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Does ecological protection compensation help to achieve carbon reduction? --Empirical evidence from transfer payments in national key ecological functional zones

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Abstract

In the process of competition for international status, environment quality has become a critical factor in assessing a country's development level, and carbon emissions have become a major challenge to national development. The ecological protection compensation mechanism is an important means of environmental management, so this paper selects the transfer payment mechanism of the national key ecological functional zones and explores in depth the positive role of ecological protection compensation in realizing carbon emission reduction. Based on the data of 1,632 county-level cities from 2005 to 2017, a staggered difference-in-difference model is constructed to study the impact of transfer payments on carbon emissions. Ecological protection compensation can not only directly achieve carbon emission reduction and increase carbon sequestration, but also reduce carbon emissions through green technological innovation, the adjustment of the scale of industrialization, and the increase in forest areas. Heterogeneity results show that regions with higher fiscal freedom and higher electricity consumption are better able to achieve carbon emission reduction. This paper enriches the effects and roles of the ecological protection compensation mechanism, further expands the strategic approach to achieve carbon emission reduction, and proposes policies such as optimizing industrial structure, upgrading the level of green innovation, and increasing fiscal freedom to further assist China in achieving the goals of carbon peak and carbon neutrality.

Keywords: *carbon emissions, ecological protection compensation, national key ecological functional zones, "dual-carbon" goal*

JEL Classification: Q58, H23

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1 INTRODUCTION

The economic system, the natural environment and the human synthesis of the formation of the whole are closely linked, where ecological security has emerged as an important factor of national competitiveness. The process of development has brought about serious environmental pollution problems, so the world is highly concerned about ecological and environmental issues. The carbon emissions that are driven by urbanization and industrialization have not only led to the greenhouse effect and the frequent occurrence of extreme weather events and longer drought periods (Zhao et al., 2024), but also influenced a country's soft power and international competitiveness. The Intergovernmental Panel on Climate Change's (IPCC) Climate Change 2023 states that global carbon dioxide (CO2) emissions must be significantly reduced by 2050 to achieve net-zero global CO2 emissions in order to curb the projected global warming of 1.5 degrees Celsius (IPCC, 2023), which requires a global effort. This requirement means the degree of green and low-carbon development has become a vital dimension in measuring a

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country's international status, with countries racing to secure technological leadership in decarbonization. Regional carbon emission reduction is the main factor affecting air quality (Xu et al., 2022). In the process of achieving global carbon emission reduction, efforts should start with emission reduction in various regions. Therefore, this paper focuses on China's carbon emission reduction.

The impacts generated by carbon emissions are analyzed from the following three dimensions: global ecological environment, economy and society. First, increased carbon emissions will affect the global ecological environment. The increase of carbon emission leads to exacerbated global warming and frequent extreme weather events, such as typhoons and droughts, which reduces the terrestrial carbon sink (Pan et al., 2020). Moreover, Gatti et al. (2021) find it increases the pressure on the ecosystem and the probability of fires occurring. And the increase in carbon emissions leads to the impairment of the value of the entire ecological service system (Mehvar et al., 2019; Zhang et al., 2024). Secondly, at the economic and society level, the carbon emissions and these extreme weather events will directly or indirectly affect the costs of traditional industries, leading to a decline in the production of wheat and corn (Wang et al., 2024), which will lead to an increase in the price of agricultural commodities. Carbon emissions have negative impacts on financial development, and innovation on economic growth (Li & Wei, 2021). Also, transportation and energy supply will be greatly affected. In order to realize the goal of sustainable development, governments need to take corresponding measures to achieve energy savings and emission reduction, and therefore need to invest a large amount of financial and technical support, which will put pressure on economic growth and inhibit its further development. Research indicates that areas featuring lower carbon intensity and greater industrial output manifest relatively higher technical efficiency, which necessitates the government's implementation of carbon reduction policies (Li et al., 2024). At the same time, climate change further deepens the uncertainty of the global economy, which has a certain impact on international trade and financial markets. In order to improve environmental standards, the European Commission proposes carbon border adjustment mechanism (CBAM) to realize carbon emission reduction. Bellora and Fontagné (2022) point out that the CBAM could reduce carbon emissions, but it has resulted in higher carbon quota prices in the European emissions trading system (ETS) market and reduced export competitiveness. In the long term, frequent extreme weather increases energy consumption in Asian and European countries, while technological innovation (Tao et al., 2023) and renewable energy (Khan et al., 2022) can significantly reduce carbon emissions. Therefore, these measures change the economic development and employment trends, thus affecting the global economy and society. As for the social influence, higher levels of carbon dioxide being emitted will lead to the emergence of more health problems (Farooq et al., 2019). Raihan et al. (2022) reveal that a 1% increase in carbon emissions will improve health expenditures by 0.95% in Bangladesh. Besides, climate changes affected by carbon emissions have an impact on social stability, which may increase future risks of conflict (Mach et al., 2019). Therefore, the level of carbon emissions is highly relevant to the global ecological environment and the economy and society, and it needs to be addressed by the whole society.

The global competition for carbon reduction leadership has spurred the adoption of diverse policy instruments, with environmental policy as a critical lever for achieving carbon emission targets. For example, a carbon emissions trading policy can significantly reduce carbon emissions (Feng et al., 2024). A low-carbon pilot city policy can also reduce carbon emissions intensity (Dong et al., 2023) and achieve comprehensive green transformation (Wang et al., 2024). At the same time, the government will also adopt a fiscal policy of transfer payments. Fiscal policy serves as a guideline for financial allocation activities and the handling of various

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financial allocation relationships formulated by the state. For example, the European Union's common agricultural policy links subsidies to environmental compliance, while the U.S. clean power plan uses market-based mechanisms to reduce industrial emissions. At present, the implementation process of carbon emission reduction is still led by the national government, because government supervision is strengthened and enterprises are incentivized by diversified subsidy policies, prompting them to participate in carbon emission reduction activities, while customers' choices also depend on government policies (Li et al., 2024). So fiscal policy is particularly important here, as an important tool for the state to intervene in the economy and achieve macroeconomic goals. In the process of carbon emission reduction, fiscal policy can guide and support green and low-carbon development through targeted financial allocation and macro-control. As seen in China's national key ecological functional area transfer payment policy, the transfer payments compensate for the opportunity cost of shutting down a business through financial investment. Reducing the cost of clean energy and low-carbon technologies improves the market competitiveness of their products, thereby realizing carbon emission reduction.

Therefore, this paper tries to further understand the role of fiscal policy for carbon emission reduction by selecting the national key ecological functional area transfer payment policy, which is a policy proposed in response to the deep understanding of ecological protection and sustainable development in China, and has gradually become one of the important means of ecological compensation. The policy aims to encourage local governments to strengthen ecological environmental protection through the transfer of financial funds, realize reasonable compensation for ecological functional zones, improve greater ecological conservation (Busch et al., 2021), and stimulate the enthusiasm of local residents for local ecological protection, which in turn promotes sustainable development and the formation of a harmonious coexistence of man and nature. Canthe transfer payment policy for national key ecological function areas reduce carbon emissions? And, what mechanisms are used to achieve carbon reductions? The main method of this paper is to construct a staggered difference-in-difference model to compare the counties that receive transfer payments with those that do not receive financial subsidies. In the data processing of this paper, the information is obtained by applying to the website of the Ministry of Finance on the basis of public information, and is then manually sorted and matched to get the list of counties receiving transfer payments from 2005 to 2017. At the same time, this paper selects the corresponding control variables from the three dimensions of economic, social and ecological foundation for consideration.Moreover, in order to further analyze the role the mechanism of transfer payments in national key ecological functional zones in depth, and the transformation to green and low-carbon technologies, the adjustment of the scale of industrialization and forest areas are selected as the mechanism variables to be studied.

We find that ecological compensation by the state through transfer payments to national key ecological function areas can significantly reduce carbon emissions, resulting in a decrease of 0.356 units of carbon emissions. Ecological compensation can not only directly prompt regions to achieve carbon emission reduction, but also through green technological innovation, the adjustment of the scale of industrialization, and the increase in forest areas as indirect mechanism variables to achieve carbon emissions. At the same time, a heterogeneity analysis shows that the region with higher financial freedom and high electricity consumption can better achieve carbon emission reduction. At the same time, the results of this paper are robust, by replacing the explanatory variables to obtain the above conclusions are still valid, the parallel trend test, and through the parallel trend sensitivity test, when the treatment of the parallel trend of the deviation before the implementation of the policy in the year of the effect of the

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implementation of the policy is still robust. At the same time, a test of heterogeneous treatment effects was conducted to obtain the results showing that it was not significant before the treatment, but significantly reduced carbon emissions after the treatment. And the results remain robust after excluding other policy interferences and taking into account the entry and exit scenarios.

This paper contributes in a number of ways. First, this paper expands the scope by examining the mechanism of action of each ecological compensation and the status of its impact on the ecological environment from a national perspective. Most of the previous literature focuses on a specific region, such as Jia and Yuan (2024), who study interregional horizontal ecological compensation measures in the Yangtze River economic belt and find a significant suppression of carbon emissions in the region. The findings align with the European Union's CAP, which demonstrates that investment subsidies increase eco-efficiency (Czyżewski et al., 2021). At the same time, ecological transfers can be viewed as a direct way to stimulate local governments' efforts to improve environmental quality (Cao et al., 2021) and can reduce pollution-intensive activities and industrial pollution (Gong et al., 2020). By studying ecological compensation in the Tibetan plateau region, it was found that most regions have excess carbon sequestration, and carbon sequestration tends to flow more closely between supplying and benefiting regions (Wang et al., 2024). For example, a study focusing on the Yangtze River delta region found that for every 10 billion yuan allocated to ecological compensation, average annual carbon emissions were reduced by about 0.26% (Wang & Wang, 2023). Some scholars determined that the transfer payment policy in key ecological function areas can significantly reduce carbon intensity (Jin et al., 2023). However, such studies on the ecological compensation mechanism and the transfer payment system of national key ecological functional zones are all limited to a specific region. This paper expands the research perspective to the national field, selecting 1,632 county-level cities across China for consideration, and determines that the transfer payment for national key ecological functional zones can significantly reduce carbon emissions.

