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REVIEW

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BON VIEW PUBLISHING

A Literature Survey of Green and Low-Carbon Economics Using Natural Experiment Approaches in Top Field Journal

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Abstract: The last 20 years or so have witnessed the academic torrent of natural experiments in environmental and climate change economics, and we have attempted to document this particular and important branch of economics. This paper reviews theoretical and empirical research in this branch using natural experiment approaches in field-top journal, including economic and scientific journals. We have organized and categorized the related papers into five major dimensions: content, identification strategies, regions, data, and theoretical models and channels. Statistics have found that causal inference and channel analysis on environmental externalities and related governance have endured for 20 years. Until about 10 years ago, a major shift toward diversification of research was taking place, with energy and low-carbon development themes making their way into these journals on the one hand, and developing countries, led by China, attracting attention because of their political systems and other factors. Identification strategies have also become more rigorous, as reflected in the identification concerns (e.g., omitted variables, selection, and reverse causation). Lastly, we also observe that the deep exploration of internal mechanisms and the availability of all types of data have dramatically impacted the traditional paradigm of economics.

Keywords: green and low-carbon economic, natural experimental approach, identification strategy, classification analysis

1. Introduction

The industrialization has promoted the process of human economic and social development, but the intensive and extensive mode of production is at the cost of the extensive exploitation and destruction of environmental resources, which has brought enormous pressure on the human living environment. The problems of "high energy consumption, high pollution, and high emissions" are leading to a chain reaction of global warming and environmental deterioration. It has become the international community's consensus to develop a green and low-carbon economy and deal with global climate change.

The term "Green Economy" originated from the book Blueprint for a Green Economy published by British environmental economist Peter Pearce in 1989. Its essence is the sustainable development economy with the coordinated development of ecology and economy as the core, and the economic development mode is characterized by the maintenance of the human living environment, reasonable protection of resources and energy, and benefit to human health. A low-carbon economy is an economic model based on low energy consumption, low pollution, and low emissions, which aims to reduce greenhouse gas (GHG) emissions and build an economic development system based on low energy consumption and low pollution in essence.

Since the 21st century, the angle of view of the study of environmental problems has gradually developed in the direction of diversification[1]. Pollution has always been a major environmental problem in various countries. It is worth mentioning that the research scope of pollution is not only limited to environmental governance and economic production but also extended to social behavior (Fu & Gu, 2017; Hanna & Oliva, 2015), individual behavior (Grainger, 2012), and vital health (Ebenstein et al., 2017; Gehrsitz, 2017; Lai, 2017). With the signing of Agenda 21, the concept of sustainable development has gained popular support, and the awareness of sustainable social and economic development has been strengthened. Research on environmental issues such as biodiversity loss, energy use, and green innovation has gradually increased. At the same time, the signing of the Kyoto Protocol and the Paris Agreement has promoted the research wave of climate change and carbon emissions, and climate change has become one of the most prominent environmental problems in the world (Smith et al., 2017).

Due to the advantages of natural experimental methods in causal inference, the empirical literature using this method is increasing. One of the focuses of environmental economics is to measure environmental quality costs and benefits, and natural experimental methods are considered to be the best way to identify exogenous variations in variables (Greenstone & Gayer, 2009). First, the implementation and occurrence of environmental policies or environmental changes (pollution or climate change)

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are influenced by local conditions or other unobservable factors. Traditional measurement methods cannot effectively separate clean policy effects from such confounding effects. Second, the counterfactual consequences of environmental policy and environmental change cannot be observed to assess the actual effects in different contexts. A natural experimental approach can take this kind of behavior as an exogenous impact, and use identification strategies such as difference in differences design or regression discontinuity designs to separate the policy processing effect, construct counterfactual results, and evaluate the effect of policy implementation, which can better overcome the defects of traditional measurement methods.

This paper analyzes the development of research issues in green and low-carbon economics in the past two decades and analyzes the logic behind a series of key socio-economic-environmental issues behind the research. This paper reviews the empirical research for the green and low-carbon economics in field-top journals since the 21st century. In a review of related topics, Zhang et al. (2022) summarized the development process of the low-carbon concept and the status quo of carbon neutrality research from 1991 to the present. Tan et al. (2022) analyzed the effects and mechanisms of national design on the development of carbon-neutral behavior using a literature review. There are several review articles in environmental economics journals. Kube et al. (2018) analyzed the development of environmental issues in the 40 years since the publication of *Journal of Environmental Economics and Management* (JEEM) (1974–2014), identified the changes in the research field, and explored the evolution of methodological methods from the perspectives of content, methods, and environmental media. Polyakov et al. (2018) summarized all the articles published between 1991 and 2015 and found that almost all the articles could be classified as application and policy studies by using the topic modeling method, and it provided a platform to close the gap between European and international environmental economic studies. There is also some literature on the evolution of metrology. Currie et al. (2020) use an important literature review to analyze how new types of experiments, identification strategies, and research methods are changing in contemporary economic research in the context of huge innovations in computing technology. Armstrong et al. (2022) reviewed the empirical studies in accounting literature and sorted out the development trend, common methods, and related concepts of causal inference in accounting research. However, few other literature reviews have analyzed the content of green and low-carbon economics articles using natural methods in as much detail. Compared with them, this review has the following advantages: Firstly, it focuses on field-top journals rather than all mainstream economics journals, aiming to focus more on research trends in the field of environmental economics. The research theme and directions of mainstream journals are complicated, and the review cycle is slow, which cannot reflect the research status in the field in time. Secondly, it analyzes its research progress from the dual perspectives of economics and natural science and examines the development of green and low-carbon economics in multiple dimensions from the perspectives of different disciplines. Finally, the paper focuses on the past and present life of natural experiment method in this field, clarifies the context, and puts forward the prospect of future research.

We take the JEL system as the relevant classification basis and combine the research content to determine the classification scheme. By the way of multi-dimensional classification, the development trend and evolution process of green and low-carbon economics are sorted out and summarized from five dimensions, including research theme, identification strategy, research area, research data, and theoretical mechanism. In the first decade of the 21st century, pollution and environmental policy tools have been the focus of empirical research in this area. Since then, as climate change and low-carbon issues have been discussed, diverse research topics have taken shape. At the same time, the application of identification strategies is more innovative. In the past 5 years, expanded forms of difference-in-differences (DID) have emerged endlessly, and it has been widely used in the causal identification of natural experiments. The use of instrumental variables (IVs) and breakpoint regression design has also increased significantly in recent years. More than 90% of studies have focused on specific regions, with North America being the dominant region. Over the past decade, the trend has slowly shifted to developing countries, especially China. The precision of the data has always been a major concern in research. In contrast, microdata is preferred by researchers. In terms of theoretical mechanism, the proportion of theoretical models used is gradually decreasing, while the mechanism analysis has been gradually paid attention to in the past decade. Finally, some future research prospects are proposed according to the conclusion.

The structure of this paper is as follows: Section 2 shows the survey scheme, survey results, and classification scheme of the research. Section 3 shows the analysis results of the five dimensions in the classification scheme, and Section 4 shows the relevant conclusions.

2. Investigation and Classification

2.1. Investigation scheme

2.1.1. Investigation method

In selecting journals, we mainly consider the following two factors. Firstly, the concept of green and low-carbon economics was put forward relatively late, which is a little immature compared with the traditional economic direction. However, the research themes and directions of the five top economics journals are complex and the review cycle is slow, which cannot timely reflect the research status in the field of green and low-carbon economics. Therefore, we selected the top journals representing the field of public and environmental economics. This allows for a better focus on changes in research trends in the field. Secondly, these selected journals are generally considered to be representative comprehensive journals in the field (comprehensive journals can show relatively complete changes in research content, topics, methods, and other aspects of the field). Other niche or specialized journals are not included in our selection. In scientific journals, we select journals based on the same criteria.

Second, we collected all articles which using a natural experiment approach published between 2000 and 2022 in top field journals on green and low-carbon economics. To observe the development of green and low-carbon economy research since the 21st century, we chose to start our study in 2000. In economics, given the breadth of research in the comprehensive journals, we selected the *Journal of Environmental Economics and Management* (JEEM), the *Journal of Public Economics* (JPE), the *Journal of Development Economics* (JDE), *the Journal of the Association of Environmental and Resource Economists* (JAERE) the four field-top journals of public and environmental economics. In the natural sciences, considering that journals related to the environment and sustainable development are more likely to receive articles on green and low-carbon economics, we selected these six field-top journals in the natural sciences (*Nature*, *Nature Climate Change* (NCC), *Nature Human Behaviors*, *Nature Sustainability* (NS), *Nature Energy* (NE), and *Proceedings of the National Academy of Sciences*).

To obtain a relatively complete sample, we first used Web of Science to collect papers in different journals with the following topics, for example, climate change, environmental policy, pollution,

low carbon, and energy economics (these keywords are frequently used in the study of green and low-carbon economy), and manually eliminate papers that do not belong to green and low-carbon economics.

