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Working Paper 38
http://ceep.bit.edu.cn/english/publications/wp/index.htm

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August 2012

This paper can be cited as: *Zhu Z-S, Liao H, Cao H-S, Wang L, Wei Y-M, Yan J. 2012. The differences of carbon intensity reduction rate across 89 countries in recent three decades. CEEP-BIT Working Paper.*

This study is supported by the "Strategic Priority Research Program" of the Chinese Academy of Sciences (XDA05150600), National Natural Science Foundation of China (71322306, 71273027, 71020107026), National Basic Research Program of China under the Grant No. 2012CB955704; and Beijing Planning Office of Philosophy and Social Science (11JGC105). The views expressed herein are those of the authors and do not necessarily reflect the views of the Center for Energy and Environmental Policy Research.

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The differences of carbon intensity reduction rate across 89 countries in recent three decades

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Abstract: In the recent decades, most countries' CO_2 intensity has decreased, but their decline rates are significantly different. Based on the data set of 89 countries from 1980 to 2008, this paper tries to quantitatively investigate the potential reasons for their differences, and discusses the possibility for developing countries to maintain a high carbon intensity reduction rate in the future as before. The econometric analysis implicate that (1) the decline rate of CO_2 intensity in countries with high initial carbon intensity will be higher, which means CO_2 intensity across the world has a significant convergence trend; (2) keeping fast and steady economic growth can significantly help CO_2 intensity decline, yet total carbon dioxide emissions will grow dramatically. Therefore, with the two objectives of intensity reduction and total amount control, carbon abatement policies need to weigh one against another. The results are robust to the initial year selection and country classification.

Key words: Carbon dioxide intensity; Carbon abatement; Convergence.

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1. Introduction

International communities are paying a lot of attention into climate change issues recently, alarmed by increasingly hot temperatures and rising sea levels. According to the IPCC Fourth Assessment Report [1], the average global temperature from 1995 to 2006 was the warmest since 1850, and the global average surface temperature has rose by 0.74℃ in a hundred years from 1906 to 2005. In particular, Asia's average surface temperature has even increased by more than 1℃ in the same period.

Global warming may pose threats to humankind, but due to a relatively weak economic foundation and the lagged technology compared to the developed countries, developing countries' ability to cope with climate change and disasters is relatively weak. For example, According to Stern Review on The Economics of Climate Change [2], if the average temperature increases by 2℃, Africa's agricultural production will fall by 5% to 10%, at least 4 to 6 million people will suffer from malaria.

Considering the severe situation faced by developing countries and its appeal to CO_2 reduction, this paper quantitatively analyzes various factors influencing each country and region's CO_2 intensity change in recent 30 years. Analyzing each country's basic status quo and characteristics of CO_2 emissions, as well as the difference of carbon intensity change from the perspective of international comparison is valuable for further analysis of developing country's carbon emission trajectory and carbon reduction strategy in future.

Literature that addresses factors influencing CO_2 emissions can be roughly classified into three categories according to their perspectives or methods.

The first category uses input-output method to analyze the sources or structures of carbon emissions from the perspective of industrial structure or demand structure, and calculates direct and indirect emissions based on the relations of different industrial sectors. Gay and Proops [3] studied the balance between different sources of power generation (fossil fuels and other sources) to reduce CO_2 emissions by a composition change of goods and services in final demand. Lin and Sun [4], Guo *et al*. [5] studied the influence of import and export scale and structure on China's carbon emissions. Zhang [6] analyzed the impact of economic development mode transformation on China's carbon intensity, and the results showed that, from 1987 to 2007, economic development mode had caused China's carbon emission intensity to decline by 66.02%. The advantage of input-output analysis is the detailed analysis of all departments with full consideration of the correlations of industries. However, there are drawbacks to this method as well. As the data of the input-output table is updated within a certain period (e.g. that of China is updated every 5 years), it is difficult to reflect the long-term historical evolution trend of carbon dioxide emissions. Moreover, different countries' input-output tables are based on different compilation methods and calibrations, which make it hard for the data to be applied to a cross-country analysis of carbon emission differences.