Second, this paper focuses on the impact of transfer payments on carbon emissions in national key ecological functional zones, enriching the scope of research on such zones. Some scholars have pointed out that ecological compensation can improve the green economic efficiency of the compensated area and promote the regional green economic development (Yang, 2023). At the same time, it was found that eco-compensation measures can also improve the value of hydrological regulation function and ecosystem service value in the Xin'an River basin (Yu et al., 2023). And ecological compensation can not only improve the water ecosystem, but also increase the yield and income level of each region and improve the welfare level (Yi et al., 2024). Liu et al. (2023) found that through the study of ecological compensation in the watershed, it can improve the protection of water ecology and the management of water environment. In the study, it was found that an increase in government funding makes the farmers in the region show a high willingness to participate in ecological compensation, which effectively protects the biodiversity of the region (Rasheed et al., 2021). Current research focuses on ecological compensation for rivers and oceans, and less literature focuses on the impact of ecological compensation on carbon emissions, and the scope of attention is small, focusing on specific regions. Therefore, this paper enriches the research scope of national key ecological function areas through empirical analysis.

Third, this paper further selects the green technological innovation, the forest areas and the scale of industrialization as the mechanism variable to measure. This paper proposes that the transfer payment of national key ecological function area helps to achieve carbon emission reduction, and provides a new development path for realizing the green and low-carbon development. Jia and Yuan (2024) study the implementation of the policy to achieve carbon emission reduction by improving the financial development and promoting scientific and technological innovation. Most studieses focus on the direct impact of ecological compensation on carbon reduction. The current academic research on the path of carbon emission reduction is more abundant, such as the pilot reform of the financial province directly supervising the county to realize the synergistic management of haze and carbon emission reduction (Xu et al., 2024). Increases in digital financial inclusiveness (Lei et al., 2024) and financial technology (Chen et al., 2024) can also achieve carbon emission reduction, and at the same time, the open policy of agricultural trade can also reduce the agricultural carbon emissions (Wang et al., 2024). In addition, the new energy model city policy (Ding et al., 2024), green finance policy (Wang & Gao, 2024), and the improvement of green technology (Zhao et al., 2024) can reduce environmental pollution, lower carbon emissions, and improve carbon efficiency. The research in this paper will provide more paths for the realization of carbon emission reduction and new ways of development.

2 INSTITUTIONAL BACKGROUND AND THEORETICAL ANALYSIS

2.1 Institutional background

The national key ecological functional area transfer payment system, which has been in place since 2008, is a vertical financial transfer from the central government to local governments to protect the ecological environment and promote sustainable development. In 1997, China launched the pilot work of national key ecological function zones and set up some demonstration zones for pilot exploration, which marked the initial formation of the transfer payment system. In 2008, China formally established the national key ecological functional zones transfer payment system. The scope of the transfer payment mainly covers ecological functional zones that are related to the regional ecological security of the country and are determined by the central authorities in charge of formulating protection plans. In 2009, the Ministry of Finance officially issued the measures for transfer payments to national key ecological functional zones (pilot), which clarified the scope of the transfer payments, allocation of funds, guidelines for performance inspection and supervision, and incentives and constraints. In 2010, the State Council enacted the national plan for main functional areas, which further clarified the scope of the national key ecological functional zones, and likewise clarified the scope of the transfer payments. And, national key ecological functional zones such as the Sanjiangyuan Nature Reserve in Qinghai, the South-to-North Water Diversion Middle Line Water Source Protection Zone, and the Central Mountainous Ecological Protection Core Zone of the International Tourism Island in Hainan were added to the list.

The issuance of the “measures for transfer payments to national key ecological functional zones” by the Ministry of Finance in 2011 further clarified the transfer payment methods for key ecological functional areas. The method of fund allocation for transfer payments has been continuously optimized, with the implementation of the “key subsidies as the mainstay, supplemented by special subsidies” method of fund allocation. The Ministry of Finance issued the “2012 measures for the transfer payment from the central government to the local government of the national key ecological functional zones,” covering 466 counties (cities) and 1,367 prohibited development zones with 37.1 billion yuan. With the passage of time, the scope of transfer payments has been continuously optimized, and corresponding policies have been issued every year or every other year to readjust the scope of counties for transfer payment, the method of fund allocation has been continuously improved, the incentive and constraint

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mechanism has been gradually improved, and the compensation standard and the use of the fund have been continuously improved. At the same time, transfer payment methods and distribution results have gradually become more open and transparent, with greater emphasis on fairness and efficiency.

In 2014, 20 counties, including Everest in Tibet, were included in the transfer payment area, with a cumulative total of 512 counties and a total of RMB 2.4 trillion in funding. The average county transfer payment amounted to RMB 94 million. The average county funding then declined year by year, rising slightly in 2018. By the end of 2017, the scope of the policy was expanded to 28 provinces across the country, with 810 county-level units and funding amounting to 62.7 billion yuan, with average county funding of about 0.77 billion yuan. This policy has played an important role in maintaining national ecological security, balancing the interests between ecological protection areas and ecological beneficiary areas, and helping to improve the synergy between economic development and green development. According to the 2016 and 2019 reports on the monitoring, evaluation and assessment of the ecological environment quality of counties in national key ecological functional zones, the scope of counties in national key ecological functional zones has been steadily increasing, basically stabilizing at 411 counties during the 2013-2015 period, and 647 counties during the 2016-2018 period. By 2020, the policy covered 818 counties in 31 provinces, with a cumulative investment of more than 600 billion yuan. It can be seen as the only direct, continuous and centralized ecological protection compensation policy for key ecological functional zones in the country to date. As can be seen from the following **Chyba! Nenašiel sa žiaden zdroj odkazov.**, there are differences in the time when each county receives transfer payments, and there are cases of entry and exit. Therefore, this policy is selected as a quasi-natural experiment.

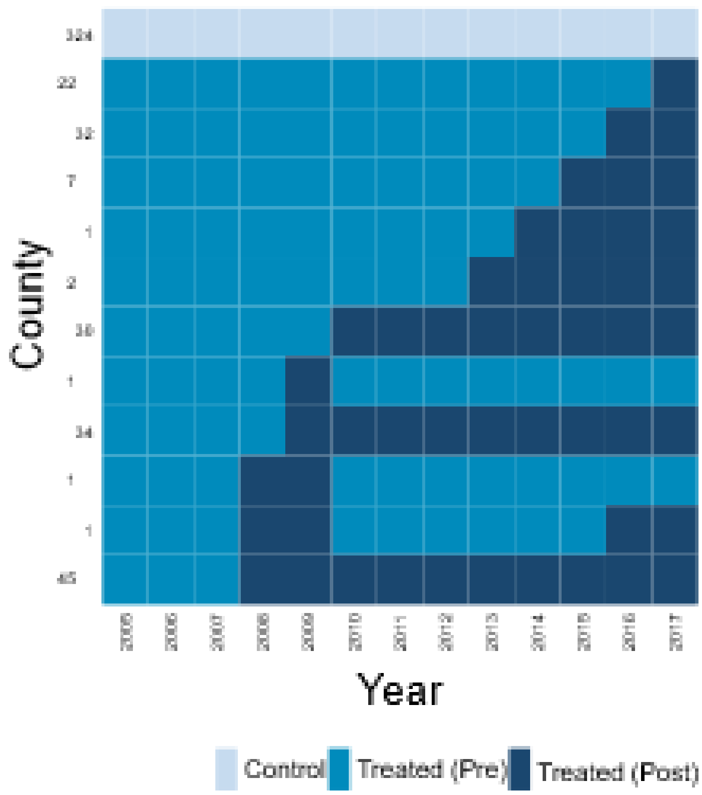

Fig. 1 – Treatment Status by Timing Group. Source: own research

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2.2 Theoretical analysis

Current studies generally agree that national key ecological function area transfer payments can effectively realize ecological environment improvement and can have a direct impact or an indirect impact on the carbon emissions of counties.

First, transfer payments to national key ecological functional zones directly affect carbon emissions. Ecological compensation transfer is a fiscal instrument used by the central government to compensate for the opportunity cost of local ecological protection through vertical transfer payments. Therefore, local governments can use this portion of funds to achieve a shift in their goals from economic development to the balanced development of the ecological economy. Fiscal transfer payments have an impact on energy saving and emission reduction (Zhou & Lin, 2023). At the same time, fiscal transfer payment policies such as the national energy conservation and emission reduction fiscal policy comprehensive demonstration city can significantly reduce the carbon emission intensity of the demonstration city (Wang et al., 2024) thus playing a role in protecting ecological resources and guaranteeing the fairness of regional development. From the perspective of environmental federalism (Oates, 2002), the national key ecological functional zones transfer payment system reflects that the central government formulates the standards, and the local governments implement them. The central government ensures the implementation intensity of local policies through means of ecological and environmental supervision and assessment. At the same time, with the establishment and guidance of the central financial transfer payments to the ecological functional zones, the local governments can effectively promote the local community to improve the ecological development mode, promote clean energy, and improve the efficiency of energy use. The institutional design of “centralized fiscal control and decentralized implementation” (Kostka & Nahm, 2017) allows for carbon emission reduction.

Hypothesis 1: Transfer payments in national key ecological functional zones reduce carbon emissions in each county.

Second, transfer payments to national key ecological functional zones can indirectly affect carbon emissions through transformation towards green and low-carbon technologies, expanding the forest areas and adjusting the scale of industrialization. Different from the emissions trading system (ETS), which relies on enterprises’ independent research and development of emission reduction technologies, the transfer payments for ecological functional areas achieve green development through institutional innovation led by local governments. Technological innovation is often accompanied by increased productivity, which may lead to increased resource and energy consumption, thus affecting carbon emissions. Environmental regulation (including ecological compensation) can improve technological innovation (Ambec et al., 2013). Technological innovation can achieve environmental improvement and improved economic performance (Yu et al., 2023). For example, the construction industry, one of the most energy intensive industries in China, leads to high carbon emissions (Zhou et al., 2023). Sixty percent of China’s total energy consumption is due to heavy industry, leading to high carbon emissions (Ke et al., 2024). Implement industrial access restrictions and capacity exit compensation for ecologically fragile areas, thus can reduce the scale of energy-intensive and polluting industries. With the support of compensation funds, traditional industrial areas can transform into green manufacturing and the service economy. Wan et al. (2022) find ecological compensation can affect industrial transfer and industrial upgrading, resulting in an adjustment of the industrial structure. The ecological protection compensation policy clearly provides financial incentives for local areas to protect or restore forest areas. In the implementation measures, the forest area is explicitly set as a standard for

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policy supervision and assessment. Therefore, this will lead to an increase in the local forest area. Forests absorb CO_2 in the atmosphere through photosynthesis and fix carbon in biomass.

Hypothesis 2: Transfer payments in national key ecological functional zones can reduce carbon emissions in each county through green technological innovation, forest areas and the scale of industrialization.

