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An assessment of financial mechanisms for green financial recovery and climate change mitigation: the case of China

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Abstract
The COVID-19 pandemic has made reaching sustainability and net-zero goals more challenging. The primary emphasis on health-related concerns constrains the pro-environmental movements' ability to advance. Particularly in developing nations, financial institutions may be critical in promoting green recovery. This research uses data from 30 Chinese provinces from 2005 to 2021 to investigate whether adaptation preparation's financial mechanism affects the impact of climate change and green economic development (a measure of productivity growth). We applied numerous robustness tests for the validation of empirical findings of the study. The results shown that increased financial mechanisms have a considerable negative impact on economic development and productivity growth. However, the severity of these impacts depends heavily on the degree of adaptive preparedness. We find that increased financial inclusion may lead to a revival in economic development for provinces with improved adaptability capabilities (banking sector). On the other hand, climate change may have long-term negative effects on economic development and productivity growth in places with a limited capacity for adaptation. Therefore, in China financial mechanisms might affect green economic development and climate change mitigation are the quality of institutions and income level. The development plan must included by the practioners for furthure policy planning about climate adaptation.

Keywords Financial mechanism · Green economic growth · Climate change mitigation · China · Robustness tests

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1 Introduction

Many people are interested in the history and development of the COVID-19 virus, as well as the results of lockdown restrictions on population movements, the global, international trade routes (Jin et al. 2022), and the volume and distribution of foreign direct investment (FDI) (all of which are cited in the As a result of the pandemic, people are using less energy. Assuming everything goes back to normal by the end of the year, daily CO2 emissions were predicted to have declined by 17% points in early April 2020, compared to 2019 levels, and annual emissions may fall by 7% points (4%). (mid-June). In addition, (Si et al. 2021) showed that between January and April of the same year, fossil CO2 emissions globally fell by 7.8%, marking a new record low. In order to quantify the effects of different government fiscal policies on achieving different climate change mitigation and adaptation goals, this study employs an international computable general equilibrium (CGE) model. Carbon pricing is associated with a statistically significant reduction in the rate of rise in emissions relative to otherwise similar countries, and the emissions trajectories of nations with and without carbon prices diverge over time, as shown by the research (Huang and Liu 2021). By increasing taxes on the environment, while cutting other taxes, the "double dividend" notion proposes that both the environment and the economy might profit. Adjustments to current spending habits are required to meet the 1.5 °C goals. More support from states is required to issue green bonds. This is because the only purpose of green bonds is to fund projects that reduce the adverse effects of human activity on the natural world (Xiao et al. 2021). China expanding energy consumption must also be addressed if the area is to contribute to meeting future energy demands. To accomplish this, investors must make significant changes to their current practices. Several countries in Asia are enacting green finance measures, such as green bond laws and grant programs. To put money toward carbon-free endeavors: green bonds are gaining traction in China. The green bond market has grown from $4.3 billion in 2012 to $162 billion (Liu et al. 2022a, b). It was not until 2005 and 2006 that the Chinese government and commercial banks issued the country's first green bonds. The issuance of green bonds has increased thanks to incentive programs (Liu et al. 2022a, b). Financing for decarburization was often provided through renewable energy and energy efficiency incentives (Li et al. 2022a, b). Policy recommendations are developed after an examination of green bond allocations. Refinancing eligibility criteria include being a citizen or permanent resident of the country from where the bonds were issued. For this reason, we have adopted a set of economic measures, including a carbon price, that together reflect this idea (Mohsin et al. 2020a). In addition, this study considers the continuation and rapid end of the pandemic. It conducts a comprehensive analysis covering the financial, energy, and environmental repercussions of the COVID-19 crisis, whereas previous research has focused either on the economic consequences or the environmental impact. With this study, we want to provide some insight into the measures under consideration for green recovery and the likely future of the global economy and ecology. Emissions of greenhouse gases (GHGs) have skyrocketed during the last century due to direct and indirect human activities. The China ecological preservation financial development and economic growth, natural resources reducing carbon emissions prevent global warming (Agyekum et al. 2021). Given the linear link between CO2 emissions and climate change, temperature targets need emission reduction targets. Since the 1980s, administrations throughout the globe have worked to lessen their nations' carbon footprints. Compared to the size of the country's economy, China's energy consumption and carbon emissions are relatively high. To generate electricity in 2019, the country used 462,108 t of traditional coals, releasing 107,107 t of CO2 into the atmosphere. This represents 28.8% of the world's total CO2 emissions. The nation was responsible for 13.9% points of global emissions and contributed 6.3% and 5.8%, respectively. China has achieved historically low carbon emissions per person, partly because of the country's moderate economic progress. Compared to the global average of 2112 t, China's emissions came in at 18.4108 t. Therefore, China's energy transition to expedite decarbonization is the primary strategy for reaching a carbon emissions peak and stabilization. China must immediately transition to a cleaner, lower-carbon energy sector (Mohsin et al. 2020b).

