

INTRA- AND INTER-REGIONAL TECHNOLOGY TRANSFER AND CO₂ EMISSIONS IN CHINA: COMPARING THE EFFECTS OF ENERGY AND ENVIRONMENTAL TECHNOLOGIES

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Abstract. The purpose of this paper is to reveal the role of regional technology transfer in reducing carbon dioxide emissions in China. By collecting a panel data of 150 observations from 30 regions of mainland China during 2006–2010, this paper extends the STIRPAT model to explore the relationship between intra- and inter-regional technology transfer and CO₂ emission intensity, and meanwhile compares the effects of energy and environmental technologies in different regions of China. The results show that, in the national level, only intra-regional transfer of energy technologies can significantly reduce the CO₂ emission intensity. When it comes to the regional level, intra-regional transfer of energy technologies has a negative influence on CO₂ emissions in the eastern and western regions. In contrast, intra-regional transfer of environmental technologies negatively affects CO₂ emissions in the central regions, and even leads to a significant increase of CO₂ emissions in the eastern regions. However, neither inter-regional transfer of energy technologies nor inter-regional transfer of environmental technologies has significant effect on CO₂ emissions reduction in China. Our findings reveal the critical role of intra-regional rather than inter-regional technology transfer, and also energy technologies rather than environmental technologies in reducing CO₂ emissions, which has important implications for future environmental policy-making in China.

Keywords: *energy and environmental technologies; regional technology transfer; CO₂ emissions; China; STIRPAT model*

Introduction

As the largest developing economy in the world, China is now facing enormous pressure in reducing carbon emissions (Li et al., 2011). In the past decade, the CO₂ emissions in China has increased continuously, accounting for more than 25% of the world's total CO₂ emissions since 2009 (*Fig. 1*). During the Copenhagen Climate Change Conference in 2009, China has promised to significantly cut down its CO₂ emissions by 40% - 45% in 2020 compared with 2005 (Wang et al., 2015). Consequently, the emission reduction targets have been included as the binding targets in the national and regional economic and social development of China (Sun et al., 2015). All regions in China have to bear huge duty of reducing carbon emissions to accomplish the targets of the national commitment.

In the past few years, technological innovation has been considered an important driver of reducing carbon emissions and promoting environmental sustainability (Wang et al., 2012a). Numerous scholars have explored the roles of different technological channels in improving the environment, which include internal research and development (R&D) activity, international knowledge spillovers and domestic technology spillovers (Yang et al., 2014). Given those studies generally investigated on

the regional level, however, an important channel of technology transfer—domestic regional technology transaction—is still underexplored. Particularly, due to the uneven distribution of regional innovation resources in China, some regions have to rely on green technologies across regional borders. Thus, the extent to which intra- and inter-regional technology transfer can influence carbon emissions in China is still an important question that needs further investigation.

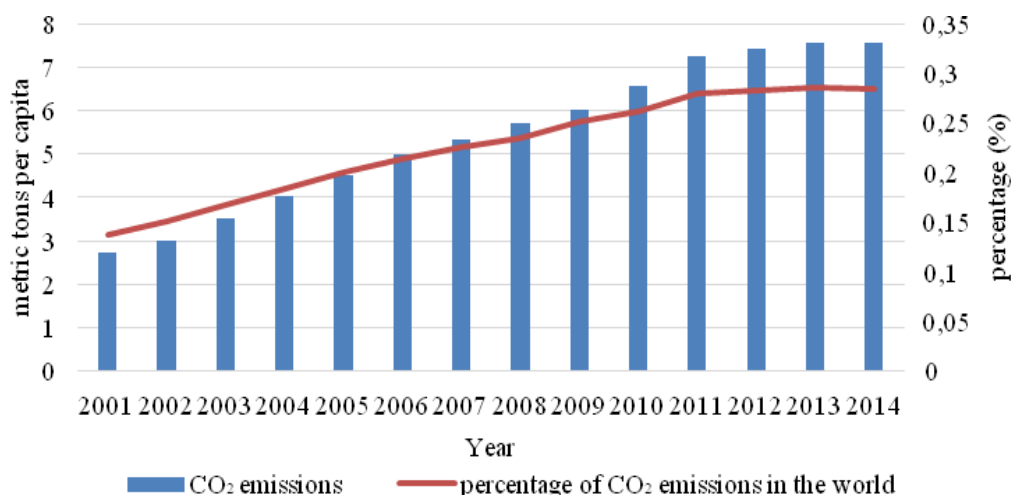


Figure 1. CO₂ emissions in China from 2001 to 2014
(Source: World Development Indicators from the World Bank)

Meanwhile, previous studies on the relationship between technological innovation and CO₂ emissions seldom distinguish the effects of different types of green technologies (Yang et al., 2014), such as energy technologies and environmental technologies. In fact, however, energy technologies and environmental technological solutions play roles in different processes of carbon emissions reduction. From a whole process treatment perspective (Zhang, 2013), energy technologies mainly serve as the solution of source prevention and process control, which promote the use of renewable energy and improve the efficiency of traditional fossil energy in the production process. In contrast, environmental technologies mostly act as the end-of-pipe technological solution, which prevent, control and decrease the carbon emissions with technical equipment such as pollution control equipment and environmental monitoring instruments. However, the different effects of energy technologies and environmental technologies on CO₂ emissions in China have been rarely taken into account in previous studies.

