. Therefore, drawing on the method of Li Hong et al, the proportion of secondary and tertiary industries in the whole industry is used to indicate industrial upgrading.

2.3.5. Control Variables

In order to more accurately analyse the impact of digital development on the decoupling effect of carbon emissions, the following two control variables are set: foreign direct investment (FDI), which is expressed by using the amount of actual foreign investment as a proportion of the regional GDP; and urbanisation (UR), which is expressed by using the proportion of the total year-end population in towns and cities as a proportion of the total regional population. Table 2 shows the results of descriptive statistics for each variable.

Table 2. Descriptive statistics for each variable

variable name	notation	observed value	average value	(statistics) standard deviation	minimum value	maximum values
Carbon decoupling index	DC	143	0.353	0.596	-0.909	1.704
Digital Technology 1	lnDE1	143	-2.200	1.083	-0.6008	-0.0325
Digital Technology 2	lnDE2	143	-1.467	0.524	-2.784	-0.281
Science, technology, and innovation	lnTE	143	8.594	1.483	4.174	10.974
Industrial upgrade	lnIU	143	3.761	0.131	3.504	4.142
Overseas foreign direct investment (OFDI)	lnFDI	143	-1.459	0.967	-3.511	0.047
Urbanization	lnUR	143	4.011	0.279	2.816	4.341

3. Results

3.1. Status of Carbon Emissions in Zhejiang Province

Overall, as shown in Figure 1, Zhejiang Province's total carbon emissions and per capita carbon emissions continued to rise from 2005 to 2012, and then began to decline slightly after peaking in 2012; carbon emissions intensity continued to decrease from 2005 to 2017. Specifically, total carbon emissions rose from 246 million tonnes in 2005 to 396 million tonnes in 2012, an increase of 61.0%, followed by a slow spiral down to 370 million tonnes in 2017, a decrease of 6.6%; per capita carbon emissions showed the same trend of change, rising from 5.35 tonnes per person in 2005 to 8.26 tonnes per person in 2012, an increase of 54.3%, followed by a slow spiral down to 7.46 tonnes/person in 2017, a decrease of 9.7%; carbon intensity showed a continuous decline, from 1.93 tonnes/million in 2005 to 0.94 tonnes/million in 2017, a decrease of 51.3%.

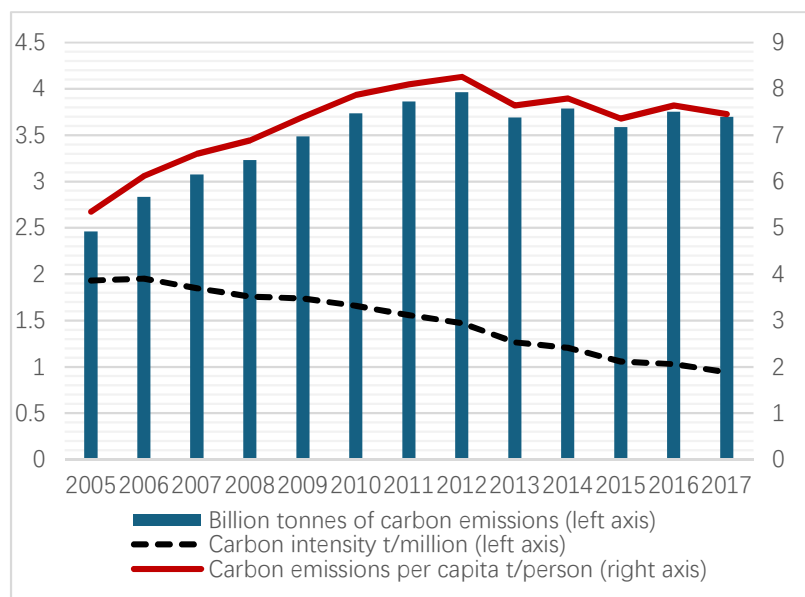


Figure 1. Trends in total carbon emissions, per capita carbon emissions and carbon intensity in Zhejiang Province, 2005-2017

Presently, carbon emissions in every prefectural city within Zhejiang Province mirror the broader scenario, showing a steady rise in both total and per capita carbon emissions from