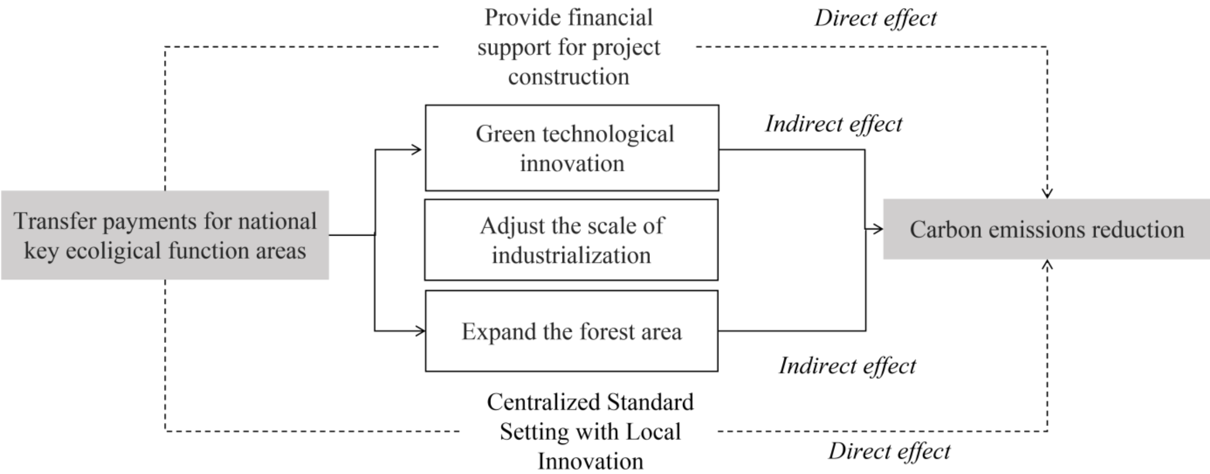

Fig. 2 – Mechanism of the impact of transfer payments on carbon emissions in national key ecological functional zones. Source: own research

3 EMPIRICAL STRATEGY AND DATA DESCRIPTION

3.1 Baseline regression model

This paper constructs a staggered difference-in-difference model, aiming to analyze the impact of transfer payments to national key ecological functional zones on carbon emissions. Based on the theoretical analysis, the following model is designed to further analyze the impact of the ecological compensation mechanism on carbon emissions as well as the analysis of the mechanism. In 2008, China began to transfer payments to national key ecological functional zones, which provides time and space feasibility for the study of the article. This paper argues that as long as the counties receiving transfer payments continue to receive the corresponding ecological compensation after the year of policy implementation. Therefore, the counties that have received transfer payments are set as the treatment group, and the counties that have never received transfer payments are set as the control group.

In the first stage, this paper considers whether the transfer payments in national key ecological functional zones have a positive or negative impact on carbon emissions. Therefore, a linear two-way fixed-effects model is chosen to estimate it, and the model is easier to be compared among different groups, such as the heterogeneity analysis after dividing according to annual fiscal freedom degree and annual electricity consumption are also adopted in the later part of the paper.

$$carbon_{it} = \alpha_0 + \alpha_1 NKEFZ_{it} + \alpha_2 X_{it} + \upsilon_i + \mu_t + \varepsilon_{it} \quad (1)$$

Where i is the county and t is the year, the explained variable $carbon_{it}$ is the carbon emissions of each county, the explanatory variable $NKEFZ_{it}$ is the DID estimator of the policy shocks. If the county i enjoys the transfer payment from the national key ecological functional zones in year t, then it has $NKEFZ_{it}=1$ in year t and the following years, otherwise $NKEFZ_{it}=0$. X_{it} is

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the ensemble of control variables, v_i is the individual fixed effect, μ_t is the year fixed effects, and ε_{it} is a randomized disturbance term.

This paper selects the following indicators as control variables, due to the large number of indicators affecting the development of county areas, this paper considers the three dimensions of economic, social and ecological foundations. First of all, for the economic dimension, this paper selects the per capita GDP (Pre_GDP_{it}). In the social dimension, level of education (edu), fiscal freedom (fid), and population density (density) are selected. At the ecological base level, this paper selects the percentage of arable land area (fram), atmospheric pollution (pm2.5), total annual precipitation in the region (rain) and regional mean temperature (tem).

3.2 Further testing

In order to further explore the mechanism and process behind the impact of transfer payments to national key ecological functional zones on carbon emissions, in the previous theoretical analysis this paper chose the green technological innovation, the scale of industrialization and forest areas as the mechanism variables, and the benchmark regression model has already explained the direct effect of the article, so this paper adopts the following model to analyze the indirect effect. The following model is constructed:

$$M_{it} = \beta_0 + \beta_1 NKEFZ_{it} + \beta_2 X_{it} + \upsilon_i + \mu_t + \varepsilon_{it} \quad (2)$$

Where M_{it} is the ensemble of mechanism variables, in which the green technological innovation (tech) is measured by the proportion of the number of invention patent applications for low-carbon technologies to the total number of invention patent applications in the county-level region of the year (Icpatent), the proportion of the number of utility model patent applications for low-carbon technologies to the total number of utility model patent applications in the county-level region of the year (Ucpatent), and the proportion of the sum of the number of invention patent applications and utility model patent applications for low-carbon technologies to the total number of patent applications in the county-level region of the year (Cpatent). The scale of industrialization (ind) is measured by the logarithm of the number of industries above scale, and the forest areas (for) is measured by the ratio of the forest area to the total area. According to this model, equations (1) and (2) can be obtained respectively for the impact of national key ecological functional zones transfer payments on mechanism variables and the impact of mechanism variables on carbon emissions. At the same time, this paper analyzes the heterogeneity according to the annual fiscal freedom degree and annual electricity consumption of each county. If the fiscal freedom of each county is lower than the median of the whole sample in the year, it is considered to be a region with high fiscal pressure, and is assigned the value of 1; otherwise it is 0, that is, it is considered to be a region with low fiscal pressure. If the electricity consumption is higher than the median value of that year, assign a value of 1.

3.3 Robustness Tests

To examine the robustness of the results, this paper conducts a parallel trend test. The parallel trend assumption is the key that the DID estimator can accurately identify the average treatment effect. The convergence assumption is a prerequisite for the validity of the DID. If the transfer payment policy for the national key ecological functional zones is not implemented, the trend of carbon emissions in the pilot cities and other cities should be parallel. In this paper, we refer to the method of Freyaldenhoven et al. (2019) to show the event study plot. To ensure the validity of causal inferences, we are comparing effects across treatment and control groups to ensure that any observed differences are due to the treatment and not due to other factors. The presence of a parallel trend enhances the validity of causal inferences, implying that there was

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no significant difference between the treatment and control groups before the policy was implemented. If there were significant differences between the two before the implementation, it may have an impact on the experimental results, thus making causal inferences difficult. Testing for parallel trends allows for better control of confounders, increases internal validity, and enhances the credibility of the findings.

$$carbon_{it} = \alpha + \sum\nolimits_{j=-6}^{6} \beta_j NKEFZ_{i,t+j} + \alpha_2 X_{it} + \upsilon_i + \mu_t + \varepsilon_{it} \quad (3)$$

Where $NKEFZ_{i,t+j}$ indicates whether the county i is in year j after the policy shock (if j is positive, it means it is in year j after the policy shock), 1 if it is in year j after the policy shock, and 0 otherwise, and in this paper, we select the period before the policy occurs as the base period for consideration.

And considering the rich source of influencing factors of carbon emissions in a county, although a certain number of control variables have been controlled in equation (1), it has not been taken into account that there will be a certain amount of other policy influences that will lead to changes in regional carbon emissions.

In order to further validate the results of this paper, it is taken into account that regional carbon emissions are also affected by other policies. Therefore, in order to further explore the impact of transfer payments on carbon emissions, this paper also further controls other policies—— low-carbon pilot city policy (LPC) and carbon emissions trading pilot city policy (CET), and the measurement model is set as follows:

$$carbon_{it} = \alpha_0 + \alpha_1 NKEFZ_{it} + \alpha_2 LPC_{it} + \alpha_3 CET_{it} + \alpha_4 X_{it} + \mu_i + \delta_t + \varepsilon_{it} \quad (4)$$

The list of pilot cities for carbon emissions trading comes from the "Notice on Carbon Emissions Trading Pilot Work" issued by the National Development and Reform Commission (NDRC) in 2011, which agrees that seven provinces and cities, including Beijing, Shanghai, Tianjin, Chongqing, Hubei, Guangdong and Shenzhen, will carry out pilot carbon emissions trading. Low-carbon city pilot data comes from the 2010 NDRC "Circular on the Pilot Work of Low-Carbon Provinces, Regions and Cities," which was updated in batches at a later stage.

3.4 Data

3.4.1 Carbon emissions: Carbon emission (carbon) is used as the dependent variable in this paper, and the carbon emission data of each county-level city is chosen for measurement, which is from the data compiled by Chen et al. (2020), covering 2,735 counties in 30 provinces in mainland China (excluding Tibet, Hong Kong, Macao, and Taiwan), which basically covers 87% of China's land area. The data used three satellite datasets, selected two types of nighttime light data and net primary productivity (NPP) data of terrestrial vegetation, and filled in the discontinuous values to make it a continuous and usable database. And, this database avoids the shortcomings of faults and discontinuities in some regions. In this paper, the carbon emissions of 1,632 county-level cities from 2005 to 2017 were selected for measurement by matching relevant data.

3.4.2 Transfer payments for national key ecological functional zones: The list of counties with transfer payments for national key ecological functional zones (NKEFZ) is used as the independent variable of this paper. This dataset was manually compiled from public information available on the Ministry of Finance's website and manually sorted and matched. Due to the restrictions on the public availability of the data, it is not possible to use samples

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from 2018 and later. Restricted by region and year, this paper selects the data of 1,632 counties from 2005 to 2017 for analysis. The goal was to understand the role of transfer payments on carbon emissions, so counties that do not receive transfer payments are analyzed as a control group, and areas that receive ecological compensation are analyzed as a treatment group. The list of key ecological functional zones is obtained through the public information of the national main functional area plan. By the end of 2017, the policy had expanded to 28 provinces, covering 810 county-level units since its inception in 2008.

3.4.3 Per capita GDP: We selected the per capita GDP of each county as a control variable, defined as the ratio of the current year's GDP to the year-end resident population. Specific data are obtained through the China County Statistical Yearbook. Regional GDP, as a key indicator for measuring the economic activities of a region, represents the ultimate success of the production activities of all permanent resident units in the region in a certain period of time, and has a certain influence on the impact of carbon emissions. The higher the GDP of a region, the more active its economic activity tends to be, and the higher the corresponding energy consumption and carbon emissions. This is because an increase in economic activity is usually accompanied by an increase in the demand for energy, the production and use of which tends to generate significant carbon emissions. Regions with high GDPs may require more energy to support their needs for industrial production, transportation, buildings, and residential living. This energy often comes from the combustion of fossil fuels, such as coal, oil and natural gas, and these combustion processes produce large amounts of greenhouse gases such as carbon dioxide.