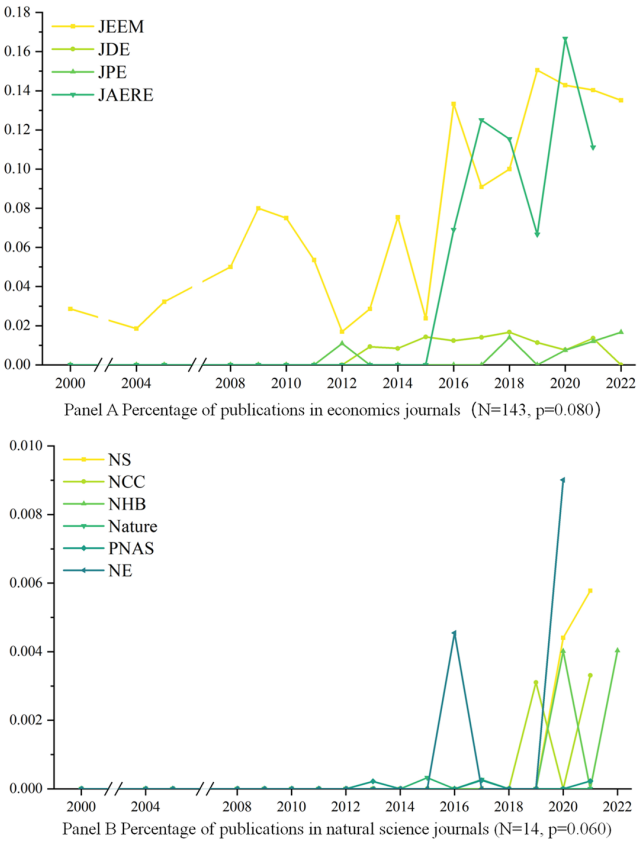
Next, we need to identify papers that use a natural experimental approach. Quantifying the effects of exogenous shocks is an important part of research in environmental economics. Among them, the application of natural experiment techniques can help us more accurately capture variations in variables of interest (Greenstone & Gayer, 2009) and draw relatively clean causal inferences from them. We selected all the papers that used at least one keyword in the title, body, or abstract of the collected papers: (1) DID, IV, regression discontinuity (RD), fixed effect (FE) (these are considered to be common identification strategies in natural experiments) and (2) natural experiment and exogenous impact. These are considered to be papers using natural experimental approaches. To prevent the selection bias caused by the subjectivity of keywords, we further select empirical research papers using natural experimental methods by reading the papers. In case of disagreement, the authors discuss and classify. We ended up with a collection of papers with 161 samples.

To get a more intuitive view of the degree of change in research trends, we used two quantitative analysis methods to observe the content of each category, following the practice of Kube et al. (2018). First, the time series line chart and pie chart are used to show the temporal variation and the overall proportion of the study. Second, we choose to look at the entire period in 5 years (2000–2007, 2008–2012, 2013–2017, 2018–2022)[2]. This has two advantages: on the one hand, it gives a clearer view of different periods; on the other hand, we can more easily use nonparametric chi-square tests to explore whether the content of each category is related to the year. Due to the limited sample period, 5-year clustering was used for testing. (The analysis was started after 2008 because the sample size before 2008 was too small and some years had less than one sample.) The null hypothesis for this test is that the number of articles in each category is evenly distributed over time. As an example, the p-value = 0.080 in Figure 1, which means that the number of articles in different journals has changed significantly over the past 15 years. Similarly, p-value = 0.410 (in Figure 4), which means that different research themes of the article number did not change significantly over the past 15 years.

2.1.2. Findings

Figure 1 shows the research trend of natural experimental methods in green and low-carbon economics. Panel A shows the proportion of publications in the top journals in the field of economics. JEEM (100 papers) was the first journal to publish papers in related fields. After 2012, JPE (8 papers) and JDE (11 papers) successively published research in related fields. In particular, JAERE (23 papers) was founded in 2014, but after 2015, its percentage of published papers increased significantly, even surpassing JEEM in 2016. Over time, a very significant change occurred (p-value = 0.080) – the number of articles in JEEM and JAERE increased significantly. This indicates that the research content of green and low-carbon economics is more favored by these two journals. They peaked in 2019 and 2020, respectively, while the proportion of papers published in JPE and JDE remained relatively low. Panel B shows the research trends in the top journals of the natural sciences. Among them, the proportion of published papers in NCC (2 papers), NS (2 papers), and NE (3 papers) showed an increasing trend, while the proportion of published papers in other journals was too small

Figure 1
The proportion of publications in the top field journals



(the trend was not obvious)[3]. In general, in the study of green and low-carbon economics, the proportion of papers using the natural experimental design is increasing. In the past 15 years, the research on green and low-carbon economy in some journals has increased significantly in the past 15 years.

2.2. Classification scheme

To analyze the collected papers in detail, we classified the papers from the following five dimensions: research theme, identification strategy, research country, research data, theory, and mechanism. In the actual classification, to ensure accuracy, two authors read the paper separately and double-checked for confirmation. The following section describes specific classification measures.

2.2.1. Research theme

First, we divide the research theme into five groups. The classification is based on the JEL classification system of the American Economic Association. However, some papers were not labeled with a specific JELcode, so they were read and manually classified by the authors. In these 5 groups, some groups also distinguish specific groups, a total of 13 content groups. As some articles cover multiple groups, we select the most representative theme and subareas in the actual classification. At the same time, the articles with unclear classification groups shall be determined by the authors after consultation.

[2]Before 2008, because the sample size of 2001–2003 and 2006–2007 was less than 1, 2000–2007 was classified as a group for analysis.

[3]The total number of published papers in natural science journals is too large, resulting in a low proportion of published papers.

Table 1
Pollution subdivisions

Category name	Subdivision field
Pollution	Air pollution
	Water pollution
	Land pollution
	Solid pollution

2.2.1.1. Pollution

We set up the category (see Table 1) based on JELcode Q53 (except Recycling), which covers the impact of pollution on economic production, residents' health, residents' livelihood, etc. Due to the diversity of pollution, we expanded the category of lower level by taking pollution media as the standard in the analysis, to distinguish specific types of articles more carefully.

2.2.1.2. Environmental policy

We established this group, which is mainly classified based on JELcode Q58 and Q48, to distinguish the research trends of different types of environmental policy assessment articles.

2.2.1.3. Climate change

We focused on a wide range of papers on climate change. In this group, parts in JELcode Q54 are mainly used as a classification basis (see Table 2). To specifically, distinguish the effects of different climate changes, we further subdivide the group into three categories, such as temperature and precipitation.

2.2.1.4. Energy economics

In this group, we identified papers related to energy economics, such as energy efficiency, energy endowment, and energy consumption (mainly based on JELcode Q4).

2.2.1.5. Low-carbon economics

At present, there is no clear research classification of the low-carbon economics in JELcode. We will use the technology innovation of Q55 and the recycling component of Q53 as the classification basis. At the same time, articles with specific words (e.g., low carbon, emission reduction, etc.) are defined as the low-carbon economics.

2.2.2. Identification strategy

In this section, we count the specific identification strategies used in natural or quasi-natural experimental papers. To distinguish the research trends well, we only counted the identification strategies and methods of causal effect in the paper, among which other unnatural experimental methods such as theoretical model or input-output method are not included in the statistics. In actual statistics, we obtained a total of 4 large categories and 11 small categories of identification strategy, respectively: DID, RDD, IV, and FE (see Table 3). It is worth mentioning that in this part, each paper is marked with at least one recognition strategy (One paper may be marked with multiple recognition strategies). DID, IV, and RDD are three natural experimental methods. In many articles using DID, IV, and RDD, the fixed effect is added to the model. In the process of statistics, w we marked the identification strategy of each paper. Since most studies of DID, IV, and RDD involve fixed effects. To avoid excessive duplication of statistics on FE, which may affect our observation of the changing trend of the overall research strategy, we only label the identification strategy of relevant papers using FE alone as FE.

Table 2
Climate change subdivisions

Category name	Subdivision field
Climate change	Temperature
	Precipitation
	Other

Table 3
Identification strategy method

Category name	Method
DID	DID
	DDD
	PSM-DID
	Staggered DID
	Generalized DID
	Event analysis
RDD	RDD (sharp)
	RDD (fuzzy)
IV	IV
FE	FE

Table 4
Research country subdivisions

Category name	Regional scope
General	Global
Developed	United States, Canada
	Europe
	Rest of Asia (KOR, JPN)
Developing	China
	Rest of Asia
	Africa
	Latin America

2.2.3. Research country

The third part mainly describes the research area background of the paper. There are two main categories used (see Table 4). The first is divided into non-specific area ranges (general range) and specific area ranges. In general, papers that do not explicitly label a particular area of study are the general scope. If there are papers that use region-specific data or study region-specific issues, they will be classified using the following classification method. The second uses developed and developing countries as the basis for classification, and papers from non-specific regions do not participate in the classification. (Each paper is assigned to a category only).

2.2.4. Research data

The fourth part mainly explores the dimension of data. Different data have macro and micro differences. We divide the dimensions of data into three categories from large to small, which are macro, medium, and micro. Macroscopical sets mostly contain national or state-level data. Medium sets include city-level and county-level data. The rest of the site-level and individual or family-level data belong to the microscopic sets. When multiple data sets of different dimensions are used for research, the data dimension of this paper is based on the data set to which the core variable belongs. The specific categories are shown in Table 5.

2.2.5. Theory and mechanism

The fifth part explores the trend of combining empirical papers with theoretical mechanisms. In this section, the classification is

Table 5
Data dimension subdivisions

Category name	Data dimension
Macroscopical	Country
	State
	Region
Medium	City
	County
Microscopic	Site
	Firm
	Family
	Individual
	Other

relatively concise. We have marked papers that contain theoretical models (even if some theoretical models only reflect part of the inference in the research), such as static theoretical models, dynamic theoretical models, and cost–benefit analysis models. In the mechanism analysis section, we have marked papers where a chapter or paragraph of "mechanism analysis" occurs and papers (directly or indirectly) that illustrate the mechanism path.

3. Analysis Result

This section contains all of the content and diagrams shown in Section 2.2 of the classification scheme. We classified 157 papers from 2000 to 2022 for testing. Overall, the number of green and low-carbon economics publications is increasing year by year, peaking in 2021 (see Figure 2). To clearly observe the publishing trends in the top field journals since the 21st century, we mainly use three forms of time series, bar chart, and pie chart to display.