2005 to 2012. In the province, Zhoushan City topped the charts for overall and individual carbon emissions, showing a rise of 87.7% and 86.8% respectively; Wenzhou City experienced the least growth, recording total and per capita carbon emissions of 50.4% and 41.0%, respectively. Following its zenith in 2012, it embarked on a gradual decline. Zhoushan City ranks first in the province with a 13.7% decrease in total carbon emissions, and Jinhua City ranks last with a 2.4% increase (except for Jinhua, the rest of the cities' carbon emissions peaked in 2012); Hangzhou City ranks first in the province with a 15.3% decrease in total per capita carbon emissions, and Jinhua City ranks last with a 0.01% decrease; and the carbon intensity has shown a continuous decline from 2005 to 2017. Among them, Quzhou City had the largest decrease of 58.3 per cent, while Taizhou City had the smallest decrease of 45.9 percent.

3.2. Decoupling of Economic Growth and Carbon Emissions in Prefectural-level Cities of Zhejiang Province

According to the situation of the actual measurement results of Tapio decoupling elasticity index of each prefecture-level city in Zhejiang Province in this study, the classification of Tapio decoupling status can be appropriately reduced because the GDP of each prefecture-level city showed a sustained increase in the interval of 2005-2017. Adopting Zhang Huaming et al.[8]'s classification method of city development types, the classification criteria are shown in Table 3. Specifically:

(1) When $e_{it}^s < 0$ When, this is the state of weak decoupling of expansion and strong absolute decoupling of expansion, which is manifested in economic growth but declining carbon emissions. It means that the economic development of this type of city is no longer dependent on excessive fossil energy consumption, and it is a low-carbon development type of city.

(2) When $0 \leq e_{it}^s < 0.8$ When, this is a state of relative decoupling of expansion, manifested by economic growth accompanied by carbon emissions growth, but the economic growth rate is faster than the carbon emissions growth rate. It means that the economic development of this type of city is still dependent on fossil energy, but to a lesser extent, and can be achieved by improving the energy utilisation rate to get rid of the dependence. The city is defined as an intensive expansionist city.

(3) When $0.8 \leq e_{it}^s < 1.2$, this is an expansionary state, which is characterised by economic growth accompanied by carbon emission growth, but both are growing year-on-year, and the intensive use of energy has not been realised, thus defining it as an inefficiently expanding city.

(4) When $e_{it}^s \geq 1.2$ When, this is a state of relative negative decoupling of expansion, which shows that economic growth is accompanied by carbon emission growth, but the growth rate of carbon emission is faster. The economic development model of this type of city is relatively loose, and the efficiency of fossil energy utilisation is extremely low, so it is defined as a roughly expanding city.

Table 3. Types of urban development

serial number	Range of decoupling values	form of expression	Type of development
1	$-0.5 \leq e_{it}^s < 0$ $e_{it}^s \leq -0.5$	Weak absolute decoupling of expansion Expansion of strong absolute decoupling	Low-carbon developmental
2	$0 \leq e_{it}^s < 0.8$	Relative decoupling of expansion	intensive and expansionist
3	$0.8 \leq e_{it}^s < 1.2$	expansionist link	Inefficient expansionist
4	$e_{it}^s \geq 1.2$	Expansion relative to negative decoupling	expansionist