3.4.4 Population density: The population density of each county is measured as the ratio of a county's population to its land area. The data comes from the China County Statistical Yearbook. There is a close correlation between population density and carbon emissions, and an increase in population density tends to bring about a scale effect, increasing in total energy consumption and carbon emissions. However, at the same time, an increase in population density may also have an agglomeration effect, which reduces carbon emissions by improving the level of technology, public transportation sharing and energy use efficiency, as well as sharing emission reduction facilities. A high population density means that more residents and businesses are clustered together, which in turn increases the total consumption of energy. Increased energy consumption, especially the burning of fossil fuel, is a significant factor in the increase in carbon emissions. As population density increases, land use patterns may change, such as more urbanized and industrialized land, which can lead to a reduction in carbon sinks such as forests and green spaces. At the same time, areas with high population densities tend to face more severe traffic congestion, and the inadequate combustion of motorized fuels can increase carbon emissions.

3.4.5 Level of education: This paper chooses the level of education (edu) as the control variable, using the number of secondary school students in school and taking the natural logarithm for the measure, where the data comes from the China County Statistical Yearbook. There is also a correlation between the level of education and carbon emissions; as the level of education increases, people tend to be more concerned about environmental issues and are more inclined to adopt environmentally friendly behaviors. This increased environmental awareness helps to reduce personal carbon emissions, such as reducing energy consumption and carbon emissions through energy conservation, choosing a low-carbon lifestyle, and using public transportation. People with higher education levels tend to participate more actively in social affairs and policy advocacy, and are able to push the government and all sectors of society to adopt more active and effective carbon emission control measures. They are likely to promote

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a low-carbon transition in society by participating in environmental organizations, initiating environmental activities, and proposing policies.

3.4.6 Fiscal freedom: This paper uses the ratio of general public budget revenue to general public budget expenditure for calculations. The data comes from the National Bureau of Statistics. Regions with a higher degree of fiscal freedom may have a lower degree of government intervention in economic activities, and the market mechanism may play a greater role in resource allocation. This may lead to the liberalization of the energy market, making energy prices more market-oriented, which may promote the development and application of clean energy and reduce carbon emissions. At the same time, the market mechanism may also prompt firms to pay more attention to energy saving and emission reduction in order to improve competitiveness. Since the heterogeneity of this paper is also measured based on the degree of fiscal freedom, counties above the median are assigned a value of 1, which is considered to have high fiscal freedom. Low fiscal freedom indicates constrained government budgetary flexibility, potentially limiting investment in emission reduction infrastructure.

3.4.7 Percentage of arable land area: The ratio of cultivated land area to total land area is used for measurement. Cultivated land area data were selected from the China land cover dataset (CLCD) produced by Yang and Huang (2021). A large proportion of cultivated land area implies that agricultural production activities are more concentrated and extensive. In the process of agricultural production, the use of chemical fertilizers and pesticides as well as the operation of agricultural machinery consume energy and generate carbon emissions. Therefore, an increase in the proportion of arable land may lead to an increase in carbon emissions in the agricultural production process. At the same time, the expansion of arable land area is often accompanied by a decrease in other types of land. This land use change can affect the balance of carbon sinks and sources. Natural ecosystems such as forests and grasslands are important reservoirs of carbon, and their reduction may lead to a decrease in the capacity of carbon sinks, thus increasing carbon emissions in the atmosphere.

3.4.8 Atmospheric pollution, regional total annual precipitation and regional mean temperature: Many factors affect carbon emissions, and the regional environment will also have a certain impact on it. In this paper, we also included atmospheric pollution (pm2.5). The pm2.5 content of each region is used for calculation, as are the regional total precipitation per year (RAIN), and the regional mean temperature (TEM). Regional pm2.5 concentration data were obtained from NASA, total precipitation from the WorldClim website, and regional mean temperature from the Era5-land database. Precipitation has a critical impact on the growth and nutrient transportation of terrestrial vegetation. A large amount of water enters the vegetation through precipitation and promotes photosynthesis and growth. In turn, plants are major participants in the carbon cycle, converting atmospheric carbon dioxide into organic matter through photosynthesis and storing it in their bodies. Thus, precipitation is inextricably linked to vegetation growth and the carbon cycle.

The descriptive statistics of this paper are shown in Tab. 1, including the observed value, minimum value, maximum value, mean and standard deviation of the observed variables.

Tab. 1 – Descriptive statistics of variables. Source: own research

Variable	Obs	Mean	Std	Min	Max
Carbon	21202	2.664	2.961	0.000	56.429
Edu	21202	9.788	0.937	5.333	11.996
Fid	21202	0.332	0.273	0.000	3.839

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Variable	Obs	Mean	Std	Min	Max
Farm	21202	0.009	0.011	0.000	0.185
Pm2.5	21202	47.583	22.894	3.342	184.555
Density	21202	0.054	0.222	0.000	45.942
Pre_GDP	21202	2.526	3.089	0.000	2.557
Rain	21202	12.564	13.364	0.045	274.506
Tem	21202	12.518	5.679	-7.474	25.556

4 ANALYSIS OF EMPIRICAL RESULTS

4.1 Baseline regression results

The results of the baseline estimated are shown in
Tab. 2, obtained after regressing 1,632 data from 2005 to 2017. The results in column (1) show that the transfer payment system for national key ecological functional zones can significantly reduce the carbon emissions of the counties at the 1% significance level. In column (2), the results still hold after adding control variables. Columns (3)-(4) add the clustering standard error for consideration. The results show that the transfer payment can still significantly reduce carbon emissions, and every increase of 1 unit in the transfer payment for the national key ecological function areas will make the carbon emissions of the region drop by 0.310 units, which verifies hypothesis one. At the same time, it can be found that the higher percentage of arable land area in the control variables also leads to an increase in carbon emissions, which is consistent with the previous conclusion. Per capita GDP also affects carbon emissions. A growth in regional economy leads to an increase in consumption demand by the population and an increase in production and living activities, thus increasing carbon emissions. Fiscal freedom, however, reduces carbon emissions, considering that regional governments can distribute subsidies more freely to incentivize society to reduce carbon emissions.

Tab. 2 – Baseline regression results. Source: own research

	(1)	(2)	(3)	(4)
NKEFZ	-0.356*** (0.019)	-0.310*** (0.017)	-0.356*** (0.041)	-0.310*** (0.037)
Edu		-0.026 (0.019)		-0.026 (0.041)
Fid		-0.216*** (0.041)		-0.216 (0.133)
Fram		5.777* (3.183)		5.777 (8.026)
Pm2.5		0.001* (0.001)		0.001 (0.001)
Density		0.741*** (0.109)		0.741*** (0.151)
Pre_GDP		0.191*** (0.03)		0.191** (0.030)
Tem		-0.019 (0.015)		-0.019 (0.014)
Rain		0.006*** (0.002)		0.006** (0.003)

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	(1)	(2)	(3)	(4)
_cons	2.731***	2.583**	2.731***	2.583***
	(0.006)	(0.261)	(0.008)	(0.448)
County FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Adj-R^2	0.9564	0.9643	0.9564	0.9643
N	21202	21202	21202	21202

(Note: Standard errors in parentheses, * p<0.10, ** p<0.05, *** p<0.01)

4.2 Robustness Checks

4.2.1 Substitution of dependent variables

In this paper, the dependent variables are replaced, and the carbon emissions data are obtained from the EDGAR (Emissions Database for Global Atmospheric Research) website, which provides the results of carbon dioxide emissions from fossil fuel combustion. The raw data are provided as satellite data, and point data are converted to raster data and then aggregated by subregion, and the final carbon emissions data are summarized by region.

Tab. 3 –Results of substituting dependent variables. Source: own research

	(1)	(2)	(3)	(4)
NKEFZ	-0.630***	-0.591***	-0.630***	-0.591***
	(0.043)	(0.043)	(0.073)	(0.070)
_cons	2.938***	0.999	2.938***	0.999
	(0.013)	(0.644)	(0.014)	(1.193)
County FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Controls	No	Yes	No	Yes
Adj-R^2	0.9407	0.9427	0.9407	0.9427
N	21059	21059	21059	21059

(Note: Standard errors in parentheses, * p<0.10, ** p<0.05, *** p<0.01)

According to the results, after replacing the dependent variables, the conclusion still holds true that the transfer payment for national key ecological functional zones can significantly reduce carbon emissions (

Tab. 3). Columns (1) and (2) are the results of regression without and with control variables respectively, which show that for every 1 unit increase in ecological compensation, carbon emissions will be reduced by 0.591 units. Moreover, after adding the clustering standard error for consideration, the results show that the transfer payment can still significantly reduce carbon emissions, which proves that the conclusions are robust.

4.2.2 Goodman-Bacon decomposition

In order to avoid bias in the estimation of variables by the two-way fixed effects model, we apply the Goodman-Bacon decomposition to the baseline regression results (Tab. 4),which is used to determine the impact of the bad control group on the percentage and impact of the coefficients to ensure that their coefficients and weights have less impact on the results of the average treatment effect. The results are shown in Tab. 4. The first two control groups are good control groups, using the trend of the results that have not been treated as the trend of the results of the treatment of individuals in the case of untreated counterfactuals. But the third group has

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included the treatment effect in the outcome variable, and therefore is a bad control group. Its coefficient is -0.0425 and weight is 7.64%, which is the same sign as that of the baseline regression, and it accounts for a smaller percentage, which means that the bad control group's impact on the results of the average treatment effect is small enough to affect the results of the benchmark regression in the previous section.

Tab. 4 – Goodman-Bacon decomposition results. Source: own research

Bacon Decomposition	ATT	weights
Treated vs never treated	-0.4437	0.8052
Treated earlier vs later	0.0230	0.1184
Treated later vs earlier	-0.0425	0.0764

4.2.3 Parallel trend assumption

This paper conducts a parallel trend test to further explore the robustness of the relationships. The results are shown in Figure 3, which shows the trend graph when no control variables are added. It can be clearly found that none of the estimated coefficients of the policy dummy variables are significant before the policy. But after the policy has taken place, it is difficult to achieve a large amount of carbon emission reduction in the short term, considering that there is a certain degree of delay in the policy's effect. However, the coefficients are significant and gradually become larger with the passage of time. After adding control variables to be considered in Figure 4, it is found that the conclusion still holds, as the parallel trend test is passed.

