Do carbon emissions trading pilots effectively reduce CO_2 emissions? County-level evidence from eastern China

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Abstract: Over the past few years, China has been committed to effectively controlling greenhouse gas emissions and achieving peak the carbon emissions in 2030 and carbon neutrality in 2060. For these purposes, China has taken a series of measures to strengthen intervention in industrial carbon emissions, among which the most important is a pilot project on carbon emissions trading since 2013. Few previous studies conducted on the emission-reduction effect of pilot projects have been from a county-level perspective. In this study, we employ a differences-in-differences method to empirically estimate the policy effect of such a pilot project, based on county-level data covering 413 units in eastern China. Our major findings show that carbon emissions trading pilots have an effective emission-reduction effect on carbon dioxide (CO_2) emissions, while reporting a positive correlation with CO_2 emission intensity. Another major finding is that the environmental Kuznets curve holds for the relationship between carbon emissions and economic growth. Our findings on the trading pilot suggest that governments at all levels should continue promoting a trading market framework that considers the regional heterogeneity. Additional measures should also be taken to create positive policy effects on carbon efficiency.

Keywords: carbon emissions trading pilot; CO_2 emissions; CO_2 emission intensity; emission-reduction effect.

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1 Introduction

In recent decades, how to combat global climate change has been a central concerned environmental issue, discussed at length by the industry and academia. To achieve the goal set by the 2016 Paris Agreement[1], governments have repeatedly promised to take measures to reduce greenhouse gas emissions. In 2020, China committed to achieving peak carbon dioxide (CO_2) emissions before 2030 and carbon neutrality before 2060. Prior to this commitment, China had already undertaken a series of measures to gradually strengthen intervention in industrial carbon emissions, the most important of which is the pilot project regarding carbon emissions trading that began in 2013. There were eight pilot provinces and cities in the first group[2]. Although the China Carbon Emissions Trade Exchange officially opened online trading in July 2021, trading scale by pilot provinces and cities still accounts for a low proportion of the country's total carbon emissions. However, the implementation of such a mechanism may have generated a reduction in carbon emissions to some extent (Huang et al., 2018).

At present, some researchers have evaluated the emission reduction effect of the pilot (Liu et al, 2019; Ren and Fu, 2019; Yu et al., 2021). Because existing studies have primarily explored the carbon emission reduction effect at the provincial level, whether their result hold true at a more micro level is unaccounted for. In addition, at provincial level, the decline of total carbon emissions does not illustrate whether carbon emissions have been effectively reduced or merely moved within a pilot area. According to the hypothesis of pollution havens (Walter and Ugelow, 1979; Copeland and Taylor, 1995), pollution emissions may transfer from countries with stricter environmental regulations to ones with permissive regulations. Based on this hypothesis, pollution may also be pollution transferred from developed areas to underdeveloped areas within a country, or even from cities to suburbs. If that is the case, policy incentives cannot reduce carbon emissions by promoting technological upgrades and can only achieve short-term emission reduction through carbon relocation. Thus, it is important to ask whether pilot projects also have emission-reduction effects at the county-level.

As mentioned above, some studies on the effect of the carbon trading pilot have drawn positive conclusions based on provincial data, where the differences-in differences (DID) method has been widely used. In these studies, scholars usually set the treatment year to 2013, when the pilot project was announced and implemented (Liu et al., 2019; Yu et al., 2021), or 2014, when all the pilot trading markets were officially put into operation (Li and Zhang, 2017; Huang et al., 2018; Ren and Fu, 2019). In 2016, the Fujian Carbon Trading Market was set up, and it began operation at the end of the year. In this study, we focus on whether the pilot project effectively reduced carbon emissions in eastern China based on the carbon emissions trading activities in Fujian province, which should revalidate the conclusion drawn by the previous research.

The influential environmental Kuznets curve (EKC) hypothesis (Grossman and Krueger, 1991, 1995; Panayotou, 1993) argues that pollutant emissions first increase and then, after reaching a turning point, decrease as economic development and income rise. Existing empirical studies have attempted to verify the situation predicted by the EKC hypothesis (Selden and Song, 1994; Cole et al., 1997; Kaufmann et al., 1998; Harbaugh et al., 2002; Xu and Song, 2010; Wang et al., 2016). In general, industrial production processes that produce pollutants also emit CO_2. Thus, this study examines whether there may also be an inverted U-shape of the EKC for carbon emissions. If the case described by the EKC hypothesis remains valid for carbon emissions, it would be reasonable to suppose that there is similarly a turning point for carbon emissions. Furthermore, if the EKC hypothesis also holds for carbon emissions, the potential factors that push the curve to the turning point may also be conducive to low-carbon transformation. This could have positive implications for energy conservation and emission reduction. This study explores the effect of the carbon emissions trading pilot on carbon emission reduction and investigates whether such pilot project also has an effect on smaller and non-central administrative divisions, in order to propose constructive suggestions for future promotion of greener economic and social development in China. We collected county-level economic data of six provinces covering 413 county-level units in eastern China from the statistical yearbooks issued by all levels of government in China. Carbon emissions data from 2013 to 2017 have been downloaded from the carbon emission accounts and datasets for emerging economics[3] estimated by Chen et al. (2020). Based on these data, we employ a DID to estimate the effect of the carbon emissions trading pilot on carbon emission reduction. As well as carbon emissions, we use carbon emission intensity to capture the trend of emission efficiency from 2013 to 2017 in eastern China.