The second category employs index decomposition analysis from the angle of carbon emission accounting process to work out the impacts of changes of industrial structure and carbon intensity of different departments on carbon emissions. In recent years, a large number of studies on this category, such as Feng *et al.* [7], Zhang [8, 9], Zha *et al.* [10], have been published. Index decomposition method decomposes CO_2 emissions into GDP per capita, energy intensity, energy consumption structure, population and other factors, and analyzes the relative importance and changing trend of each factor based on the decomposition. In applications, index decomposition methods are varied according to different decomposition formula and index, yet the results are similar. Nearly all studies have found that energy intensity and economic scale change are the primary driving factors of CO_2 emissions, while the influence of economic structure and energy consumption is less important. Akbostancı *et al.* [11] used Divisia Index method, and decomposed the changes of CO_2 emissions in manufacturing industry into five parts, and found that changes of the whole industrial activity and energy intensity were the main factors determining the changes in CO_2 emissions during 1995-2001 in Turkey's manufacturing industry. Index decomposition method is simple and clear, and the identities can be changed to a certain extent according to specific problem being examined. However, this method has some limitations, since it often takes endogenous factors into account, and many other factors are hard to be incorporated into the study, for example, the probable nonlinear relation between the level of economic development and CO_2 emissions, the impact of technological advances and the influence of ownership etc. On the basis of index decomposition results, energy conservation and emission reduction policies may lead to implications of adopting administrative interference means and central-planning thinking, such as energetically adjusting industrial structure, reducing the proportion of carbon intensive industries, restricting or closing "high pollution" and "high energy consuming" enterprises.

The third category is the employment of larger sample or a longer historical period for econometric analysis. Glen and Hertwich's [12] study found that, 72% of Norway's CO_2 emissions were caused by its export. Ang [13] inspected China's influence factors based on macroeconomic time series data and found that CO_2 emissions were negatively correlated with R&D strength, technology transfer and absorption capacity, and positively related with income level, the amount of energy used and openness of trade. Chang [14] employed multivariate co-integration Granger causality test to study the relationship between enrgy consumption, CO_2 emissions and economic growth. It was found that blind pursuit of economic growth would increase energy consumption and CO_2 emissions, which would have bad effects on climate change. Hatzigeorgiou *et al*. [15], using cointegration tests and Granger-causality test based on a multivariate VEC Model, resulted that the decoupling of CO_2 emissions and economic growth seemed quite separate in Greece from 1977 to 2007.

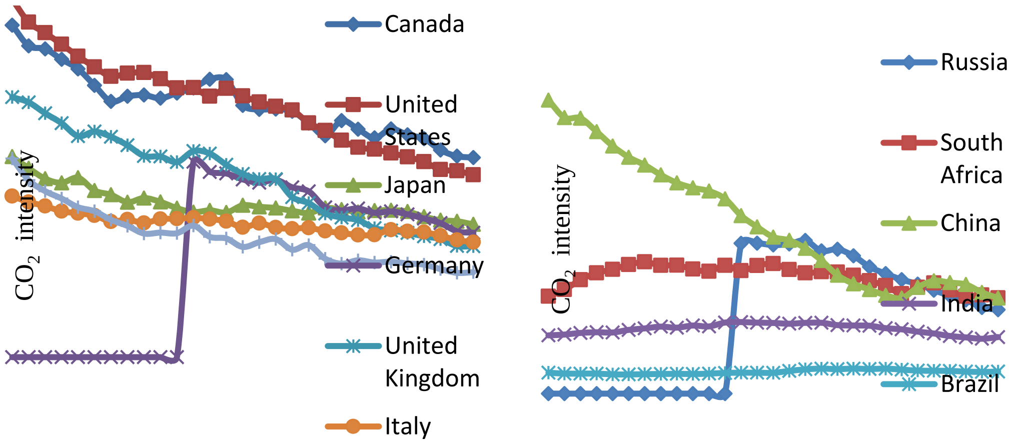
The econometric analysis can not only overcome the input-output analysis limitations of data lag and different compilation methods, but also avoid administrative intervention conclusions drawn by index decomposition method to a great extent. In addition, the cross-sectional data analysis can avoid, to some extent, the sequence of non-stationary and spurious regression problem brought by time series analysis, and the conclusion of cross-sectional analysis is robust as well. Thus, in this paper, cross-sectional data econometric analysis is applied. In order to ensure the reliability of the results of cross-sectional analysis, the variable data is the average numbers of nearly 3 decades instead of one year, which is able to ensure that the conclusions are representative.

Most of the present studies focus on the analysis of CO_2 intensity or CO_2 emissions per capita, while in current policy practices, we pay more attention to the direction and speed of carbon intensity change. In addition, most of the current researches are based on a specific nation's carbon emissions with a lack of internationally comparative analysis. This paper employs the CO_2 emission data of 89 countries from 1980 to 2008, in a hope to seek out the influence factors of CO_2 emission intensity change differences of different countries.

2. Methodology and data sources

2.1. Methodology and variable selection

Affected by the economic development level, energy consumption structure and other factors, the changes of each country's CO_2 emission intensity are significantly differing. However, due to technological progress and economic structure adjustment, CO_2 emissions per unit of GDP in most countries and regions declined to some distinct extent. From 1980 to 2008, a general decline in CO_2 emissions per unit of GDP occurred in the developed countries, CO_2 intensity was decreased by 57.32% in the United Kingdom, and 28.63% in Italy. In Contrast, the situation in developing countries is a little complicated. China had a sharp decline by 67.44% in CO_2 intensity. The data in South Africa and India decreased only a little, while Brazil increased by 5.45%. Main countries are shown in Fig.1.



