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Income Inequality and Carbon Emissions

－ Evidence from China

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1 Introduction

1.1 Background and motivation

Because the issue of climate change has been attracting worldwide attention, studies of the driving forces behind CO_2 emissions have been of considerable interest to researchers and policymakers. Selden and Song (1994) and Stern et al. (1996) note that because income is not normally distributed but very skewed, with much larger numbers of people below mean income per capita than above it, the total emissions of a pollutant can continue growing beyond the turning point which is estimated by the reduced Environmental Kuznets curve (EKC) form taking the mean per capita income as the explanatory variables. Therefore, the turning point of the EKC may be underestimated when using the mean income per capita as the income variable since the distribution pattern of income is not taken into consideration. However, only a few studies have been conducted to examine the impact of income inequality on carbon emissions. Therefore, it remains difficult to fully understand the effect of income distribution on the mean carbon emissions levels. This study is motivated by the recent literatures which emphasize that income distribution plays an important role in the environmental Kuznets curve.

According to the EKC and the Kuznets hypothesis (Kuznets,1955), emissions of pollutants and income inequality first increase but then hit a “turning point” and begin to decline, along with the growth of income. Apparently, pollutant emissions and income inequality exhibit the same trend, indicating that narrowing the income disparity and reducing CO_2 emissions may each benefit from and contribute to the success of the other.

Since the reform and opening up, China's economic growth has made remarkable achievements, with the average annual GDP growth rate of 9.8%. However, China's economic growth is accompanied by increased household income inequality and the deterioration of environmental quality. Not surprisingly, China has become the largest CO_2 emitter with the highest urban-rural household income inequality in the world. Fig 4-1 is the scatter of household income inequality and CO_2 emissions per capita in China in the period 1978 to 2010. It is clear that China's CO_2 emissions keep growing with the increased household income inequality. This situation of China reveals that the inequality might be bad for the environment.

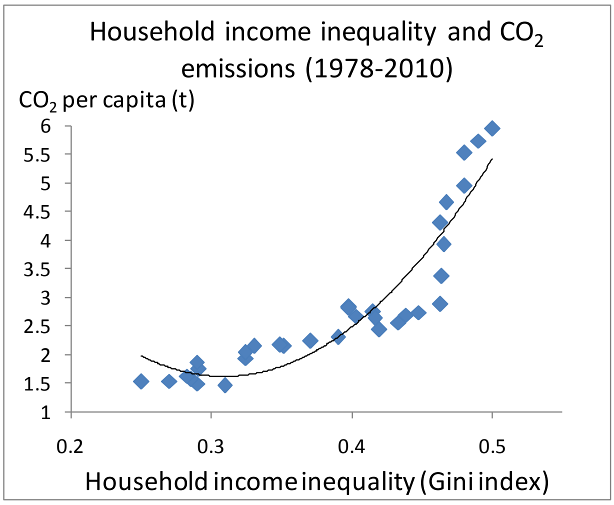


Fig. 1-1 Household income inequality and carbon emissions in China

Data source: household Gini index is calculated by author.

However, if we consider this issue at the regional level, it provides some evidence for the trade-off between narrowing regional income disparity and reducing CO_2 emissions. China is now the largest emitter of CO_2 in the world, having passed the USA in 2009. The pressure to save energy and reduce carbon emissions comes not only from international criticism but also from domestic concerns about energy shortages and environmental degradation. Meanwhile, the rapid economic growth that has taken place in China has been marked by a growing regional income disparity during the period of 1990 to 2005 (the Gini index of inequality of GDP per capita across regions rises from 0.27 to 0.32). In order to help the western half of China catch up with the eastern half, ‘Western China Development Strategy’ guidelines were clarified in 2000 and the Law on Promoting Western Development was listed on the legislative plan of the 10th National People's Congress in 2004. ‘Central China Rise Strategy’ to accelerate the development of central China was announced in March 2004. The effects of these policies appear gradually. The the Gini index of disparity of GDP per capita across regions decreases from 0.32 to 0.26 during the period of 2005 to 2010. Moreover, according to the report of China’s State Information Center in 24th Dec. 2012, the relative regional economic gap will narrow further in 2013. The economic growth rate of western China exceeds that of eastern China in 2007, and the regional economic growth of central, western and northeastern areas exceed that of eastern area for four years (from 2008 to 2011). The every year growth rate of CO_2 emissions is 4.5% during the period of 1990 to 2005 (regional income gap growing period), while the every year growth rate of CO_2 emissions is 7.2% from 2005 to 2010 (regional income gap narrowing period). Therefore, the CO_2 emissions increase faster when the regional income gap is reducing (1.6 times), which reveals that reducing regional economic gap may lead to more CO_2 emissions. In addition, due to the huge differences among the provinces regarding income disparity and energy structure, the difficulties and costs of carbon reduction in different provinces are various. However, several local governments of provinces with higher energy intensity elasticities may protect the local, energy-intensive industries for the sake of narrowing the income gap, despite poor environmental performance. It seems that a trade-off exists between reducing CO_2 emissions and narrowing the regional income disparity, which may distort the implementation of energy saving and emissions-reducing policies from the central government.

1.2 Objectives of the research

This paper aims to study the impact of income inequality on carbon emissions at both regional and household level, to answer the following three questions:

- What's the role that regional income disparity plays in the "income-CO_2 emissions" relationship?
- What's the way through which household income inequality impacts on carbon emissions?
- How does the change in household income distribution affect carbon emissions

via the change in the consumption pattern?

Chapter 3 in this paper focuses on the relationship between CO_2 emissions and income disparity at the regional level. This relationship is of great significance to the central government, which could benefit from obtaining greater energy savings and reductions in carbon emissions. Chapter 4 explores the impact of household income inequality on per capita CO_2 emissions in China, and answer following three questions: Whether there exists the Carbon Kuznets Curve (CKC) in China? How could household income inequality affect CO_2 emissions per capita? The income inequality effects of different regions on CO_2 emissions are the same, or not the same? Chapter 5 analyzes the impact of household income inequality on carbon emissions through its impact on consumption structure.

2 Literature Review

2.1 Environmental Kuznets curve

Panayotou (1993) first coined the term ‘environmental Kuznets curve’ (EKC) because of its resemblance to the Kuznets hypothesis (Kuznets, 1955). Panayotou (1993), Selden and Song (1994) and Grossman and Krueger (1995) have found evidence that the level of environmental degradation and per capita income follow an inverted-U-shaped pattern. Subsequently, the EKC has become a key concept in describing the relationship between environmental quality and per capita income.

Plenty of empirical studies have supported the EKC hypothesis at the cross-country level using international data. There are also several studies that confirm the EKC hypothesis over long historical periods for individual countries, namely Roca et al (2001) in Spain (1973-1996), Lindmark (2002) in Sweden (1870-1997) and Friedl and Getzner (2003) in Austria (1960-1999). Detailed surveys can be found in the EKC studies by Dinda (2004) and Stern (2004). Meanwhile, several other papers are sceptical of this hypothesis and argue that the empirical results are sensitive to the time period considered (Harbaugh et al., 2002) and to the selected countries (Stern and Common, 2001). In addition, another limitation of the empirical analysis is that the reduced-form relationships reflect correlation rather than causation. In reality, environmental quality is likely to have a feedback effect on income growth (Stern et al., 1996). Upon examination of the bidirectional causation, income and CO_2 emissions are found to directly affect each other; therefore, there is a feedback effect (Dinda and Coondoo, 2006). This bi-directional causality has also been tested in China using a simultaneous system function by He (2006) and by Shen (2006). Therefore, the economy and the environment are jointly determined. More recently, a wide range of theoretical models have been developed whose results are broadly consistent with the findings from the empirical literature. A survey of theoretical models of the EKC can be found in Kijima et al. (2010)

2.2 Income inequality and EKC

Most studies on EKC have typically expressed environmental quality as a function of average income and ignored the distribution of the income as a potential factor. An approach to improving research in this field is to introduce distribution into the income-pollution relationship. Studies that consider the distribution of income have obtained conflicting conclusions:.