The empirical results of this study show that the carbon emissions trading pilot effectively reduced carbon emissions of the county-level units in Fujian (the pilot province). In addition, the pilot project has had a statistically significant positive impact on the carbon emission intensity while the economic significance is not so strong. Furthermore, county-level carbon emissions show a positive association with per capita gross domestic product (GDP) and a negative correlation with the square of per capita GDP, which implies that the trend of carbon emissions conforms to the EKC. On the other hand these findings suggest that governments at all levels should promote the carbon emissions trading market and its corresponding legal system. On the other hand, at present, the trading system does not seem to be sufficient to effectively improve carbon efficiency, the optimisation of the energy structure and technological upgrading are still critical for the green-oriented transition in China.

The remainder of this paper is organised as follows: Section 2 provides a literature review; Section 3 describes the data and the variables, definitions, and methods for empirical analysis; Section 4 includes empirical results and discussions; and Section 5 concludes the paper.

2 Literature review and the development of hypotheses

2.1 *The practice of emissions trading*

According to Coase (1960), the externality problem can be effectively handled by a clearly defined property and well-designed transaction mechanism. However, the design of an efficient trading mechanism is not that simple. How to organise the distribution of ownership and arrange the transaction mechanism will substantially affect the efficiency of the corresponding institutional arrangements (Grossman and Hart, 1986; Hart and Moore, 1990). Dales (1968) applies this framework to the field of environmental governance. Montgomery (1972) argues that markets for rights (licenses) will be the most inexpensive approach to cutting emissions. In recent decades, as an effective incentive mechanism, the market and trading mechanism has been advocated by more research (Pizer, 2002), and has been applied to emissions reduction projects (Brännlund et al., 1998; Calel, 2013).

Current carbon markets primarily include a project and quota-based market (Liu et al., 2015), the latter is being characterised by emissions trading and carbon quotas allocated by regulators. According to the World Bank, more than 20% of global greenhouse gas emissions have been covered by carbon taxes and emissions trading systems by 2021 (World Bank, 2021), about a third of which is included by the China Emissions Trading System. Although emissions rights trading policies have been prevalent throughout the world in recent years, differences in environmental regulations and trading mechanism designs in specific countries and regions have caused research conclusions on the emission-reduction effect of emissions rights trading to be controversial. While positive views are the mainstream (see, for example Stavins, 1998; Capoor and Ambrosi, 2011), there is also the view that the emission-reduction effect is not significant (Wang et al., 2004; Tu and Shen, 2015). Thus, it is necessary to explore such issues on a case-by-case basis.

2.2 The reduction effect of emissions trading in China

Chinese carbon emissions rights trading pilot began gradually in eight provinces and cities in 2013. From the perspective of trading mechanisms and market risks, some studies argue that potential defects might weaken the emission reduction effect of the pilot policy. Liu et al. (2015) explore and analyse the challenges hampering China's carbon-trade market development. Deng and Zhang (2019) consider the risks in China's carbon trading pilots a major obstacle to guiding enterprises on how to make low-carbon technology investments and also how to meet the national emission reduction goals. Jiang et al. (2018) argue that more regulatory attention and economic measures are needed to improve market efficiency, and that the mechanisms of carbon emissions trading programs should be improved. Wang et al. (2022a) finds that the efficient market hypothesis does not hold true in China's carbon trading market and advocates the improvement of information disclosure in the carbon trading market.

In the past few years, with the gradual enrichment of China's carbon trading and carbon emissions data, empirical research on the emission-reduction efficiency of carbon trading has become feasible. The findings of several studies show that the emission reduction effect of the carbon trading pilot is significant. Wang et al. (2022b) explored the impact path of carbon trading policy and found that the trading mechanism is a sustainable approach to realising carbon neutrality. Yu et al. (2021) found that the trading mechanism effectively improved the carbon performance level of the pilot regions based on a panel data of 30 provinces in China from 2005 to 2017. Ren and Fu (2019) also argue that China's carbon emissions trading policy has reduced carbon intensity in the pilot regions. The previous two studies each employed a representative method (the synthetic control method and DID method, respectively) to empirically explore whether the carbon trading policy has achieved China's carbon emission reduction goal. Similar studies by Huang et al. (2018), Liu et al. (2019) and Wang et al. (2021) have drawn similar conclusions. In addition, Yang et al. (2021) found that the carbon trading pilot has reduced the carbon emissions of China's Hubei province, while previous policies are invalid. However, the empirical research mentioned above is based on provincial data, and few scholars have explored this issue from a more micro perspective. Some scholars have put forward supporting views from interesting angles. For example, Liu et al. (2021) argue that carbon emissions trading has significantly promoted China's green innovation efficiency, which will likely improve carbon emissions efficiency. Lü and Bai (2021) suggest that both a high carbon trading price and high price volatility enhance corporate carbon-reduction innovation, which indicates the effectiveness of carbon trading. Xia et al. (2021) found a reduction in carbon emissions from land use under the influence of carbon trading policies.