To address the above gaps, this paper uses a unique data of regional technology transaction of province-level in China, and explores the relationship between intra- and inter-regional technology transfer and CO₂ emissions, and meanwhile compares the different effects of energy and environmental technologies in different regions of China.

Literature review

As an important environmental issue, the influencing factors of CO₂ emissions have been studied by many scholars. In recent years, scholars have paid more attention to the role of green technological innovation in reducing carbon emissions (Jiang et al., 1998;

Goulder and Schneider, 1999), especially for those developing countries facing greater pressure to lessen carbon emissions. Specifically, three different technological channels in reducing carbon emissions have been investigated, including indigenous innovation, international knowledge spillover and inter-regional knowledge spillover.

The impact of indigenous innovation on CO₂ emissions

Numerous studies have investigated the impacts of indigenous R&D and technological innovation on CO₂ emissions. At first, some scholars mainly related the R&D investment to CO₂ emissions, aiming to recognize the positive role of internal R&D activity. Cole et al. (2005) found that in the UK, the industry's R&D expenditure was negatively correlated with air pollution intensity. Lee and Min (2015) also revealed the negative impact of green R&D on carbon emissions in Japan. However, Garrone and Grilli (2010) examined 13 advanced economies and indicated that public energy R&D could significantly improve energy efficiency, but had no significant effect on carbon intensity. When it came to China's case, Feng and Yuan (2016) showed that increasing R&D intensity could decrease the carbon intensity.

Apart from the literatures on R&D input, the impact of green patent output on CO₂ emission has also attracted much attention. Yan et al. (2017) used patent data of 15 major economies during 1992-2012, and found no evidence of the influence of low-carbon innovation on CO₂ emission. Wang et al. (2012b) revealed that the carbon-free energy patents were significantly negatively correlated with CO₂ emissions in the eastern regions of China, but had no significant effects in the central and western regions. Ding et al. (2015) showed that green patents had positive influences on the CO₂ emission reduction in the whole country as well as the eastern and western regions of China, except the central region. Wang et al. (2012c) also confirmed the negative relationship between energy technology patents and CO₂ emissions in Beijing city.

The impact of international knowledge spillovers on CO₂ emissions

In addition to indigenous R&D and innovation for improving the environment, international knowledge spillovers through trade and foreign direct investment (FDI) have also been investigated. Researchers suggested that trade and FDI can lead to knowledge spillovers by means of competition effects, demonstration effects, employee turnover and vertical linkages (Yang et al., 2014), which may result in local technological improvement. However, trade and FDI can also lead to scale and structure effects, which may be harmful to local environment sustainability because of more energy use and more carbon emissions (Zhang, 2012).

Several studies examined the impact of trade or FDI on CO₂ emissions separately. For instance, Yan and Yang (2010) revealed that the rapid growth of China's CO₂ emissions was mostly caused by the manufacture of exports, confirming the scale and structure effects of international trade in China. Zhang and Zhou (2016) found that the FDI's impact on CO₂ emissions decreased from the western region to the eastern and central regions. Moreover, many scholars have explored the effects of trade and FDI simultaneously. Ren et al. (2014a) revealed that trade surplus and FDI inflows in China contributed to the increasing CO₂ emissions. Ren et al. (2014b) suggested that China should reduce the scale of FDI inflows, and import and export more green products with other countries. However, Yang et al. (2014) did not find the positive spillover effects of FDI and trade in reducing carbon emissions.

The impact of inter-regional knowledge spillovers on CO₂ emissions

Another important technological channel—inter-regional knowledge spillovers within a country—has also been explored in recent years. First of all, just like international trade, domestic trade within a country could also improve regional technology capabilities through positive embodied knowledge spillovers, and thus reduce its CO₂ emissions. But the side effect of domestic inter-regional trade may also exist, which is known as “the pollution haven hypothesis” (Ren et al., 2014a, b). A developed region may shift its intensively polluting industry to lagged regions through inter-regional trade, which instead increases the CO₂ emissions of lagged regions. Zhang et al. (2014) showed that inter-regional imports and exports can lead to more carbon emissions in the coastal and inland provinces. Guo et al. (2012) confirmed that the eastern area has transferred embodied CO₂ emissions to the central area, and inter-regional trade in China has an effect on regional CO₂ emissions. Zhang (2017) also discovered that inter-regional trade has significant spillover effects on provincial CO₂ emissions in China.