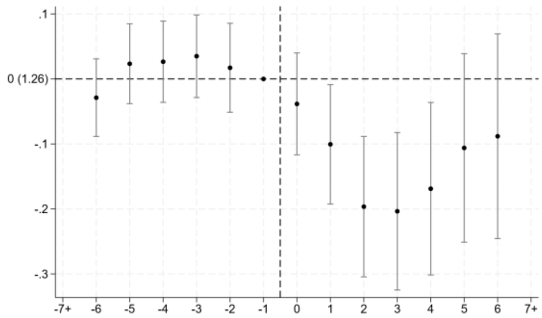

Fig. 3 – Parallel trend test plot (a). Source: own research

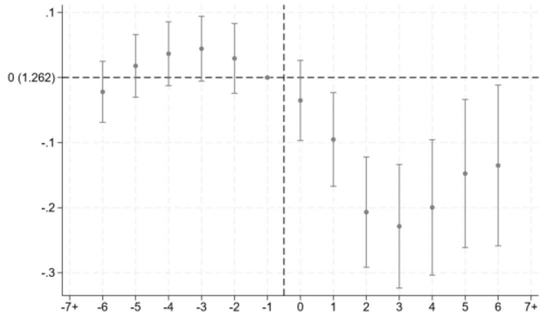

Fig. 4 – Parallel trend test plot (b). Source: own research

However, current academic research suggests that the parallel trend assumption is inherently untestable, and that tests based on the event study method can be biased if a trend exists ex ante (Roth et al., 2023). Based on this, this paper adopts the method of Rambachan and Roth (2023) to conduct a sensitivity analysis of the results of the event-study method in cases where the parallel trend hypothesis may be violated to varying degrees. The first step is to construct the maximum degree of deviation (Mbar) from the parallel trend, and in constructing robust confidence intervals for the processed estimates corresponding to the maximum degree of deviation. In this paper, we refer to Roth's method and define the maximum degree of deviation (Mbar) as 1 × standard error, which in turn is used to test the sensitivity of the article to the parallel trend. At present, the main methods used are relative deviation degree limitation and smoothing limit. Among them, the relative deviation limit holds that the degree of violation of the parallel trend in the post-treatment period will not be greater than the degree of parallel trend violation in the pre-treatment period. The idea of smoothing limits is that the degree of parallel trend violations after processing does not deviate too much from dealing with front-line extrapolated trends.

As shown in Figures 5-8, the robust confidence intervals when the degree of parallel trend deviation gradually increases. Figure 5 throughFigure 8 are parallel trend sensitivity test charts for periods 1-4 under the smoothing limit, respectively. According to the parallel trend hypothesis, the transfer payment of national key ecological function areas is significantly negative in the 1st, 2nd, 3rd and 4th periods after the implementation of the policy, and it is found that these four periods still pass the sensitivity test of the parallel trend hypothesis. Therefore, the test results show that, even if there is a certain degree of deviation from the parallel trend, the transfer payment policy of national key ecological functional zones can still significantly reduce the carbon emissions of the counties.

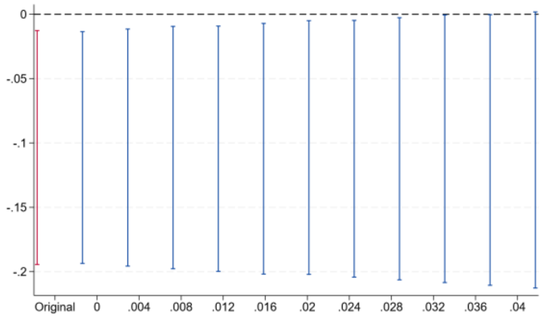

Fig. 5 – Sensitivity test of parallel trend hypothesis (a). Source: own research

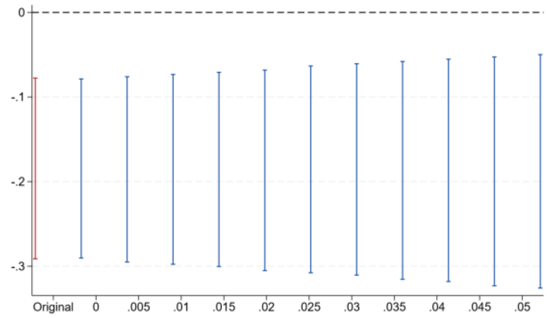

Fig. 6 – Sensitivity test of parallel trend hypothesis (b). Source: own research

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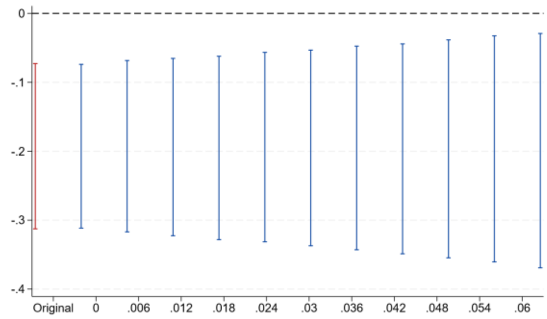

Fig. 7– Sensitivity test of parallel trend hypothesis (c). Source: own research

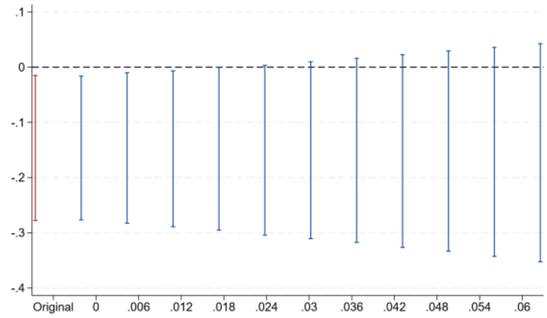

Fig. 8 – Sensitivity test of parallel trend hypothesis (d). Source: own research

4.2.4 Counterfactual Estimation

Using a two-way fixed effects model to address the issue of multi-time-point policies may lead to estimation bias due to differences in individual and temporal dimensions. To eliminate the bias in the evaluation of the policy effects of ecological protection compensation caused by unobservable time-varying confounders, referring to the counterfactual estimation proposed by Liu et al. (2022), the interactive fixed effects counterfactual estimator is selected to verify whether there is estimation bias.

The dynamic treatment effects and placebo test are shown in Figure 9 and Figure 10. The result obtained after regression analysis using the IFEct estimator is -0.1761, which is basically the same as the conclusion of the traditional TWFE model. Meanwhile, the calculated minimum range is within the equivalence boundary, indicating that the equivalence test has been passed.

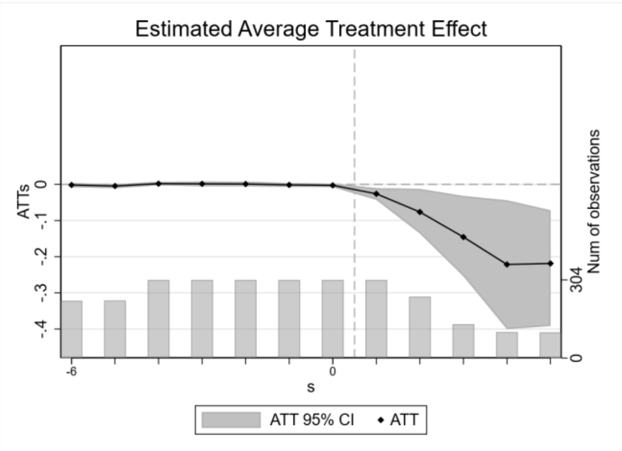

Fig. 9 – Counterfactual Estimation. Source: own research

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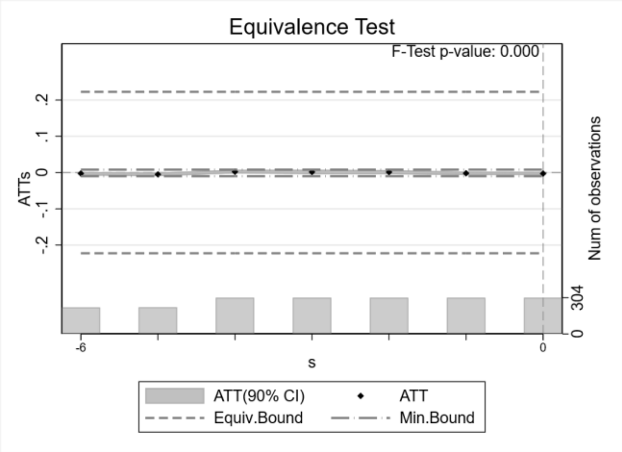

Fig. 10 – Equivalence Test. Source: own research

4.2.5 Placebo test

Another potential problem regarding the DID approach is the effect on the estimation results of the presence of other unobservable urban characteristics that change over time. Although this paper includes individual fixed effects in the empirical model construction to exclude bias in the estimates due to changes in the characteristics of the area, and includes a series of control variables such as population density and GDP per capita, there are still certain characteristics that are not considered. Therefore, this paper chooses the placebo test. The research years are 2005-2017, so this paper sets up 11-year cross-sections, excludes the starting year and the final year, randomly sets up any of these year cross-sections, randomly selects counties subject to policy shocks as the treatment group, and sets up the rest of the counties as the control group, so as to construct the spurious policy dummy variables, and validate the tests by repeating them 1,000 times.

According to Figure 11, the centers of the distribution of the estimated coefficients of the random sample are all strictly around 0 and follow a normal distribution, and the true estimated coefficient of -0.29 lies strictly outside the probability density distribution of the estimated coefficients of the randomized experiment, in line with the results of the placebo test. This suggests that the policy effect is not due to other factors or unobserved influences, but is a real influence effect.

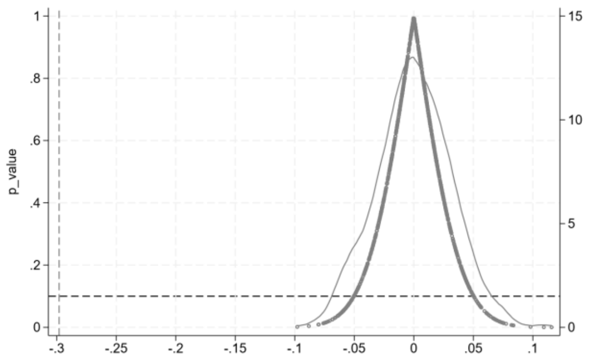

Fig. 11 – Placebo test. Source: own research

4.2.6 Heterogeneous treatment effect test

Since there are multiple starting times for this policy effect, it is considered that there may be differences in the treatment effect between groups receiving treatment at different times. There is heterogeneity. In the empirical process, the following two situations may occur: first, the

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control group is not eliminated when calculating the treatment effect, and the early or late treatment group may be analyzed as the control group; second, the treatment effect may be heterogeneous for different time points and different individuals. When these two problems occur simultaneously, the so-called "heterogeneous treatment effect" problem may arise. In this case, the estimated ATT may be biased. Therefore, in this paper, LP-DID is chosen to analyze the heterogeneous treatment effect, and this test can make the results more robust by not treating the early treatment group as a control group when estimating the late treatment group. The following figures demonstrate the results of the test, Figure 12 (a) and Figure 13 (b), considering only the relationship between the dependent and independent variables, respectively, and Figure 13 (b) is considered exclusively with districts that were never treated as a control group, ruling out the possibility that the later treatment group would still be treated as a control group when estimating the treatment effect for the earlier treatment group, making the results more robust. The results show that the coefficients are insignificant at the 1% significance level and fluctuate around 0 before the policy treatments. After the treatments, the transfers are significant in reducing carbon emissions, and the effect grows as the policy is implemented. Figure 14 (c) and Figure 15 (d) are regressions after the inclusion of control variables. Fig. 15 (d) is also only the area that has never been treated as a control group, and the results before the treatment are insignificant, but after the treatment, carbon emissions are significantly reduced, which is consistent with the empirical results.