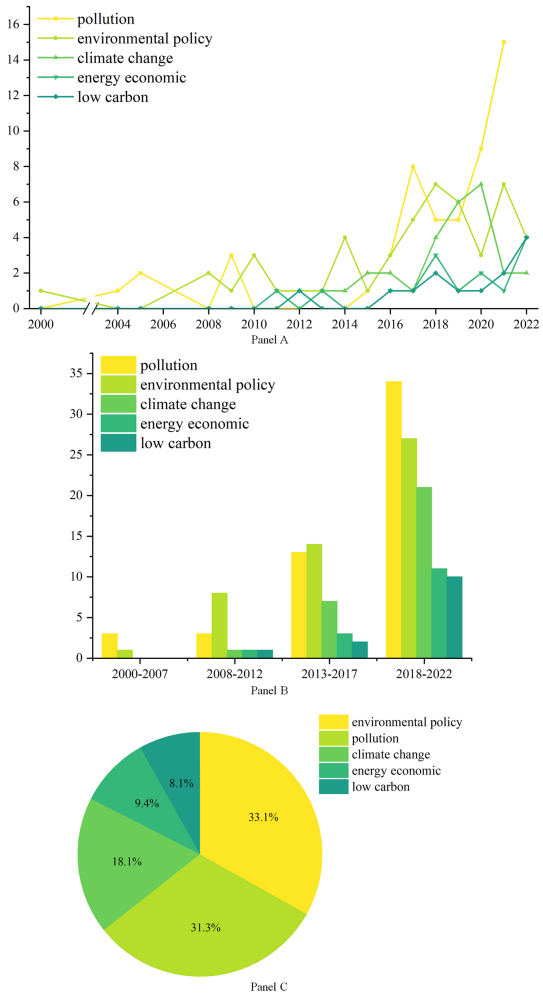
First of all, the timing chart can visually observe the overall publication trend of papers. For each unique section, a pie chart can be used to better observe the proportion of the whole to the different categories. Secondly, because different classification schemes may lead to a large number of zero values in some years during the sample period, we choose to observe the overall sample in 5 years (2000–2007, 2008–2012, 2013–2017, 2018–2022) (see Section 2.1.1 for details).

3.1. Research theme

Figure 2 (Panel A) shows the publication trends of five different content groups. Similar to the views of Kube et al. (2018), the topic with the largest number of studies is pollution (53 papers), followed by environmental policy (50 papers) and climate change (30 papers), energy economics (15 papers), and low-carbon economics (13 papers). Before 2010, the application of natural experiments in the field of green and low-carbon economics was relatively small, mainly distributed in the field of pollution and environmental policy, but after 2010, it was gradually popularized in other fields. In the past 10 years, the academic community has gradually warmed up its attention to the field of green and low-carbon economics, with an obvious upward trend after 2014. At the same time, the research content has gradually shifted to the direction of diversification after 2014 (Panel B, as shown in Figure 2). More attention has been paid to energy economics and low-carbon economics, but pollution has always been the main object of concern. According to the *p*-value, the number of articles in the subcategories of research topics has not changed significantly in the past 15 years (*p*-value = 0.536).

In terms of pollution content, we further distinguish the research trends of different pollution categories. In the first 10 years, scholars

Figure 2
Research theme ($N = 157$, $p = 0.536$)



mainly focused on the study of air pollution. With the advance of time, natural experiment methods are gradually applied to the research of various pollution problems. For example, they have been used to study the impact of water pollution on health and life (Lai, 2017) and the issue of water pollution discharge in the process of government control (Cai et al., 2016a) began to come into public view (6 articles in total). In recent years, the number of articles related to solid and toxic waste pollution (Akbulut-Yuksel & Boulatoff, 2021; Alacevich et al., 2021) (3 articles in total) and land pollution (Clay et al., 2021) (1 article in total) is also increasing (Figure 3).

In terms of environmental policy content, Dean et al. (2000) evaluated the impact of environmental policy on enterprise generation and cost. After that, the overall number of studies showed a steadily rising trend and reached its peak in 2021.

Among them, ***the Clean Air Act*** implemented in the United States plays an important role in the study (Greenstone, 2004; Raff et al., 2022). Similarly, there is China's ***TCZ*** policy (Hering & Poncet, 2014).

In terms of climate change, in the early 21st century, there were relatively few empirical studies using natural experiment methods to assess the impact of climate change, and the number of studies gradually increased after 2011. Until 2020, the number of publications on this topic peaked (Figure 4). Among the 29 papers, the impact of climate change on health, production, energy, and resource allocation are the main areas of research.

Figure 3
Pollution category ($N = 50$, $p = 0.503$)

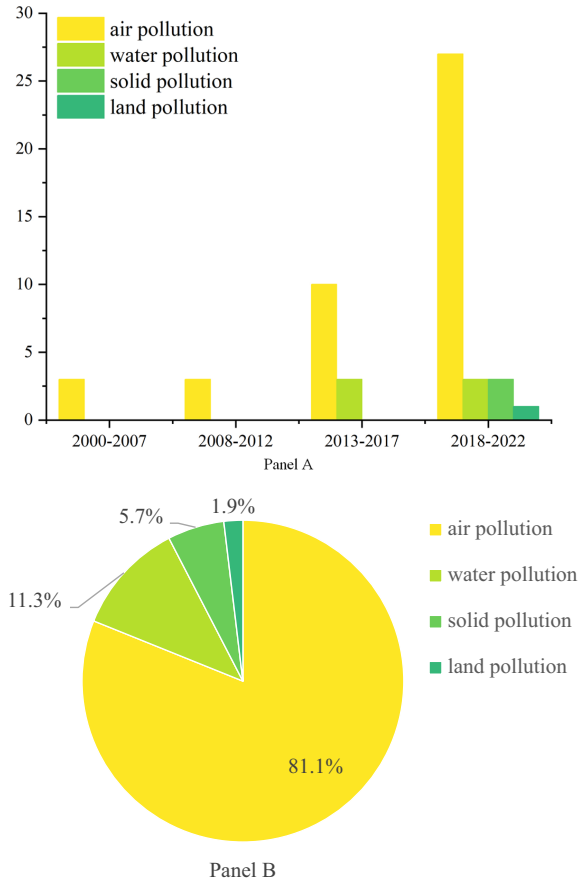
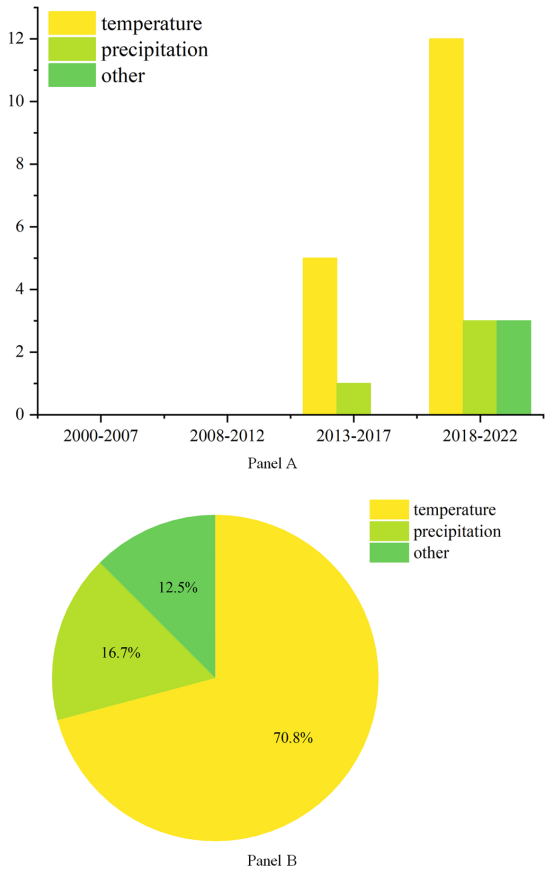


Figure 4
Climate change category ($N = 25$, $p = 0.410$)



More than 70% of the papers focused on temperature change, with the rest on precipitation and other topics. Similar to the composition of other subject subcategories, the subcategories of climate change articles have not changed significantly over the past 15 years (p-value = 0.410).

In terms of energy economy and low-carbon content, although energy and low-carbon economy are closely related to sustainable development, they account for the least amount of content in our statistics. Energy economics research peaked in 2022, with much of it focusing on energy efficiency, energy consumption, and externality impacts, such as the 2011 survey on the market power of rail in the transportation of fuel ethanol (Hughes, 2011). In terms of low-carbon economy, enterprise innovation, and development (Amore & Bennedsen, 2016), GHG emission and carbon reduction are the main research contents.

3.2. Identification strategy

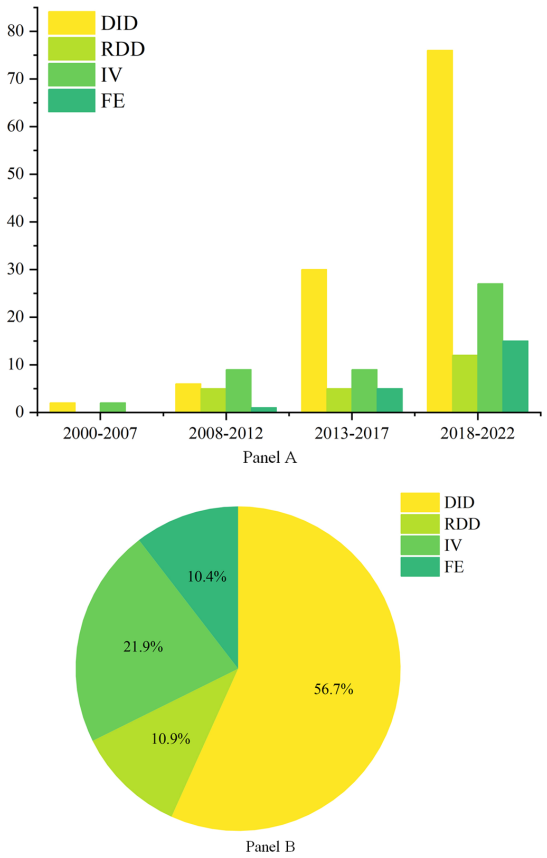
The evaluation of causality is the core problem of all scientific research. Natural experiments are one of the most effective tools for assessing causality. The findings in Section 2.1 of this paper indicate that there is a growing interest in using natural experimental methods to assess causality in the field of green and low-carbon economics. However, many studies have explored the origin and development of causal inference research in positive economics (Deschenes & Meng, 2018; Fuchs-Schündeln & Hassan, 2016). Therefore, in this section, we mainly discuss the identification strategies of natural experimental methods and their applications and trends in the field of green and low-carbon economics.