To reduce emissions, a more comprehensive approach that integrates sector-specific goals and activities for environmental decrease into a unified plan may be more successful. Including solutions for avoiding and adapting to climate change in a single document can be more effective than two separate publications, while China's resource carbon discharges would decrease by 30% points per year. Numerous studies have shown a connection between coal combustion emissions and ecosystem decline (Iqbal et al. 2022). Ancient Chinese industry was built on the back of coal-based goods. This demonstrates how the existing corporate system in China depends on a steady supply of coal for the country's economic growth and the welfare of its people. Even Despite this, there are several ecological effects of coal mining. Some examples include the tainting of air and the cutting down of trees. Greenhouse gases produced by burning coal may be an issue. Coal remains an essential part of China's power grid (Iqbal et al. 2019).

By analyzing the effects of financial mechanisms on the green economic recovery and climate change mitigation in 30 Chinese provinces from 2005 to 2021, we seek to fill this gap in this research. The findings show a detrimental impact of climate change and a beneficial relationship between adaptability and climate change on economic and product development. It indicates that the amount of financial mechanism depth greatly influences how the impact of climate change on economic development and productivity growth. The region-specific net marginal results show significant differences in the off-setting potential of climate adaptation on the increase in production and productivity. Our results do not provide vital support to the assertion that the direct relationship between climate change and adaptation depends on the degree of vulnerability to climate risk and the level of green economic development, as the evidence demonstrates that failing to account for omitted variable bias and uncertainties leads to an upward bias in the approximate interaction effect. We examine how financial system practices affect the green economy's expansion and the averting of climate change. The bottom line will benefit, and banks will be encouraged to concentrate more on green financing if there is a favorable association between green economic development and climate change reduction. The capital adequacy criteria are upported by a negative correlation between sustainable lending and the possibility of default, which will serve as risk mitigation. From the standpoint of a green recovery, our findings are optimistic since banks gain from boosting funding to sustainable business units.

2 Literature review

Numerous studies have been conducted on funding low-carbon technologies from various perspectives, such as the financial mechanism, influencing variables, implementation impacts, and optimization of the financing mechanism (Yang et al. 2022). Micro-level processes of low innovation financing were analyzed, current barriers to technical collaboration were investigated, and policy recommendations were made mainly using qualitative approaches such as literature research, questionnaires, and case studies. (Shah et al. 2019). The funding of clean technologies was thoroughly addressed by, who also recommended an adaptive strategy to address particular obstacles to the growth of low technology. Ikram et al. (2019) reviewed funding strategies and innovation development/deployment requirements comprehensively.

The studies Asbahi et al. (2019), Zhang et al. (2021) that looked at what variables affected the financing of low-carbon technologies and what implications that financing had on their deployment used quantitative methodologies. Additional expenditure on innovation in the context of cooperative efforts was estimated using the OECD ENV-linkages model (Alemzero et al. 2021). Economic transition risk factors, such as technological innovation and adoption, were included in the theoretical framework proposed. Utilizing a time-varying causality test, investigated the link between green financing, clean energy, environmental responsibility, and green technology (Xia et al. 2020).

Several researchers used game and technology-economy models to find the most effective ways to finance technological developments. Using a bottom-up techno-economic paradigm, advocated hybrid policies to facilitate the rollout of low-carbon technology (Iqbal et al. 2021). The decision-making conditions of low-carbon technology innovation and cooperation of businesses supported by green economics were investigated by Mohsin et al. (2019), who developed an evolutionary game model of collaborative innovation of low-carbon technology with multi-subjects, including economic organizations.