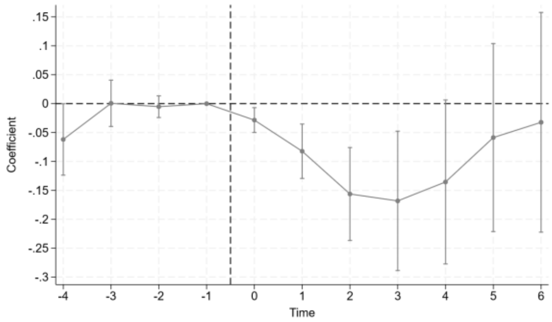

Fig. 12 – Heterogeneous treatment effects (a). Source: own research

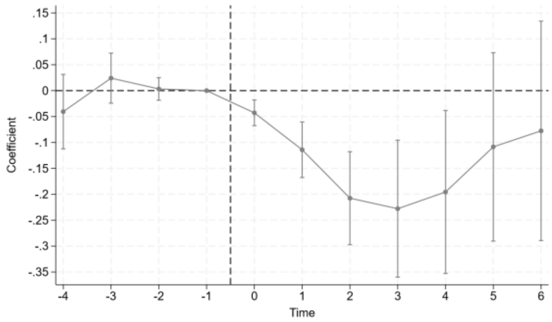

Fig. 13 – Heterogeneous treatment effects (b). Source: own research

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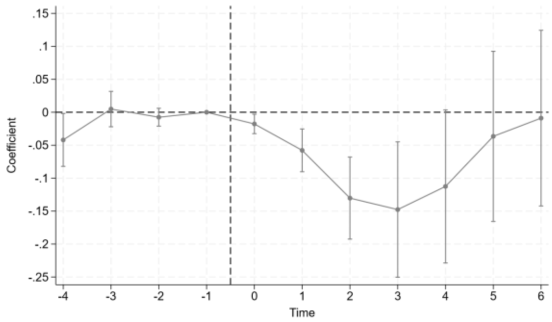

Fig. 14 – Heterogeneous treatment effects (c). Source: own research

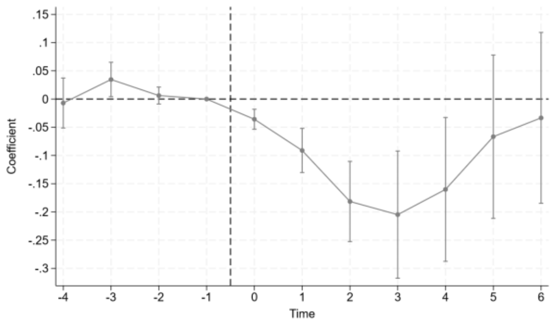

Fig. 15 – Heterogeneous treatment effects (d). Source: own research

4.2.7 Consideration of entry and exit scenarios

In the process of organizing the transfer payment system of key ecological functional zones in this paper, it is found that there is an entry and exit situation in some counties. So this paper reconsiders the situation of having an entry and exit situation, and empirically tests and analyzes it by using the LP-DID method. The following results are obtained: Figure 16 (a) and Figure 17 (b) are without considering the control variables, where Figure 17 (b) takes the never treated counties as the control group. The results show that, in the case of having an entry and exit, it is still insignificant before the policy, but after the policy, the transfer payment can significantly reduce carbon emissions. Figure 18 (c) and Figure 19 (d) consider the control variables, while Figure 19 (d) also takes the never treated counties as the control group. The results obtained are the same, which verifies that the national key ecological functional zones can still significantly reduce carbon emissions in the presence of entry and exit.

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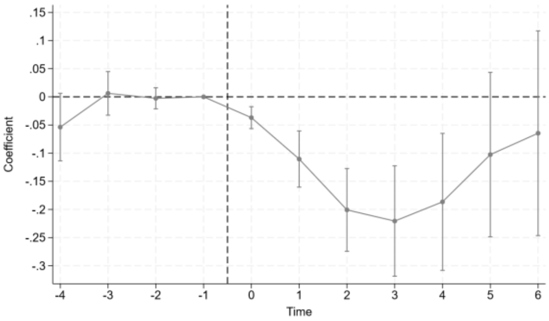

Fig. 16 – Considering entry and exit (a). Source: own research

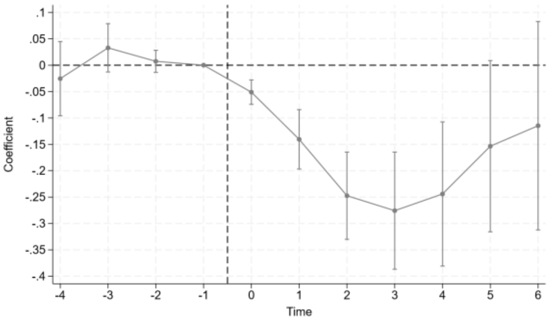

Fig. 17 – Considering entry and exit (b). Source: own research

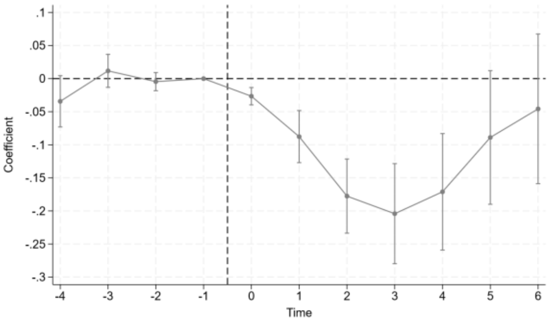

Fig. 18 – Considering entry and exit (c). Source: own research

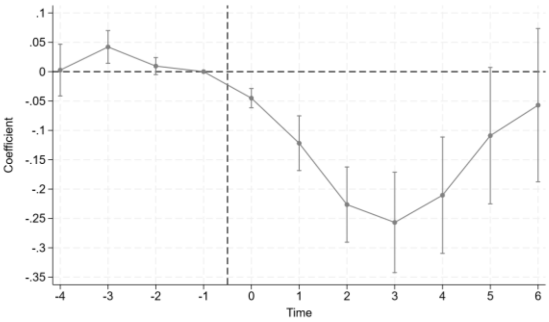

Fig. 19 – Considering entry and exit (d). Source: own research

4.2.8 Exclusion of other policy interference

The carbon emissions of a certain county are not only affected by the transfer payment policy of key ecological function zones, but also by other policies. Therefore, in order to further explore the impact of transfer payments on carbon emissions, this paper also further controls for other policies: low-carbon pilot city policy (LPC) and carbon emissions trading pilot city policy (CET).

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Tab. 5 shows that, after incorporating these two policies into the examination, the transfer payments can still significantly reduce carbon emissions. Columns (3) and (4) are added to the clustering standard error. The results also show that the national key ecological functional zones transfer payment system can decrease the carbon emissions of the region by 0.310 units, effectively realizing the carbon emission reduction target.

Tab. 5 – Exclusion of other policy interferences. Source: own research

	(1)	(2)	(3)	(4)
NKEFZ	-0.358***	-0.310***	-0.358***	-0.310***
	(0.019)	(0.017)	(0.041)	(0.37)
LPC	-0.090***	-0.137***	-0.090*	-0.137**
	(0.019)	(0.018)	(0.047)	(0.041)
CET	-0.374***	-0.467***	-0.374***	-0.467***
	(0.037)	(0.034)	(0.075)	(0.069)
_cons	2.751***	2.748***	2.751***	2.747***
	(0.006)	(0.260)	(0.011)	(0.436)
County FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Controls	No	Yes	No	Yes
Adj-R^2	0.9567	0.9648	0.9567	0.9648
N	21202	21202	21202	21202

(Note: Standard errors in parentheses, * p<0.10, ** p<0.05, *** p<0.01)

4.2.9 Deletion of special value tests

In order to further verify the robustness of the conclusions, this paper winsorizes the dependent variable carbon emissions. First, we find the quartiles corresponding to 1% and 99% of the carbon emissions, respectively, and replace the quartile values corresponding to less than 1% of the data, and replace the data larger than 99% of the data, so as to make the data smooth. And then we improve the accuracy of the data by deleting the extreme values in the samples and reliability by removing extreme values from the samples and reducing the effect of outliers to get a more accurate analysis. As extreme values may have a significant impact on the results of statistical analysis, leading to bias, by winsorization, the impact of extreme values on the mean, variance and other statistical indicators can be reduced, to estimate the overall parameters more accurately. Winsorization can help to improve the symmetry of the data distribution, making it closer to the normal distribution, thus improving the effectiveness of some statistical methods.

The results obtained in this paper after winsorizing treatment are shown in

Tab. 6. After changing the carbon emission outliers, columns (1) and (2) show the results of the baseline regression and the regression results with the addition of control variables, and the results still show that the transfer payment in national key ecological function zones can significantly reduce the carbon emissions, and when the ecological compensation increases by 1 unit, the carbon emissions will decrease by 0.299 units, which can effectively reduce carbon emissions. Columns (3) and (4) show the regression results after adding the clustering robust standard errors, and the results show that the conclusions still hold, verifying the robustness of our conclusions.