2.3 Methods of measuring reduction effects

The single-difference method was once a conventional method for exploring the effectiveness of carbon-reduction policies (see, for example, Xiao and Yin, 2017). However, the single-difference approach cannot distinguish between the impact of different variables; hence, it is gradually being replaced by other quantitative methods that factor in group-specific difference (heterogeneity between a treatment and control group) and time-specific difference. In recent years, the DID (Huang et al., 2018; Wang et al., 2018; Ren and Fu, 2019; Wang et al., 2022b) and synthetic control method (Liu et al., 2019; Yu et al., 2021; Wang et al., 2022b) have been employed more often in empirical research in this field. The DID method and its extension (Heckman et al., 1998; Abadie, 2005) is the most popular tool in the evaluation of the effects of policies or other exogenous shocks. The synthetic control method, first used and improved by Abadie and Gardeazabal (2003), generates a counterfactual control group to simulate a situation wherein in the policy is not implemented and estimates the policy impact. Furthermore, to improve the validity of regression based on a large sample, some scholars have introduced PSM-DID method to obtain a better match (Fan et al., 2017; Li and Zhang, 2017; Tian et al., 2022). Of these scholars, Tian et al. (2022) explored both carbon emissions and carbon emission intensity while considering the spatial differences and proposed a series of suggestions based on spatial heterogeneity. With the increasing carbon emissions data, one can predict that relevant empirical research will develop further. In addition to the direct investigation of the carbon emission reduction effect of the carbon trading pilot, studies of similar projects have also shown interesting findings. Tu and Shen (2015) used a DEA method to estimate whether a sulphur dioxide trading pilot in China achieved the Porter Effect and found that it failed to cut down on sulphur dioxide emissions in both the short and long run. However, Qi et al. (2018) argued that the sulphur dioxide trading pilot increased green innovation among companies in pilot regions based on a firm-level dataset. It seems that the efficacy of emissions trading pilot projects varies by contract object and specific trading mechanism.

Globally, the trading mechanism has become a popular emissions reduction program. Since the carbon trading pilot in China, a number of empirical studies have discussed the emission-reduction effect; however, some issues about the policy's impact remain unaccounted for. On the one hand, limited previous studies have examined county-level data (which characterise the most basic governmental units in China), even though counties emissions data could better capture regional heterogeneity (Chen et al., 2020). On the other hand, almost all studies have focused on the first seven provinces and cities in the pilot, beginning in 2013 or 2014. As the markets operated for at least two years in these seven regions, it is also interesting to examine whether the carbon trading pilot that began in the province of Fujian in 2016 can reveal any special conclusions. These issues reflect the expected marginal contributions of this study. Therefore, based on the steady implementation of the pilot project and the discussion of previous studies, we establish the following two hypotheses, which will be empirically tested in subsequent sections.

Hypothesis 1 (H1) The carbon emissions trading pilot project has effectively reduced carbon emissions from a county-level perspective.

Hypothesis 2 (H2) The carbon emissions trading pilot project has improved the carbon emission efficiency of the county-level units.

3 Data and methodology

3.1 Data descriptions

3.1.1 Data sources

We obtained a county-level economic panel dataset of six provinces covering 413 county-level units from 2013 to 2017 in eastern China from the statistical yearbooks issued by all levels of government in China. It should be noted that this dataset excludes these provinces' municipal districts, which are the core metropolitan areas of the cities with few industrial enterprises and are not this study's focus of interest. The eastern Chinese region includes Anhui, Fujian, Jiangsu, Jiangxi, Shandong, Zhejiang, Shanghai and Taiwan. However, data from Taiwan are partially missing. In Shanghai, the most economically developed city in China, almost all of the districts are metropolitan areas. Therefore, our dataset includes only the other six provinces. Carbon emissions data from 2013 to 2017 are published by the Carbon Emission Accounts and Datasets for Emerging Economics. Using a series of data processing and matching, we obtained 2,065 sample observations from 413 cities.

3.1.2 Variables

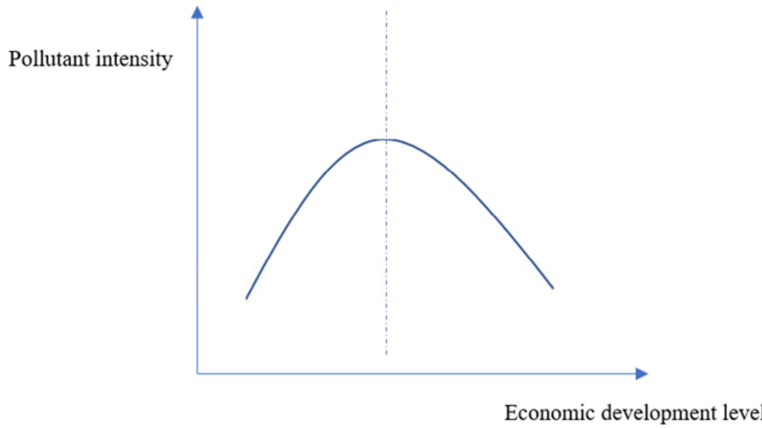
As shown in Table 1, we chose CO_2 emissions and CO_2 emission intensity as the dependent variables in this study. The former is estimated by Chen et al. (2020) and characterises the total carbon emitted in a county-level area in one sampling period. The latter is calculated as the ratio of CO_2 emissions to regional GDP, which shows the carbon efficiency of a county-level unit. We use these two dependent variables to capture how the implementation of the pilot project has influenced total carbon emissions and to test whether carbon quota allocation and trading has promoted carbon source utilisation. The independent variable is the interaction term of the time and policy dummy, which will be discussed in detail in Section 3.2.1.