The decoupling calculation results show that in 2005, all cities in Zhejiang Province did not realise decoupling, and economic growth had a big negative impact on the ecological environment, specifically Hangzhou and Jiaxing were in the stage of expansion relative to negative decoupling, and economic development was more relaxed, and economic growth consumed a large amount of energy, and a large amount of carbon was discharged into the environment; the remaining nine cities were in the stage of expansion linkage, and economic development was not able to realise intensive energy use, although the situation was better than the first two cities, but economic growth still needed to rely on a large amount of carbon emission. In 2006, Quzhou City was the first city in Zhejiang Province to enter the phase of relative decoupling of expansion, initially realising the decoupling of economic growth and carbon emissions, and becoming the first city in Zhejiang Province to become an intensively expanding city. 2007 was an extremely important year for Zhejiang Province, with all cities in the province successfully realising the relative decoupling of expansion, and the province's intensive and expanding mode of economic development being established at an initial stage. Between 2007 and 2012, all cities in the province maintained their relative decoupling of expansion and achieved low carbon emission growth rates in exchange for high economic growth; however, there was a collective retraction in 2009, with six cities - Jiaxing, Jinhua, Ningbo, Shaoxing, Taizhou, and Wenzhou - reverting back to expansionary linkages. 2013 was another year of progress in Zhejiang's ecological protection efforts, with all cities entering a stage of strong decoupling of expansion and carbon emissions, and a strong decoupling of economic growth and carbon emissions. In 2013, the strong decoupling of economic growth and carbon emissions meant that the cities achieved both economic growth and a reduction in carbon emissions, with the initial realisation of a low-carbon development-oriented city. However, this trend could not be sustained, and by 2017 all cities had regressed to different degrees, with Taizhou in 2014 and Jinhua in 2016 regressing to the expansionary linkage stage, while the rest of the cities have been in the decoupling state, and the overall situation has been maintained relatively well, with high economic growth and low carbon emission growth, or even zero or negative carbon emission growth, being maintained. It is worth noting in the decoupling measurement results that, in the process of the transformation of the prefectural-level cities in Zhejiang Province from the rough expansion type, inefficient expansion type, intensive expansion type and finally to the low-carbon development type, the upgrading of the development type is a rapid breakthrough in a short period of time, accompanied by a substantial change in the economic growth and carbon emissions decoupling index, but after the breakthrough of the economic growth and carbon emissions decoupling index all take a longer time to retracement adjustments until stable, but the The magnitude of retraction adjustment is limited. Therefore, the decoupling of economic growth and carbon emissions in all cities in Zhejiang Province is generally in a positive trend. Low-carbon development-oriented cities have been built, and the results of green development are remarkable.

3.3. Catch-up Decoupling Analysis of Prefecture-level Cities in Zhejiang Province

The study of the decoupling situation of cities in Zhejiang Province can be an excellent way to examine their own development status, in order to further study the decoupling situation of cities in depth, this paper examines the dynamic process of catching up to the benchmark city by using the catching up decoupling model. In the catch-up decoupling model, the economic growth of a city is shown by its GDP per capita, and the quality of its economic development is reflected by its carbon intensity. Cities in the same stage of economic development with a leading level of green development (i.e., good GDP per capita and carbon intensity) are designated as benchmark cities, while other cities can be considered as ordinary cities, so that the economic development status and quality of economic development of ordinary cities in the

process of catching up with benchmark cities can be examined to determine whether their development patterns are healthy and sustainable. In the case that the economic development of an ordinary city is better and the economic gap between it and the benchmark city is narrowing, if the gap of its carbon emission intensity is also narrowing, then the development mode of that city is sustainable intensive expansion or low-carbon development; if the gap of its carbon emission intensity is widening, then the city is still in inefficient and crude development. This paper chooses Hangzhou as the benchmark city of Zhejiang Province according to the principle of the highest per capita GDP and the lowest carbon emission intensity in 2004. The results of the catching-up decoupling model are shown in Table 4.

Table 4. Catch-up decoupling classification by city (with Hangzhou as the benchmark city)

Typology	2005	2007	2013	2016	2017
Expansion relative to negative decoupling	Jiaxing, Zhoushan	Zhoushan		Zhoushan	Wenzhou
Recessionary relative negative decoupling		Ningbo	Ningbo		
expansionist link				Jinhua	
Relative decoupling of expansion	Jinhua, Lishui				
Recession relative decoupling			Jiaxing	Jiaxing, Shaoxing	Jiaxing, Zhoushan, Shaoxing
Weak absolute decoupling of expansion	Huzhou, Quzhou, Ningbo	Jiaxing, Huzhou, Jinhua, Taizhou		Ningbo	Ningbo
Expansion of strong absolute decoupling	Shaoxing, Wenzhou, Taizhou	Shaoxing, Wenzhou, Lishui, Quzhou	Huzhou, Zhoushan, Jinhua, Shaoxing, Wenzhou, Taizhou, Lishui, Quzhou	Huzhou, Wenzhou, Taizhou, Lishui, Quzhou	Huzhou, Jinhua, Taizhou, Lishui, Quzhou