A number of studies support the positive effect of income inequality on pollution. Boyce (1994) uses the public good choice theory to argue that a society's choice of the environmental quality level can be determined by the distribution patterns of income and societal power. Greater inequalities of power and wealth lead to a greater level of environmental degradation.. Torras and Boyce (1998) support their hypothesis that a more equitable distribution of power contributes to improved air and water quality using an empirical analysis of international variations with seven indicators of air and water quality. Boyce (2003, 2007) measures the environmental, social inequality from another angle. He finds that the more wealthy people can take advantage of existing economic resources to change their living environment rather than governance the environment. The riches are the smallest victims of environmental degradation. The poorer people are the biggest victims of environmental pollution. Vornovytskyy and Boyce (2010) conduct an empirical analysis on the impact of intraregional and interregional income inequality on environmental quality in Russia. The study found that the increase in intra-regional income gap and inequality in the provision of public goods will be accompanied by more environmental pollution. Magnani(2000) finds that moments of the income distribution function, other than the mean income, may be important in the emergence of a virtuous path of sustainable growth among high-income countries.

Marsiliani and Thomas (2002) adopt both the static and inter-temporal models to find that a larger income distribution gap reduces the ability of the go -between and the equilibrium of the political economy shall pay less attention to environmental protection. Gawande et al. (2001), and Bimonte (2002) adopt the Gini coefficient to measure the gap in income distribution and confirm that a greater gap in income distribution would deteriorate environmental quality. Bimonte (2002) also finds that the balance of income distribution would accelerate the coming of the inflexion of EKC. Grunewald et al. (2011) suggest that, in the rich country with high income inequality, the pro-poor growth can help to reduced per capita CO2 emissions. While, for the poor country with equal income distribution, there is a trade off between pro-poor growth and emissions reduction.

Still other studies provide evidence for the negative effect of income inequality. Ravallion et al. (1997) identify the trade-off between climate control and social equity, and Scruggs (1998) shows that equality may or may not be necessary to minimize degradation. Under a few plausible conditions, greater inequality may even be conducive to lower levels of degradation. Ravallion et al. (2000) find that higher inequality both between and within countries is associated with lowered carbon emissions at given average income levels. Heerink et al. (2001) demonstrate the importance of income distribution as an explanatory variable in the ‘income-pollution’ relationship at the household level.

Meanwhile, several studies have focused on the effect of income inequality on pollution in individual countries. Nugent and Sarma (2002) use an environmentally extended computable general equilibrium model (EECGE) in India to demonstrate that simple policy changes can be made that would simultaneously raise distributional equity, environmental sustainability and growth-increasing efficiency. Yang et al. (2011) conclude that there is currently a significantly negative relationship between environmental quality and income inequality in China. Clarke-Sather et al. (2011) find that on the national scale, interprovincial levels of inequality in per capita CO_2 emissions are similar to, but slightly lower than, inequality in per capita GDP in China.

Moreover, the income distribution may also affect the distribution of CO_2 emissions. Duro and Padilla (2006) suggest that international inequality in per capita CO_2 emissions is mainly attributable to inequalities in per capita income levels, which helps to explain its recent reduction. Padilla and Serrano (2006) conclude that much of the inequality in CO_2 emissions is explained by the inequality between groups with different per capita income levels. Coondoo and (2008) confirm that inter-country income inequality has a significant effect on the mean emissions levels and on the inter-country inequality of emissions for most of the country-groups considered.

In addition, income inequality may also affect carbon emissions through its impact on consumption patterns. Brännlund and Ghalwash (2008) analyze the relationship between pollution and income at the household level by formulating a model for estimating the consumption of goods by various types of households. The empirical analysis shows that an equalization of incomes will give rise to an increase in emissions. Household-level studies have a significant effect on policy because they help predict both the effects of changes in income distribution on emissions and the regressivity of environmental policies that target emission reductions (Kahn 1998).

2.3 Methodologies

2.3.1 Vector error correction model and Granger causality test

Many studies have focused on the relationship between economic growth and energy consumption using the vector error correction model (VECM) and the Granger causality test. Several of these studies employ the EKC hypothesis as the basis of their model specifications, performing a multivariate non-linear VECM and the Granger causality test based on panel or time series data. Ang (2007) examines the dynamic causal relationships between CO_2 emissions, energy consumption, and output in France using cointegration and VECM techniques based on the quadratic function of GDP. Following his study, Halicioglu (2009) examines CO_2 emissions, energy consumption and foreign trade in Turkey; Apergis and Payne (2009) estimate the same relation in Central America; and Pao and Tsai (2010) test this relationship in BRIC countries. Similar research has also been carried out by Jalil and Mahmud (2009), Iwata et al. (2010), Nasir and Rehman (2011), Wang, S.S. et al. (2011) and Jayanthakumaran et al. (2012). There are also a few studies that introduce both cubic and quadratic terms of GDP into the VECM and the Granger causality test (see Fodha and Zaghdoud (2010) on Tunisia, Piaggio and Padilla (2012) on 31 countries, and Ozturk (2010) for more details). In this paper, we adopt the quadratic form from Ang (2007).

2.3.2 Input-output analysis for estimating carbon emissions

Carbon emissions from consumption goods of household is defined as the carbon emissions caused by energy consumption of consumer goods in its raw materials, production, transportation, sales and end-use and so on, involved in all aspects of the life cycle of consumer goods. Due to the wide variety of consumer goods, complex intermediate production process and data limitation, the estimation of carbon emissions from consumption goods of household is facing many challenges. The existing studies of consumer goods embodied carbon emissions can be divided into two categories: Consumer Life-cycle Analysis (CLA) and input-output analysis (IOA).

There are few studies that use consumer life-cycle analysis to estimate carbon emissions from the resident consumption. Shui Bin et al (2005) use the CLA method to analyze the relationship between the U.S. consumer behavior and energy use and CO2 emissions in 1997. The study indicates the 28% of U.S. energy consumption and 41% of the CO2 emissions come from the direct consumption of households, and more than 80% of carbon emissions is attributed to consumer direct energy demand and indirect energy demand. A. M. Reinders et al.(2003)) pointed out that the life-cycle analysis of consumer goods need to provide highly detailed product life cycle data, including production, storage, transportation, consumption and recycling use. Therefore the application of this method is limited. Input-output model from the complex input-output relationships between departments, the physical movement and the movement of value of the economic system organically integrated, has a unique advantage in consumer goods carrier energy modeling, is currently the main method of carbon emissions from consumer goods. R. D. Kok et al.(2006) conducted a comprehensive survey of the energy consumption and carbon emissions calculation method based on input-output analysis and divided the methods into three categories:

“Basic input-output energy analysis method”, the “input-output + household spending” and “hybrid energy analysis method”. Eleni Papathanasopoulou (2010) analyzed the effect of consume pattern changes on energy consumption and carbon emissions of Greek using input-output analysis method in 1990-2006. The study found that 60% of the carbon emissions growth is attributed to the consumer. Rosa Duarte et al.(2010) estimated the impact of consumption patterns on CO2 emissions through 1999 Spanish Social Accounting Matrix (SAM) and households survey data. The study found the relation between the resident consumption and carbon emissions are mainly determined by the level of income. Meanwhile, the changes in consumption patterns caused by the increase in income play a complementary role in reducing carbon emissions.