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Tab. 6 – Results after Winsorizing. Source: own research

	(1)	(2)	(3)	(4)
NKEFZ	-0.337***	-0.299***	-0.337***	-0.299***
	(0.016)	(0.015)	(0.035)	(0.032)
Edu		-0.074***		-0.074**
		(0.017)		(0.060)
Fid		-0.046		-0.046
		(0.035)		(0.094)
Fram		12.416***		12.415*
		(2.755)		(6.745)
Pm2.5		0.001**		0.001*
		(0.001)		(0.001)
Density		0.700***		0.700***
		(0.094)		(0.135)
Pre_GDP		0.131***		0.131**
		(0.003)		(0.016)
Tem		-0.014		-0.014
		(0.013)		(0.012)
Rain		0.006***		0.006**
		(0.001)		(0.002)
_cons	2.672***	2.948**	2.672***	2.948***
	(0.005)	(0.226)	(0.007)	(0.391)
County FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Adj-R^2	0.9589	0.9641	0.9589	0.9641
N	21202	21202	21202	21202

(Note: Standard errors in parentheses, * p<0.10, ** p<0.05, *** p<0.01)

4.2.10 Adding other control variables

We selected certain control variables in the analysis to exclude the influence of other potential factors on carbon emissions, but it should be clear that the factors affecting carbon emissions are more extensive. So in the robustness test, we selected the level of agricultural development and regional electricity consumption as additional control variables, and ran a re-regression. Rugged terrain may also affect energy production. The proportion of added value of the primary industry in GDP is a key indicator to measure the relative importance of agriculture in the economy, and its change has a significant impact on carbon emissions. Meanwhile electricity production is one of the major sources of carbon emissions, especially in regions that rely mainly on fossil fuels for electricity production. When regional electricity consumption increases, the demand for electricity production also increases, which may result in more fossil fuels being burned to generate electricity. Burning fossil fuels releases large amounts of carbon dioxide and other greenhouse gases, which in turn increases carbon emissions. Therefore, in this paper, the new control variables are selected as the added value of the primary industry accounts for the proportion of GDP (Agr) and regional electricity consumption (ele). These are obtained by taking the logarithm of them, and the regression results are shown in the following table. After adding control variables, the national key ecological functional area transfer payments can still significantly reduce carbon emissions. Column (2) in the addition of control variables based on the addition of clustering robust standard error, to get when the ecological compensation for each increase of 1 unit, will inhibit the carbon emissions, so that it fell by 0.189 units. (

Tab. 7)

Tab. 7 – Results of adding control variables. Source: own research

	(1)	(2)
NKEFZ	-0.189*** (0.014)	-0.189*** (0.030)
Edu	0.071*** (0.027)	0.071* (0.037)
Fid	-0.232*** (0.038)	-0.232** (0.099)
Fram	23.061*** (2.558)	23.061*** (5.991)
Pm2.5	0.002** (0.001)	0.002** (0.000)
Density	0.378*** (0.097)	0.110 (0.141)
Pre_GDP	0.127*** (0.003)	0.127*** (0.016)
Tem	--0.007 (0.012)	-0.007 (0.012)
Rain	0.007*** (0.001)	0.007** (0.003)
Agr	1.390*** (0.093)	1.390*** (0.233)
Ele	3.531*** (0.065)	3.531*** (0.280)
_cons	-71.020*** (1.367)	-71.020*** (5.887)
County FE	Yes	Yes
Year FE	Yes	Yes
Adj-R^2	0.9523	0.9650
N	21202	21202

(Note: Standard errors in parentheses, * p<0.10, ** p<0.05, *** p<0.01)

4.3 Influence mechanism analysis

The results of the benchmark regression have shown that the transfer payment for national key ecological functional zones can significantly reduce carbon emissions, and the theoretical part of this paper has already explained that the transfer payment will reduce carbon emissions by the green technological innovation, forest areas and the scale of industrialization in the region. In this paper, to measure green technology innovation, we select the proportion of the number of invention patent applications for low-carbon technologies to the total number of invention patent applications in the county-level region of the year (Icpatent), the proportion of the number of utility model patent applications for low-carbon technologies to the total number of utility model patent applications in the county-level region of the year (Ucpatent), and the proportion of the sum of the number of invention patent applications and utility model patent applications for low-carbon technologies to the total number of patent applications in the

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county-level region of the year (Cpatent). The regression results are shown in Tab. 8, which shows that transfer payments can significantly increase the green technological innovation and forest areas. The ecological protection compensation policy requires the achievement of ecological environment protection or restoration. The investment of funds will lead to an increase in the local demand for the number of green patents. As a result, the local area will transform towards green and low-carbon technologies, thus achieving carbon emission reduction. At the same time, since the central government has established a reward-and-punishment system, local governments will expand the proportion of local forest area through measures such as returning farmland to forests. But, transfer payments reduce the scale of industrialization in the counties, considering that the implementation of the policy has higher local environmental requirements, which leads to the decline in the number of industrial enterprises. The government requires the vigorous development of clean industries, such as ecotourism, which has led to the downsizing of industrial enterprises. Based on this analysis, it can be determined that the transfer payment for national key ecological functional zones will improve green technological innovation and forest areas but reduce the number of industrial enterprises in the region, which will lead to a decrease in carbon emissions, realize the goal of energy conservation and emission reduction, and achieve green sustainable development. Hypothesis 2 is therefore valid.

Tab. 8 – Mediating effect test. Source: own research

	(1) Tech			(2) Ind	(3) For
	Icpatent	Ucpatent	Cpatent		
NKEFZ	0.103** (0.041)	0.138** (0.040)	0.248*** (0.047)	-0.038** (0.012)	0.076*** (0.027)
_cons	-1.391 (0.624)	-0.646 (0.604)	-0.829 (0.715)	6.630*** (0.178)	4.813*** (0.369)
Controls	Yes	Yes	Yes	Yes	Yes
County FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
Adj-R^2	0.1018	0.1724	0.1110	0.9349	0.9999
N	21202	21202	21202	21202	21202

(Note: Standard errors in parentheses, * p<0.10, ** p<0.05, *** p<0.01)

4.4 Heterogeneity analysis

4.4.1 According to the degree of fiscal freedom of the region

In this paper, divisions are made based on fiscal freedom for heterogeneity analysis. If the fiscal autonomy of each county is lower than the median of the whole sample in that year, then it is a region with high fiscal pressure, which means low fiscal freedom. The results are presented in the Tab. 9, where columns (1) and (3) show regions with high fiscal pressure, and columns (2) and (4) indicate regions with low fiscal pressure. The transfer payments in national key ecological functional zones can significantly reduce regional carbon emissions in the context of both high and low fiscal pressures. The Chow test shows that the p-value is less than 10%, and there is a significant difference in the coefficients between groups. After comparing the coefficients, it is found that the transfer payments can reduce carbon emissions to a greater extent in regions with higher fiscal freedom. More fiscal freedom means more flexible and efficient government policies in terms of taxation and expenditure, which can tax enterprises

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and individuals within a reasonable range, reasonably allocate resources, provide a more level playing field for enterprises and individuals, and thus reduce transaction costs. In regions with a higher degree of fiscal freedom, as the government has more policy space and flexibility, it can make more effective use of transfer funds to promote industrial structure optimization, technological innovation and energy transformation, thus reducing carbon emissions. These regions tend to have better market mechanisms and a more efficient allocation of resources, which in turn promotes the development of environmentally friendly industries, such as clean energy and low-carbon technologies, and reduces the proportion of high-carbon industries, thereby reducing carbon emissions. At the same time, a higher degree of fiscal freedom also means that the government's investment in environmental protection may be more adequate, which can better support carbon emission reduction efforts.

Tab. 9 – Results of heterogeneity analysis. Source: own research

	(1) High fiscal pressure	(2) Low fiscal pressure	(3) High fiscal pressure	(4) Low fiscal pressure
NKEFZ	-0.207*** (0.023)	-0.185*** (0.037)	-0.039*** (0.010)	-0.107*** (0.034)
_cons	1.730*** (0.009)	2.741*** (0.471)	-42.511*** (1.101)	-107.803*** (2.627)
County FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Controls	Yes	Yes	Yes	Yes
Other controls	No	No	Yes	Yes
Other Policy	No	No	Yes	Yes
Coefficient difference P-value	0.000		0.000	
Adj-R^2	0.9538	0.9601	0.9612	0.9626
N	10530	10509	10473	9626

(Note: Standard errors in parentheses, * p<0.10, ** p<0.05, *** p<0.01)

4.4.2 According to the electricity consumption of the region

At the same time, considering that the level of regional electricity consumption will also show certain differences in the implementation of regional carbon emission reduction, this paper conducts a heterogeneous analysis according to the level of regional electricity consumption. If the electricity consumption of a certain area in the current year is higher than the median value, it is a region with high electricity consumption, and it is assigned a value of 1, otherwise the value is assigned to 0. The results obtained by heterogeneity analysis are shown in Tab. 10. The Chow test shows that the p-value is less than 10%, and there is a significant difference in the coefficients between groups. It is found that in areas with high electricity consumption, the transfer payment for national key ecological function zones will increase by one unit, and carbon emissions will decrease by 0.187 units, but in areas with low electricity consumption, only 0.104 units will be reduced, and there is a certain gap. Regions with higher electricity consumption usually have a larger carbon emission base, because the carbon emissions caused by production and living are higher. Eco-compensation measures will also lead to more carbon emission reductions. At the same time, areas with higher regional electricity consumption are often densely populated, more economically developed, and with larger land areas, and thus

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they can adjust their technology investment and energy structure in a timely manner after receiving ecological compensation, and adopt clean energy faster and easier. In addition, the government and society may pay more attention to environmental protection and green and low-carbon development, which is more conducive to promoting the implementation and promotion of ecological protection compensation, to achieve increased carbon emission reduction.

Tab. 10 – Results of heterogeneity analysis. Source: own research

	（1） High electricity consumption	（2） Low electricity consumption	（3） High electricity consumption	（4） Low electricity consumption
NKEFZ	-0.327*** (0.029)	-0.136*** (0.007)	-0.187*** (0.027)	-0.104*** (0.007)
_cons	5.231*** (0.362)	2.511*** (0.002)	-103.335*** (0.613)	-25.594*** (0.748)
Controls	Yes	Yes	Yes	Yes
County FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Other controls	No	No	Yes	Yes
Other Policy	No	No	Yes	Yes
Coefficient difference P-value	0.000		0.000	
Adj-R^2	0.9580	0.9621	0.9606	0.9675
N	10592	10598	9805	10445

(Note: Standard errors in parentheses, * p<0.10, ** p<0.05, *** p<0.01)

5 FURTHER ANALYSIS

In the process of achieving ecological protection, in addition to directly reducing carbon emissions, vigorously developing carbon sequestration capacity is also of crucial importance.

5.1 The Impact of Ecological Protection Compensation on Carbon Sequestration

This section will further analyze the impact of ecological protection compensation on carbon sequestration. Carbon sequestration refers to the process or activity of removing carbon dioxide from the atmosphere. An increase in carbon sequestration capacity helps achieve carbon emission reduction.

$$carbon\ sequestration_{it} = c_0 + c_1 NKEFZ_{it} + \alpha_2 X_{it} + v_i + \mu_t + \varepsilon_{it} \quad (4)$$

where i is the county and t is the year, and the explanatory variable carbon $sequestration_{it}$ is the carbon sequestration values related to terrestrial vegetation.