Furthermore, many scholars argued that inter-regional trade is not the only way of regional knowledge spillovers, the R&D activities of neighboring regions can also result in inter-regional knowledge spillovers, thus benefiting local innovation. Yang et al. (2014) revealed that R&D intensity of neighboring regions have statistically significant spillover effects in China, confirming the role of inter-regional R&D spillovers in decreasing CO₂ emissions. Yang et al. (2014) was the first to consider domestic inter-regional R&D spillover effect in environmental issues. However, their focus is only the indirect spillovers of neighboring regions. In fact, however, the channel of technology transaction is a more direct way to transfer technologies outside. Recently, some studies began to examine regional technology transfer through the channel of technology transaction. For example, Sun and Liu (2016) investigated the evolution of inter-regional technology transactions in China. However, there is still few research on the effect of direct technology transaction on regional CO₂ emissions.

To sum up, studies on the first channel of indigenous innovation mainly focused on the impact of R&D input and patent output, while paid little attention to intra-regional technology transfer, thus neglecting the diffusion and commercialization of regional green technologies. Meanwhile, literature on the second and the third channels took external knowledge spillovers across the regional borders as important ways to reduce carbon emissions. However, compared with the direct technology transaction between regions, the effects of international and inter-regional knowledge spillovers were relatively indirect. Therefore, it can be summarized that prior research on the relationship of “technological innovation-CO₂ emissions” ignored the direct channel of intra- and inter-regional technology transaction through technology market, which has been considered as an important channel for local innovation in technological innovation and regional studies. Meanwhile, previous literature seldom compared the effects of energy and environmental technologies on CO₂ emissions, which actually act as different types of technological solutions in the whole process of carbon emissions. Thus, this paper aims to fill the above gaps. In the following parts, we will investigate the impacts of intra- and inter-regional technology transfer on CO₂ emission intensity, and meanwhile compare different effects of the energy technologies and environmental technologies in different regions of China.

Methodology and data

STIRPAT model

Ehrlich and Holdren (1971) firstly proposed the IPAT model (Human impact on the environment, Population, Affluence, and Technology) to address the factors influencing environmental pressure. The general form of IPAT model is $I = PAT$. Here, I denotes human impact on the environment, P denotes population, A denotes affluence, T denotes technological factor. However, the determinants in IPAT model are limited, and the equal ratio relationship also limits its generality (Ding, 2015). So some scholars like Dietz and Rosa (1994) extended the IPAT model to the STIRPAT model (Stochastic Impacts by Regression on Population, Affluence and Technology), and used it to investigate multiple influencing factors of environmental issues. The STIRPAT model is an equation with the random form as follows.

$$I = aP^bA^cT^de \quad (\text{Eq.1})$$

In this equation, a represents the constant term, b , c , d represent the exponential terms of the P , A and T , and e means the error term. *Eq. (1)* is often transformed into a logarithmic form in empirical studies:

$$\ln I = a + b \ln P + c \ln A + d \ln T + e \quad (\text{Eq.2})$$

By reviewing the literatures on “technological innovation-CO₂ emissions”, we find that most scholars used the STIRPAT model to empirically study the environmental issues, such as Li et al. (2011), Ding et al. (2015) and Wang et al. (2012c). Although these studies did not reach the consistent result due to their focus on different technological channels, they generally proved the fitness of the STIRPAT model in “technological innovation-CO₂ emissions” research. In this study, we also use the STIRPAT model to study the effect of regional technology transfer on CO₂ emissions. Specifically, I means CO₂ emission intensity, P means population size, A is measured by per capita GDP (PGDP). As for the technological factor T , some scholars like York et al. (2003) suggest that it can be broken down into several measurable indicators, such as the industrial structure, energy consumption structure and energy intensity. Later, more and more researchers begin to add more direct indicators like R&D investment and patent output into the model to measure the impact of technological level (Wang et al., 2012; Ding, 2015). In this paper, apart from the decomposed factors like industrial structure (IS), energy intensity (EI) and energy consumption structure (ES), we take regional technology transfer as a central technology channel of improving technological level. According to the regional and sectoral boundary of technology transfer activity, we set up four variables to extend the model, including intra-regional transfer of energy technologies (IntraEY), inter-regional transfer of energy technologies (InterEY), intra-regional transfer of environmental technologies (IntraET) and inter-regional transfer of environmental technologies (InterET). Then, the extended STIRPAT model is as follows.