Table 1 Variables and data definitions

Variable	*Definition*	*Calculation*	*Unit*
CE	Total CO_2 emission	-	Million tons
CI	CO_2 emission intensity	The ratio of total CO_2 to gross domestic product (GDP)	Tons per 100 Yuan
PGDP	Per capita GDP	Ratio of gross domestic product to the population	10,000 Yuan per capita
PGDPS	Square of per capita GDP	The square of per capita GDP	-
IND	Degree of industrialisation	The ratio of added value of secondary industry to GDP	-
POP	Total population of a region	-	10,000 people per unit
EDU	Regional education level	The ratio of number of high school students to population	-

We introduce five control variables in the empirical model. Among these, PGDP refers to per capita GDP and PGDPS is the square of PGDP. The EKC (Grossman and Krueger, 1991, 1995; Panayotou, 1993) implies an inverted U-shaped relation (as shown in Figure 1) between economic growth and environmental pollution, that is, pollution intensity increases at a lower level of economic development and decreases when the economy has fully developed. PGDP should confirm whether the EKC holds for carbon emissions in China. If the EKC holds in our case, the coefficients of PGDP and PGDPS would be positive and negative respectively.

Figure 1 Environmental Kuznets curve (see online version for colours)



IND represents the degree of industrialisation, which is the proportion of added value of the secondary industry in regional GDP. A number of existing studies have found that the scale of the secondary industry has a positive impact on carbon emissions (Liu et al., 2007; Zhang and Xue, 2011). POP refers to the regional population. The regional economic scale, which is the major source of carbon emission sources, is closely related to each region's population (Knapp and Mookerjee, 1996; Rehman et al., 2022). However, carbon emissions may also be restrained by the increase in technological density caused by population clustering (Li and Li, 2010). EDU is the ratio of high school students to the regional population. Limited by insufficient county-level statistical data, we used the proportion of high school students in the population to characterise the regional education infrastructure level.

3.1.3 Descriptive statistics

The descriptive statistical characteristics of the variables in this study are listed in Table 2. As shown in this table, there are significant differences in dependent variables between the treatment and control group. Most variables displayed significant volatility and the economic development level and scale of the control group were slightly higher than those of the treatment group.

Table 2 Descriptive statistics of the variables

Variables	*Treatment group*			*Control group*			*Difference*
	Obs.	*Mean*	*Std. dev.*	*Obs.*	*Mean*	*Std. dev.*	
CE	290	2.679	2.789	1,775	4.469	3.591	1.790
CI	290	0.010	0.004	1,775	0.014	0.006	0.004
PGDP	290	5.294	3.004	1,775	5.310	4.513	0.016
PGDPS	290	37.024	60.770	1,775	48.549	114.386	11.525
IND	290	0.485	0.094	1,775	0.486	0.092	0.001
POP	290	47.276	32.273	1,775	70.712	38.243	23.436
EDU	290	0.041	0.010	1,775	0.044	0.010	0.003

3.2 Methods

3.2.1 The DID method

To rule out the group-specific difference (regional heterogeneity between units in the treatment and control groups) and time-specific difference, we employed a DID method as shown in equation (1):

$$CE_{it} = \beta_0 + \beta_1 PILOT_i + \beta_2 POST_t + \beta_3 PILOT_i * POST_t + \varepsilon_{it} \tag{1}$$

In equation (1), $PILOT_i = 0$ refers to county-level units in the pilot province; otherwise, $\text{PILOT}_i = 1$. Next, $POST_t = 0$ refers to the period (from 2013 to 2015) before the implementation of the pilot project; otherwise, $POST_t = 1$ (the period from 2016 to 2017). Therefore, the coefficient of the interaction term (that is, $PILOT_i * POST_t$), β_3, captures the effect of the pilot project ruling out the group- and time-specific difference (shown in Figure 2).

Figure 2 Effect of the pilot project

	Treatment	Control	Group difference
Befor Pilot	$\beta_0+\beta_1$	β_0	β_1
After Pilot	$\beta_0+\beta_1+\beta_2+\beta_3$	$\beta_0+\beta_2$	$\beta_1+\beta_3$
Time difference	$\beta_2+\beta_3$	β_2	β_3

3.2.2 Model specification

For the large individual differences among county-level units and the fixed time trends of the variables, the econometric models in this study employed fixed-effects models to deal with the influence of individual and time effects. Based on the aforementioned analysis and introduction of the DID method, we employed the models for carbon emissions and carbon emission intensity respectively, as follows:

$$CE_{it} = \beta_0 + \beta_3 PILOT_i * POST_t + \theta X + \delta_i + \gamma_t + \varepsilon_{it} \tag{2}$$

$$CI_{it} = \beta_0 + \beta_3 PILOT_i * POST_t + \theta X + \delta_i + \gamma_t + \varepsilon_{it} \tag{3}$$

The sole difference between equation (2) and equation (3) is the dependent variable. In these two equations, i represents the i^{th} county-level unit, and t represents the t^{th} year. β_3 is the coefficient of the policy effect. X refers to the group of other control variables introduced in Section 3. Coefficients β_2 and β_3 are replaced by δ_i and γ_t, which are the individual fixed effects and time fixed effects respectively. In these empirical models, δ_i captures factors affecting CO_2 emissions and CO_2 emission intensity that cannot be observed; it is constant in the time dimension. γ_t captures the time trend, and ε_{it} is the error term.