(a) (b)

Fig. 1. Main countries and their CO_2 intensity decline in 1980-2008(kg/$, 2005PPP)

The dependent variable in our study is the annual decline rate of CO_2 emissions per unit of GDP (E) from 1980 to 2008. The independent variables are as follows:

(1) CO_2 emissions per unit of GDP (m_0) in the initial year (1980). For a certain country, the higher initial carbon emissions per unit of GDP, the larger reduction potential there is. Therefore, the coefficient of m_0 is expected to be positive.

(2) Energy consumption structure change (s). Coefficients of carbon emissions from different kinds of energy are not the same; the amount of CO_2 emissions from coal combustion is 1.6 times as that of natural gas, and 1.2 times as that of oil. The nuclear power, hydropower, wind power, and solar energy are clean energies, and do not directly emit CO_2. The impact of energy consumption structure change on carbon intensity change is significant, which has been found by Zhang [16]. In this paper, we use the average annual change of fossil energy's proportion in total energy consumption from 1980 to 2008 to represent the energy mix change. Fossil energy here includes coal, petroleum and natural gas.

(3) GDP per capita of the initial year of 1980 (PPP, 2005 constant price). GDP per capita can largely reflect the level of a country or a region's economic development. When a country steps into industrialization and post-industrialization stage, the direction or speed of the change of CO_2 intensity may alter. In the initial stage and metaphase of industrialization, with GDP per capita increases, CO_2 emissions per unit of GDP increase rapidly, and then the growth gradually slows down. After reaching a peak, CO_2 emissions per unit of GDP may decrease as GDP per capita increases, so an inverted "U" curve is shaped. Considering this point, this essay also adopts the GDP per capita and its square form.

(4) Economic growth rate (g). This paper utilizes the average annual economic growth rate from 1980 to

2008 to represent economic growth. When the GDP elasticity of CO_2 emissions is less than one, the faster the economy grows, the quicker CO_2 emissions per unit of GDP will decrease. However, if high economic growth is driven by fast energy infrastructure construction, CO_2 emissions per unit of GDP may rise instead. Therefore, the sign of coefficients cannot be pre-assumed. The long-term economic growth (or potential economic growth rate) has certain erogeneity, which is related to resource endowment structure and long-term government policies and regulations.

(5) Resource endowment (endow). Resource endowment can be represented by domestic production divided by consumption. In this essay, the relationship between the change of CO_2 intensity decline and annual average change of resource endowment is studied.

(6) International trade dependence (trade). International trade dependence depicts the external dependence of a country's economy; here we use the average annual change of the ratio of import and export volume to GDP from 1980 to 2008 to represent this variable. International trade affects environment mainly through scale effect, technology effect and structure effect [17], therefore, total effect of international trade on CO_2 emission is not easy to be anticipated.

(7) The level of urbanization (urban). Annual change of the rate of urbanization from 1980 to 2008 is employed. In the process of city construction, a large amount of energy is consumed; thereby a large amout of CO_2 is emitted. In addition, due to different lifestyle, cities emit more carbon than rural areas. As a result, higher level of urbanization of a country always means more CO_2 emissions, and slower decrease in CO_2 intensity, thus we expect negative coefficient here.

It is noteworthy that in the data accounting process, higher proportion of carbon intensive (or energy intensive) industries in a nation's economy means higher carbon emission intensity of the entire country. The evolution of industrial structure and carbon emissions also have a strong correlation, but there is no significant causality between the two factors. The evolution of industrial structure is largely endogenous. In the long term, if variables mentioned above remain unchanged, a country or a region is difficult to adjust its industrial structure directly. Therefore, we do not consider it as an explanatory variable.

Based on the description above, the general form of our model can be described as:

$$E = \beta_0 + \beta_1 \ln m_0 + \beta_2 s + \beta_3 \ln pgdp + \beta_4 g + \beta_5 endow + \beta_6 trade + \beta_7 urban + u \quad (1)$$

All the variables descriptions are listed in Supplementary. Particularly, our intention is not to measure the impacts of all the independent variables on dependent variable, some of them are adopted to check the robustness of the model.

2.2. Date sources

In this paper, all the data sets, without special notification, are from World Bank World Development Indicators Database. The data sets contain 89 countries from 1980 to 2008, which are very representative for this study. The dataset of Year 1980, 1990 and 2000 and their descriptions are shown in Supplementary.