DID (114 articles) is the most commonly used natural experiment method (Figure 5). Other methods are used relatively infrequently and in relatively small quantities. Interestingly, a very significant difference is emerging (p-value = 0.059). Before 2012, the IV method (47 articles) and DID were used in similar numbers. However, in the last decade, there has been a significant increase in the proportion of DID use. It may be due to the advantage of DID in evaluating policy effects. This was accompanied by a significant shift in the diversity of methods, with RDD (22 articles) and FE model (22 articles) also on the rise. The articles that use the FE model here do not include articles that use DID, RDD, or IV methods. Next, we discuss the different identification strategies in detail.

3.2.1. Difference-in-differences

In a natural experiment (or quasi-experiment), some naturally occurring event or exogenous shock can lead to a scenario similar to a randomized controlled experiment. These events are out of people's control, and they randomly divide the sample into different groups and receive different treatments. And this difference between the treatment group and the control group, because of the different treatments, is something that we are very interested in. This is known as the average treatment effect (ATT) of the treatment group. To identify this difference, DID design is a frequently adopted approach.

Figure 5
Identification strategy (at least one method per article, $N = 198$, $p = 0.059$)



With the continuous innovation of measurement technology, the types of DID also showed significant changes ($p = 0.085$). The number of traditional DID (63 papers) kept growing, while the number of DDD (17 papers) and propensity score matching (PSM)-DID (11 papers) also increased significantly in the past decade. The number of staggered DID (6 papers) and generalized DID (2 papers) was relatively small.

1. Traditional DID

$$Treat_i = \begin{cases} 1 & if\ i \in treatment\ group \\ 0 & if\ i \in control\ group \end{cases}$$

$$Post_t = \begin{cases} 1 & if\ i \in post\ treatment \\ 0 & if\ i \in before\ treatment \end{cases}$$

$$y_{it} = \alpha + \beta Treat_i + \gamma Post_t + \delta Treat_i * Post_t + \varepsilon_{i,t}$$

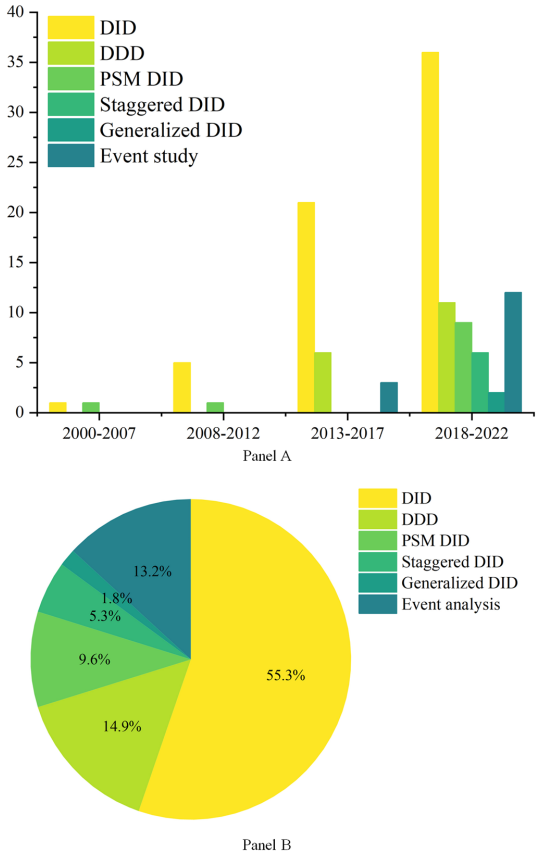
In the traditional DID specification, if individual i is affected by policy implementation, the corresponding $Treat_i$ is 1; if the policy is implemented, the corresponding $Post_t$ is 1. Coefficient δ is the variable coefficient of our interest, which reflects the net effect of the policy implementation.

In traditional DID, the time to receive processing is the same. In Table 6, it can be seen that the average treatment effect of the policy is δ. It represents the difference in the individual after the treatment. Generally, time and individual fixed effects are used to replace

Table 6
Coefficient of traditional DID

	$Post_t = 0$	$Post_t = 1$	Difference
Treatment	$\alpha + \beta$	$\alpha + \beta + \gamma + \delta$	$\gamma + \delta$
Control	α	$\alpha + \gamma$	γ
Difference	β	$\beta + \delta$	δ

Figure 6
Types of DID design (at least one method per article, $N = 112$, $p = 0.032$)



and respectively. In relatively early research, standard DID has often been used to assess the actual effects of various environmental policies and regulations (Bratberg et al. 2005, Cai et al. 2016b). Later, it was further used to assess the impact of policies on social needs (Liu et al. 2017), and residents' behaviors (Carrillo et al. 2018). It has also been applied to the evaluation of pollution effects (Persico and Johnson 2021, Xue et al. 2021). Judging from the historical trend, the application of DID may be better in the future (Fig. 6).

2. DDD

An important premise of DID is to satisfy the parallel trend hypothesis. This is also a key step in obtaining unbiased estimates. When the parallel trend was not established, a control group could be constructed to satisfy the hypothesis. This is called the triple difference model. In earlier studies, Cai et al. (2016a) first compared the differences between water pollution and non-water

pollution industries in neighboring provinces and counties (near the river), then introduced the differences in neighboring provinces and counties not near the river, and finally got the real clean policy effect by subtracting. It is also widely used in the assessment of environmental policy effects and their externalities (Konishi & Managi, 2020; Moffette et al., 2021). In Figure 6, the use of triple difference has increased significantly over the decade.

3. Staggered DID

Compared with traditional DID, one characteristic of staggered DID is that the processing stages of samples may be different. For example, if a policy is implemented in different cities in batches, the $Post_t$ in different cities will not be completely consistent. In a recent study, Lin et al. (2022) studied the impact of high-speed rail opening on GHG emission reduction. He took advantage of the staggered opening of high-speed trains, which reduced traffic on parallel roads. Therefore, the ATT of the staggered opening of high-speed rail can be compared by the changes in time dimension (before and after the opening of high-speed rail) and city dimension (cities without high-speed rail service within the sample period). Staggered DID had shorter development times than other DID methods and may still have some problems (Goodman-Bacon, 2021). This is also an important factor affecting its numbers.

4. PSM-DID

The model is composed of a PSM model and DID model. Among them, PSM was responsible for screening control individuals for treated individuals, and DID was responsible for identifying the impact of policy impact. In an earlier study, Greenstone (2004) considered that the observed differences between the treatment group and the control group were caused by the inadequate implementation of the policy. This will make policy assessment more difficult. So he used PSM-DID to control for confusion in the assessment of effects caused by differences. In current studies, PSM-DID has also been used to deal with endogeneity problems.

5. Generalized DID

The above DID methods all assume that there is a difference between the treatment group and the control group. However, in the actual situation, when some policies are implemented uniformly across the country or samples are subjected to the same impact at the same time, there is only a treatment group and no control group. In this case, generalized DID is necessary. When we build the model, we replace treat with intensity, which represents the intensity affected. In this case, the cross multiplication term represents the marginal change of the individual treatment effect of the policy with different intensities. In this case, much information is lost by compressing the intensity of continuity into simple binary variables.

In recent studies, there were two articles that used generalized DID. Zhu & Wang (2021) assessed the effect of emission control areas (ECA) regulations on pollution mitigation and mortality by using wind direction and wind speed at ports as intensity. Lohmann et al. (2022) analyzed the influence of different carbon footprint labels on people's dietary choice preferences and the sustainable behavior changes brought about in the consumer field.

6. Event Study Methodology

Event study methodology (ESM) is a measurement method to study the impact of major events on dependent variables. Although it belongs to one of the natural experimental methods, it does not belong to the DID design above. There are two reasons for placing it here: one is to facilitate readers' reading and classification; the second is that there is a similarity between it and DID design, which facilitates the reader to compare the differences between them.

In an earlier study, Cozad & LaRiviere (2013) used the increase in oil price as an exogenous shock and found that the increase in oil price would significantly reduce carbon dioxide emissions. In addition, Curtis & Lee (2019) studied whether the implementation of environmental laws and regulations affected the output and efficiency of factories from the perspective of policies.

Due to its high efficiency and easy operation, the usage of ESM has been on the rise significantly in recent years (Figure 6).