2.1 Economic growth and carbon neutrality

Global warming conservation both gain from increased funding (van der Ploeg and Rezai 2020). Carbon dioxide emissions are very sensitive to economic growth (as measured by GDP). They developed the Environmental Kuznets Curve (Kalli and Griffin 2015) to show the correlation between GDP and carbon dioxide emissions. The model predicts that GDP and CO2 emissions will have a reverse U-shaped relationship (Anh Tu et al. 2021). The research found that economic development during the modernizing era boosted global CO2 emissions (Li et al. 2021). However, once a nation enters the time of comments, it will be able to reduce CO2 emissions due to economic expansion. Using panel data approaches from the twenty-first century and yearly data from 1990 to 2014, the authors could account for cross-sectional interdependence across nations (Emrouznejad and Yang 2018). The findings demonstrate a U-shaped relationship between real income and ecological cost, suggesting that using non-renewable energy in EU nations significantly contributes to ecological deterioration. Carbon emissions and economic development in BRICS nations from 1994 to 2018 were examined by (Khan et al. 2021). According to empirical studies, expanding economies lead to more carbon emissions (Ahmad et al. 2021). used CS-ARDL and causality to investigate both the short- and long-term connections between GDP and CO2 emissions. Later, academics looked at the link between CO2 pollution and GDP to verify the EKC theory. When trying to ascertain the negative impacts of CO2 emissions, most research questions focused on GDP. There was inconsistency in the evidence for the EKC: However, research shows that GDP causes more CO2 to be released into the atmosphere (Li et al. 2022a, b; Dong et al. 2022). Multiple studies show an inverse relationship between GDP and CO2 intensity. Several studies have verified the EKC connection; however other studies have drawn different findings (Zhang et al. 2022; Sun et al. 2022).

2.2 Renewable energy utilization and environment

The financial development is the most remarkable point in historical carbon dioxide emissions for a specific location or industry. When human activities are carbon neutral, they emit and absorb the same amount of greenhouse gases. Tracking one's carbon production and offsetting it via reforestation, energy efficiency, and renewable electricity usage may help businesses, neighborhoods (Balakrishnan et al. 2020), and individuals achieve carbon neutrality. Even if the electricity industry is expanded using renewable energy, it is difficult for other industries, such as cement producers, to obtain zero emissions. To achieve carbon neutrality, almost zero net carbon emissions are required, either via the use of equivalent carbon sinks or the purchase of global carbon emission reduction certificates (Wu et al. 2022).

To limit global warming to below a specific level, net global GHG emissions must be close to zero. When removals from the atmosphere balance greenhouse gas emissions, we have achieved neutrality (Zhao et al. 2022). Pursuing a carbon dioxide emission-free state is a common focal point in many nations' quests to reach emission-free status. Current terms used to describe efforts to reduce greenhouse gas emissions include "carbon neutrality," "net-zero carbon emissions," "weather neutrality," and "net-zero emissions".

According to Xiuzhen et al. (2022), carbon neutrality is consistent with zero net carbon emissions. A future with net-zero CO2 emissions would be one in which human CO2 emissions worldwide were exactly balanced by anthropogenic CO2 removal over all of time. Regarding the planet's climate, "climate neutrality" refers to a state in which human activities have no discernible effect. This requires a harmony between residual and removal emissions related to the effects of human activities on regional or local bio-geophysics, including surface albedo or local temperature (CO2). It is possible to reach net-zero emissions when the quantity of greenhouse gases released by humans equals the amount of GHGs taken out. The number of CO2 emissions for which net-zero emissions are possible depends on the climate indices used to make the comparison (Umair and Dilanchiev 2022).

Achieving climate neutrality, however, is different from reaching a net-zero emissions status. Getting to climate neutrality means that human activities have no overall impact on the climate. Any greenhouse gas (GHG) emissions must be matched by an equal and opposite amount of GHG removal to reach net-zero emissions. On the other hand, the term "climate neutrality" alludes to the impact of human actions on the environment. So, being completely ineffectual is different from causing no pollution (Wang et al. 2022). CO2 emissions are a significant contributor to warming the planet, but they are not the only ones. Surface albedo and local weather patterns are also affected by other human activities, such as urbanization (Zhang and Zhou 2020).

Second, having zero greenhouse gas emissions is a prerequisite for reaching carbon neutrality. The emissions of short-lived greenhouse gases like carbon oxide have a negligible impact on climate change. Therefore, maintaining a constant GHG production is necessary for climate neutrality (Irshad 2017) rather than achieving net-zero emissions. While the International Panel on Climate Change has defined concepts like "carbon neutrality," "climate neutrality," and "net-zero emissions," not all countries strictly adhere to these standards and have different opinions on emission aims; most countries. For instance, there has yet to be a consensus on the scope of gas coverage among countries that have established neutralizing targets in the form of laws, regulations, and proposed legislation. In the long run, China would want to be carbon neutral and produce no net emissions (Iqbal and Bilal 2021).