$$\ln I_{it} = a + b \ln P_{it} + c \ln PGDP_{it} + d_1 \ln IS_{it} + d_2 \ln EI_{it} + d_3 \ln ES_{it} + d_4 \ln IntraEY_{it-1} + d_5 \ln InterEY_{it-1} + d_6 \ln IntraET_{it-1} + d_7 \ln InterET_{it-1} + e \quad (\text{Eq.3})$$

In the equation, *i* represents regions, *t* represents year; *a* represents the constant term, *b*, *c*, *d*₁, *d*₂, *d*₃, *d*₄, *d*₅, *d*₆, and *d*₇ represent the exponential terms of the *P*, *PGDP*, *IS*, *EI*, *ES*, *IntraEY*, *InterEY*, *IntraET* and *InterET*, and *e* means the error term. Considering the possible lag effect of regional technology transfer, all technology transfer variables are lagged for one year in the model.

Variables and data

The dependent variable in the model is the CO₂ emission intensity (*I*). We measure it with the ratio of CO₂ emissions to GDP. So far, China has no direct statistics about CO₂ emissions on regional level, thus most scholars have to estimate it on the basis of energy consumption in each region (Ren et al., 2014a, b). According to the China Statistics Bureau, there are 8 major types of energy sources in China, which are coal, coke, crude oil, gasoline, kerosene, diesel, fuel oil and natural gas. Therefore, we use the method proposed by IPCC (Intergovernmental Panel on Climate Change) Guidelines for National Greenhouse Gas Inventories to estimate CO₂ emissions of Chinese regions (IPCC, 2006).

$$CO_{2jt} = \sum_{j=1}^8 E_{jt} \times NCV_j \times CEF_j \times COF_j \times \frac{44}{12} \quad (\text{Eq.4})$$

In Eq.4, *E_j* represents the consumption of energy type *j*. *NCV_j* is net calorific value, *CEF_j* is carbon emission factor, and *COF_j* is carbon oxidation factor. 44 and 12 represent the molecular weight of CO₂ and carbon. Data of *NCV_j* is collected from China Energy Statistical Yearbook, and *CEF_j* and *COF_j* are collected from IPCC (IPCC, 2006).

The industry structure (*IS*) is measured by the percentage of industry added value to GDP, the energy intensity (*EI*) is measured by the ratio of energy consumption to GDP, and the energy consumption structure (*ES*) is measured by the percentage of coal consumption to total energy consumption. All types of energy consumption data derive from China Energy Statistical Yearbook, and the data of *P*, *GDP*, and industry added value are from the China Statistical Yearbook.

Moreover, this study uses technology transaction data to measure regional technology transfer. In China, there are four types of technology transaction in technology markets, including technology development, service, transfer and consulting (Sun and Liu, 2016). A Chinese official institution, the Technology Market Management & Promotion Centre, is responsible for organizing and managing technology transaction activities, thus owning all contract data on regional technology transaction. We obtain the unique inter-regional technology contract data in 2006-2010 from this official source. This dataset contains intra- and inter-regional technology transaction data in the province level of China. And it is also divided into 11 technology sectors, in which the energy technologies and environmental technologies are the focus of this paper. Specifically, intra-regional transfer of energy technologies (*IntraEY*) is measured by the contract value of energy technology transaction within the same region, while inter-regional transfer of energy technologies (*InterEY*) is measured by the contract value of energy technology transaction across different regions. Similarly, intra-regional transfer of environmental technologies (*IntraET*) is measured by the

contract value of environmental technology transaction within the same region, and inter-regional transfer of environmental technologies (InterET) is measured by the contract value of environmental technology transaction across different regions. The detail description and interpretation of all variables is presented in *Table 1*.

Table 1. Description and explanation of variables

Variables	Definition and measurement	Unit
I	The ratio of CO ₂ emissions to GDP	ton per Yuan
P	The number of total population	Million
PGDP	per capita GDP	Yuan
IS	The percentage of industry added value to GDP	%
EI	The ratio of energy consumption to GDP	ton per Yuan
ES	The percentage of coal consumption amount to energy consumption	%
IntraEY	Contract value of energy technology transaction within the same region	Million Yuan
InterEY	Contract value of energy technology transaction across different regions	Million Yuan
IntraET	Contract value of environmental technology transaction within the same region	Million Yuan
InterET	Contract value of environmental technology transaction across different regions	Million Yuan

Our data of regional technology transfer is between 2006 and 2010, so we collect the data between 2007 and 2011 of other variables with the consideration of one-year lag effect of technology transfer activity. Meanwhile, the mainland China has 31 administrative regions, including provinces and municipalities. Due to the lack of statistics of the Tibet in “China Energy Statistical Yearbook”, we only collect data from 30 regions of the mainland China. So the sample size includes a panel data of 150 observations.