3. Empirical tests and findings

As the model involves a number of explanatory variables, correlations among these variables will make the estimated coefficients differ greatly from their real values, which may affect the effectiveness of the model. Therefore, before the regression analysis, it is necessary to do variable correlation analysis and multicollinearity test to discriminate their relevance. Table 1 reports the result of correlation analysis between the dependent variable (E) and each independent variable. In order to enhance robustness of the results, three different methods of correlation analysis are used. According to Table 1 we can draw the following conclusions: (1) annual decline rate (in average) of CO_2 emissions per unit of GDP has positive correlation with initial carbon intensity, initial GDP per capita, and annual average change of resource endowment, yet negative correlation with annual change of the proportion of fossil energy consumption and the level of urbanization. (2) Annual decline rate of carbon intensity does not have manifest correlation with international trade dependence or economic growth under all three different correlation analysis methods.

Table 1. Correlation analysis between dependent variable and the explanatory variables.

	Pearson	**Spearman rank-order**	**Kedall's tau**
$\ln m_0$	0.582	0.536	0.382
	[0.000]	[0.000]	[0.000]
s	-0.549	-0.562	-0.395
	[0.000]	[0.000]	[0.000]
$\ln pgdp$	0.192	0.299	0.219
	[0.071]	[0.004]	[0.002]
g	0.029	-0.113	-0.084
	[0.785]	[0.290]	[0.245]
Endow	0.215	0.242	0.173
	[0.043]	[0.023]	[0.017]
$trade$	0.149	0.142	0.099

	Pearson	Spearman rank-order	Kedall's tau
	[0.162]	[0.186]	[0.171]
urban	-0.190	-0.263	-0.183
	[0.075]	[0.013]	[0.011]

Note: *p*-values are given in the square brackets.

Based on the analysis above, Table 2 shows the result of multicollinearity test. Variance inflation factor (VIF) values of the explanatory variables are all less than 10, which are all acceptable and will not affect the regression results. The analysis results of the regression are shown in Table 3.

Table 2. Multicollinearity test.

Independent variable	$\ln m_0$	s	$\ln pgdp$	g	$endow$	$trade$	$urban$
VIF	1.41	2.10	2.07	1.86	1.24	1.12	1.17

Table 3. Regression analysis of influence factors of annual decline rate of carbon intensity.

Model	I	II	III	IV	V	VI	VII	VIII	IX
Intercept	2.564	2.210	2.110	5.705	3.751	3.815	2.855	3.430	0.170
	[0.000]	[0.000]	[0.128]	[0.000]	[0.021]	[0.022]	[0.073]	[0.045]	[0.925]
$\ln m_0$	1.755	1.358	1.729	1.437	1.213	1.190	1.325	1.340	
	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	
s		-1.662		-2.207	-2.580	-2.575	-2.232	-2.197	-3.017
		[0.000]		[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]
$\ln pgdp$			0.049	-0.391	-0.292	-0.287	-0.153	-0.206	-0.075
			[0.736]	[0.009]	[0.056]	[0.063]	[0.324]	[0.208]	[0.685]
g					0.259	0.188	0.214	0.177	0.451
					[0.036]	[0.582]	[0.075]	[0.154]	[0.001]
g^2						0.008			
						[0.823]			
$endow$							0.052	0.053	0.035
							[0.009]	[0.009]	[0.120]
$trade$								0.114	0.077
								[0.247]	[0.496]
$urban$								-0.184	-0.351
								[0.714]	[0.543]
F - statistic	44.460	40.117	22.061	31.061	25.401	20.101	23.263	16.736	11.258
	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]
$D.W.$	1.948	1.873	1.948	1.916	1.994	1.999	1.945	1.925	2.147
R^2	0.338	0.483	0.339	0.523	0.547	0.548	0.584	0.591	0.452
$\overline{R^2}$	0.3331	0.471	0.324	0.506	0.526	0.520	0.558	0.556	0.412
Obs.	89	89	89	89	89	89	89	89	89

Note: the models are tested using White method, and the results show that there is no significant heteroscedasticity. In square brackets is the corresponding p - values.

3.1. CO_2 intensity convergence

In Model I-VIII the coefficient of β_1 is approximately 1.5 and statistically significant, which means if CO_2 emissions per unit of GDP in 1980 are 10% higher, the average annual velocity of CO_2 intensity decline will be 0.15% faster in the next three decades. As CO_2 emissions per unit of GDP in the developing countries in 1980 are generally higher than that of developed countries in the same period, annual decline rate of carbon intensity in developing countries will be higher. Therefore, the distinction among each country's carbon intensity gradually narrows and there is a convergence trend. The result is a little different from the study by Panopoulou *et al.* [18], Camarero *et al.* [19] and Timilsina [20]. That is mainly because of that, in order to reduce CO_2 emission intensity, developing countries, with "the advantage of backwardness", have accelerated domestic technological progress through introduction of technology and imitation. Their partial relationship can be clearly drawn with other variables controlled, shown in Fig. 2. According to Fig. 2, the higher initial CO_2 intensity is, the quicker CO_2 intensity declines.