According to the results of the catching-up and decoupling index for each prefecture-level city in Zhejiang Province, table 5 shows that the economic development of each city in Zhejiang Province is generally stable and upward, and the gap with the benchmark city is constantly narrowing, with recession occurring only in Jiaxing, Zhoushan, Shaoxing and Ningbo in some years; the cities that have achieved relative decoupling or absolute decoupling have reached 60 per cent or more in each year, and the catching-up path is generally intensive or low-carbon and sustainable. In terms of time latitude, no cities except Ningbo were in recession before 2012, but Jiaxing, Shaoxing and Zhoushan have been in recession since 2013, and according to the results of the pre-2012 catching-up decoupling of these four cities, their catching-up has been unstable, and thus their economic recession may be related to the tightening of ecological

governance. From the results of the cities' catching-up decoupling, Huzhou and Quzhou have the best catching-up paths, with strong absolute decoupling in most years and weak absolute decoupling in the rest of the years, and absolute decoupling of economic growth and carbon emission intensity, so that a low-carbon and sustainable catching-up path has been established. Zhoushan has the worst performance in catching up, with more than half of the statistical years showing a negative decoupling of expansion, and the gap in carbon emission intensity expanding at a higher rate than the gap in economic development, the catching-up mode is extremely sloppy and unsustainable, and faced with the pressure of tightening ecological governance, Zhoushan finally experienced a recession in 2017. Ningbo and Wenzhou's performance in catching up is poorer. Ningbo has experienced a negative decoupling in five years, with the gap between its economic development and Hangzhou widening and its carbon intensity not decoupled; Wenzhou has experienced a negative decoupling in four years, and although the gap between its economic development and Hangzhou's has narrowed, its development relies on a large amount of energy consumption and carbon emissions, and fails to realise its goal of low-carbon development. The rest of the cities have achieved decoupling of economic growth and carbon intensity in most years, but the results are unstable and may be related to the fact that the low-carbon catch-up route has not been implemented as in the past.

3.4. Mediated Effects Modelling Results

According to the constructed mediating effect model, the effect of digital development in promoting the decoupling of economic growth and carbon emissions through the promotion of scientific and technological innovation and industrial upgrading is empirically examined. The results are shown in Table 5.

Table 5. Regression results of the mediating effect of digital development on the decoupling of economic growth and carbon emissions

variant	(1) DC	(2) IU	(3) DC	(4) TECH	(5) DC
DE1	-0.602*** (-4.73)	0.096** (2.04)	-4.524*** (-5.20)	1.175*** (2.52)	-0.440*** (-4.09)
IU			-1.554*** (-3.81)		
TE					-0.135*** (-4.17)
Sobel test			-1.696*		-2.568**
time effect	containment	containment	containment	containment	containment
city effect	containment	containment	containment	containment	containment
R2	0.392	0.311	0.4241	0.3485	0.398
N	143	143	143	143	143
Notes: ***, ** and * represent 1 per cent, 5 per cent and 10 per cent significance levels, respectively; values in parentheses indicate t-values.					

Among the regression results of the first-stage benchmark model, as shown in Column (1), the coefficient of the core explanatory variable, digital development, is -0.602 and is significant at the 1 per cent level, implying that digital development is able to effectively play a role in the decoupling of economic growth and carbon emissions. Columns (2) and (3) test the mediating role of industrial upgrading in digital development in promoting the decoupling of economic

growth and carbon emissions. In column (2), the coefficient of industrial upgrading is significantly positive, implying that digital development can effectively improve industrial structure to promote industrial upgrading; in column (3), industrial upgrading is introduced into the regression equation of digital development and decoupling of economic growth and carbon emissions, the coefficient of industrial upgrading is significantly negative, and the coefficient of decoupling of carbon emissions is significantly negative and smaller than that in the first-stage benchmark regression results, indicating that digital development can promote carbon decoupling through improving industrial structure. Hypothesis 1 is verified. Columns (4) and (5) test the mediating role of STI in digital development in promoting economic growth and carbon decoupling. In column (4), the coefficient of science and technology innovation is significantly positive, implying that digital development can effectively enhance science and technology innovation; in column (5), when science and technology innovation is introduced into the regression equation between digital development and decoupling of economic growth and carbon emissions, the coefficient of science and technology innovation is significantly negative, and the coefficient of decoupling of carbon emissions is significantly negative and smaller than that of the first-stage baseline regression results, which indicates that digital development can promote decoupling of carbon through the enhancement of science and technology innovation. Hypothesis 2 is verified.