3 Methodology

3.1 Theoretical framework

Scenario studies of China's circumstances may be done using various approaches. Based on their analysis of historical data, (Seghier et al. 2020) predicted that China would emit 482 CO2. While looking at past actions may provide a reasonable prediction of the future, it needs to consider the possibility of technological advancement, efficiency improvements, social transformations, and decoupling activities from CO2 growth.

$$\text{Total CO}_2 = \text{population} \times \frac{\text{CF}}{\text{AF}} \times \frac{\text{MF}}{\text{CF}} \times \frac{\text{CO}_2}{\text{MF}} \tag{1}$$

$$\text{CO}_2^t = \pi^1 + \pi^2\text{CF}^t + \pi^3\text{MF}^t + \pi^4\text{AF}^t + \pi^5\text{POP}^t + \varepsilon^{it} \tag{2}$$

Numerous mathematical models are utilized to evaluate CO2 scenarios, including the Data Envelope Analysis (DEA). Financial development and economic growth were recently evaluated, with the need to analyze the model's applicability being highlighted quantitatively. (Zhou et al. 2020). It is a model examining how different demographic, economic, and ecological factors affect carbon dioxide emissions. An expanding population, GDP,CF,MF energy intensity, and carbon intensity are all considered. In Eq. (1), we can see how decisions on population size, POP per capita, energy intensity, and carbon intensity (CO2) add up to a sum of CO2 emissions (Hosseinzadeh Lotfi et al. 2011).

3.2 Data

This analysis is based on national statistics for China's provinces from 2005 to 2021. (excluding Tibet, Hong Kong, Macao, and Taiwan, because of a lack of data). The China Statistical Yearbook, China Environmental Statistics, and Technology Publication are the only sources of all data.

3.3 Model specification and variable measurement

We agreed with (Petrovskiy et al. 2015) that manufactured businesses' services marketing processes might be examples of their inventive spirit. We design our experiments to learn how the rise of digital finance has contributed to servicing production operations. The model was established:

$$\ln \ln \mathrm{GCC}_{i,t} = \alpha_0 + \alpha_1 * \mathrm{Index}_{i,t} + \gamma * X_{i,t} + \delta_i + \theta_t + \sigma_j + \varepsilon \tag{3}$$

The output-oriented G.C.C. refers to the "green climate change mitigation' of outsourcing. The percentage of a company's revenues from its business solutions compared to its overall operational revenues was used to determine this. It is the most widely accepted metric for gaging performing the function using available information from secondary research. Additionally, fictitious support for the provision Serv was utilized to reflect businesses' openness to change by indicating how much they wanted to adopt provider methods. If there is utility provision in a particular year, then this dummy is reported as 1, else it is documented as 0. We used the term "DFI" to keep things simple. The estimated coefficient of revenue over operational expenses represents control over the market. Economic growth, or the ratio of corrected growth to labor force size, was the measure of concentration. In terms of scale, the logarithmic asset value was used. We included Similar, Haleemunnissa et al. (2021) which indicates if the presidents and managing partners are precisely the same people, as a controllable factor since management decisions are crucial to the growth of businesses.

Additionally, our model accounted for the year (t), business I, and the region as fixed effects. As a further measure of reliability, we additionally corrected company explanatory variables. Measurement deviations tended to concentrate (Ikram et al.,

2019) within and across cities. Incorrect terminology was used. As a precaution against the potential impact of outlying numbers on the study, we rounded all factors to the nearest 1%.