In recent years, some researchers are devoted to the impact of China's consumer on the demand for energy and carbon emissions. Kuishuang Feng et al (2009) conducted a regional comparative study of the impact of consumption patterns and technological progress on China's carbon emissions based on IPAT model from year 1949 to 2002. They suggested that the consumer mode is important for mitigation of carbon emissions and sustainable development. Golley Jane et al. (2008) conducted a study on China's industrial sector energy and output data, as well as the pattern of household consumption mode in 2005. The findings of the their study shown that the indirect energy demand of urban households in China accounted for 32% of the industry's total energy demand. Wei Yiming et al.(2007) using the CLA method to analysis the 1999-2002 the impact of Chinese urban and rural residents consumption behavior of final energy consumption on CO_2 emissions. The study shows that 30% of the carbon emissions is generated directly by the household's consumption behavior each year, and the indirect energy consumption of household's consumption is 2.44 times of the direct energy consumption.

3 Regional Income Disparity and Carbon Emissions

3.1 Motivation for empirical analysis

The increase in CO_2 emissions due to growth depends not only on income level but also on how this growth is distributed (Brännlund and Ghalwash, 2008).Therefore, the distributional inequality of income should be an explanatory variable in the EKC relationship, along with the mean income level (Coondoo and Dinda, 2008). Although the inverted-U-shaped curve seems to reflect cross-country experience accurately, each country has its own income-pollution trajectory, the shape of which depends on its natural, economic and even social characteristics. Therefore, an analysis of the impact of regional income disparities on CO_2 emissions in individual countries can help to capture both the country effects and the effect of regional growth disparity.

In this chapter, we theoretically analyze the impact of regional income disparity on CO_2 emissions based on the EKC hypothesis and find that the regional income disparity will affect CO_2 emissions through the marginal emission propensities (MEP) of incomes in different regions. Finally, we obtain the hypothesis from our theoretical analysis.

Suppose that the relationship between income and CO_2 emissions has an inverted-U-shape at the region level. Therefore, c_i (per capita CO_2 emissions of region i) is a smooth function of y_i (per capita income of region i), and c_i is described by the function $G(\cdot)$, which is the same for all regions. Therefore, the per capita CO_2

emissions of region i and the whole country, respectively, as follows:

$$c_i = G(y_i) \quad i = 1, 2, \cdots, m \tag{3-1}$$

$$C = \frac{n_1 c_1 + \cdots n_m c_m}{N} \tag{3-2}$$

Where C is the per capita CO_2 emissions of the whole country, N denotes total population, n_i is the population of region i and m denotes the total number of regions in the country.

The way in which differences in regional income impact CO_2 emissions will depend on the properties of the function $G(\cdot)$. Consider following special case.

Assume that a country has two regions. Consider two income distribution cases: in case A, region2is richer than region 1, namely, there exists a regional income disparity in this country ($y_1 < y_2$). In case B, region 1 and region2 have the same per capita income $\bar{y}$, which is equal to $\frac{n_1 y_1 + n_2 y_2}{N}$. Therefore, the average per capita income of the country in both case A and case B are equal.

The comparison of CO_2 emissions in case A and case B can tell us the differences in CO_2 emissions resulting from the regional income disparities in the country, by holding the average per capita income of the country constant.

Therefore, the per capita CO_2 emissions in case A and case Bare defined by equation (3-3) and (3-4), respectively.

$$C_A = \frac{n_1}{N} G(y_1) + \frac{n_2}{N} G(y_2) \tag{3-3}$$

$$C_B = \frac{n_1}{N} G(\bar{y}) + \frac{n_2}{N} G(\bar{y}) \tag{3-4}$$

The differences in per capita CO_2 emissions between case A and case B are defined by the following equation:

$$C_A - C_B = \frac{n_1}{N}[G(y_1) - G(\bar{y})] + \frac{n_2}{N}[G(y_2) - G(\bar{y})] \tag{3-5}$$

According to the Lagrange mean value theorem $f(a) - f(b) = f'(\xi)(a-b)$ $(a < \xi < b)$, if the derivative of the function $G(\cdot)$ is continuous, then there exist ξ_1 ($y_1 < \xi_1 < \bar{y}$) and ξ_2 ($\bar{y} < \xi_2 < y_2$), such that

$$G(y_1) - G(\bar{y}) = G'(\xi_1)(y_1 - \bar{y}) = G'(\xi_1)(y_1 - \frac{n_1 y_1 + n_2 y_2}{N}) = G'(\xi_1)(\frac{n_2 y_1 - n_2 y_2}{N}) \tag{3-6}$$

$$G(y_2) - G(\bar{y}) = G'(\xi_2)(y_2 - \bar{y}) = G'(\xi_2)(y_2 - \frac{n_1 y_1 + n_2 y_2}{N}) = G'(\xi_2)(\frac{n_1 y_2 - n_1 y_1}{N}) \tag{3-7}$$

Thus, $C_A - C_B$ is

$$C_A - C_B = \frac{n_1 n_2}{N^2}[G'(\xi_1) - G'(\xi_2)](y_1 - y_2) \tag{3-8}$$

Under above assumptions, because $y_1 < y_2$, $\xi_1 < \xi_2$ and $G'(y_i)$ define a decreasing function ($G''(y_i) < 0$) in the EKC hypothesis, $y_1 - y_2 < 0$, $G'(\xi_1) - G'(\xi_2) > 0$ and $C_A - C_B < 0$. The result ($C_A - C_B < 0$) denotes that the per capita CO_2 emissions of case A, which has a regional income disparity, are lower than that of case B, which does not have a regional income disparity. Therefore, regional income disparity has a negative effect on carbon emissions.

This result indicates that the differences in per capita CO_2 emissions resulting from regional income disparity can be expressed as a weighted population ($\frac{n_1 n_2}{N^2}$), the first derivative of the function $G(\cdot)$ ($G'(\xi_1) - G'(\xi_2)$) and the differences in per capita income($y_1 - y_2$). The first derivative $G'(y_i)$ of the function $G(\cdot)$ is just the MEP of income. It is clear that this negative effect depends on the MEP of income. Under the hypothesis of the inverted-U relation, $G'(y_i)$ is a decreasing function, which means that the MEP of the low-income region is higher than that of the high-income region.

According to above theoretical analysis, we find that the disparity reduction of regional income will increase the average level of CO_2 emissions through different MEPs, under the EKC hypothesis. This finding opposes the effect that is postulated by Boyce (1994) based on political economy but agrees with the effect postulated by Ravallion et al. (2000) and Heerink et al. (2001) based on the EKC hypothesis.

To summarize briefly, one of the channels through which a regional income inequality may affect the 'income-pollution' relationship is through the differential MEPs of income between a wealthy region and a low-income region. As a result, reducing the income gap between regions could increase carbon emissions. Therefore, fighting poverty by either raising the average income or lowering the income gap will exacerbate global warming. According to the above analysis, we can propose our hypothesis. Hypothesis 1: regional income inequality has a negative, indirect impact on the average level of CO_2 emissions through the decreasing MEP of the GDP, for cases in which the relationship between CO_2 emissions and income is an inverted U-shaped relation

3.2 Empirical study

3.2.1 Model

The econometric model to examine Hypothesis 1 can be specified by Eq.(3-9):

$$LCO_2per_t = \alpha_0 + \alpha_1 LGDPper_t + \alpha_2 (LGDPper_t)^2 + \alpha_3 disparity_t + \alpha_4 LEG_t + \varepsilon_t \quad (3\text{-}9)$$

where the variables $disparity_t$, LCO_2per_t, $LGDPper_t$, $(LGDPper_t)^2$, and LEG_t denote the value of inequality measures, the natural logarithms of the per capita CO_2 emissions, the per capita real GDP, the square of the per capita real GDP and the technological progress(indicated by the energy intensity), respectively. Here, we employ three inequality measures: the Theil, Gini and Kakwani indexes. Because the technological progress of energy use plays an important role in CO_2 emissions and because greater technological progress can save more energy and reduce CO_2 emissions, we introduce this variable into the reduced form of the EKC specification. In this model, technological progress is indicated by the energy intensity, which is calculated as the energy consumption per unit of GDP. t and ε_t denote the time period and error terms, respectively; and ε_t is assumed to be independent and identically distributed with a zero mean and a constant variance. The sign of α_4 is expected to be positive because a higher energy intensity (lower technology) leads to higher CO_2 emissions. According to Hypothesis 1, α_1 is expected to be positive, whereas α_2 and α_3 are expected to be negative.