In order to study the influence of regional technology transfer in different groups of regions, we divide 30 provinces and municipalities into three sub-sample economic regions like other studies (Wang et al., 2012b, c; Ding et al., 2015), including the eastern, central and western regions. Specifically, in China, the eastern regions include 11 provincial administrative regions (Beijing, Fujian, Guangdong, Hainan, Hebei, Jiangsu, Liaoning, Shandong, Shanghai, Tianjin, Zhejiang), the central regions include 8 provincial administrative regions (Anhui, Henan, Heilongjiang, Hubei, Hunan, Jilin, Jiangxi, Shanxi), and the western regions include 11 provincial administrative regions (Gansu, Guangxi, Guizhou, Inner Mongolia, Ningxia, Qinghai, Shaanxi, Sichuan, Xinjiang, Yunnan, Chongqing). The specific location of the eastern, central and western regions in mainland China is shown in *Fig. 2*.

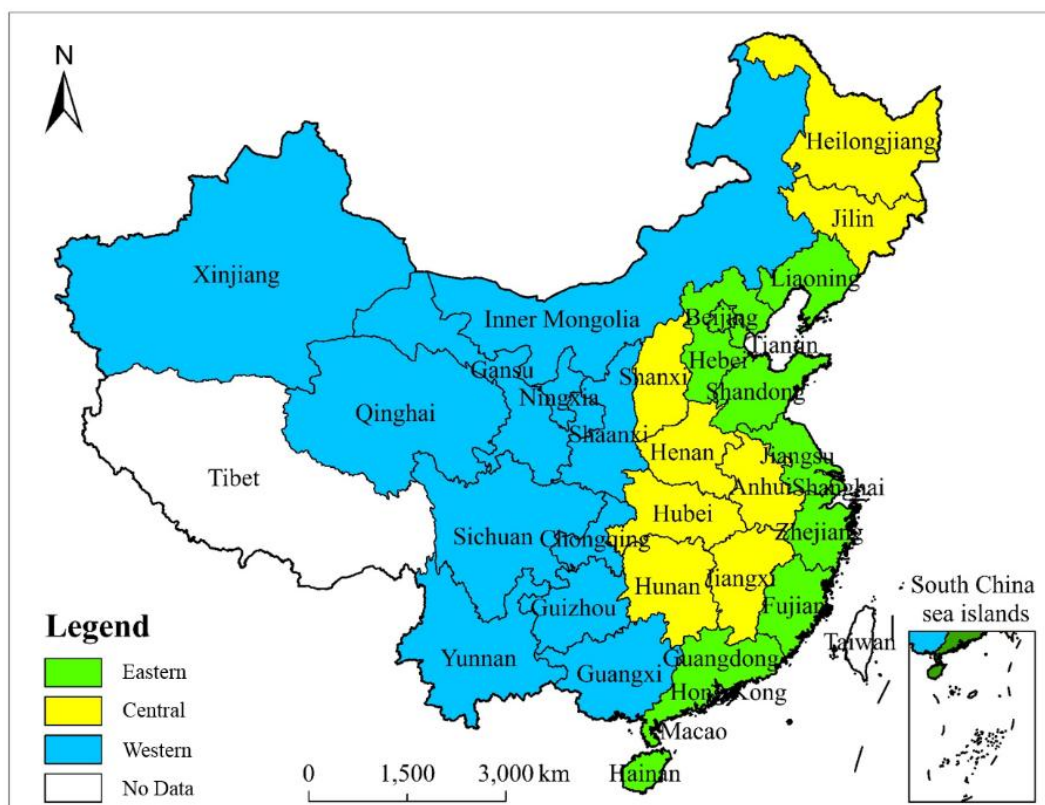


Figure 2. The location of the eastern, central and western regions in mainland China

Estimation procedure

Considering the panel data of 5 years and 30 sections, this research uses traditional panel regression model to empirically study the role of regional technology transfer in reducing CO₂ emissions for 30 Chinese regions from 2006 to 2010. We will firstly estimate the relationship between regional technology transfer and CO₂ emissions within all regions of China. Then, we split the full dataset into three sub-samples, and estimate the corresponding relationships in the eastern, central and western regions.

In each panel data estimation, we use the Hausman's test to decide on the fixed-effect or random-effect model. After the tests of all regression models, the results all support the fixed-effect models. Meanwhile, in order to overcome the heteroscedasticity problem, the cross-section weighted generalized least squares (GLS) technique is employed in all panel estimations.