4 Summary statistics

In Table 1, we provide summary data for the research variables. The table shows the total amount of observations and their averages, standard deviation and variance, minimums, and maximums. There were significant differences in DFI, suggesting

Table 1 Descriptive statistics

Variable	Observation	Mean	Std. dev	Min	Max
Panel A: full sample					
CO2	1420	1.876	2.265	0.087	15.676
CF	1420	0.008	0.007	0	0.087
MF	1420	0.004	0.004	0	0.052
AF	1420	0.007	0.008	0	0.065
POP	1420	16.098	1.909	11.498	21.098
IVA	1420	9.101	1.078	4.987	12.687
FDI	1420	4.398	6.289	− 10.234	86.976
EI	1420	6.845	4.915	1.155	34.990
FD	1420	0.398	0.287	0	1.623
SID	1420	0.198	0.376	0	2
Panel B: SIDS					
CO2	280	1.476	2.187	0.133	5.989
CF	280	0.008	0.098	0	0.009
MF	280	0.009	0.007	0	0.045
AF	280	0.005	0.008	0	0.087
POP	280	14.343	2.487	12.445	17.187
IVA	280	8.187	0.709	7.198	11.890
FDI	280	4.098	4.789	− 11.277	39.087
EI	280	4.265	3.845	3.087	15.491
FD	280	0.390	0.298	0	0.946
Panel C: non-SIDS					
CO2	1290	1.967	3.465	0.076	14.654
CF	1290	0.002	0.009	0	0.032
MF	1290	0.002	0.000	0	0.033
AF	1290	0.000	0.007	0	0.022
POP	1290	17.698	2.487	14.44	19.065
IVA	1290	8.076	2.198	5.987	13.623
FDI	1290	5.145	5.376	− 4.219	90.976
EI	1290	6.198	4.185	2.155	41.967
FD	1067	0.324	0.323	0.024	2.624

that not all towns are equally advanced in their use of digital finance. (Zhang et al. 2020) This result accords with what is already known about the circumstance in China. Additionally, the mean service marketing number over global output was just 2.2946, indicating that service innovation still was low. The Internet usage rate ranged from 56.71% on the low end to 78.00% on the top end nationally. There is much opportunity for improvement with a 4.37% intensity level of R&D investments. Digitization in the industry had an aggregate rating of 2.3114.

5 Results and discussion

5.1 Benchmark results analysis

Government funding for clean energy technology in several ways may affect greenhouse gas (GHG) emissions and energy-sector employment. The overall effect of such assistance tends to generate extra energy-sector employment and reduce GHG emissions since clean energy innovations are typically traditional equivalents. (Mi et al. 2019) However, this does not imply that investing in clean energy technology is a cost-effective policy tool, and not all such investments. The cost-effectiveness of each innovation, its influence on the entire energy mix, and the relative variations in emission and job variables between the supported innovation and the alternatives it displaces all play a role in determining the success of economic assistance in descriptive statistics of Table 1.

Even more importantly, the regional context must be taken into account. Funding new investments that would have been made regardless of funding availability is a typical example of wasteful funding. 42 Since a regulator cannot tell the difference between necessary and unnecessary expenditures, people who were planning to put money into an innovation anyhow could get a (Gondal et al. 2018) windfall if the regulator decides to subsidize their efforts. Additional monetary assistance may be limited in its efficacy due to physical barriers like the intermittent nature of renewable technology and the scarcity of bioenergy supplies. Short-term financial assistance pushes a technology's capability into integration boundaries that would have

Table 2 Effects of climate finance on carbon dioxide emissions (full sample)

	(1)	(2)	(3)
C.F	– 10.865** (5.139)		
M.F		– 16.785**(8.044)	
A.F			– 13.198* (7.198)
POP	– 1.798** (0.709)	– 1.743** (0.701)	– 1.734** (0.790)
IVA	0.482* (0.870)	0.487** (0.222)	0.401* (0.233)
FDI	0.007 (0.007)	0.007 (0.009)	0.008 (0.007)
EI	0.098*** (0.087)	0.098*** (0.076)	0.078*** (0.087)
Observations	1420	1420	1420
R-squared	0.987	0.987	0.987

***< 0.01, **< 0.05, *< 0.01

been reached anyhow at a later stage, then there is a temporal inefficiency in Table 2. In this situation, financial aid in one era would have only short-term impacts since it would diminish expenditure prospects in the next period.

IAMs that accurately depict the energy system may help policymakers and planners choose the most effective mix of technologies to reduce their programs' adverse effects on the environment and the economy. We accomplish this by layering region-specific (pre-pandemic) energy and climate policies with increasing subsidy rates for nine clean technologies and then gaging the marginal effectiveness in lowering emissions and raising employment with three IAMs that vary considerably in their solution mechanisms and temporal dynamics. We then apply a robust portfolio analysis to each region-model combination, optimizing emissions reduction and job creation within each region's pre-announced green COVID-19 recovery budget. This yields a Pareto-optimal set (Liu et al. 2021). 40 The goal of the obtained Pareto frontiers (the sets of all Pareto-efficient solutions) is to identify trade-offs between the cumulative amount of CO2 emissions abated, the number of job-years created over this entire decade, and the number of short-term job-years created.