3.2.2 Data and methodology

3.2.2.1 Data

The focus of this study is to test the hypothesis above in China from 1978 to 2010. The annual data for per capita real GDP was obtained from the World Bank Development Indicators(WDI) from 1978 to 2010.The data for energy consumption and energy intensity were also obtained from the WDI from 1978 to 2009.The data on energy consumption and energy intensity in 2010 were collected from China Statistical Energy Yearbook (2011) published by the National Bureau of Statistics of China (NBSC).The source of the per capita CO_2 emissions data is the WDI from 1978 to 2008, and the data on CO_2 emissions per capita (2009 and 2010) were calculated based on energy consumption data according to the approach proposed by the Intergovernmental Panel on Climate Change(IPCC)(IPCC,2006).The per capita real GDP was measured using a constant US$ (2000). The CO_2 emissions per capita, energy consumption and energy intensity were measured using metric tons, kt of oil equivalent and (kg of oil equivalent) per $1,000 GDP.

There are several ways to measure inequality, each of which offers unique advantages and disadvantages. We have focused on the measures of concentration and entropy: the Gini index, the Kakwani index and the Theil index. The purpose of using three measures is to make a comparison and to test the sensitivity of the result across various measures. These measures can be calculated by the following three equations, using GDP per capita as the indicator of per capita income of the province. The data on per capita GDP of 31 provinces in China were obtained from the China Statistical Yearbook (2011) published by NBSC.

$$Gini = (1/2\mu)[1/n(n-1)\sum_{i=1}^{n}\sum_{j=1}^{i}\left|y_i - y_j\right|] \qquad (3\text{-}10)$$

$$Theil = \frac{1}{n}\sum_{i=1}^{n}(\frac{y_i}{\mu}\cdot\ln\frac{y_i}{\mu}) \qquad (3\text{-}11)$$

$$Kakwani = \frac{1}{(\mu\phi_n(k))}\sum_{i=1}^{n}(\mu - y_i)(n+1-i)^k \qquad (3\text{-}12)$$

where y_i, μ and n denote the per capita GDP of region i ,the average per capita GDP of all of the regions and the total number of regions in the country, respectively, and i is the position of the region in the ordered income distribution, k is a parameter and the function $\phi_n(k)$ either increases, decreases or remains constant with i depending on the value of k . The value of k may be chosen according to the society's preference for the sensitivity to an income transfer at various income positions (Kakwani, 1980).Here we substitute $k=1$.

3.2.2.2 Methodology

The empirical evidence from China can be found by testing whether the long-run and short-run dynamic causal relationships described in Eq.(3-9) exist. The primary estimation problem of the econometric model is spurious regression which may arise when time series data are employed in the level or non-stationary form. One solution is to make the series stationary by differencing. However, the differencing of the series would prevent a long-run analysis. To capture both the long-run and the short-run relations, we chose the vector error correction (VEC) model. The VEC model suggested by Engle and Granger (1987) is a restricted vector autoregression (VAR) model designed for using non-stationary series that are known to be cointegrated. The VEC model has cointegration relations built into the specification to restrict the long-run behavior of the endogenous variables to converge on their cointegrating relationships while allowing for short-run adjustment dynamics. The

VEC approach serves our estimation purpose well because it embodies both the long-run equilibrium (through the cointegration term) and short-run dynamics (through the lagged first difference terms of the explanatory variables).The cointegration term is known as the error correction term (ECT).VEC model based on the hypothesis in Eq.(3-9),is specified by Eq.(3-13). The quadratic VECM and Granger causality test can also be found in Ang (2007), Pao and Tsai (2010), Wang et al.(2011)and Jayanthakumaran et al. (2012).

$$\begin{bmatrix} \Delta LCO_2 per_t \\ \Delta LGDPper_t \\ \Delta(LGDPper_t)^2 \\ \Delta disparity_t \\ \Delta LEG_t \end{bmatrix} = \begin{bmatrix} a_1 \\ a_2 \\ a_3 \\ a_4 \\ a_5 \end{bmatrix} + \sum_{j=1}^{p} \begin{bmatrix} b_{11j} & b_{12j} & b_{13j} & b_{14j} & b_{15j} \\ b_{21j} & b_{22j} & b_{23j} & b_{24j} & b_{25j} \\ b_{31j} & b_{32j} & b_{33j} & b_{34j} & b_{35j} \\ b_{41j} & b_{42j} & b_{43j} & b_{44j} & b_{45j} \\ b_{51j} & b_{52j} & b_{53j} & b_{54j} & b_{55j} \end{bmatrix} \begin{bmatrix} \Delta LCO_2 per_{t-j} \\ \Delta LGDPper_{t-j} \\ \Delta(LGDPper_{t-j})^2 \\ \Delta disparity_{t-j} \\ \Delta LEG_{t-j} \end{bmatrix} + \begin{bmatrix} \theta_1 \\ \theta_2 \\ \theta_3 \\ \theta_4 \\ \theta_5 \end{bmatrix} ECT_{t-1} + \begin{bmatrix} e_{1t} \\ e_{2t} \\ e_{3t} \\ e_{4t} \\ e_{5t} \end{bmatrix} \tag{3-13}$$

where $\Delta LCO_2 per_t$, $\Delta LGDPper_t$, $(\Delta LGDPper_t)^2$, $\Delta disparity_t$ and ΔLEG_t denote the first differences of the same variables in Eq.(3-9); ECT_{t-1} denotes the ECTs that capture the long-run equilibrium in Eq.(3-9); t and e_t denote the time period and error term, respectively; and p is the optimal lag lengths determined by the Schwarz Information Criterion (SIC)and the Akaike Information Criterion (AIC).

Because the VEC specification only applies to the cointegrated series, the estimation procedure of the VEC specification involves four steps: the unit root test, the cointegration test, the Granger causality test of VEC models and the analysis of the impulse response function. In the following sections, we describe this procedure step by step.

In the first step, we verify the order of integration for the variables because the various cointegration tests are valid only if the variables have the same order of integration. We perform the unit root test using three approaches: the ADF test (Dickey and Fuller, 1979), the D-GLS test (Elliot et al., 1996) and the KPSS test (Kwiatkowski et al., 1992). The null hypotheses of both the ADF and the DF-GLS are that there is a unit root, whereas the null hypothesis of the KPSS is that the series is stationary.

In the second step, we test for cointegration using the approach of Johansen (1988) for the VEC model, constructed in levels. The purpose of the cointegration test is to determine whether a group of non-stationary series is cointegrated or not. The presence of a cointegrating relational form is the basis of the VEC specification.