Results

Descriptive statistics

Firstly, we present the descriptive statistics of all variables, and we specifically describe the difference of variables in three sub-sample regions of China, just as shown in Table 2.

From Table 2 we can see that, the intensity of CO₂ emissions in China during 2007-2011 is 4.25 on average, and the western regions have the highest CO₂ emissions (5.58

on average), followed by the central regions (4.56 on average), and then the eastern regions (2.69 on average). Obviously, in China, the eastern regions have the least environmental problems of CO₂ emissions during economic development. The average population of China in 2007-2011 is 44 million, and is mainly concentrated in the central and eastern regions, 52.67 and 49.05 million, respectively. The average per capita GDP in 2007-2011 is 30343 Yuan. As the most developed regions in China, the eastern regions' per capita GDP reaches up to 45577 Yuan, far higher than that in the central and western regions (22436 and 20860 Yuan, respectively). The ratio of industry sector added value is 0.49 on average, and there is only small difference of industry structure among the eastern, central and western regions. The regional distribution of energy intensity is very similar to CO₂ emission indicator. The highest energy intensity is in the western regions (1.72), followed by the central regions (1.34), and then the eastern regions (0.96). As for the energy consumption structure, there is 62% coal consumption on average, and the central regions rely more on coal consumption (72%), followed by the western and eastern regions.

Table 2. Descriptive statistics of all variables in different regions of China

Variables	All regions		Eastern regions		Central regions		Western regions	
	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
I	4.25	2.75	2.69	1.37	4.56	3.03	5.58	2.83
P	44	26.53	49.05	31.97	52.67	20.20	32.64	20.30
PGDP	30343	17525	45577	18786	22436	6245	20860	9595
IS	0.49	0.08	0.47	0.11	0.51	0.05	0.49	0.05
EI	1.34	0.75	0.96	0.44	1.34	0.79	1.72	0.78
ES	0.62	0.16	0.49	0.15	0.72	0.08	0.67	0.13
IntraEY	316.90	484.79	557.15	708.10	212.52	185.93	152.55	166.58
InterEY	456.64	483.11	629.30	576.92	301.68	249.92	396.70	462.88
IntraET	188.11	322.25	365.71	464.33	104.84	139.57	71.08	75.15
InterET	296.95	282.33	292.11	238.37	381.37	392.06	240.40	208.66

Finally, in general, the average value of intra- and inter-regional transfer of energy technologies is higher than that of environmental technologies. Specifically, the eastern regions are most active in both intra- and inter-regional transfer of energy technologies, and the western regions are more dependent on inter-regional technology transfer of energy technologies than the central regions. By contrast, in environmental technologies, the eastern regions are more active in intra-regional technology transfer, while the central and western regions are more dependent on inter-regional technology transfer.

Table 3 shows the correlation coefficients of all variables. We can see that the population (P) and per capita GDP (PGDP) show significant negative correlations with CO₂ emission intensity, while the industrial structure (IS), energy intensity (EI) and energy consumption structure (ES) have significant positive correlations with CO₂ emission intensity. For all technology transfer variables, only the intra-regional transfer of energy technologies (IntraEY) and intra-regional transfer of environmental

technologies (IntraET) are significantly negatively related to CO₂ emission intensity. Furthermore, most independent variables have correlations with each other, but all the coefficients are lower than 0.8, meaning the multicollinearity does not have any effect on the following regression analysis.

Table 3. Correlation coefficients of all variables (after logged)

	1	2	3	4	5	6	7	8	9	10
1.I	1.00									
2.P	-0.22**	1.00								
3.PGDP	-0.55**	-0.04	1.00							
4.IS	0.35**	0.28**	-0.01	1.00						
5.EI	0.97**	-0.36**	-0.51**	0.22**	1.00					
6.ES	0.50**	0.37**	-0.34**	0.62**	0.28**	1.00				
7.IntraEY	-0.14*	0.34**	0.38**	0.30**	-0.22**	0.29**	1.00			
8.InterEY	0.02	0.27**	0.41**	0.08	0.001	0.08	0.48**	1.00		
9.IntraET	-0.16*	0.27**	0.42**	0.25**	-0.20*	0.14*	0.77*	0.51*	1.00	
10.InterET	0.02	0.28**	0.26**	0.12	-0.03	0.15*	0.39**	0.46**	0.32**	1.00

Notes: * and ** mean significance at 5%, and 1% level (two tailed).

Panel regression results

Then, we implement the panel regressions with Eviews 7.0 software to reveal the effects of intra- and inter-regional technology transfer on CO₂ emissions. *Table 4* presents all panel regression results.