3.2.2. RDD

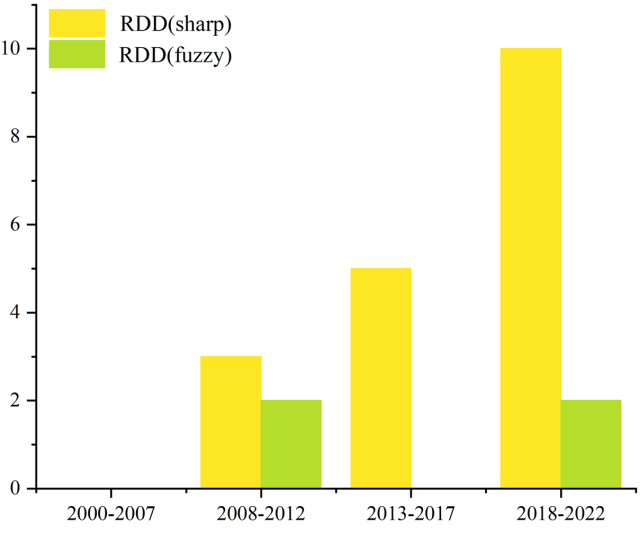
RDD is also an experimental method to conduct causality assessment through exogenous changes. Different from DID, RDD takes threshold as its judgment basis. The samples higher than the threshold were the treatment group, while the samples lower than the threshold were the control group. If a subsample is intercepted near the threshold value, the units in the sample can be regarded as having similar characteristics in all aspects except whether to accept processing.

RD can be divided into sharp RD (SRD) and fuzzy RD (FRD). The former is that at the breakpoint $x = c$, the probability of an individual being processed jumps from 0 to 1. The latter is that at the breakpoint $x = c$, the probability of the individual being processed jumps from a to b, where $0 < a < b < 1$.

Figure 7 shows the number of studies on different types of RD. It can be seen that the number of SRD has an obvious upward trend, while the number of FRD does not change significantly. The increase in RDD has also been partly contributed by the 2021 Nobel Prize in Economics for David Card, Joshua Angrist, and Guido Imbens.

In one of the classic studies, they took the Qinling Mountains and Huaihe River as the breakpoint to study the impact of China's heating policy on residents' life expectancy (Chen et al., 2013; Ebenstein et al., 2017).

Figure 7
Types of regression discontinuity design
(at least one method per article, $N = 22$, $p = 0.190$)



3.2.3. IV method

IV methods determine causal effects by isolating exogenous components of treatment allocation (Deschenes & Meng, 2018).

IV has the same logic as other quasi-experimental designs, with samples divided into treatment and control groups based on IVs. However, IV provides causal estimates on the premise that: (1) IV must be strongly correlated and monotonous with processing variables and (2) IV must be exogenous.

In our sample, IV is most commonly used in studies of air pollution. Among them, temperature inversion and wind speed (Hanna & Oliva, 2015; Sager, 2019) are considered to be very effective IVs to deal with pollution problems. Second, IV has been used to assess the impact of climate change (Sarsons, 2015), environmental policy benefits (Hausman & Muehlenbachs, 2019), and energy economics (Cali et al., 2022).

3.2.4. FE model

When the standard of ordinary least squares (OLS) assumption is satisfied, the estimator can be seen as a causal effect. In practice, missing variables are the main cause of biased estimation. The FE model is an effective method to deal with omitted variables. Of course, to avoid confusion with the above methods, the statistical papers containing FE models only included the FE identification strategy. In our statistics, FE is mainly used to assess the impacts caused by climate change, and the representative ones are the impacts of temperature on economic production (Burke et al., 2015; Zhang et al., 2018) and agriculture (Chen et al., 2016). In addition, the effects of temperature on life and health (Agarwal et al., 2021) and criminal behavior (Ranson, 2014) were included, as well as articles assessing the effects of precipitation (Eyer & Wichman, 2018) and humidity (Barreca, 2012). With continuous attention to climate change, the application of the FE model will have a more positive prospect.

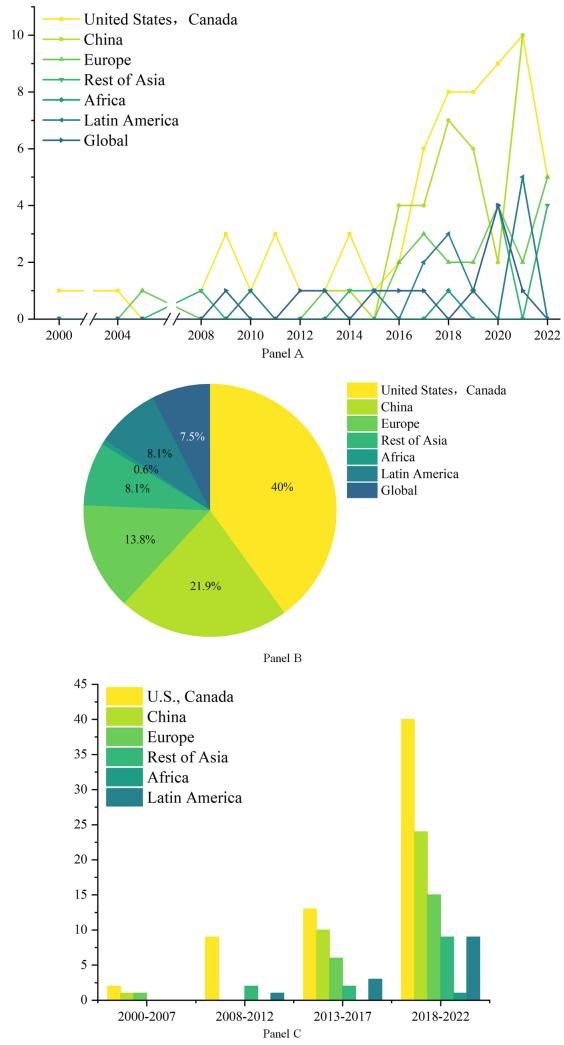
3.3. Research country

More than 90% of the articles are set in a specific region or country. In Panel B of Figure 8, 40% focus on the United States and Canada (64 articles in total), the second and third are China (36 articles in total) and Europe (22 articles in total), and the rest are distributed in the Rest of Asia (13 articles in total), Latin America (14 articles in total), and Africa (1 article in total). From the time dimension, North America was the main research area before 2013. After 2015, China gradually became another focus. On the one hand, the continuous development of Chinese education leads to the further improvement of the number and academic level of Chinese scholars, which increases their voice in top field journals. On the other hand, China's economic rise has led international scholars to re-examine China's institutions and policies. In addition, various sustainable development policies and concepts introduced by the Chinese government since the 21st century have also provided a solid foundation for the development of low-carbon economics in China.

Between 2008 and 2017, there was a significant difference (p-value = 0.011) in articles from different research countries, which means that Europe, Latin America, and Asia are also gradually attracting academic attention.

Figure 8

Research country ($N = 145$, $p = 0.154$), ($N = 46$, $p = 0.011$)[4]



Only 7% of the papers (12 in total) were in a non-specific scope (global) context. In Panel C, it can be intuitively observed that after 2018, the main body of the research area is still North America, but compared with before 2010, the research area shows a trend of diversified development.

Figure 9 shows the research trends of developed and developing countries. Since 2015, the attention paid to developing countries has skyrocketed (even if it is not statistically significant), with more than half of the articles on China. This shows that after the signing of the Paris Agreement, green and low-carbon economics are no longer just the responsibility and obligation of developed countries but are developing toward the trend of globalization.

3.4. Research data

Figure 10 shows article distribution and time series analysis for each dimension of data. More than half of the papers used microdata (52%), and the use of micro data has increased significantly since 2015. This suggests that microdata may be increasingly favored by field-top journals. Although the use of macro data (27%) and medium data (21%) has also increased in recent years, their percentages have declined. Part of the reason for this is that huge

[4]Samples from 2008–2012 and 2013–2017 were used for chi-square tests.

Figure 9
National development level ($N = 145$, $p = 0.241$)

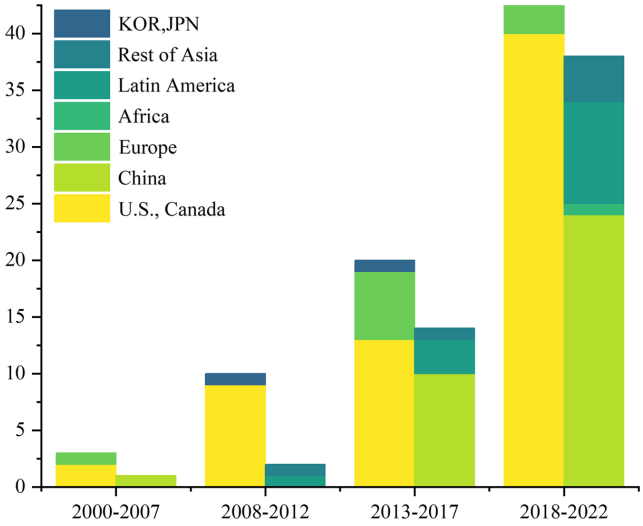


Figure 10
Type of research data ($N = 157$, $p = 0.917$)