The third step consists of the causality tests. The VEC model is often used to examine the Granger causality among the variables. Because the VEC model allows for long-run equilibrium as well as short-run dynamics, it makes three different sources of causality available. The first causality is the long-run causality, which can be tested through the test for cointegration. The existence of cointegration indicates that there is a long-run equilibrium relationship among the variables in at least one direction. Hence, the long-run causal relationship described in Eq.(3-9) can be captured in the ECT_{t-1} through the estimation of the VEC model (Eq.(3-13)). The statistical significance of the parameters in Eq.(3-9) provides evidence of this long-run causal relationship. The second type of causality is the short-run causality, which can be estimated using the Granger causality (Block exogeneity Wald tests) after estimating the VEC model. For each equation in the VEC model, this test displays the Wald statistics for the joint significance of the lagged terms of each of the endogenous variables in each equation. This approach also provides the statistic for the joint significance of all of the endogenous variables in the equation. The third type of causality is reflected through the significance of the coefficients of the ECTs. The coefficients of the ECTs indicate the error correction mechanism that drives the short-run changes of the variables back to their long-run relationship. Therefore, the statistical significance of the coefficient of the ECT provides evidence of this error correction mechanism, implying that the long-run equilibrium deviation has a significant impact on the short-run changes of the variables.

In the fourth step, we construct an impulse response function (IRF) based on the VEC model. The IRF can trace the effect of a one-standard-deviation shock in the i-th variable on current and future values of the other endogenous variables through the dynamic (lag) structure of the VEC model. In our study, we use the generalized impulse response function (GIRF) following Pesaran and Shin (1998), rather than the approaches that are based on a Cholesky decomposition, which are sensitive to the ordering of the variables in the VEC system. In the following sections, we describe this procedure step by step.

3.2.3 Empirical result

3.2.3.1 Unit root test

To assess the stationary properties of the series, we adopt the three different unit root tests mentioned above (ADF, DF-GLS and KPSS). The results of these unit root tests are reported in Table 3-1. Because both the ADF and DF-GLS tests share a null hypothesis that there is a unit root, a rejection of the null hypothesis indicates that the series is stationary. The results of the ADF and DF-GLS tests for all of the variables in VEC model appear to contain a unit root in their levels but are stationary in their first differences. The null hypothesis of the KPSS test is that there is no unit root; therefore, rejection of the null hypothesis means that there is a unit root. The results of the KPSS test for all of the variables suggest that all of the series are non-stationary in their levels but become stationary after taking the first difference. Hence, we conclude that all of the series are integrated at order one, i.e., I(1).

Table 3-1. Unit root test

Variables	ADF		DF-GLS		KPSS	
	Levels	First differences	Levels	First differences	Levels	First differences
LCO_2per	-2.4366	-2.6524*	-2.5547	-2.5660**	0.1249*	0.2371
LGDPper	-3.1851	-3.9974***	-4.2558***	-3.6381***	0.1038**	0.0423
$LGDPper^2$	-2.1554	-3.2113**	-2.1629	-2.8059***	0.1841**	0.0405
LEG	-1.6458	-3.1594**	-1.9276	-3.1920***	0.1485**	0.2936
Theil	-2.0114	-2.1715**	-1.3301	-1.7629*	0.1409*	0.2109
Gini	-0.7979	-2.1953**	-1.2791	-1.8582*	0.1471**	0.1755
Kakwani	-1.7801	-2.1226**	-1.3076	-1.8190*	0.1449*	0.1888

Notes：The regressions of levels include an intercept and trend, whereas the regressions of first differences are without intercept and trend. The lag lengths are selected using Schwarz information criterion (SIC). The nulls for all tests except for the KPSS test are unit roots.

* indicates the rejection of the null hypothesis at 10% levels of significance.
** indicates the rejection of the null hypothesis at 5% levels of significance.
*** indicates the rejection of the null hypothesis at 1% levels of significance.

3.2.3.2 Cointegration test

After taking the unit root tests, we verify that all of the variables in the VEC model are I(1), indicating that the cointegration tests of these variables are valid. We can now proceed to test for the presence of the long-run cointegration relationships. The Johansen cointegration tests are performed for the VEC model. The results of the trace statistic and the maximum eigenvalue statistic are indicated in Table 3-2. These results support the conclusion that there is at least one cointegrated relationship in VEC model.

Table 3-2. Cointegration Test of VEC Model

Model	Hypothesized No. of CE(s)	Eigenvalue	Trace Statistic	Maximum Eigenvalue Statistic
Model a	r = 0	0.989702	290.2104***	132.6989***
	r ≤ 1	0.912958	157.5115***	70.79960***
	r ≤ 2	0.762058	86.71191***	41.63609***
	r ≤ 3	0.593857	45.07582***	26.13042***
	r ≤ 4	0.479669	18.94540***	18.94540***
Model b	r = 0	0.974320	240.6466***	106.1997***
	r ≤ 1	0.891465	134.4469***	64.39983***
	r ≤ 2	0.668287	70.04706***	32.00103***
	r ≤ 3	0.552453	38.04603***	23.31522**
	r ≤ 4	0.398278	14.73082**	14.73082**
Model c	r = 0	0.990237	281.3162***	134.2443***
	r ≤ 1	0.904679	147.0719***	68.16467***
	r ≤ 2	0.734301	78.90724***	38.43633***
	r ≤ 3	0.573132	40.47091***	24.68711***
	r ≤ 4	0.419734	15.78381**	15.78381**

Notes: Model 1a, Model 1b and Model 1c represent the VEC model using the Theil index, Gini index and Kakwani index as inequality measures, respectively. r denotes the number of cointegrating equation.
* indicates the rejection of the null hypothesis at 10% levels of significance.
** indicates the rejection of the null hypothesis at 5% levels of significance.
*** indicates the rejection of the null hypothesis at 1% levels of significance.

Because the tests of the first two steps have provided enough evidence to carry out estimations of the VEC model, we estimate the VEC model to find the specific long-run cointegration equations and the short-run relations among the variables. The optimal lag lengths are found to be three in VEC model 1, based on the SIC, SBC and AIC. The estimated results of the ECTs of the VEC model are summarized in Table 3-3. By normalizing the coefficients of LCO_2per_t to one in the ECTs of the VEC models, we can obtain the cointegration equations of the VEC models in Eq. (3-14), in which *, ** and *** denote the 10%, 5% and 1% levels of significance, respectively. The subscripts a, b and c denote models using the Theil index, Gini index and Kakwani index as the inequality measures, respectively.

Table 3-3. Cointegration equation of VEC Model 1

Dependent	Independent variables					
LCO_2	$LGDP^2$	LGDP	LEG	Disparity Measures		
				Theil	Gini	Kakwani
1.0000	-0.0099**	1.5495***	0.9438***	-0.6288***		
	(0.0038)	(0.0571)	(0.01964)	(0.03983)		
	[-2.5818]	[27.1545]	[48.0487]	[-15.7850]		
1.0000	-0.0549***	2.2978***	1.1215***		-0.2108*	
	(0.0059)	(0.0965)	(0.0404)		(0.1032)	
	[-9.3398]	[23.8189]	[27.7486]		[-2.0428]	
1.0000	-0.0199***	1.8334***	0.9766***			-1.2411***
	(0.0035)	(0.0529)	(0.0199)			(0.0915)
	[-5.6657]	[34.6728]	[48.8693]			[-13.5589]

Notes: The values in parentheses are Standard errors, and t-statistics are in brackets The regressions include an intercept and trend.
* indicates the rejection of the null hypothesis at 10% levels of significance.
** indicates the rejection of the null hypothesis at 5% levels of significance.
*** indicates the rejection of the null hypothesis at 1% levels of significance.

$$LCO_2per_t = \begin{bmatrix} 1.5495_a*** \\ 2.2978_b*** \\ 1.8334_c*** \end{bmatrix} LGDPper_t + \begin{bmatrix} -0.0099_a** \\ -0.0549_b*** \\ -0.0199_c*** \end{bmatrix} (LGDPper)^2{}_t + \begin{bmatrix} -0.6288_a*** \\ -0.2108_b* \\ -1.2411_c*** \end{bmatrix} disparity_t + \begin{bmatrix} 0.9438_a*** \\ 1.1215_b*** \\ 0.9766_c*** \end{bmatrix} LEG \quad (14)$$

The results of Eq. (3-14) reveal the long-run relationship among CO_2 emissions, average income level, regional income disparity and energy intensity. All of the coefficients of the variables in Eq. (3-14) are statistically significant. Therefore, the estimation results support the EKC hypothesis in China. Our findings are broadly consistent with Ang (2007), Halicioglu (2009), Apergis and Payne (2009), Pao and Tsai (2010), Wang Y. et al. (2011), Jayanthakumaran et al. (2012), Iwata et al. (2010), and Nasir and Rehman (2011), who have all also reported an inverted U-shaped relationship between pollution and output based on the cointegration test without considering the income disparity variable. However, this result is different from the result of Wang S. S. et al. (2011), who find a U-curve relation. Meanwhile, all of the coefficients of inequality measures are negative and statistically significant, providing support for Hypothesis 1. Furthermore, the effect of energy intensity is positive, as expected.