In the first model of all regions (Model 1), the population (ln P) is significantly and negatively correlated with CO₂ emission intensity, indicating that as the population size increases, the growth rate of GDP exceeded the growth rate of CO₂ emissions in China. The Energy intensity (ln EI) and the energy consumption structure (ln ES) have significant positive impacts on CO₂ emissions, which means that the greater the energy consumption and the higher ratio of coal consumption is, the greater the CO₂ emission intensity will be. As for the regional technology transfer variables, only intra-regional technology transfer of energy technologies (ln IntraEY) has significant negative effect on CO₂ emission intensity ($d_4 = -0.00083$, $p < 0.05$), implying that intra-regional technology transfer in energy technologies can significantly decrease a region's CO₂ emissions in economic development.

Then, we observe the regression models of three sub-samples of the eastern, central and western regions (Model 2-4). The results show that, the Population (ln P) is significantly negatively correlated with CO₂ emission intensity in the eastern regions, but positively affects CO₂ emission intensity in the western regions. The per capita GDP (ln PGDP) only has significant negative effect on CO₂ emission intensity in the eastern regions. And the industry structure (ln IS) is significantly positively correlated with CO₂ emission intensity in the eastern regions, but negatively affects CO₂ emission intensity in the western regions. The above significant differences among the three regions might be related to their diverse level and stage of economic development. As the most developed regions in China, the eastern regions' population increase, economic growth and industrial upgrading are more related with low-carbon green development. By contrast, the central and western regions are still in an investment-dependent and factor-

driven development stage; the population expansion and economic growth are usually accompanied by an increase in carbon emissions. Furthermore, the energy intensity (ln EI) and the energy consumption structure (ln ES) are significantly positively correlated with CO₂ emissions in the eastern, central and western regions, which is consistent with theoretical and practical expectations.

The impacts of regional technology transfer on CO₂ emission intensity also show some differences among the three regions. In the eastern regions, intra-regional transfer of energy technologies (ln IntraEY) has a significant negative effect on CO₂ emission intensity ($d_4 = -0.004969$, $p < 0.01$), while intra-regional transfer of environmental technologies (ln IntraET) is significant positively correlated with CO₂ emission intensity ($d_6 = 0.005445$, $p < 0.01$). This suggests that in the eastern regions, energy technologies do play important roles in reducing carbon emissions by focusing on source prevention and process control, while environmental technologies as end-of-pipe treatments, may instead encourage more polluting activities, thus exacerbating carbon emissions.

Table 4. Panel regression results of different regions in China

Variables	Model 1 All regions	Model 2 Eastern regions	Model 3 Central regions	Model 4 Western regions
Constant	1.925734*** (0.115844)	2.450626*** (0.297816)	1.651618*** (0.421081)	0.643102* (0.334736)
ln(P)	-0.071447*** (0.012129)	-0.107773*** (0.033599)	-0.028888 (0.046515)	0.086713** (0.042275)
ln(PGDP)	0.000138 (0.003576)	-0.021526** (0.009525)	0.000226 (0.006489)	0.002912 (0.004787)
ln(IS)	-0.008151 (0.006199)	0.038317* (0.019727)	-0.022962 (0.013454)	-0.032934*** (0.011737)
ln(EI)	1.008786*** (0.006196)	0.957938*** (0.015285)	0.994867*** (0.011739)	1.015423** (0.009291)
ln(ES)	0.426151*** (0.007728)	0.403168*** (0.015962)	0.498978*** (0.025271)	0.432017** (0.015872)
ln(IntraEY)	-0.000830** (0.000414)	-0.004969*** (0.000515)	0.000323 (0.000658)	-0.001534** (0.000513)
ln(InterEY)	-0.000235 (0.000576)	-0.000530 (0.000981)	-0.000471 (0.000685)	-0.000502 (0.000648)
ln(IntraET)	-0.000079 (0.000428)	0.005445*** (0.000598)	-0.002888*** (0.000890)	0.000104 (0.000263)
ln(InterET)	0.000479 (0.000374)	0.000593 (0.000997)	0.000019 (0.000518)	-0.000447 (0.000675)
R-squared	0.999987	0.999973	0.999985	0.999981
Adjusted R-squared	0.999983	0.999958	0.999975	0.999970
F-statistic	233576	68231	96895	94708
Prob(F-statistic)	0.000000	0.000000	0.000000	0.000000
Observations	150	55	40	55

Notes: *, **, and *** mean significance at 10%, 5%, and 1% level. Standard errors are in parentheses.