5.2 Industry heterogeneity

The first two goals are broad enough to be addressed by policymakers when they explore various funding options. The second aim was selected because it is directly related to the need for recovery from the COVID-19 issue and because it is usual for policymakers to seek rapid returns on their investment. All information on the used CO2 emissions and recovery packages and the exact technique may be found in the experimental protocols, we aimed to find the best way to allocate the green portion of the China recovery money to maximize short-term, and long-term increases in energy-sector employment while simultaneously reducing CO2 emissions (Zheng et al. 2022). We discovered a clear trade-off between emissions reductions and employment gains in both scenarios, with portfolios that did well in terms of net-positive employment increases being shown to be suboptimal in carbon decreases and vice versa. When comparing the existing policy baseline with the possibility for cumulative (Sueyoshi et al. 2017) emissions savings of 596–750 CO2 up to 2040, we found that 766–914 thousand additional job years might be produced in the energy industry by 2026. Taking into account this trade-off, a green recovery portfolio and effects of climate finance on carbon dioxide emission are presented in Table 3.

Here, prioritizing the long-term viability of new energy job possibilities has no appreciable impact on the range of carbon reductions, which is now somewhat more significant than before (Padilla-Rivera et al. 2018). One way in which the economic crisis of the late twentieth century improved corporate efficiency was by hastening the departure of low-productive enterprises and optimizing resource distribution in preparation for a restructure of the corporate industry and the advancement of technology. However, even though the carbon reduction brought about by the ecological control policy did not directly lead to the enhancement of industrial efficiency, this was not sufficient to establish that the environmental strategy had a modest impact on bettering the GDP. According to the Porter hypothesis, increased ecological

Table 3 Effects of climate finance on carbon dioxide emissions

	(1)	(2)	(3)
C.F	– 9.367* (4.898)		
M.F		– 13.545* (7.589)	
A.F			– 11.687* (6.7987)
POP	– 1.476** (0.698)	– 1.478** (0.687)	– 1.498** (0.609)
IVA	0.245* (0.198)	0.301* (0.170)	0.274* (0.198)
FDI	0.008 (0.007)	0.007 (0.009)	0.007 (0.009)
EI	0.054*** (0.033)	0.045*** (0.033)	0.087*** (0.033)
Observations	1420	1420	1420
R-squared	0.955	0.955	0.955

***< 0.01, **< 0.05, *< 0.01

regulations might boost productivity by encouraging enterprises to invest in new technologies, streamline operations, and reallocate resources (Ramli et al. 2016). Initiating a program of ecological control in China at the turn of the twenty-first century has helped the country rid itself of outdated methods of production and better use its resources, laying the groundwork for future industrial growth. We found that conventional funds generated higher returns than their green alternatives. Our findings may have implications for global environmental initiatives led by the (Sun et al. 2019a, b) China. Investing $102 billion annually in green energy projects worldwide is necessary to reach sustainability targets set for that year. Green energy expenditure needs the confidence that comes from vetting potential projects is presented in Table 4. Our research demonstrates that businesses need more economic incentives to become environmentally friendly, even though green mutual funds have underperformed consistently.

Because of this, the gap between green finance and traditional finance may expand. In this part, we analyzed the actual data for two important variables: the influence of DID and the impact of post-treatment and treatment-related factors taken together (Table 5). In particular, we use three different techniques for estimating the dependent variables. Our estimates for the innovation dummy variable are

Table 4 Robustness check: alternative smoothing strategy

	(1)	(2)	(3)
C.F	– 12.387** (5.787)		
M.F		– 21.998** (9.698)	
A.F			– 14.587* (8.032)
POP	– 1.798** (0.798)	– 1.767** (0.709)	– 1.778** (0.798)
IVA	0.498* (0.222)	0.498* (0.222)	0.409* (0.222)
FDI	0.007 (0.007)	0.007 (0.009)	0.008 (0.007)
EI	0.054*** (0.066)	0.098*** (0.045)	0.087*** (0.076)
Observations	1420	1420	1420
R-squared	0.987	0.978	0.987

***< 0.01, **< 0.05, *< 0.01

Table 5 Robustness check: endogeneity concerns (one-year lagged independent variables)

	(1)	(2)	(3)
L1.CF	− 7.955** (3.754)		
L1.MF		− 13.085** (6.376)	
L1.AF			− 9.587* (5.65)
Controls	Yes	Yes	Yes
Observations	1420	1420	1420
R-squared	0.976	0.976	0.976

***< 0.01, **< 0.05, *< 0.01

Table 6 Robustness check: endogeneity concerns (two-step system G.M.M.)