3.2.3.3 Granger causality test

Because cointegration equations cannot reflect the short-run causal relationship, we perform the VEC-based Granger causality tests to find the short-run dynamic causalities among the changes in variables. The estimation results in Table 3-4 provide the short-run causal relations in the above VEC models. Fig. 3-1 summarizes the short-run Granger causality tests that are presented in Table 4.

The results in Table 4 provide some evidence of two bidirectional Granger causality relations and two unidirectional causality relations in VEC model (see Fig. 3-1). The 'CO_2—GDP' and 'GDP—disparity' bidirectional causality relationships indicate that there is an indirect causality running from disparity to CO_2 emissions through GDP in the short term (disparity→GDP→CO_2). These findings support Hypothesis 1. Meanwhile, the two reverse causalities ('CO_2→GDP' and 'GDP→disparity'), which are not analyzed in our theoretical analysis, are observed in the short run. The reverse causality from CO_2 to GDP suggests that the environmental degradation is a bottleneck of economic development, and it is consistent with the empirical results of Halicioglu (2009) and Pao and Tsai (2010). The reverse causality from GDP to income disparity supports the Kuznets hypothesis (Kuznets, 1955). Furthermore, the unidirectional causality from energy intensity to GDP (in model 1b and 1c) is similar to the empirical results of Ang (2007), Apergis and Payne (2009), Pao and Tsai (2010) and Wang S. S. et al. (2011) who use energy consumption instead of energy intensity. In addition, the unidirectional causality from energy intensity to CO_2 reveals that energy intensity has a causal impact on CO_2 emissions, which is consistent with most studies.

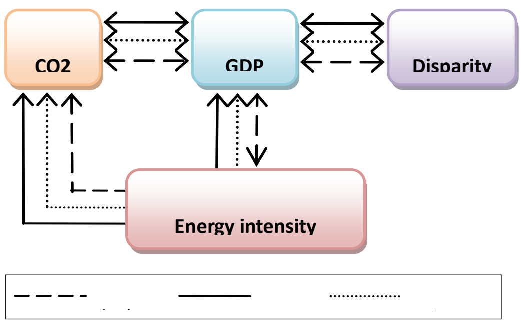


Fig. 3-1 Short-run causalities of VEC model

In addition, the causal relationship that indicates the impact of a long-run equilibrium on the short-run changes of variables can be judged by the statistical significance of the coefficients of the ECTs. Table 4 indicates that the coefficients of the ECTs that measure the speed of adjustment back to the long-run equilibrium value are statistically significant and negative in all of the GDP equations. This result indicates that when a shock occurs in the system, GDP will bear the burden of the short-run adjustments to re-establish the long-run equilibrium.

Table 3-4. Granger Causality test of VEC Model 1

Model	Depen.Var.	Long run ECT	Independent Variables: Short run Joint	△LCO₂	△GDPper	△LGDPper²	△LEG	△disparity: △Theil	△Gini	△Kakwani
		t statistics	Chi-sq statistics							
Model a	△LCO_2	-1.1261	22.0873**	-----	5.6697	7.7111*	7.8093*	2.2361	-----	-----
		[-1.0364]	(0.0366)		(0.1288)	(0.0524)	(0.0501)	(0.5249)		
	△GDPper	-2.1500***	23.1218**	16.9451***	-----	-----	14.2543***	18.6085***	-----	-----
		[-3.8238]	(0.0267)	(0.0007)			(0.0026)	(0.0003)		
	△$LGDPper^2$	-24.0076***	19.7749*	13.1248***	-----	-----	11.1598**	14.7931***	-----	-----
		[-3.2896]	(0.0715)	(0.0044)			(0.0109)	(0.0020)		
	△LEG	1.9637*	15.8914	1.8404	6.5511*	6.8246*	-----	4.4083	-----	-----
		[1.8048]	(0.1963)	(0.6062)	(0.0877)	(0.0777)		(0.2206)		
	△Theil.	0.0077	36.6978***	6.0807	16.6301***	17.5786***	2.1975	-----	-----	-----
		[0.0534]	(0.0003)	(0.1077)	(0.0008)	(0.0005)	(0.5324)			
Model b	△LCO_2	-0.9663	19.8272*	-----	5.4056	7.0651*	7.5631*	-----	2.3307	-----
		[-1.1587]	(0.0704)		(0.1444)	(0.0699)	(0.0560)		(0.5067)	
	△GDPper	-1.7368***	28.1693***	21.3732***	-----	-----	18.0919***	-----	22.8941***	-----
		[-4.4474]	(0.0052)	(0.0001)			(0.0004)		(0.0000)	
	△$LGDPper^2$	-19.3579***	24.9033**	16.8623***	-----	-----	14.3344***	-----	18.8286***	-----
		[-3.8289]	(0.0153)	(0.0008)			(0.0025)		(0.0003)	
	△LEG	1.4308	15.1437	1.3668	5.0226	5.5287	-----	-----	4.5791	-----
		[1.7666]	(0.2337)	(0.7133)	(0.1701)	(0.1369)			(0.2053)	
	△Gini	0.0942	28.9738***	4.1922	10.9411**	11.2277**	1.7325	-----	-----	-----
		[0.7718]	(0.0040)	(0.2414)	(0.0120)	(0.0106)	(0.6297)			
Model c	△LCO_2	-1.0862	20.8919*	-----	5.4372	7.2784*	7.3940*	-----	-----	2.4248
		[-1.0514]	(0.0520)		(0.1424)	(0.0635)	(0.0603)			(0.4890)
	△GDPper	-2.0797***	25.7732**	19.3411***	-----	-----	16.4699***	-----	-----	21.0249***
		[-4.1089]	(0.0116)	(0.0002)			(0.0009)			(0.0001)
	△$LGDPper^2$	-23.1213***	21.7571**	14.9149***	-----	-----	12.8643***	-----	-----	16.5403***
		[-3.5135]	(0.0403)	(0.0019)			(0.0049)			(0.0009)
	△LEG	1.7559	15.0435	1.5719	5.7594	6.0606	-----	-----	-----	3.8732
		[1.7005]	(0.2391)	(0.6658)	(0.1239)	(0.1087)				(0.2755)
	△Kakwani	0.0429	38.5147***	5.4419	16.0346***	16.8563***	1.7177	-----	-----	-----
		[0.6583]	(0.0001)	(0.1422)	(0.0011)	(0.0008)	(0.6330)			

Notes: The values in parentheses are p-values, and t-statistics are in brackets. 'joint' indicates the joint test of all the lagged independent variables in each equation. Model a, Model b and Model c represent the VEC model using the Theil index, Gini index and Kakwani index as the inequality measures, respectively. * indicates the rejection of the null hypothesis at 10% levels of significance. ** indicates the rejection of the null hypothesis at 5% levels of significance.*** indicates the rejection of the null hypothesis at 1% levels of significance.