4 Results and discussion

4.1 Emission reduction effect

The estimation results are reported in Table 3. Columns (1) and (3) show the regression results without control variables for CO_2 emissions and CO_2 emission intensity, respectively. Columns (2) and (4) show the results with control variables.

Table 3 Effect of the pilot project on CO_2 emissions and CO_2 emission intensity

Variables	*CO_2 emission (CE)*		*CO_2 emission intensity (CI)*	
	(1)	*(2)*	*(3)*	*(4)*
PILOT*POST	–0.1117**	–0.1312***	–0.0001	0.0003*
	(0.0431)	(0.0400)	(0.0002)	(0.0001)
PGDP		0.0875**		–0.0015***
		(0.0432)		(0.0003)
PGDPS		–0.0028**		0.0000***
		(0.0014)		(0.0000)
IND		0.1008		–0.0071**
		(0.3451)		(0.0028)
POP		0.0240***		–0.0001
		(0.0070)		(0.0001)
EDU		2.1085		–0.0021
		(1.5183)		(0.0091)
Constant	4.1609***	2.1197***	0.0157***	0.0289***
	(0.0125)	(0.4946)	(0.0001)	(0.0039)
Time and regional	YES	YES	YES	YES
Sample size	2065	2065	2065	2065
Within-R^2	0.1387	0.1713	0.6952	0.7343

Notes: Standard errors in parentheses. ***, **, and * indicate the significance levels of 1%, 5% and 10%, respectively.

The empirical results confirm the positive relationship between the pilot project and the trend of carbon emissions. The negative coefficient of PILOT*POST shows both statistical and economic significance. Compared to the average level of carbon emissions in the pilot regions, the coefficient indicates a considerable reduction effect. Results for per capita GDP and the square of per capita GDP suggest some probable EKC features and will be discussed in Section 4.2. It seems that the effect of the degree of industrialisation on CO_2 emissions is not statistically significant; at least, that is the case for the proportion of added value of the secondary industry to GDP. The population of a region has an evident positive impact on carbon emissions as expected. The regional education level, represented by the ratio of high school students to the population shows insignificant effect on carbon emissions.

The empirical results reported in column (4) show that CO_2 emission intensity is significantly positively influenced by the pilot program. In other words, there is more CO_2 emitted per unit of GDP under the influence of pilot. However, such impact is not as large as it on carbon emissions. Issues regarding per capita GDP and its square will be discussed in the next section. The degree of industrialisation has a significant negative impact on the carbon emission intensity, which is possibly due to the potential industry upgrading that accompanies industrialisation. The scale of population has insignificant relationship with carbon emission intensity, which indicates hardly any emission reduction effect caused by the clustering of residents.

Hence, the first two main empirical results are as follows:

Result 1 The carbon emissions trading pilot has effectively reduced carbon emissions in of the county-level units in the pilot regions.

Result 2 The pilot project has a statistically significant but not large positive impact on carbon emission intensity.

4.2 Carbon emissions and economic growth

The positive coefficient of per capita GDP and the negative coefficient of the square of per capita GDP outline an inverted U-shaped curve in which the level of carbon emissions increases at the primary stage of economic development and decreases once it reaches a turning point. The relationship between carbon emission intensity and economic growth is unexpected. Contrary to the former inverted U-shaped curve for carbon emissions, there seems to be a U-shaped relationship between carbon emission intensity and economic growth. In terms of the economic development and industrialisation, the promotion of productivity and technological upgrading leads to the improvement of carbon efficiency, which can effectively explain this negative coefficient of per capita GDP. While an economic explanation for the positive coefficient of the square term remains ambiguous, it is statistically significant (although not very significant in an economic sense). To some extent, there is an approximately negative relationship between carbon emission intensity and economic growth. Thus, here is the third main result:

Result 3 The trend of carbon emissions is consistent with the EKC; that is, there is an inverted U-shaped relationship between carbon emissions and economic growth.

4.3 Discussion

The emission-reduction effect of emissions trading is not a completely unexplored topic, particularly in China. Our interest lies in how the pilot project works under different scales. Moreover, the existing empirical studies have not been without controversy. As for the carbon emission reduction effect of the pilot, our results are consistent with those of Li and Zhang (2017), Huang et al. (2018), Liu et al. (2019), Xia et al. (2021), Wang et al. (2021), and Wang et al. (2022b). Furthermore, out results are partly inconsistent with those of Tian et al. (2022) and Wang et al. (2018), who have demonstrated that the carbon trading mechanism can effectively reduce emissions only when the quota allocated is lower than the carbon emissions demand. In general, our county-level empirical research verifies the view that a carbon trading pilot effectively reduces carbon emissions. However, this is not the case when it comes to carbon emission intensity. Our results oppose those of Ren and Fu (2019) and Li and Zhang (2017) who found that pilot project has significantly cut down carbon emission intensity. The potential regional heterogeneity might explain our empirical results. Future studies could be improved by extending the sample extends to all over China. At present, there are already some studies that have examined the mechanism of the impact of carbon trading on carbon emissions. The proposed impact paths include energy structure (Wang et al., 2021), and technological innovation (Liu et al., 2021; Wang et al., 2021), among others. However, the mechanism research is generally not robust, and how carbon trading affects carbon emissions remains to be further explored. The verification of EKC is another interesting part of our empirical analysis. The inverted U-shaped relationship is consistent with previous studies on various explanatory variables (Menegaki and Tsagarakis, 2015; Huang et al., 2018; Zhan, 2018). As for carbon emission intensity, we found a counterintuitive U-shaped relationship, which is similar to the conclusion of Kaufmann et al. (1998), in which the atmospheric concentration of SO_2 is the dependent variable. In general, the EKC could be explained by factors like the scale effect, technological upgrading, or environmental regulation. Considering these different and controversial theoretical explanations, the estimation of EKC would be an interesting question for additional study. The effect of the degree of industrialisation on CO_2 emissions is insignificant which is consistent with Huang et al. (2018), while it is significant when comes to CO_2 emission intensity. The insufficiency of county-level data largely limits the formulation of variables. The variable EDU could only characterise the regional education level to a limited extent.