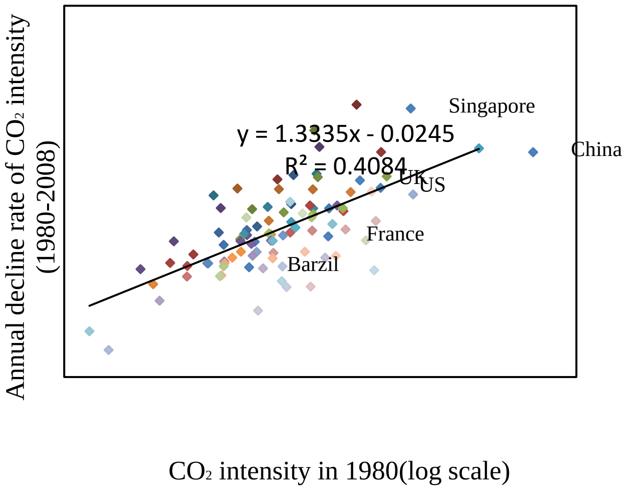


Fig. 2. The partial correlation between the CO_2 intensity decline rate and initial CO_2 intensity.

Note: the residual serial is sourced from model VIII, we standardize it, recorded as ε. Then we can calculate the fitted E, with the formula $E = \hat{\beta}_0 + \hat{\beta}_1 \ln m_0 + \varepsilon$.

3.2. Fossil energy mix changes

Annual change of the proportion of fossil energy consumption has a large influence on the decline rate of CO_2 intensity, and the influence is both practically and statistically significant. In model II and IV-IX, the coefficient is approximately -2.3. When annual fossil energy proportion increases by 1%, the decline rate of a country's CO_2 emissions will slow down by 2.3%. We can also draw the partial correlation between the change of energy consumption mix and CO_2 intensity decline rate with other variable controlled as shown in Fig. 3.

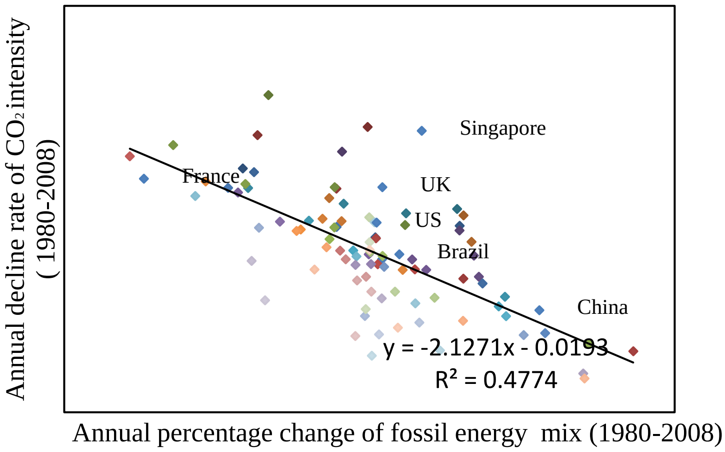


Fig. 3. The partial correlation between the CO_2 intensity decline rate and energy mix change.

In addition to reduce the proportion of fossil fuels in energy consumption, the fossil energy mix internal-adjustment can also contribute to the decline in CO2 intensity. Due to the relatively low carbon emissions, increasing the proportion of natural gas consumption instead of oil or coal can effectively reduce CO2 intensity. Besides, formation and movement of one country's energy mix depend mainly on the country's natural resource endowments, international trade, as well as relative prices among different energy varieties. Take China and Brazil for example. Due to different types of resource endowment, China has formed a coal-domianted energy mix, and Brazil hydropower (see Fig. 4). It is obvious that Brazil's energy mix is relatively low-carbon and clean. Thus, in the case of other conditions remain unchanged, with the world trend of energy mix more clean in the future, the potential of Brazil's decline in CO2 intensity will be far less than China.