With regard to the central and western regions, only intra-regional transfer of environmental technologies (ln IntraET) is significant negatively correlated with CO₂ emission intensity in the central regions ($d_6 = -0.002888$, $p < 0.01$). In contrast, only intra-regional transfer of energy technologies (ln IntraEY) has a significant negative effect on CO₂ emission intensity in the western regions ($d_4 = -0.001534$, $p < 0.05$). The results reveal that the central regions are inclined to commercialize their own environmental technologies to reduce CO₂ emissions by focusing on the end-of-pipe treatment, while the western regions are just similar to the eastern regions, relying more on energy technologies within regional boundary in terms of source prevention and process control.

Discussion

According to the above results, in addition to indigenous R&D, international and inter-regional knowledge spillovers (Yang et al., 2014), intra- and inter-regional technology transfer through direct technology transaction is confirmed as another important channel to reduce carbon emissions on the regional level of China. We get some new findings and enrich our understanding about the technological channels in reducing carbon emissions.

First, in addition to the confirmed positive effects of energy R&D and patent output (Wang et al., 2014a, b; Ding et al., 2015), our findings suggest that the diffusion and commercialization of intra-regional green technologies are also critical for reducing a region's CO₂ emissions. Previous studies have paid much attention to the input and output of green technological innovation, while our study highlights the crucial role of the transfer and commercialization of green technologies, which obviously calls for more research on the roles of international and domestic technology market in the low-carbon economic development.

Second, Yang et al. (2014) has compared the effects of indigenous R&D, spillovers through increasing openness, and interregional R&D spillovers on CO₂ emissions. However, they have not compared the different roles of intra- and inter-regional technology transfer. Our findings reveal that although the contract value of inter-regional technology transfer is generally higher than that of intra-regional technology transfer, only intra-regional transfer of green technologies has significant effects on CO₂ emission intensity, and there are certain barriers to impede the effective use of technology across different regions.

Finally, we followed the whole process treatment perspective (Zhang, 2013), and compared different roles of energy and environmental technologies in reducing CO₂ emissions. The results show that intra-regional transfer of energy technologies can significantly reduce CO₂ emissions in the national, eastern and western regions, while intra-regional transfer of environmental technologies can only decrease CO₂ emissions in central regions. It indicates that in reducing CO₂ emissions, source prevention and process control with energy technologies are much more effective than the end-of-pipe treatment solutions using environmental technologies.

Conclusions

In this paper, using regional technology transaction data in energy and environmental technologies of mainland China during 2006–2010, we extended the STIRPAT model to investigate the relationship between intra- and inter-regional technology transfer and

CO₂ emission intensity, and meanwhile compared the effects of energy and environmental technologies in different regions of China. We found that on the national level, only intra-regional transfer of energy technologies can significantly reduce the CO₂ emission intensity. When it comes to the regional level, intra-regional transfer of energy technologies has a negative influence on CO₂ emissions in the eastern and western regions. By contrast, intra-regional transfer of environmental technologies negatively affects CO₂ emissions in the central regions, but leads to a significant increase of CO₂ emissions in the eastern regions. However, neither inter-regional transfer of energy technologies nor inter-regional transfer of environmental technologies plays a significant role in reducing CO₂ emissions.

The contribution of this paper can be summarized in three aspects. First, in addition to the indigenous technological innovation and indirect knowledge spillovers, this paper confirms another important technological channel of reducing CO₂ emissions—domestic regional technology transfer through technology transaction, which not only offers a new insight into the research on “technological innovation-CO₂ emissions” relationship research from the perspective of technology transfer, but also has important implications for the development of domestic technology market to improve environmental performance in China. Second, this paper identifies the significant role of intra-regional technology transfer rather than inter-regional technology transfer in reducing CO₂ emissions, which verifies the significance of regional boundary in absorbing and utilizing technology transfer for green development, and therefore calls for more efforts to put into improving absorptive capability of regions in China to make full use of external technological resources. Third, this paper reveals the much more essential role of energy technologies than environmental technologies in reducing CO₂ emissions, which not only advances our understanding of the heterogeneous effects of different types of green technology from the perspective of whole process treatment, but also has practical significance for the technology choice in developing green low-carbon economy of China. Obviously, more attention should be paid to the source- and process-oriented technological solutions in energy technologies.

The findings of this study may also provide some implications for the policy-makers in China. First, in the context of green and low-carbon development, Chinese government should further optimize the environment of technology market development, and establish the market-oriented service system of technology market, thus promoting technology transfer in energy and environmental sector. Second, on the basis of utilizing intra-regional technology transfer, local governments should place more emphasis on the establishment of cross-regional information exchange and communication platforms, and improve regional absorptive capability to fully use advanced technology across regional boundaries. Third, it's difficult and insufficient to fundamentally ease the pressure of carbon emissions in China by relying on the end-of-pipe environmental protection solutions, so local governments should pay more attention to new energy and energy-saving technology development and application, and reduce CO₂ emissions in the source and the process of economic production activities.

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