In this paper, the independent variables are taken logarithmically while the dependent variables are not, thus the total effect is not equal to the direct effect plus the mediating effect. To ensure the significance of the mediating effect, further Sobel test was conducted. The Z value is -1.696 when industrial upgrading is used as the mediating variable, and the Z value is -2.568 when science and technology innovation is used as the mediating variable, both of which are significant at least at 10% confidence level, and the significance of the mediating variable is verified again.

3.5. Robustness Test Results

Table 6. Robustness test for replacing explanatory variables

variant	(1) DC	(2) IU	(3) DC	(4) TECH	(5) DC
DE2	-0.993*** (-8.41)	0.170*** (3.70)	-0.837*** (-7.46)	2.130*** (5.57)	-0.808*** (-5.78)
IU			-0.916*** (-2.69)		
TE					-0.086*** (-2.84)
Sobel test			-1.716*		-2.310**
time effect	containment	containment	containment	containment	containment
city effect	containment	containment	containment	containment	containment
R ²	0.374	0.513	0.382	0.510	0.379
N	143	143	143	143	143

Notes: ***, ** and * represent 1 per cent, 5 per cent and 10 per cent significance levels, respectively; values in parentheses indicate t-values.

Considering that the selection of core explanatory variables may have an impact on the findings, the core explanatory variables are made to be replaced and the model is re-tested in order to ensure the reliability of the findings. Specifically, the core explanatory variable is replaced with DE2. the estimation results are shown in Table 6. The test results show that the sign and significance of the coefficients are in general agreement with the previous paper, as well as the significance of the Sobel test. Table 7 reports the endogeneity tests done with the IV-2SLS

model. The results of Kleibergen-Paap rk's LM statistic and Wald F statistic are significant and DE1 is significantly negative. The robustness tests all proved that the results of the study are robust and reliable. Table 8 reports the heterogeneous impact of digital development on the decoupling effect of economic growth and carbon emissions. In regions where economic growth is strongly decoupled from carbon emissions, the stronger the role of digital development in promoting decoupling, while the role played by digital development diminishes as the degree of decoupling weakens, but all are significantly negative.

Table 7. Robustness test for endogeneity

variant	instrumental variable approach		
	(1) DC	(2) DC	(3) DC
DE1	-0.778***	-1.671***	-1.125***
	(-4.70)	(-3.22)	(-3.62)
IU		-6.752***	
		(-3.49)	
TE			-0.870***
			(-4.69)
Kleibergen-Paap rk LM statistic	18.892***	11.374***	12.598***
Kleibergen-Paap rk Wald F-statistic	31.134***	14.140***	19.077***
control variable	containment	containment	containment
time effect	containment	containment	containment
city effect	containment	containment	containment
F-value	21.67	20.88	21.52
R ²	0.282	0.573	0.563
N	104	104	104

Table 8. Robustness test for heterogeneity

quartile \ model	0.1	0.3	0.5	0.7	0.9
DE1	-0.7123**	-0.6220***	-0.592***	-0.562***	-0.531***
	(-2.50)	(-5.12)	(-6.67)	(-5.97)	(-3.99)
DE2	-1.387***	-1.101***	-0.959***	-0.836***	-0.734***
	(-3.74)	(-5.73)	(-7.62)	(-6.54)	(-4.31)

4. Discussion

This paper examines the decoupling of economic growth and carbon emissions in prefecture-level cities of Zhejiang Province with the help of decoupling model based on the panel data of 11 cities in Zhejiang Province from 2004 to 2017, and empirically examines the impact of digital development on the decoupling effect of carbon emissions in Zhejiang Province with the help of mediation effect model. The conclusions of the study are as follows:

4.1. Conclusion

(1) From 2005 to 2017, Zhejiang Province witnessed a steady decline in carbon emissions, marked by a 51.3% reduction. Subsequently, there was a gradual increase in total and per capita carbon emissions from 2005 to 2012, peaking at 54.3%, followed by a downward spiral

in total and per capita carbon emissions from 2012 to 2017, culminating in a 9.7% decrease over five years. a total reduction of 9.7 percent. Prefecture-level cities, like the entire province, face a similar scenario where carbon emission intensities keep decreasing, while overall and per capita carbon emissions rise pre-2012 and gradually decrease post-2012.