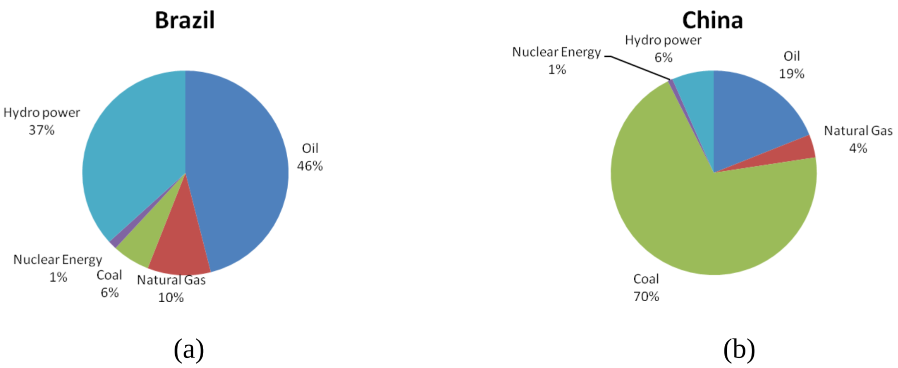


Fig. 4. The energy mix of China and Brazil in 2008

3.3. Initial GDP per capita

In model IV-VI, the coefficient is about -0.3, and statistically significant at 10% significance level. If GDP per capita in 1980 is 10% higher, the average annual velocity of CO_2 intensity decline will be 0.03% slower. It can be also seen that the negative impact of this factor is very weak in Fig. 5.For the other models, it is not statistically significant, but according to the *F* test, they are jointly statistically significant. The reason is possibly the relatively smaller potential of developed countries on the decline of CO_2 intensity. The qualitative judgment that initial GDP per capita has significant negative relationship with carbon intensity reeducation rate, though the factors are not robust quantitatively. Therefore, for the developing world, with their economic development and carbon intensity reduction, the natural potential for the further carbon intensity decline is becoming much less. When they set the climate change policy targets, it is suggested to consider this "empirical law". Targets that are more ambitious may result in excessive burdens and costs.

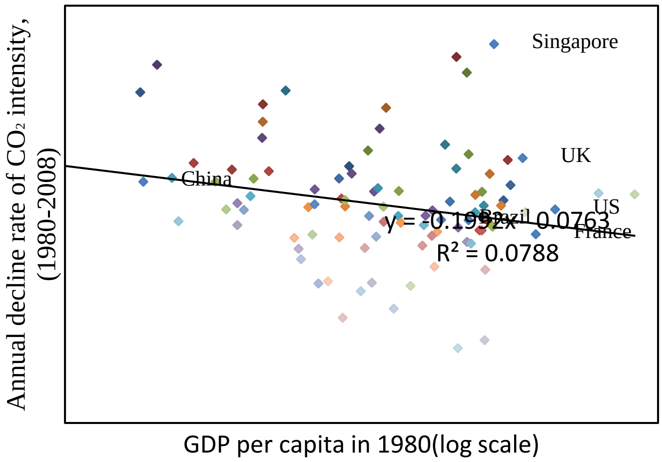


Fig. 5. The partial correlation between the CO_2 intensity decline rate and initial GDP per capita.

3.4. Economic growth rate

In model V, VII and IX, the coefficient is about 0.3, and statistically significant. However, in model VI and VIII, statistical test show this variable is not significant, mainly because of the high positive correlation between the initial CO_2 intensity and economic growth. Nations of high initial CO_2 intensity are mostly developing countries, whose economic growth potential is relatively larger. As we keep the initial CO_2 intensity and other factors unchanged, when economic growth increases by 1%, the decline rate of carbon intensity will accelerate by 0.3%. The conclusion does not conflict with the view- "rapid economic growth leads to a slower decline, or even increase, of carbon intensity in the short run driven by energy intensive investment", the emphasis here is on stable and rapid long-term economic growth, yet short-term growth is not smooth or sustainable. The partial correlation is shown in Fig.6. Economic growth will lead to higher total carbon emissions growth. Therefore, intensity reduction and total amount control are not entirely consistent, and need to be weighed and considered as a whole. In model VI, we also study the square form of GDP growth rate *(g^2)*, the result shows that there is no evidence of "inverted U" curve[1], which means speedy economic growth will do no harm to the decline of CO_2 intensity.

An interesting finding is that, when a country's average annual economic growth rate (such as Myanmar, Singapore and China) is more than 5%, its decline in CO2 intensity tends to be faster than others (See Fig. 6).

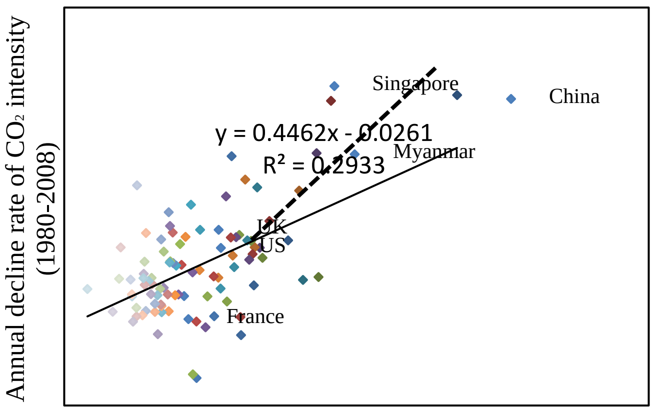


Fig. 6. The partial correlation between the CO_2 intensity decline rate and economic growth.

Note: the original residual serial is from model IX.

3.5. Resource endowment changes

In model VII- IX, the coefficient is approximately 0.05, and statistically significant. It means that there will be a 0.5% decline of CO_2 intensity if the energy self-sufficiency rate is increased by 10%. We do not find the "Resource Curse" phenomenon in the study from the view of intensity change rate in Fig. 7.