5 Conclusions and policy implications

5.1 Limitations and insights for future research

A limitation of our study is that the empirical results indicate a certain policy effect of the carbon emissions trading pilot project, without revealing this mechanism works. The trading scale is only a small proportion of total carbon emissions in China, especially when compared with the policy effect it generates. Therefore, its specific mechanism needs to be further explored in subsequent research. With the exception of the degree of industrialisation and population, CO_2 emissions are potentially influenced by other factors, such as energy structure and research and development input. Previous studies have usually been based on provincial or city data, while county-level datasets were not available, which is still a problem at present. Further studies would be improved by enhanced data collection and mining technology. Another limitation is the relatively small sample size resulting from the limited pilot region and trading scale. However, this is expected to improve because China’s Carbon Emission Trade Exchange has officially opened online trading and will largely mitigate the scarcity of data.

5.2 Conclusions

This study investigates the impact of the carbon emissions trading pilot project on carbon emissions and its intensity through a DID approach. Based on county-level data, we found that the carbon emissions trading pilot has had an effective emission-reduction effect on CO_2 emission, while it shows an adverse result on CO_2 emission intensity. The empirical methods also verify the inverted U-shaped relationship between carbon emissions and economic growth. In addition, economic growth is approximately negatively correlated with CO_2 emission intensity as expected. Industrialisation has a significant influence on the CO_2 emission intensity, but this is not that case with CO_2 emissions. When it comes to the population, we found that it significantly affects CO_2 emissions. In general, the major finding is that the emission-reduction effect is confirmed at the county-level. However, there is more to be done from the perspective of carbon efficiency (carbon emission intensity).

5.3 Policy implications

The samples in this study were collected from provinces and cities in eastern China, where the economy is relatively developed. It is reasonable to speculate that low carbon transformation may be more difficult in the central and western regions, where energy infrastructure and industrialisation are less developed. Thus, the Chinese government should cautiously take regional heterogeneity into account when formulating and implementing policies. The results of this study show that even at the county-level perspective, the argument that the carbon trading pilot project effectively reduces carbon emissions through trading mechanisms is still valid. This conclusion suggests that China's administrative units at all levels are the beneficiaries of the pilot carbon trading policy, and basic-level governments have an obligation to participate in energy conservation and low-carbon transformation. Furthermore, this study found that the impact of the carbon trading pilot on carbon emission efficiency is not significant, which means that the pilot policy only reduces total carbon emissions, while carbon emission efficiency does not improve. This requires China to make a greater effort to reduce carbon emissions and improve the emission-reduction efficiency. A potential path is to improve the trading mechanism and energy structure and enhance the technical efficiency.

Thus, our major findings on the trading pilot suggest that all levels of government should continue promoting the trading market framework and its corresponding legal system. As the national trading market has opened online, regional heterogeneity should be sufficiently considered to fulfil the institutional arrangements. Because the trading system has not yet effectively improved carbon efficiency, the optimisation of energy structures and technological upgrading are critical for a green-oriented transition in China. Subsidies and other incentives might be alternative policy instruments for promoting green innovation and technological upgrading. Finally, carbon quotas could combine with carbon finance to improve the effective allocation of resources by a price mechanism.

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References

Abadie, A. and Gardeazabal, J. (2003) 'The economic costs of conflict: a case study of the Basque country', *American Economic Review*, Vol. 93, No. 1, pp.113–132.

Abadie, A. (2005) 'Semiparametric difference-in-differences estimators', *The Review of Economic Studies*, Vol. 72, No. 1, pp.1–19.

Brännlund, R., Chung, Y., Färe, R. and Grosskopf, S. (1998) 'Emissions trading and profitability: the Swedish pulp and paper industry', *Environmental and Resource Economics*, Vol. 12, pp.345–356.

Calel, R. (2013) 'Carbon markets: a historical overview', *WIREs Clim. Change*, Vol. 4, pp.107–119, https://doi.org/10.1002/wcc.208.

Capoor, K. and Ambrosi, P. (2011) 'State and trends of the carbon market 2008', *World Bank Other Operational Studies*, Vol. 1, No. 1, pp.3–16.

Chen, J., Gao, M., Cheng, S., Hou, W., Song, M., Liu, X., Liu, Y. and Shan, Y. (2020) 'County-level CO_2 emissions and sequestration in China during 1997–2017', *Scientific Data*, Vol. 7, p.391, https://doi.org/10.1038/s41597-020-00736-3.

Coase, R.H. (1960) 'The problem of social cost', *Journal of Law & Economics*, Vol. 3, No. 4, pp.1–14.

Cole, M.A., Rayner, A.J. and Bates, J.M. (1997) 'The environmental Kuznets curve: an empirical analysis', *Environment and Development Economics*, Vol. 2, No. 4, pp.401–416.