	(1)	(2)	(3)
L1.CO2	0.976*** (0.005)	0.987*** (0.006)	0.987*** (0.009)
C.F	− 8.998*** (0.798)		
M.F		− 19.787*** (1.087)	
A.F			− 12.445*** (3.598)
Controls	Yes	Yes	Yes
Observations	1420	1420	1420
AR(2) (*p*-value)	0.438	0.882	0.845
Sargan (*p*-value)	0.167	0.187	0.087

***< 0.01, **< 0.05, *< 0.01

based on exponentiated (Li et al. 2020) and Tobit models. We use fixed-effect models to evaluate the marginal impact of tax reduction policy for low-energy businesses (Dafermos and Nikolaidi 2019). We examined H2 using two estimating strategies to show that our main results are robust. Businesses with minimal energy needs can often benefit significantly from decreases and exemptions in tax liability, which has been found to influence the company's willingness to invest in new technologies. Based on our analysis of the explanatory and controlling factors, a one-unit shift in confidence would have a marginal influence on originality of 0.5%. Our results demonstrate that government monetary strategy may sustain tax credits, which may help foster the growth of a poor economy. Here, we give unique evidence that may aid in our understanding of the impact of green recovery on creativity (Sun et al. 2019a, b) and demonstrate that hypothesis 2 is valid. We look at how income mediation may affect a control system when it has been used to bridge the gap between companies with limited resources and those with much more to offer. Now, we will discuss the monetary transmission processes as a distinction since they explain why the marginal impact is muted. The discrepancy is more in line with what might be observed with several financial variables (Table 5).

When the expenses of climate change are assumed to be 5% of global GDP in the absence of any actions, the outcomes are similar but accentuated (Table 6). In this scenario, the loss in economic output due to implementing a global mitigation agreement is less, at 2.8% points of GDP by 2040, than it would be if climate costs were not considered. Furthermore, the most vulnerable nations gain even more economically from mitigation thanks to two mechanisms: (Ning et al. 2022) first, the larger the reactivity of the damage expense function to PPM concentration, the more significant the gap among expenses in the case of BAU compared to CF; second, mitigation actions bring a comparative advantage to those nations with small abatement targets, (Baladeh et al. 2019) following the POP method. However, in the event of active engagement in mitigation activities, China and India suffer more considerable POP loss compared to the inactivity scenario under any evaluated damage function and robustness check is presented in Table 6.

Based on these findings, it is clear that free-riding incentives are substantial for major emitters also sensitive to climate change. When it comes to reducing greenhouse gas emissions, the Paris Accord aim is far off the mark if China and India refrain from actively participating in mitigation as part of a global agreement.

Similar to China EEx, free-riding incentives may arise in different locations. When the lower damage function is taken into account Tables 6, mitigation costs lead to a net loss in GDP by 2040 compared to the BAU situation without any strategy enforcement. According to Soytas and Sari (2006), a more substantial susceptibility to climate change raises the motivation to cooperate at a global agreement. Thus a higher damage cost function Table 6 eliminates the incentive to free ride. It is clear that compensation measures are needed, regardless of the damage function studied, to encourage the most significant possible level of engagement from nations with both high emissions and high vulnerability to climate change. (Miandad et al. 2017) As a result, the third stage involves evaluating the advantages to the area from taking part in the abatement efforts under different distribution criteria based on the many possible situations where the CF is in effect.