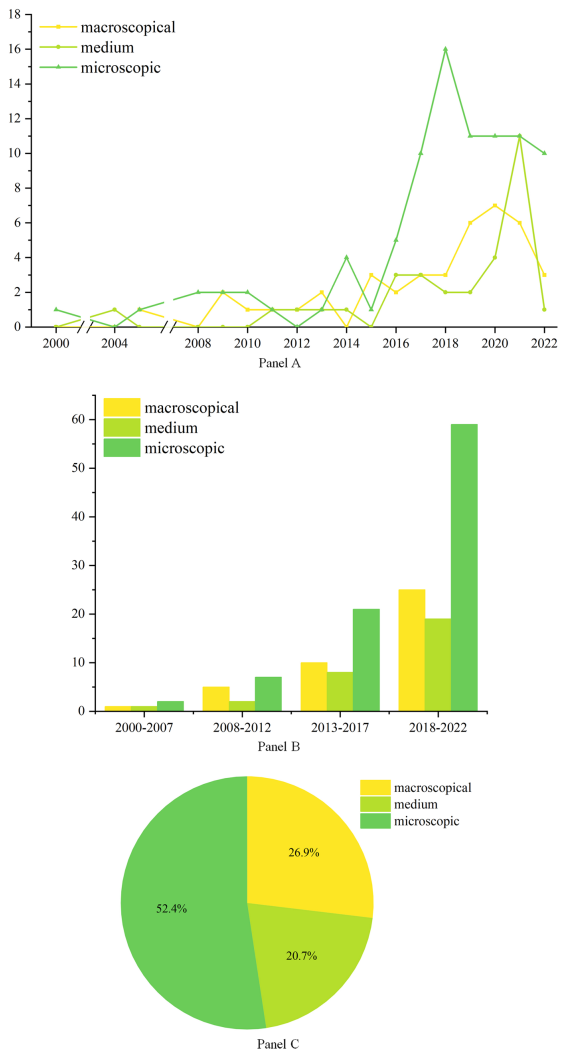
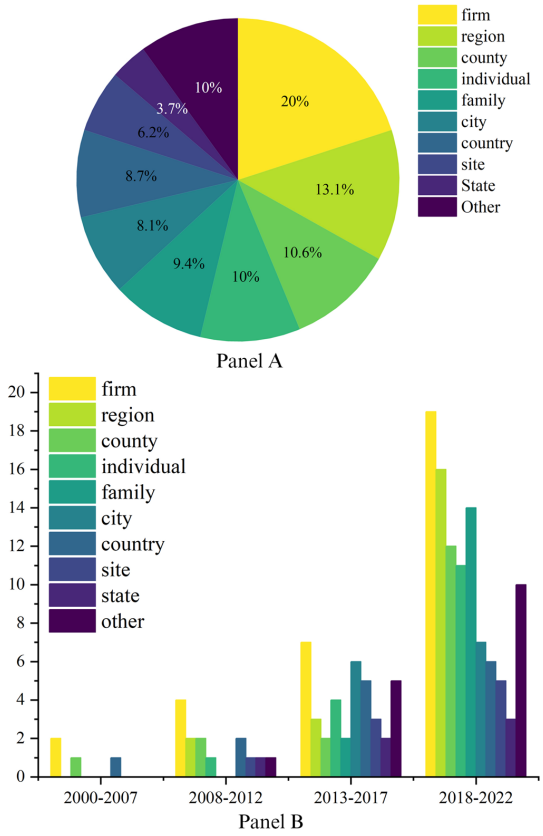


Figure 11
Research data ($N = 157$, $p = 0.491$), ($N = 143$, $p = 0.353$)



innovations in computing have driven changes in economics (Currie et al., 2020). In Figure 11, firm-level data (21%) are the most popular data type over the last 20 years. In particular, in papers using firm-level data, the sample size and information density of the data show an overall upward trend. Fine microdata may be one of the important reasons affecting whether a paper is accepted or not. The amount of state-level data (4%) is relatively small. Other types of data are used relatively evenly. Data-oriented research has gradually taken a dominant position in empirical research. Chi-square test results of research data show that there is no significant change in the composition of this subcategory (p-value = 0.491).

3.5. Theory and mechanism

In Figure 12, the number of papers containing theoretical models (28%) in field-top journals is increasing, but the percentage is decreasing. This possible reason lies in the fact that papers using natural experimental methods attach more importance to the selection of identification strategies and the generation of credible estimates (Nevo & Whinston, 2010). However, this does not mean that the role of theoretical models has been ignored, but the requirements on whether a paper contains theoretical models are not as strict as before.

Figure 13 shows publication trends for papers that include a mechanism analysis (18%). Its quantity increased obviously and changed significantly (p-value = 0.026). This means that in the future, analysis of the mechanism pathway may be as important as environmental impact assessment.

Figure 12
Theoretical model ($N = 157$, $p = 0.685$)

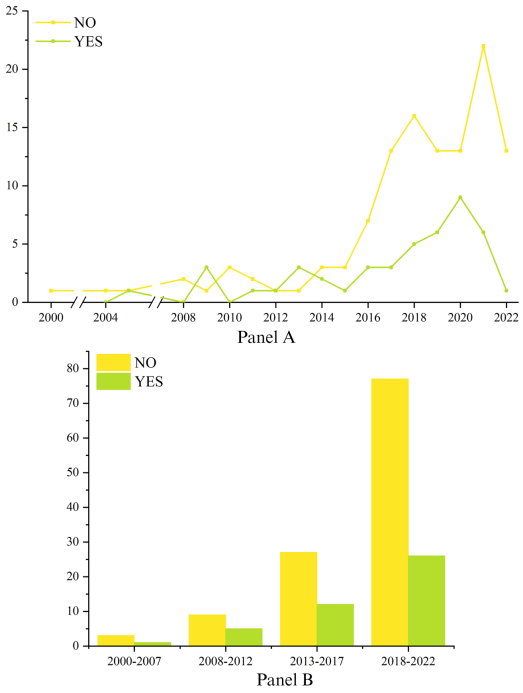
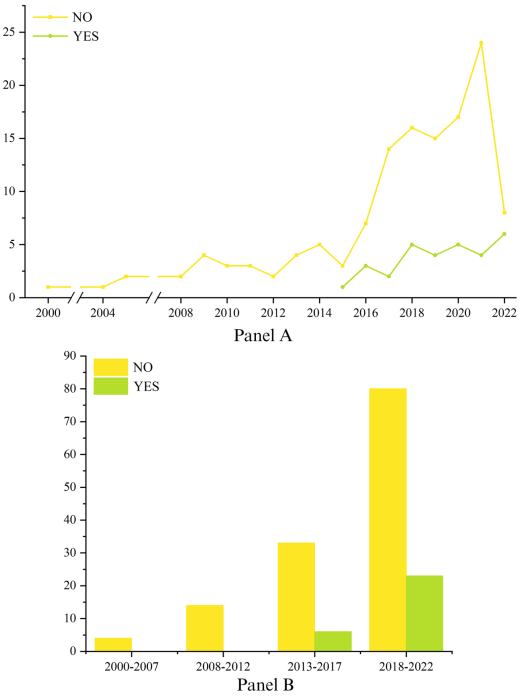


Figure 13
Mechanism analysis ($N = 157$, $p = 0.026$)



4. Conclusion

In this paper, we investigate and analyze trends in green and low-carbon economics research using natural experimental methods in a field-top journal from 2000 to 2022. By establishing a classification scheme, we illustrate the specific details from five dimensions of the research topic, identification strategy, research area, research data, theoretical model, and channel and show the changing trends of research within each group.

This paper evaluates changes in the field of green and low-carbon economics in the field-top journal of Economics and Natural Sciences. It is more diverse in its overall content, still focusing on pollution and environmental policy assessment. Air pollution is the most concerned among many pollution problems. In addition, the amount of research on climate change and energy issues is increasing. Natural experimental methods are growing in popularity, and there has been a significant shift toward diversification. The number of papers using DID identification strategy is increasing greatly, which may be due to its excellent policy identification effect and constant innovation. The number of IV and RDD is also steadily increasing. The credibility revolution is gradually promoting the development of natural experimental methods. The majority of countries studied are still North America, and more research has been done on developing countries since a decade ago. In which, China is the country with the fastest growing degree of attention, which benefits from the rapid improvement of its educational and economic level. Microdata has been a favorite of researchers for the past two decades, and it seems likely to continue to grow. Finally, we see that the proportion of theoretical models is decreasing. One possible reason is that articles using natural experimental methods pay more attention to the generation of credible estimates. It is worth mentioning that the popularity of mechanism analysis is increasing significantly.

It is foreseeable that in the future, the research on green and low-carbon economics will develop in an overall diversified direction. Not only the research topics but also the research methods and research areas will change, and they are gradually developing in a richer and more novel direction in more innovative. Among them, the environmental problems of developing countries will be increasingly worthy of study. Secondly, the promotion of the credibility revolution will encourage people to find and use more accurate identification strategies to evaluate processing effects, which will even trigger a data revolution (microdata, a more detailed microscopic data, is applied to empirical research), which promotes the development of economics in the direction of big data machine learning. Thirdly, research tends to be integrated, structured, and systematic. The assessment of environmental problems no longer focuses solely on the partial derivative effect of a single factor, for example, it may focus on the combined effect of multiple environmental factors (temperature, precipitation, humidity, various pollutants, etc.). It is not just assessing the effects of a single policy.

Conflicts of Interest

Ning Zhang is the Editor-in-Chief for *Green and Low-Carbon Economy*, and was not involved in the editorial review or the decision to publish this article. The authors declare that they have no conflicts of interest to this work.