[1] Inverted-U curve is from Environmental Kuznets Curve (EKC), which was proposed by Panayotou in 1992, EKC reveals that, with increase in GDP per capita, the environmental quality degrades at first, and then improves when the income level reaches a certain extent. There is an inverted-U relationship between environmental quality and income.

Resource curse thesis was first proposed by Auty [21], who pointed out that the abundance of natural resources might have adverse effect on the economic growth of some countries. Sachs and Warner [22, 23] did empirical tests about the hypothesis.

It is worth noting that , for most countries, with little change of their natural resources in the past 30 years(see Fig. 7), their CO_2 intensities still have been declined.This fully shows that the natural endowment change has hardly impact on the CO_2 intensity decline for these countrie, R^2 is only 0.06 as well.

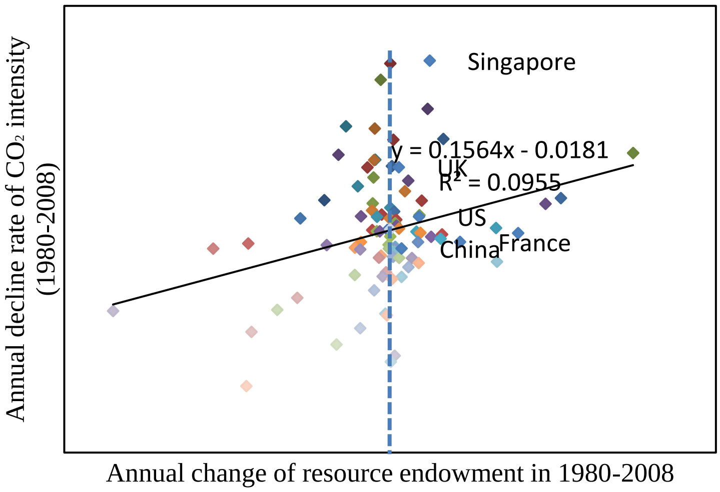


Fig. 7. The partial correlation between the CO_2 intensity decline rate and resource endowment.

Note: Five countries (United Arab Emirates, Brunei, The Republic of Congo, Norway and Saudi Arabia) have been excluded as outliers.

According to model VII, almost 58% difference of each country's CO_2 intensity decline rate from 1980 to 2008 can be explained by four factors: each country's initial carbon intensity ($\boldsymbol{m_0}$), the average annual change of fossil energy consumption proportion(***s***), average annual economic growth (***g***) and annual change of resource endowment (***endow***). The estimation of trade and urbanization is not significant. Model VII is able to explain the CO_2 intensity decline rate of major economies (e.g. US, UK, France, China and Brazil) for nearly three decades (See Fig.2, 3, 5-7).

It is noteworthy that about 42% of decline rate of CO_2 intensity still cannot get a good explanation (i.e. some outliers observed lying far away from the normalized trend in the each figure). This is mainly because some variables (e.g. institutional factors, lifestyle) are not considered in the model. In the case of Singapore, which ranks number one in the country set regarding annual CO_2 intensity decline rate (with an average annual deceleration of 6.32%). In addition to fast economic growth (an average annual rate of 6.85%, second only to China), Some energy-saving projects promoted by the Government and participated by the whole society, such as Green Mark Program and Eco-Living Program [24,25], have greatly contributed to the decline in energy intensity and CO_2 intensity.In conclusion, a good governance system and energy-saving mode of production and lifestyle have a very important role for the decline of CO_2 intensity.

4. Robustness analysis

4.1. Different initial years

In order to test the robustness of the model, we chose two other different initial years (1990 and 2000). The results are shown in the Table 4. It can be found there is no much difference of each model on numbers and significant levels. Still, some small differences here need to be paid attention to.

Table 4. Robustness test of the initial year.

Initial Year	1980	1990	2000
Intercept	3.430	1.417	1.969
	[0.045]	[0.491]	[0.344]
$\ln m_0$	1.340	1.219	0.631
	[0.000]	[0.000]	[0.062]
s	-2.179	-1.856	-2.273
	[0.000]	[0.000]	[0.000]
$\ln pgdp$	-0.206	0.060	-0.065
	[0.208]	[0.754]	[0.737]
g	0.177	0.173	0.439
	[0.154]	[0.198]	[0.000]
$endow$	0.053	2.849	3.143
	[0.009]	[0.341]	[0.099]
$trade$	0.114	0.063	-0.031
	[0.247]	[0.511]	[0.558]
$urban$	-0.184	-0.702	-2.598
	[0.714]	[0.269]	[0.001]
F - statistic	16.737	10.452	20.480
	[0.000]	[0.000]	[0.000]

$D.W.$	1.925	1.865	2.262
R^2	0.591	0.446	0.546
$\overline{R^2}$	0.556	0.403	0.520
Obs.	89	99	127

Note: In square brackets is the corresponding p - values.