Copeland, B.R. and Taylor, M.S. (1995) 'Trade and environment: a partial synthesis', *American Journal of Agricultural Economics*, Vol. 11, No. 3, pp.756–771.

Dales, J.H. (1968) 'Land, water and ownership', *Canadian Journal of Economics*, Vol. 1, No. 4, pp.791–804.

Deng, M. and Zhang, W. (2019) 'Recognition and analysis of potential risks in China's carbon emission trading markets', *Advances in Climate Change Research*, Vol. 10, No. 1, pp.30–46.

Fan, D., Wang, W. and Liang, P. (2017) 'Analysis of the performance of carbon emissions trading right in China: the evaluation based on the difference-in-difference model', *China Environmental Science*, Vol. 37, No. 6, pp.2383–2392.

Grossman, G.M. and Krueger, A.B. (1991) *Environmental Impacts of a North American Free Trade Agreement*, NBER 867, Working paper No. 3914, https://doi.org/10.3386/w3914.

Grossman, G.M. and Krueger, A.B. (1995) 'Economic growth and the environment', *Quarterly Journal of Economics*, Vol. 869110, pp.353–377, https://doi.org/10.2307/2118443.

Grossman, S. and Hart, O. (1986) 'The costs and benefits of ownership: a theory of vertical and lateral integration', *Journal of Political Economy*, Vol. 94, No. 4, pp.691–719.

Harbaugh, T.W., Levinson, A. and Wilson, M.D. (2002) 'Reexamining the empirical evidence for an environmental Kuznets curve', *The Review of Economics and Statistics*, Vol. 84, No. 3, pp.541–551.

Hart, O. and Moore, J. (1990) 'Property rights and the nature of the firm', *Journal of Political Economy*, Vol. 98, No. 6, pp.1119–1158.

Heckman, J.J., Ichimura, H., Smith, J.A. and Todd, P.E. (1998) 'Characterizing selection bias using experimental data', *Econometrica*, Vol. 66, pp.1017–1099.

Huang, X., Zhang, X. and Liu, Y. (2018) 'Does China's carbon emissions trading policy fulfill the environmental dividend?', *Economic Review*, Vol. 6, pp.86–99.

Jiang, Y., Lei, Y., Yang, Y. and Wang, F. (2018) 'Factors affecting the pilot trading market of carbon emissions in China', *Petroleum Science*, Vol. 15, pp.412–420.

Kaufmann, R.K., Davidsdottir, B., Garnham, S. and Pauly, P. (1998) 'The determinants of atmospheric SO2 concentrations: reconsidering the environmental Kuznets curve', *Ecological Economics*, Vol. 25, No. 2, https://doi.org/10.1016/S0921-8009(97)00181-X.

Knapp, T. and Mookerjee, R. (1996) 'Population growth and global CO_2 emissions: a secular perspective', *Energy Policy*, Vol. 24, No. 1, pp.31–37, https://doi.org/10.1016/0301-4215(95)00130-1.

Li, G. and Li, Z. (2010) 'The impact of population, economy and technology on carbon dioxide emissions – a study based on dynamic panel model', *Population Research*, Vol. 34, No. 3, pp.32–39.

Li, G. and Zhang, W. (2017) 'Research on industrial carbon emissions and emissions reduction mechanism in China's ETS', *China Population, Resources and Environment*, Vol. 27, No. 10, pp.141–148.

Liu, L., Chen, C., Zhao, Y. and Zhao, E. (2015) 'China's carbon emissions trading: overview, challenges and future', *Renewable & Sustainable Energy Reviews*, Vol. 49, pp.254–266.

Liu, L., Fan, Y., Wu, G. and Wei, Y. (2007) 'Using LMDI method to analyze the change of China's industrial CO_2 emissions from final fuel use: an empirical analysis', *Energy Policy*, Vol. 35, No. 11, pp.5892–5900.

Liu, C., Sun, Z. and Zhang, J. (2019) 'Research on the effect of carbon emission reduction policy in China's carbon emissions trading pilot', *China Population, Resources and Environment*, Vol. 29, No. 11, pp.49–58.

Liu, B., Sun, Z. and Li, H. (2021) 'Can carbon trading policies promote regional green innovation efficiency? Empirical data from pilot regions in China', *Sustainability*, Vol. 13, No. 5, p.2891.

Lü, M. and Bai, M. (2021) 'Evaluation of China's carbon emission trading policy from corporate innovation', *Finance Research Letters*, Vol. 39, p.101565.

Menegaki, A.N. and Tsagarakis, K.P. (2015) 'Rich enough to go renewable, but too early to leave fossil energy?', *Renewable and Sustainable Energy Reviews*, Vol. 41, pp.1465–1477, https://doi.org/10.1016/j.rser.2014.09.038.

Montgomery, D. (1972) 'Markets in licenses and efficient pollution control programs', *Journal of Economic Theory*, Vol. 5, No. 3, pp.395–418.

Panayotou, T. (1993) *Empirical Tests and Policy Analysis of Environmental Degradation at Different Stages of Economic Development*, Working Paper No. 238, Technology and Employment Programme, International Labor Office, Geneva.

Pizer, W. (2002) 'Combining price and quantity controls to mitigate global climate change', *Journal of Public Economics*, Vol. 85, No. 3, pp.409–434.