(2) By 2005, every city at the prefectural level in Zhejiang Province was experiencing a phase of either a relative negative or weak absolute separation in terms of expansion and linkage, with their economic growth and carbon emissions being somewhat disjointed. However, by 2017, these cities had transitioned to a state of low-carbon development. An analysis of the era revealed that by 2007, despite the ongoing increase in total and per capita carbon emissions across all cities, they were in the initial phase of a relative separation in their growth, leading to the economy's shift towards a more intensive, low-carbon approach. A year following the zenith of total and per capita carbon emissions, in 2013, all cities first achieved a robust absolute separation in their expansion, successfully separating economic growth from carbon emissions. Subsequently, in the following years, every city and their carbon emissions were in a phase of either strong absolute or weak absolute separation, with economic growth and carbon emissions becoming separate. Over the subsequent years, urban and municipal areas experienced a decline in both their overall and individual carbon emissions, striving to sustain a robust, expanding state of absolute decoupling, albeit with some regression, yet the general pattern remained positive and positive.

(3) Take Hangzhou as a benchmark city and analyse the dynamic process of catching up from other cities to the benchmark city. In the face of tightened ecological governance, a green, low-carbon and sustainable catching-up mode will show its advantages in later economic development, while sloppy catching-up will have a negative impact on the city's economic development. Specifically, Huzhou and Quzhou have the best performance in catching up, with the economic gap and carbon intensity gap between them and Hangzhou narrowing, which is an ideal state of decoupling; Zhoushan has the worst performance in catching up and decoupling, with its economy narrowing but carbon intensity expanding in most of the years, which makes the catching up route more sloppy. Ningbo and Wenzhou have performed poorly in catching up, with economic growth and carbon intensity not decoupled in some years. The remaining cities have generally better but less stable catching-up paths.

(4) With the help of the mediation effect model to empirically test the impact of digital development on the decoupling effect of carbon emissions, the results are positive, digital development can synergistically contribute to the decoupling of economic growth and carbon emissions through the improvement of industrial structure and the promotion of scientific and technological innovation. The results of the panel quartile show that in regions with strong decoupling of economic growth and carbon emissions, the stronger the role of digital development in promoting decoupling, and as the degree of decoupling weakens, the role played by digital development gradually weakens.

4.2. Suggestions

Based on the above findings, in order to promote the decoupling of economic growth and carbon emissions in prefectural-level cities in Zhejiang Province, and to accelerate the realisation of carbon peak and carbon neutrality to form a demonstration experience that can be replicated across the country, this paper puts forward the following suggestions:

(1) Strongly support the introduction of foreign capital and deepen the environmental supervision of foreign capital. Foreign-funded enterprises are capital providers and technology owners, Zhejiang Province to achieve high-quality low-carbon development cannot be separated from foreign-funded enterprises of capital and technology, to strongly support the entry of foreign-funded enterprises at the same time to put a good access to the customs and supervision of the customs, and actively guide the foreign-funded enterprises in the green and

low-carbon industries and green energy-saving technology investment, strict control of foreign capital in the development of high-energy-consuming, high-polluting industries.

(2) Promoting industrial upgrading and strengthening scientific and technological innovation. On the basis of actively promoting urbanisation, the disadvantages associated with urbanisation should be reasonably controlled, the operational efficiency of cities should be improved by promoting industrial upgrading and strengthening scientific and technological innovation, the impact of environmental problems brought about by urbanisation should be reduced, and the hindering effect of urbanisation on the decoupling of economic growth and carbon emissions should be controlled within a reasonable range.

(3) Addressing digital transformation and fostering digital industries. Continue to promote the integration and development of digital technologies with key emission areas such as power, industry, construction and transport, strengthen technological innovation and enhance the rate of technological transformation. In general, continue to strengthen the innovation and enhancement of digital technologies represented by big data, digital twins, artificial intelligence, blockchain, etc. Locally, rely on digital technologies to increase the innovation of technologies targeting low-carbon energy, carbon sequestration technologies, etc., and further enhance the conversion rate of the technologies in a demand-oriented manner.

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