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Appendix A

A.1: Classification of articles in field-top journals

Research theme	Journal	N	Percent
climate change		**30**	**18.63%**
	Journal of Development Economics	5	3.11%
	Journal of Environmental Economics and Management	14	8.70%
	Journal of Public Economics	2	1.24%
	Journal of the Association of Environmental and Resource Economists	5	3.11%
	Nature	1	0.62%
	Nature Climate Change	1	0.62%
	Nature human behaviour	2	1.24%
energy economics		**15**	**9.32%**
	Journal of Environmental Economics and Management	11	6.83%
	Journal of the Association of Environmental and Resource Economists	3	1.86%
	Nature Energy	1	0.62%
environmental policy		**50**	**31.06%**
	Journal of Development Economics	4	2.48%
	Journal of Environmental Economics and Management	36	22.36%
	Journal of Public Economics	4	2.48%
	Journal of the Association of Environmental and Resource Economists	4	2.48%
	Nature	1	0.62%
	Nature Sustainability	1	0.62%
low carbon		**13**	**8.07%**
	Journal of Environmental Economics and Management	10	6.21%
	Journal of the Association of Environmental and Resource Economists	1	0.62%
	Nature Climate Change	1	0.62%
	PNAS	1	0.62%
pollution		**53**	**32.92%**
	Journal of Development Economics	2	1.24%
	Journal of Environmental Economics and Management	33	20.50%
	Journal of Public Economics	3	1.86%

	Journal of the Association of Environmental and Resource Economists	10	6.21%
	Nature Sustainability	1	0.62%
	PNAS	2	1.24%
	Nature Energy	2	1.24%
Total		**161**	**100.00%**

Pollution	Journal	N	Percent
air pollution		**43**	**81.13%**
	Journal of Development Economics	2	3.77%
	Journal of Environmental Economics and Management	26	49.06%
	Journal of Public Economics	3	5.66%
	Journal of the Association of Environmental and Resource Economists	7	13.21%
	Nature Sustainability	1	1.89%
	PNAS	2	3.77%
	Nature Energy	2	3.77%
land pollution		**1**	**1.89%**
	Journal of the Association of Environmental and Resource Economists	1	1.89%
solid pollution		**3**	**5.66%**
	Journal of Environmental Economics and Management	3	5.66%
water pollution		**6**	**11.32%**
	Journal of Environmental Economics and Management	5	9.43%
	Journal of the Association of Environmental and Resource Economists	1	1.89%
Total		**53**	**100.00%**

Climate change	Journal	N	Percent
other		**4**	**13.79%**
	Journal of Environmental Economics and Management	3	10.34%
	Nature human behaviour	1	3.45%
precipitation		**5**	**17.24%**
	Journal of Development Economics	4	13.79%
	Journal of Environmental Economics and Management	1	3.45%
temperature		**20**	**68.97%**

	Journal of Development Economics	1	3.45%
	Journal of Environmental Economics and Management	10	34.48%
	Journal of Public Economics	2	6.90%
	Journal of the Association of Environmental and Resource Economists	4	13.79%
	Nature	1	3.45%
	Nature Climate Change	1	3.45%
	behaviour	1	3.45%
Total		**29**	**100.00%**

Identification strategy	Journal	N	Percent
DDD		**17**	**8.29%**
	Journal of Development Economics	1	0.49%
	Journal of Environmental Economics and Management	16	7.80%
DID		**63**	**30.73%**
	Journal of Development Economics	3	1.46%
	Journal of Environmental Economics and Management	44	21.46%
	Journal of Public Economics	3	1.46%
	Journal of the Association of Environmental and Resource Economists	8	3.90%
	Nature	1	0.49%
	Nature Climate Change	1	0.49%
	Nature Sustainability	2	0.98%
	PNAS	1	0.49%
DID(PSM)		**11**	**5.37%**
	Journal of Development Economics	2	0.98%
	Journal of Environmental Economics and Management	9	4.39%
DID(staggered)		**6**	**2.93%**
	Journal of Environmental Economics and Management	4	1.95%
	Nature Climate Change	1	0.49%
	Nature human behaviour	1	behaviour
Event analysis		**15**	**7.32%**
	Journal of Environmental Economics and Management	10	4.88%
	Journal of Public Economics	2	0.98%
	Journal of the Association of Environmental and Resource Economists	1	0.49%

	Nature human behaviour	1	0.49%
	Nature Sustainability	1	0.49%
IV		**47**	**22.93%**
	Journal of Development Economics	5	2.44%
	Journal of Environmental Economics and Management	27	13.17%
	Journal of Public Economics	2	0.98%
	Journal of the Association of Environmental and Resource Economists	10	4.88%
	Nature Energy	3	1.46%
RDD(fuzzy)		**4**	**1.95%**
	Journal of Environmental Economics and Management	3	1.46%
	Journal of Public Economics	1	0.49%
RDD(sharp)		**18**	**8.78%**
	Journal of Environmental Economics and Management	12	5.85%
	Journal of Public Economics	2	0.98%
	Journal of the Association of Environmental and Resource Economists	1	0.49%
	Nature human behaviour	1	0.49%
	PNAS	2	0.98%
Generalized DID		**2**	**0.98%**
	Journal of Environmental Economics and Management	2	0.98%
FE		**22**	**10.73%**
	Journal of Development Economics	1	0.49%
	Journal of Environmental Economics and Management	13	6.34%
	Journal of Public Economics	2	0.98%
	Journal of the Association of Environmental and Resource Economists	4	1.95%
	Nature	1	0.49%
	Nature human behaviour	1	0.49%
Total		**205**	**100.00%**

Research country	N	Percent
United States	**62**	**38.51%**
Journal of Environmental Economics and Management	40	24.84%
Journal of Public Economics	6	3.73%
Journal of the Association of Environmental and Resource Economists	14	8.70%
Nature	1	0.62%
Nature Energy	1	0.62%
China	**36**	**22.36%**
Journal of Development Economics	4	2.48%
Journal of Environmental Economics and Management	24	14.91%
Journal of Public Economics	1	0.62%
Journal of the Association of Environmental and Resource Economists	2	1.24%
Nature Climate Change	1	0.62%
Nature Sustainability	1	0.62%
PNAS	3	1.86%
Global	**12**	**7.45%**
Journal of Development Economics	1	0.62%
Journal of Environmental Economics and Management	7	4.35%
Journal of the Association of Environmental and Resource Economists	1	0.62%
Nature	1	0.62%
Nature human behaviour	1	0.62%
Nature Energy	1	0.62%
Brazil	**6**	**3.73%**
Journal of Environmental Economics and Management	4	2.48%
Journal of the Association of Environmental and Resource Economists	2	1.24%
United Kingdom	**5**	**3.11%**
Journal of Environmental Economics and Management	3	1.86%
Journal of the Association of Environmental and Resource Economists	1	0.62%
Nature Climate Change	1	0.62%
Sweden	**4**	**2.48%**
Journal of Environmental Economics and Management	4	2.48%
Japan	**3**	**1.86%**
Journal of Environmental Economics and Management	3	1.86%
Germany	**3**	**1.86%**
Journal of Development Economics	1	0.62%
Journal of Environmental Economics and Management	2	1.24%

Ecuador	**3**	**1.86%**
Journal of Environmental Economics and Management	1	0.62%
Journal of Public Economics	1	0.62%
Nature Sustainability	1	0.62%
Thailand	**2**	**1.24%**
Journal of Development Economics	1	0.62%
Journal of Environmental Economics and Management	1	0.62%
Switzerland	**2**	**1.24%**
Journal of Environmental Economics and Management	2	1.24%
Singapore	**2**	**1.24%**
Journal of the Association of Environmental and Resource Economists	1	0.62%
Nature human behaviour	1	0.62%
Mexico	**2**	**1.24%**
Journal of Environmental Economics and Management	1	0.62%
Journal of Public Economics	1	0.62%
Korea	**2**	**1.24%**
Journal of Development Economics	1	0.62%
Nature Energy	1	0.62%
India	**2**	**1.24%**
Journal of Development Economics	1	0.62%
Journal of the Association of Environmental and Resource Economists	1	0.62%
France	**2**	**1.24%**
Journal of Environmental Economics and Management	1	0.62%
Journal of the Association of Environmental and Resource Economists	1	0.62%
Europe	**2**	**1.24%**
Journal of Environmental Economics and Management	2	1.24%
Canada	**2**	**1.24%**
Journal of Environmental Economics and Management	2	1.24%
Columbia	**1**	**0.62%**
Journal of Environmental Economics and Management	1	0.62%
Tanzania	**1**	**0.62%**
Journal of Development Economics	1	0.62%
Ottoman Empire， Germany, France， United Kingdom	**1**	**0.62%**
Journal of Development Economics	1	0.62%
Netherlands	**1**	**0.62%**
Journal of Environmental Economics and Management	1	0.62%
Italy	**1**	**0.62%**
Journal of Environmental Economics and Management	1	0.62%
Indonesia, Mexico	**1**	**0.62%**
Journal of Environmental Economics and Management	1	0.62%
Finland	**1**	**0.62%**

Journal of Environmental Economics and Management	1	0.62%
Chile	**1**	**0.62%**
Journal of Environmental Economics and Management	1	0.62%
Bhutan	**1**	**0.62%**
Journal of Environmental Economics and Management	1	0.62%
Total	**161**	**100.00%**

Research Data	N	Percent
firm	**32**	**19.88%**
Journal of Development Economics	2	1.24%
Journal of Environmental Economics and Management	26	16.15%
Journal of Public Economics	1	0.62%
Journal of the Association of Environmental and Resource Economists	2	1.24%
PNAS	1	0.62%
region	**21**	**13.04%**
Journal of Development Economics	3	1.86%
Journal of Environmental Economics and Management	9	5.59%
Journal of Public Economics	4	2.48%
Journal of the Association of Environmental and Resource Economists	5	3.11%
county	**18**	**11.18%**
Journal of Development Economics	1	0.62%
Journal of Environmental Economics and Management	12	7.45%
Journal of Public Economics	3	1.86%
Journal of the Association of Environmental and Resource Economists	2	1.24%
family	**16**	**9.94%**
Journal of Environmental Economics and Management	7	4.35%
Journal of the Association of Environmental and Resource Economists	5	3.11%
Nature Sustainability	1	0.62%
Nature human behaviour	1	0.62%
Nature Energy	2	1.24%
individual	**16**	**9.94%**
Journal of Environmental Economics and Management	14	8.70%
Journal of the Association of Environmental and Resource Economists	1	0.62%
Nature Climate Change	1	0.62%
country	**14**	**8.70%**
Journal of Development Economics	2	1.24%
Journal of Environmental Economics and Management	8	4.97%
Journal of the Association of Environmental and Resource	1	0.62%