Qi, S., Lin, S. and Cui, J. (2018) 'Do environmental rights trading schemes induce green innovation? Evidence from listed firms in China', *Economic Research Journal*, Vol. 53, No. 12, pp.129–143.

Rehman, A., Ma, H., Ozturk, I. and Ulucak, R. (2022) 'Sustainable development and pollution: the effects of CO_2 emission on population growth, food production, economic development, and energy consumption in Pakistan', *Environmental Science and Pollution Research*, Vol. 29, pp.17319–17330, https://doi.org/10.1007/s11356-021-16998-2.

Ren, Y. and Fu, J. (2019) 'Research on the effect of carbon emissions trading on emission reduction and green development', *China Population, Resources and Environment*, Vol. 29, No. 5, pp.11–20.

Selden, T.M. and Song, D. (1994) 'Environmental quality and development: is there a Kuznets curve for air pollution?', *Journal of Environmental Economics and Environmental Management*, Vol. 27, No. 2, pp.147–162.

Stavins, R.N. (1998) 'What can we learn from the grand policy experiment? Lessons from SO2 allowance trading', *Journal of Economic Perspectives*, Vol. 12, No. 3, pp.69–88.

Tian, G., Yu, S., Wu, Z. and Xia, Q. (2022) 'Study on the emission reduction effect and spatial difference of carbon emission trading policy in China', *Energies*, Vol. 15, No. 5, pp.1–20.

Tu, Z. and Shen, R. (2015) 'Can emissions trading scheme achieve the porter effect in China?', *Economic Research Journal*, Vol. 50, No. 7, pp.160–173.

Walter, I. and Ugelow, J.L. (1979) 'Environmental policies in developing countries, technology, development and environmental impact', Vol. 8, Nos. 2–3, pp.102–109.

Wang, J., Yang, J., Ge, C., Cao, D. and Jeremy, S. (2004) 'Controlling sulfur dioxide in China: will emission trading work?', *Environment: Science and Policy for Sustainable Development*, Vol. 46, No. 5, pp.28–39.

Wang, Y., Han, R. and Kubota, J. (2016) 'Is there an environmental Kuznets curve for SO2 emissions? A semi-parametric panel data analysis for China', *Renewable and Sustainable Energy Reviews*, Vol. 54, pp.1182–1188.

Wang, W., Xie, P., Li, C., Luo, Z. and Zhao, D. (2018) 'The key elements analysis from the mitigation effectiveness assessment of Chinese pilots carbon emission trading system', *China Population, Resources and Environment*, Vol. 28, No. 4, pp.26–34.

Wang, C., Shi, Y., Zhang, L, Zhao, X. and Chen, H. (2021) 'The policy effects and influence mechanism of China's carbon emissions trading scheme', *Air Quality, Atmosphere & Health*, Vol. 14, No. 12, pp.2101–2114.

Wang, X.Q., Su, C., Lobont, O.R., Li, H. and Nicoleta-Claudia, M. (2022a) 'Is China's carbon trading market efficient? Evidence from emissions trading scheme pilots', *Energy*, Vol. 245.

Wang, X.X., Huang, J. and Liu, H. (2022b) 'Can China's carbon trading policy help achieve carbon neutrality? A study of policy effects from the five-sphere integrated plan perspective', *Journal of Environmental Management*, Vol. 305, p.114357.

World Bank (2021) *State and Trends of Carbon Pricing*, World Bank, Washington, DC [online] https://openknowledge.worldbank.org/handle/10986/35620 (accessed 2 April 2023).

Xia, Q., Li, L., Dong, J. and Zhang, B. (2021) 'Reduction effect and mechanism analysis of carbon trading policy on carbon emissions from land use', *Sustainability*, Vol. 13, No. 17, pp.1–22.

Xiao, Y. and Yin, H. (2017) 'China's carbon emission trading pilot programs: operation and effect', *Ecological Economy*, Vol. 33, No. 5, pp.57–62.

Xu, G. and Song, D. (2010) 'An empirical study of the environmental Kuznets curve for China's carbon emissions-based on provincial panel data', *China Industrial Economy*, No. 5, pp.37–47.

Yang, B., Liu, L. and Yin, Y. (2021) 'Will China's low-carbon policy balance emission reduction and economic development? Evidence from two provinces', *International Journal of Climate Change Strategies and Management*, Vol. 13, No. 1, pp.78–94.

Yu, X., Chen, H. and Li, Y. (2021) 'Impact of carbon emission trading mechanism on carbon performance based on synthetic control method', *China Population, Resources and Environment*, Vol. 31, No. 4, pp.51–61.

Zhan, H. (2018) 'The effect of income inequality on environmental pollution: reassessment of the environmental Kuznets curve of China', *Economic Review*, No. 6, pp.100–112+166.

Zhang, Z. and Xue, Q. (2011) 'Low-carbon economy, industrial structure and changes in China's development mode based on the data of 1996-2009 in empirical analysis', *Energy Procedia*, Vol. 5, pp.2025–2029.

Notes

1 One of the most important provisions of the Paris Agreement is to substantially reduce global greenhouse gas emissions to limit the global temperature increase in this century to 2°C while pursuing efforts to limit the increase even further to 1.5°C, https://www.un.org/en/climatechange/paris-agreement.

2 Shenzhen, Beijing, Shanghai, Guangdong, Tianjin, Hubei, Chongqing, and Fujian in chronological order.

3 https://www.ceads.net.cn/.