Tab. 11 – Results of further analysis. Source: own research

	(1)	(2)	(3)	(4)
NKEFZ	0.259*** (0.020)	0.240*** (0.020)	0.259*** (0.030)	0.204*** (0.027)

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	(1)	(2)	(3)	(4)
_cons	5.129*** (0.006)	6.974*** (0.297)	5.129*** (0.006)	6.974*** (0.522)
County FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Controls	No	Yes	No	Yes
Adj-R^2	0.9883	0.9894	0.9883	0.9894
N	21202	21202	21202	21202

(Note: Standard errors in parentheses, * p<0.10, ** p<0.05, *** p<0.01)

The results are shown in Tab. 11. It can be clearly seen that ecological protection compensation can effectively increase terrestrial carbon sequestration, which also means that carbon emission reduction can be effectively achieved. After adding control variables and clustered robust standard errors, the conclusion still holds, thus realizing the sustainable development of ecology.

5.2 Dynamic policy effects

From the proposal and implementation of the policy to the realization of its results, a certain amount of time is required, which leads to the heterogeneity of policy effects in the temporal dimension. This paper uses the following model to explore the long-term dynamic effects of the policy:

$$carbon_{it} = \delta_0 I(t = T_0) + \delta_1 I(t = T_i + 1) + \cdots + \delta_\Lambda I(t = T_\Lambda + 1) + d_2 X_{it} + v_i + \mu_t + \varepsilon_{it} \quad (5)$$

T_i is the year in which county i receives the transfer payment. I(.) is an indicator function, which takes the value of 1 when the condition in the brackets is true, and 0 otherwise. Λ is the maximum number of years that the policy has been in effect for the earliest pilot county in the sample.

Tab 12– Results of dynamic policy analysis. Source: own research

	(1)	(2)
I(t=T_i)	-0.181*** (0.022)	-0.181*** (0.020)
I(t=T_i+1)	-0.252*** (0.024)	-0.251*** (0.028)
I(t=T_i+2)	-0.356*** (0.027)	-0.356*** (0.035)
I(t=T_i+3)	-0.389*** (0.028)	-0.389*** (0.043)
I(t=T_i+4)	-0.386*** (0.029)	-0.386*** (0.047)
I(t=T_i+5)	-0.354*** (0.029)	-0.354*** (0.049)
I(t=T_i+6)	-0.368*** (0.030)	-0.368*** (0.049)
I(t=T_i+7)	-0.379*** (0.030)	-0.379*** (0.051)
I(t=T_i+8)	-0.386*** (0.034)	-0.386*** (0.058)

	(1)	(2)
I(t=Ti+9)	-0.476***	-0.476***
	(0.044)	(0.073)
_cons	3.011***	3.011***
	(0.227)	(0.388)
County FE	Yes	Yes
Year FE	Yes	Yes
Controls	Yes	Yes
Adj-R^2	0.9643	0.9643
N	21202	21202

(Note: Standard errors in parentheses, * p<0.10, ** p<0.05, *** p<0.01)

According to Tab 12, there is a trend of reducing carbon emissions in the short term, medium term, and long term after the transfer payment. In the three years before the policy starts, ecological protection compensation continuously reduces carbon emissions, and the emission reduction effect is getting increasingly better. In the medium term, the policy effect decreases to a certain extent, but in the long term, the effect of transfer payment on carbon emission reduction becomes better again. This indicates that the policy has a certain long-term effect and can continuously achieve carbon emission reduction.

5.3 Spatial spillover effect

Due to the fluidity of ecosystems and the spatial correlation of economic activities, the ecological protection policies in a single region may generate spillover effects on neighboring regions or even regions at a distance through factor mobility and environmental externalities. Ignoring this spatial dependence may lead to an underestimation of the policy effects.

$$carbon_{it} = \theta_0 + \theta_1 NKEFZ_{it} + \sum_{s=50}^{450} \delta_s N_{it}^s + d_2 X_{it} + v_i + \mu_t + \varepsilon_{it} \tag{6}$$

This formula introduces a new set of control variables N_{it}^s, where the parameter s represents the geographical distance between counties. If within the spatial range of (s - 50, s] from county i in year t, there exists a county that receives transfer payments, it is set to 1; otherwise, it is set to 0.

According to Figure 20, within a range of 100 kilometers and 400-450 kilometers from the local region itself, ecological protection compensation has significantly reduced carbon emissions. In geographically adjacent areas, due to the dense transportation network and frequent flow of production factors, ecological compensation policies can directly drive the emission reduction of surrounding areas through methods such as technological diffusion or industrial collaboration. However, beyond a certain distance, the spatial spillover effect may not be obvious, taking into account that the fragmentation of administrative regions may hinder cross-regional cooperation. The impact at a long distance may be related to macro-ecosystem services, such as the conversion of farmland to forest improving the ecological conditions in downstream areas.

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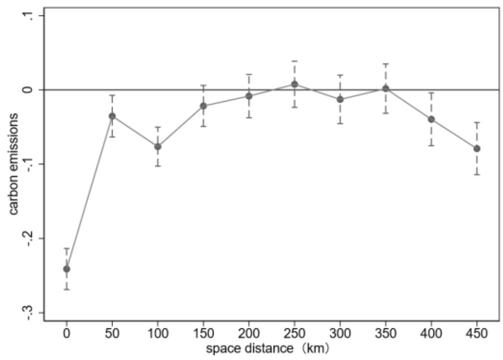

Fig. 20 – Spatial spillover effect. Source: own research

6 CONCLUSIONS AND POLICY IMPLICATIONS

This paper analyzes the impact of transfer payments from national key ecological functional zones on regional carbon emissions by selecting the data of 1,632 county-level cities from 2005 to 2017 and constructing a staggered DID model. The following conclusions are made:

First, the transfer payment of national key ecological function areas can significantly reduce the carbon emissions of each region and improve carbon sink, which provides a new avenue to achieve energy savings and emission reduction. After a series of robust tests, such as adding control variables and eliminating other policy interference, it is found that the conclusions are still valid, so the conclusions of this paper are reliable. At the same time, this policy has a long-term effect and a spatial spillover effect. This provides a broader research scope for the effect of ecological compensation.

Second, in addition to directly reducing regional carbon emissions, the transfer payments for national key ecological functional zones can also affect carbon emissions through indirect effects. This paper takes the green technological innovation, forest areas and the scale of industrialization as the mechanism variables, and the research results find that the ecological compensation increases the green technological innovation and forest areas and reduces the scale of industrialization to achieve carbon emission reduction.

Third, according to the financial freedom of the region to divide, research and development of financial freedom of high and low can make the ecological compensation to achieve carbon emission reduction, but the financial freedom of the region, can have less financial pressure, and then the rational allocation of funds to achieve energy saving and emission reduction goals more efficiently. After analyzing the electricity consumption of each region, it is found that carbon emission reduction can be more effective in areas with higher regional electricity consumption.

Finally, this provides new development strategies and guidelines for ecological protection to countries with development strategies similar to those of China. Compared with other countries' policies, such as the European Union's common agricultural policy, REDD + in forest conservation, there are some differences. China's ecological protection compensation mainly involves the central government directly controlling local ecological performance, implementing a reward and punishment system through supervision and assessment, balancing ecological protection and regional development, and achieving the synergy between poverty reduction and emission reduction through financial compensation. However, the common agricultural policy (CAP) is implemented through decentralized governance. Member states

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independently design and implement strategies, making it difficult to achieve uniformity in specific implementation. Moreover, only a small portion of the funds is subsidized for environmental protection-related purposes. Regarding REDD + (reducing emissions from deforestation and forest degradation), it aims to reduce deforestation and forest degradation through economic incentives. But, due to the involvement of multilateral funds, the funds are subject to the supervision of donor countries.

China's ecological compensation mechanism features mandatory and clearly defined fund allocation, ensuring financial resources are channeled directly toward environmental protection objectives. By contrast, CAP subsidies primarily promote agricultural practices regardless of their contributions to climate resilience, resource conservation, and environmental protection (Heyl et al., 2021). In conclusion, China's ecological protection compensation demonstrates unique advantages in the synergy between rapid emission reduction and poverty alleviation: the mechanism of directly intervening in local development rights via transfer payments and linking the payments with performance strengthens the implementation of policies. It provides a new perspective for developing countries to achieve ecological protection and economic development.

However, at the same time, there are also certain problems in the implementation process of China's ecological protection compensation. As examples, funds are used in non-ecological fields, there is a lack of implementation efforts, the coordination of cross-regional ecological compensation is insufficient, it relies too much on central coordination, and there is a lack of local cooperation.

This paper makes the following recommendations:

First, the national transfer payment policy for key ecological functional zones should be promoted continuously as a key strategy for energy conservation and emission reduction. Carbon emission reduction policies and planning should be instantly adjusted according to regional conditions. Because the ecological protection compensation has spatial spillover effects, it is necessary to strengthen regional cooperation to jointly achieve carbon emission reductions. In addition, the upstream and downstream regions within the same ecological zone should also cooperate with each other to establish a horizontal ecological compensation mechanism. The upstream region needs to make more investments during the governance process. Therefore, the downstream region should also provide certain compensation.

Second, give priority to the use of renewable energy. Promote the transformation and upgrading of industrial structure, and especially accelerate the transformation of industries with high carbon emissions. The increase of regional industrialization level and innovation level will instead lead to an increase in regional carbon emissions. Additionally, strengthen scientific and technological innovation and research and development, establish a low-carbon technology innovation system, promote the transformation and application of scientific and technological achievements, such as carbon capture technologies to reduce carbon emissions in the atmosphere, and encourage cooperation in research and development among enterprises, universities and regions.

Third, increasing the degree of freedom in regional development, and greater regional financial freedom can more effectively achieve energy conservation and emission reduction, so it is necessary to simplify and decentralize government, adapt to local conditions, and rationally plan the development goals and directions of each region. Allocate compensation funds intelligently according to the local development situation, and allow local governments to

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achieve independent allocation of funds within certain areas, such as developing local characteristic industries.

Fourth, it is necessary to strengthen the regulatory efforts to prevent the misappropriation of funds for non-ecological fields. Build a digital supervision platform, conduct monitoring through AI, and incorporate the achievements of ecological protection into the performance assessment of local officials. Based on REDD+ cases, the integration of the government and the market can be further achieved. For example, allowing earnings through carbon sinks can help alleviate the financial pressure. Besides, China can strengthen international cooperation, promote the establishment of an ecological compensation cooperation network for the Belt and Road Initiative, and share green development experiences.

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