Economists		
Nature	1	0.62%
Nature human behaviour	1	0.62%
Nature Energy	1	0.62%
city	**13**	**8.07%**
Journal of Development Economics	2	1.24%
Journal of Environmental Economics and Management	5	3.11%
Journal of the Association of Environmental and Resource Economists	2	1.24%
Nature Climate Change	1	0.62%
Nature Sustainability	1	0.62%
PNAS	2	1.24%
site	**9**	**5.59%**
Journal of Environmental Economics and Management	8	4.97%
Journal of the Association of Environmental and Resource Economists	1	0.62%
state	**6**	**3.73%**
Journal of Environmental Economics and Management	4	2.48%
Journal of Public Economics	1	0.62%
Journal of the Association of Environmental and Resource Economists	1	0.62%
house	**4**	**2.48%**
Journal of Environmental Economics and Management	4	2.48%
industry	**3**	**1.86%**
Journal of Development Economics	1	0.62%
Journal of Environmental Economics and Management	1	0.62%
Journal of the Association of Environmental and Resource Economists	1	0.62%
bank	**1**	**0.62%**
Journal of Environmental Economics and Management	1	0.62%
car	**1**	**0.62%**
Journal of Environmental Economics and Management	1	0.62%
fishing ground	**1**	**0.62%**
Nature	1	0.62%
flight	**1**	**0.62%**
Journal of Environmental Economics and Management	1	0.62%
hospital	**1**	**0.62%**
Journal of the Association of Environmental and Resource Economists	1	0.62%
metropolitan areas	**1**	**0.62%**
Journal of the Association of Environmental and Resource Economists	1	0.62%
province	**1**	**0.62%**
Journal of Environmental Economics and Management	1	0.62%

railway routes	**1**	**0.62%**
Journal of Environmental Economics and Management	1	0.62%
school	**1**	**0.62%**
Journal of Environmental Economics and Management	1	0.62%
Total	**161**	**100.00%**

Theoretical model	N	Percent
No	**116**	**72.05%**
Journal of Development Economics	1	0.62%
Journal of Environmental Economics and Management	82	50.93%
Journal of Public Economics	7	4.35%
Journal of the Association of Environmental and Resource Economists	12	7.45%
Nature	2	1.24%
Nature Climate Change	2	1.24%
Nature Sustainability	2	1.24%
PNAS	3	1.86%
Nature human behaviour	2	1.24%
Nature Energy	3	1.86%
YES	**45**	**27.95%**
Journal of Development Economics	10	6.21%
Journal of Environmental Economics and Management	22	13.66%
Journal of Public Economics	2	1.24%
Journal of the Association of Environmental and Resource Economists	11	6.83%
Total	**161**	**100.00%**

Mechanism analysis	N	Percent
No	**130**	**80.75%**
Journal of Development Economics	8	4.97%
Journal of Environmental Economics and Management	83	51.55%
Journal of Public Economics	5	3.11%
Journal of the Association of Environmental and Resource Economists	21	13.04%
Nature	2	1.24%
Nature Climate Change	2	1.24%
Nature Sustainability	2	1.24%
PNAS	3	1.86%
Nature human behaviour	2	1.24%
Nature Energy	2	1.24%
YES	**31**	**19.25%**
Journal of Development Economics	3	1.86%
Journal of Environmental Economics and Management	21	13.04%
Journal of Public Economics	4	2.48%

Journal of the Association of Environmental and Resource Economists	2	1.24%
Nature Energy	1	0.62%
Total	**161**	**100.00%**

A.2: Chi-squared tests for figures

Figure 1 The proportion of publications in the top field journals

Panel A Percentage of publications in economics journals

Item	group			Total
	1	**2**	**3**	
JAERE	0	7	16	**23**
JDE	0	6	5	**11**
JEEM	13	21	66	**100**
JPE	1	1	7	**8**
Total	**14**	**34**	**95**	**143**
Likelihood-ratio chi2(6) =	*11.2772*	*Pr = 0.080*		

Figure 1 The proportion of publications in the top field journals

Panel B Percentage of publications in natural science journals

Item	group		Total
	2	**3**	
NCC	0	2	**2**
NHB	0	2	**2**
NS	0	2	**2**
Nature	2	0	**2**
PNAS	2	1	**3**
NE	1	2	**3**
Total	**5**	**9**	**14**
Likelihood-ratio chi2(5) =	*10.6110*	*Pr = 0.060*	

Figure 2 Research theme

Category name	group			Total
	1	**2**	**3**	
climate change	1	7	22	**30**
Energy-economic	1	3	11	**15**
environmental policy	8	14	27	**49**
low carbon	1	2	10	**13**

pollution	3	13	34	**50**
Total	**14**	**39**	**104**	**157**
	Likelihood-ratio chi2(8) =	*7.0047*	*Pr = 0.536*	

Figure 3 Pollution category

Item	**group**			**Total**
	1	**2**	**3**	
Air pollution	3	10	27	**40**
Land pollution	0	0	1	**1**
Solid pollution	0	0	3	**3**
Water pollution	0	3	3	**6**
Total	**3**	**13**	**34**	**50**
	Likelihood-ratio chi2(6) =	*5.3199*	*Pr = 0.503*	

Figure 4 Climate change category

Item	**group**		**Total**
	2	**3**	
other	0	3	**3**
precipitation	1	3	**4**
temperature	5	13	**18**
Total	**6**	**19**	**25**
	Likelihood-ratio chi2(2) =	*1.7850*	*Pr = 0.410*

Figure 5 Identification strategy

Item	**group**			**Total**
	1	**2**	**3**	
DID	6	30	76	**112**
FE	1	5	16	**22**
IV	9	8	25	**42**
RDD	5	5	12	**22**
Total	**21**	**48**	**129**	**198**
	Likelihood-ratio chi2(6) =	*12.1502*	*Pr = 0.059*	

Figure 6 Types of difference-in-difference design (15 years)

Item	**group**			**Total**
	1	**2**	**3**	
DDD	0	6	11	**17**
DID	5	21	36	**62**
Event analysis	0	3	12	**15**
Generalized DID	0	0	2	**2**

PSM DID	1	0	9	**10**
Staggered DID	0	0	6	**6**
Total	**6**	**30**	**76**	**112**
	Likelihood-ratio chi2(10) =		*19.7242*	*Pr = 0.032*

Figure 7 Types of regression discontinuity design

Item	**group**			**Total**
	1	**2**	**3**	
RDD(fuzzy)	2	0	2	**4**
RDD(sharp)	3	5	10	**18**
Total	**5**	**5**	**12**	**22**
	Likelihood-ratio chi2(2) =		*3.3185*	*Pr = 0.190*

Figure 8 Research country (15 years)

Item	**group**			**Total**
	1	**2**	**3**	
Africa	0	0	1	**1**
China	0	10	25	**35**
Europe	0	6	15	**21**
Latin America	1	3	9	**13**
Rest of Asia	2	2	9	**13**
U.S., Canada	9	13	40	**62**
Total	**12**	**34**	**99**	**145**
	Likelihood-ratio chi2(10) =		*14.4266*	*Pr = 0.154*

Figure 8 Research country (10 years)

Item	**group**		**Total**
	1	**2**	
China	0	10	**10**
Europe	0	6	**6**
Latin America	1	3	**4**
Rest of Asia	2	2	**4**
U.S., Canada	9	13	**22**
Total	**12**	**34**	**46**
	Likelihood-ratio chi2(4) =	*12.9937*	*Pr = 0.011*

Figure 9 National development level

Item	**group**			**Total**
	1	**2**	**3**	
developed	10	20	60	**90**
developing	2	14	39	**55**
Total	**12**	**34**	**99**	**145**
	Likelihood-ratio chi2(2) =		*2.8427*	*Pr = 0.241*

Figure 10 Type of research data

Item	group			Total
	1	2	3	
macroscopical	5	10	25	**40**
medium	2	8	20	**30**
microscopic	7	21	59	**87**
Total	**14**	**39**	**104**	**157**
	Likelihood-ratio chi2(4) =	*0.9512*	*Pr = 0.917*	

Figure 11 Research data (15 years)

Item	group			Total
	1	2	3	
city	0	6	7	**13**
country	2	5	6	**13**
county	2	2	13	**17**
family	0	2	11	**16**
firm	4	7	19	**30**
individual	1	2	11	**16**
other	1	5	10	**16**
region	2	3	16	**21**
site	1	3	5	**9**
state	1	2	3	**6**
Total	**14**	**39**	**104**	**157**
	Likelihood-ratio chi2(18) =	*17.4697*	*Pr = 0.491*	

Figure 11 Research data (10 years)

Item	group		Total
	2	3	
city	6	7	**13**
country	5	6	**11**
county	2	13	**15**
family	2	14	**16**
firm	7	19	**26**
individual	4	11	**15**
other	5	10	**15**
region	2	16	**19**
site	3	5	**8**

state	2	3	**5**
Total	**39**	**104**	**143**
	Likelihood-ratio chi2(9) =	*9.9708*	*Pr = 0.353*

Figure 12 Theoretical model

Item	**group**			**Total**
	1	**2**	**3**	
NO	9	27	77	**113**
YES	5	12	27	**44**
Total	**14**	**39**	**104**	**157**
	Likelihood-ratio chi2(2) =	*0.7567*	*Pr = 0.685*	

Figure 13 Mechanism analysis

Item	**group**			**Total**
	1	2	3	
NO	14	33	80	**127**
YES	0	6	24	**30**
Total	**14**	**39**	**104**	**157**
	Likelihood-ratio chi2(2) =	*7.3162*	*Pr = 0.026*	