3.2.3.4 Generalized impulse response function

The short-run Granger causality test does not explain how each variable responds to innovations in other variables and whether the response is negative or positive. Therefore, the GIRFs, based on the VEC models, are performed and shown in Fig. 3-2. According to the Granger causality test, none of the variables are the cause of the energy intensity in VEC model . Therefore, we only report the accumulated responses of CO_2, GDP and three inequality measures to the shocks from each variable in Fig. 3-2. The years after the impulse shocks are indicated on the horizontal axis, whereas the vertical axis measures the magnitude of the response, scaled in such a way that 1.0 is equal to 1 standard deviation. Here, we choose five years as the observation period. Our findings from VEC model 1, indicated in Fig. 3-2, include the following. (1) No matter which inequality measure is adopted, the shocks from GDP per capita and energy intensity have a positive impact on CO_2 emissions in China, whereas the regional income disparity has an increasingly negative impact on CO_2 emissions. (2) The shocks from CO_2 emissions and regional income disparity have a positive impact on GDP, whereas the shock of energy intensity has a negative impact on GDP. These results remain unchanged when a different inequality measure is used. (3) The shocks from GDP have a negative impact on the regional income disparity using the Theil index and the Kakwani index, whereas this effect changes from positive to negative when the Gini index is used.

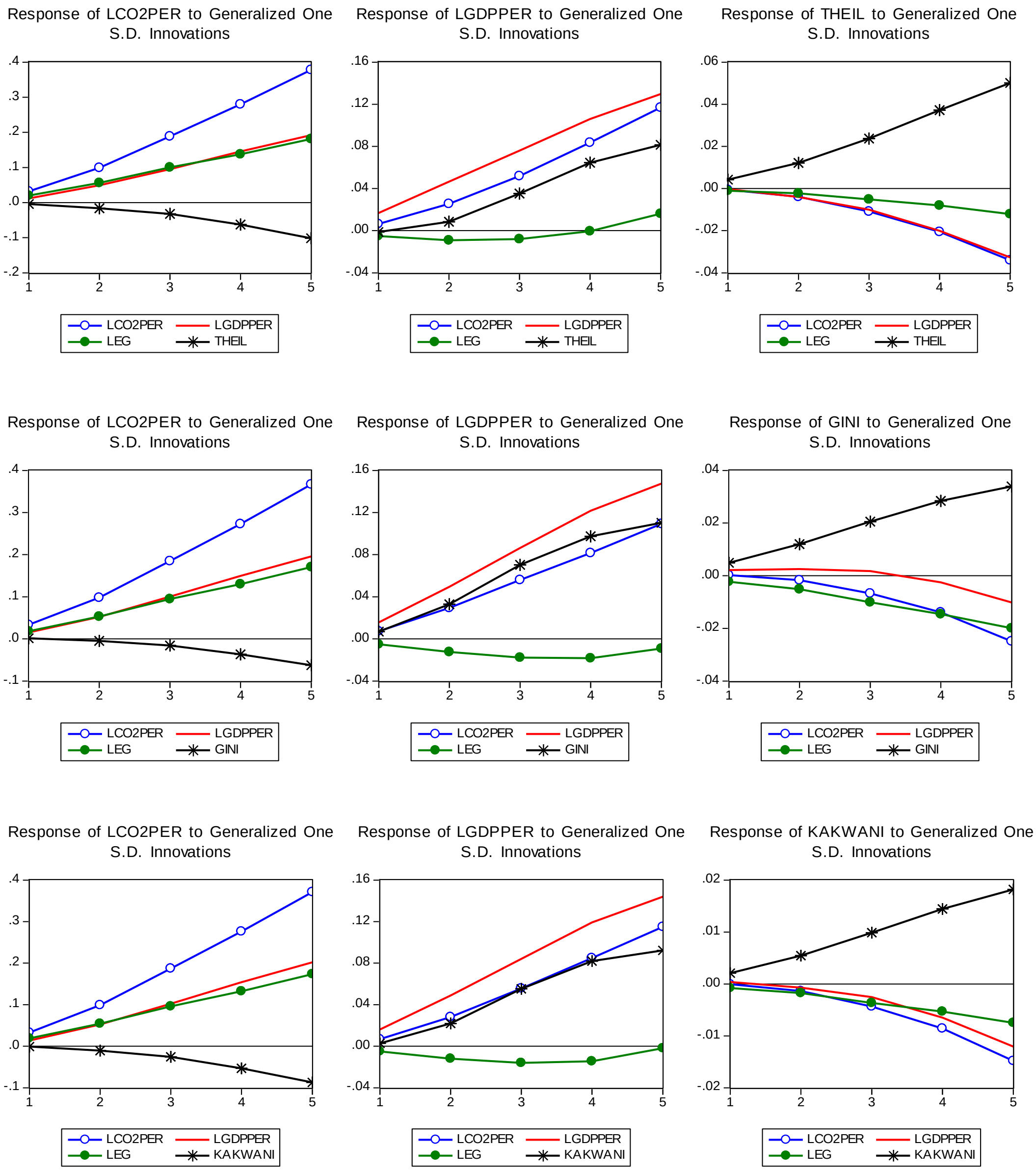


Fig. 3-2. Accumulated response of VEC model

3.3 Discussion and implications

3.3.1 Discussion

The empirical results of the VEC models provide some evidence for Hypothesis 1. The main findings of VEC model lead to the following implications.

(1) The regional income disparity has a negative effect on CO_2 through GDP in both the long run and the short run (disparity→GDP→CO_2). This result implies that there is a long-run trade-off between narrowing the income gap and reducing CO_2 emissions. The different MEP of GDP is considered to be the reason for this negative impact. The fact that different industries have different emission intensities led to a shift away from agriculture towards heavy industry during the earlier phases of development, with a consequent increase in the emissions per unit of output, whereas during the later stages of development, there is a shift from the heavy industrial sectors towards services and lighter manufacturing, with a subsequent decrease in the emissions per unit of output. Accordingly, the MEP of GDP falls (along with economic development), and the high-income region has a lower MEP of GDP than does the low-income region.

(2) This negative impact can be found in the following two ways. 1) In most developing countries, such as China, developing traditional industries to reduce inequality will definitely lead to a sharp rise in CO_2 emissions. This rise in CO_2 emissions occurs because the rapid growth of industry simultaneously increases energy consumption and industrial pollution in the initial stage of traditional industrialization. Environmental awareness in low-income regions is low; therefore environmental protection often gives way to economic growth. Even if low-income populations are informed that industrial pollution is not good for their health or for sustainable development, the limitations of financial support will make it difficult for

these communities to develop technological yet low-energy use industries. In fact, reducing the economic development disparity is associated with increases in CO_2 emissions. 2) Another way to reduce regional income disparity is inter-regional industry transfer and technology diffusion. This process of industry transfer from wealthy regions to low-income regions is primarily heavy and energy-intensive industry transfer, which is accompanied by the transfer of pollution and high carbon emissions. Consequently, before the elimination of the income gap, pollution and carbon emissions spread widely and have resulted in an increase in the average level of pollution and CO_2 emissions. Fig. 3-3 shows the increase in CO_2 emissions dues to the increase in secondary industry among provinces in China. It is obvious that the Gini index of secondary industry declines over the period of 1978 to 2010, which indicates that secondary industry (heavy and energy-intensive) among provinces has obtain an extensive development, along with a subsequent increase in CO_2 emissions.