(1) The convergence trend of CO_2 intensity has become slower compared with last two decades, and the coefficient is about 0.6, which is much less than 1.3 and 1.2 in the first two models respectively. It shows that the convergence is becoming slower.

(2) The negative impact of urbanization on the decline of CO_2 intensity has emerged in the third model, which reflects the energy-consuming and carbon-intensive characteristic of urbanization.

4.2. Country Grouping

The results are not significantly different whether it's a high-income country, a country in the Annex I of Kyoto Protocol, a member country in G7, BRIC, G20 or not, which are shown in the Table 5. No dummy variables are statistically significant. We have found no evidence that countries in some special group can have a special impact on the trend of the world CO_2 intensity change.

Table 5. Robustness test of the country groups.

Model	A	B	C	D	E	F
Intercept	3.430	4.787	3.614	3.512	3.571	3.326
	[0.045]	[0.025]	[0.037]	[0.042]	[0.039]	[0.054]
$\ln m_0$	1.340	1.359	1.288	1.324	1.405	1.388
	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]
s	-2.179	-2.063	-2.133	-2.181	-2.128	-2.147
	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]
$\ln pgdp$	-0.206	-0.373	-0.258	-0.225	-0.216	-0.186
	[0.208]	[0.097]	[0.140]	[0.179]	[0.190]	[0.264]
g	0.177	0.120	0.197	0.181	0.184	0.181
	[0.154]	[0.372]	[0.120]	[0.146]	[0.140]	[0.145]
$endow$	0.053	0.053	0.045	0.051	0.053	0.053
	[0.009]	[0.008]	[0.041]	[0.012]	[0.008]	[0.009]

trade	0.114	0.125	0.102	0.122	0.114	0.106
	[0.247]	[0.205]	[0.304]	[0.220]	[0.246]	[0.286]
urban	-0.184	0.031	-0.081	-0.146	-0.157	-0.140
	[0.714]	[0.955]	[0.875]	[0.773]	[0.755]	[0.783]
D_1		0.561				
		[0.274]				
D_2			0.381			
			[0.382]			
D_3				0.373		
				[0.526]		
D_4					-0.635	
					[0.376]	
D_5						-0.275
						[0.462]
F-statistic	16.737	14.835	14.700	14.588	14.707	14.631
	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]
$D.W.$	1.925	2.251	2.251	2.229	2.263	2.238
R^2	0.591	0.597	0.595	0.593	0.595	0.594
$\overline{R^2}$	0.556	0.557	0.555	0.553	0.555	0.553
Obs.	89	89	89	89	89	89

Note: D_1 =1, high-income countries; D_2 =1, Annex I countries; D_3 =1, member country in G7; D_4 =1, member country in BRIC; D_5 =1, member country in G20. In square brackets is the corresponding p -values.

5. Conclusions

With the frequent extraordinary weather and extreme climate events in the world, international communities have shown great concern on climate change issues. To address potential global warming, many countries have adopted various CO_2 emission reduction measures. This paper, from the perspective of international comparison, studies the difference of each country's CO_2 intensity change, aiming at providing a reference for further analysis of future carbon emission trajectory and carbon reduction strategy of developing countries.

There is much economic development and carbon emission unbalance across countries, and across regions within a country. To some extent, the development of regions in a country, especially those with large territory, is a microcosm of the development of countries in the world. Therefore, the evolution of other countries' CO_2 emission intensity has important implications for those regions. For example, the regions with higher CO_2 intensity have larger potential for CO_2 reduction, thus higher targets can be assigned.

According to the results of this study, several conclusions can be drawn. Firstly, almost 58% of the CO_2 intensity reduction rate variation for these countries in 1980-2008 can be explained by four factors: initial CO_2 intensity, the average annual change of fossil energy consumption proportion, average annual economic growth rate, and resource endowment. Then, the higher initial CO_2 intensity of a country is, faster of its CO_2 intensity decreases. Furthermore, maintaining a steady, rapid economic growth is conducive to CO_2 intensity decline, but also causes total CO_2 emissions to grow much rapidly. Therefore, it is necessary for the regulators to weigh the relations of the two when setting policy goals. Finally, reducing fossil energy consumption proportion can effectively promote CO_2 intensity decline.

After robustness analysis, it is noteworthy that, the results of each model with different initial years are similar, and no countries in some special group can have an impact on the trend of the world CO_2 intensity change.

Along with the continuous economic improvement in developing countries, as well as continuous decline of CO_2 emission intensity, without effective measures, their carbon intensity decline rate in the future will slow down, which is a great challenge for the completion of energy-saving and emission-reduction goal. Gradually reducing the proportion of coal in energy consumption, vigorously developing natural gas (including unconventional natural gas, especially coal-bed gas and shale gas) and clean energy, such as hydroelectricity and wind power, have important and realistic sense for developing countries to achieve a low carbon development.

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