Table 6 shows the global equilibrium price for abatement, which is the amount needed to reduce emissions by one tonne of CO2 if the predicted damage amounts to a 3% drop in GDP by 2040. The CF-neg 20%-EE scenario has the lowest global GDP losses out of the two CF distribution methods. However, significant differences exist between the areas that would get the funds at the subnational level. Compared to China and other Emerging and Energy Exporting Developing Nations (DCS), the Alternative allocation is more beneficial for developing countries and India. If the finance share is raised to 20% (from 10%), GDP performance is guaranteed to improve indefinitely. However, the influence of the allocation between energy efficiency and renewable dictates variable outcomes among qualifying locations. For the most part, nations with an allocation between adaptation and mitigation favoring energy efficiency see more significant changes in GDP, except developing countries in China countries (Qiao et al. 2020), which see the opposite, namely financing only renewables. Last but not least, it is essential to remember that the alternative distribution (20%RW) means that every area benefits (or at least stays on par) with the MF without CF, except the China nations.

The findings shown in Table 6 also apply to the scenario when the damage cost function is calibrated to a 5% GDP loss by 2050. The CF mitigation quota may be invested in renewables regardless of the leverage of carbon tax tested or the distribution criteria across nations, guaranteeing a Pareto improvement as all regions are treated equally well or better than in the no CF scenario. (Ferreira et al. 2020) This last finding, which compares the benefits of various negotiating strategies, suggests that there is room for constructing an allocation rule of CF that guarantees a compensation measure to discover the route for a core solution that enables the grand coalition to remain stable.

6 Conclusion and policy implications

This study investigates the asymmetric relationships between China's renewable energy, green finance, economic development, sector architecture, and carbon neutrality. Particularly in developing nations, financial institutions may be critical in promoting green recovery. This research uses data from 30 Chinese provinces from 2005 to 2021 to investigate whether adaptation preparation's financial mechanism affects the impact of climate change and green economic development (a measure of productivity growth). The frequency domain causality test supports long-term co. Integrating correlations among model variables. The frequency domain causality test indicated that the system would adjust to a change of 11.4% points from the steady-state equilibrium after one year. Financial development, energy usage, trade, and FD contribute to increasing CO2 emissions, while expenditures in green finance, renewable energy, and economic growth assist in decreasing trends.

Additionally, progress in sustainable finance might help China achieve carbon neutrality. It is ludicrous that green money, via the effect of renewable energy, can immediately result in carbon neutrality. However, the immediate and long-term advantages of green funding for carbon neutrality are far more significant.

This study also highlights the many policy initiatives implemented by low-carbon pilot cities in China. The evaluations show that most cities use a small handful of distinct strategic innovations. China's efforts to adapt to climate change and achieve low-carbon growth would benefit from constructing a pilot city. However, a large number of carbon emissions have been created by the expanding economy due to this and other businesses. Carbon emissions as a share of GDP are not strictly regulated at the federal level. As a result, China's overall carbon emissions from all sources have risen over the last three years, commencing in 2018. As a result, national carbon reduction targets should be made obligatory. This will aid local administrations in formulating workable strategies and meeting their carbon emission reduction targets.

This research compiled a catalog of new ordinances passed by Chinese municipalities, stressing the potential use of comparing activities across various Chinese towns to help spread effective strategies for cutting carbon emissions from urban areas. Some cities may take inspiration from Jincheng and Zhenjiang's policy experiments, while others may develop their unique approach, considering their particular development conditions. Current low-carbon pilot towns in China need to catch up to the low-carbon development techniques utilized by cities in industrialized nations, particularly in market procedures and public engagement. Based on the analysis presented here and the experience of China's countries, conclusions for modern low-carbon city development and strategy technology design are presented.

1) CO2 emissions industry and inter-provincial sharing of financial development are examples of sector techniques supporting emission decrease management that local governments may examine.

2) By encouraging collaboration between the state, companies and sector affiliations, consulting corporations, spending businesses, and research institutions, a local state may create a carbon fund with autonomous legal person status to manage and disburse a share of global warming tax money.

3) The media and the public should be commended for their role in facilitating a reporting and data for households with limited financial resources. Businesses and their leaders may be better equipped to take on the challenges of a low-carbon future if they have a more robust understanding of their roles in promoting and executing these development and usage.

These studies provide insight into developing and executing strategies for China's low-carbon pilot cities and highlight five projects currently undertaken by Chinese cities. This study's findings support the idea that low-carbon societies in various nations should follow growth strategies tailored to their specific requirements. The research may have benefited from looking at the factors that encourage creative policymaking in low-carbon metropolises were not addressed. There has to be more study done into the benefits of strategy innovations for low-carbon pilot cities and how they can be enhanced to better account for mitigation and adaptation measures for global warming obstacles.

Declarations

Conflict of interest There is no known conflict of interest.

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