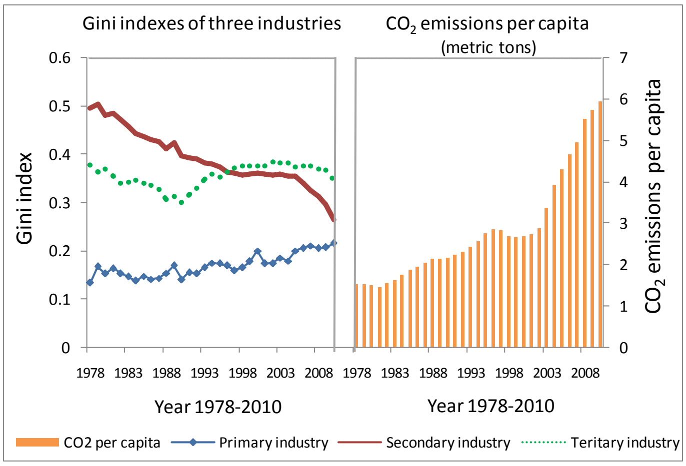


Fig.3-3 Industrial disparity and CO_2 emissions

Note: The Gini indexes of the three industries were calculated by author using equation (10). The data on the three industries of 30 provinces (1978 to 1994) were obtained from the 'China Compendium of Statistics (1949-2004)'compiled by NBSC, and the source of the data (1995 to 2010) is 'China Statistical Yearbook (2011)' published by NBSC.

(3) Fig.3-4 illustrates the group decomposition of the Gini index and CO_2 emissions per capita. The 30 provinces of China are divided into three subgroups: eastern region, central region and western region. According to Fig.3-4, we find that the between-group disparity accounts for the major part of the total regional income disparity. Chinese government has implemented the ‘Western China Development Strategy’ and ‘Central China Rise Strategy’ to narrow the income disparity between eastern, central and western China. However, these strategies result in the increase in CO_2 emissions when promoting the economic growth of central and western China. Therefore, the reduction of between-group disparity is the biggest contributor to this negative effect.

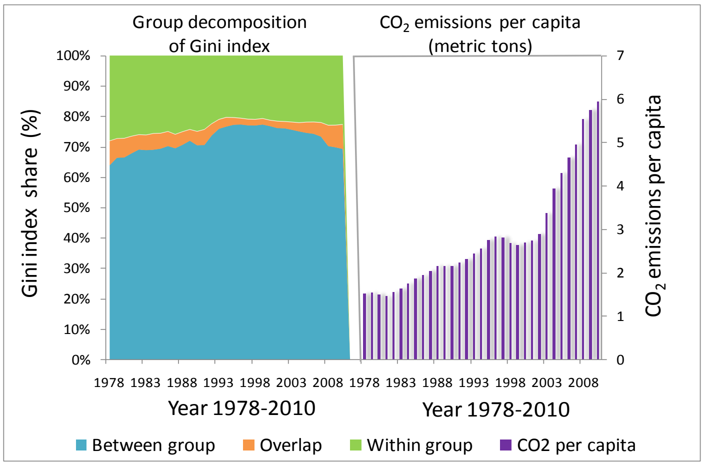


Fig.3-4 Group decomposition of disparity and CO_2 emissions

Note: The Group decomposition of Gini index is calculated by author according to the decomposition approach of Pyatt (1976). The 30 provinces are divided into three subgroups: eastern region, central region and western region. Table A2 in the appendices provides the composition of the subgroups.

(4) The Granger causality test and GIRF analysis indicate that energy intensity has a negative impact on GDP, which means higher energy intensity may restrain economic growth and is not good for sustainable development. Reducing energy

intensity is an effective way for developing countries to systematically rid themselves of energy-dependent industries.

3.3.2 Policy implications

Our findings emphasize the trade-off between reducing CO_2 emissions and reducing the regional income disparity, which indicates that the effects of energy-saving and emission-reducing policies will be altered by the actions that reduce the regional income disparity. Therefore, the policymakers of the central government should be conscious of this potential obstacle to energy-saving and emission-reducing policies, allowing the policies of the central government to be implemented successfully by the local governments. Because narrowing the economic disparity, reducing energy use and reducing CO_2 emissions are targets of social and economic development in most developing countries, such as China, we offer several policy suggestions to address this trade-off.

First, as it is indicated in VEC model , the difference of the MEP of GDP is the channel through which the regional income disparity may impact CO_2 emissions in a negative way. (1) To reduce the MEP of the GDP, the government should accelerate the transformation of industrial structures in low-income regions. Low-income regions can no longer rely on developing traditional industries to narrow the income gap with wealthy regions. (2) Because of the higher cost of environmental governance in low-income regions compared to wealthy regions, low-income regions can no longer accept the heavy industry or energy-intensive industry transfer from wealthy regions. To ensure that these industries are not transferred, local governments should set higher emission assessment criteria for new project investments. (3) Meanwhile, the targets for saving energy and reducing carbon in regions with different MEP s should consequently be different. (4) Furthermore, the negative causal relationship from energy intensity to GDP indicates to the policymakers of both central and local governments that lower energy efficiency will undoubtedly hamper economic growth, and thus greater investment is needed to develop technologies for improving the efficiency of energy use. (5) To reduce energy intensity, developing countries, such as china, may need to rely more on renewable energy sources by establishing a price mechanism to encourage the use of renewable energy, which will ensure an uninterrupted energy supply when traditional energy sources become scarcer. (6) In addition, it is the responsibility of the central government to increase transfer payments and investments in human capital and social infrastructure, especially encouraging capital and labor mobility, which is an effective way to reduce regional disparity without bearing the considerable pressure of CO_2 emissions and energy consumption.

3.4 Concluding remarks

This paper analyzes the relationship between regional income disparity and CO_2 emissions based on time series data in China over the period of 1978 to 2010, by employing the VECM, the Granger causality test and GIRF analysis. The motivation of this paper is from recent literature that emphasizes the important role that income distribution plays in the environmental Kuznets curve. Compared with previous studies, the main features of this study include the following. 1) The impact of income distribution on carbon emissions is studied at a regional level in an individual country, whereas other studies primarily focus on the effect of household income inequality on emissions using cross-country data. 2) The VECM, the Granger causality test and

GIRF analysis are employed in this study, whereas other studies adopt fixed effects and random effects methods based on panel data. 3) This paper chooses three measures of income inequality to make comparisons, whereas other studies use only the Gini coefficient as the measure. 4) An indirect causal relation that regional income disparity affects CO_2 emissions through the MEP of GDP is observed, whereas other studies primarily focus on the direct correlation between income inequality and CO_2 emissions.

The main findings of this study reveal that there is an inverted-U relationship between per capita CO_2 emissions and income in China, and the regional income disparity has a negative effect on the average level of CO_2 emissions through the decreasing MEP of the GDP. Meanwhile, the Granger causality test and the GIRF analysis show that energy intensity has a negative impact on GDP, which results in higher energy intensity that may restrain economic growth and does not promote sustainable development. Therefore, the policymakers of the central government should be conscious of this potential trade-off between narrowing the income gap and reducing CO_2 emissions. The policy implications include accelerating the transformation of the industrial structure in low-income regions, setting different targets of saving energy and reducing carbon for different regions, improving energy efficiency, refusing the transfer of heavy and energy intensive industries from wealthy regions, making higher emission assessment criteria for new project investments, encouraging capital and labor mobility, imposing eco-taxes or carbon-taxes and developing a market for emissions trading.

The weakness of this study stems from the restrictive assumptions of the theoretical analysis. Meanwhile, the time period in China needs to be extended, and the other driving forces of CO_2 emissions, such as industrialization and urbanization, should be introduced in the model. Further research in this field should include these variables and use a longer time series dataset. This study could also be improved by analyzing the interaction effects between GDP and regional income disparity and their effects on carbon emissions. The work to improve this study is currently underway.

4 Household Income Inequality and Carbon Emissions

4.1 Model specification

4.1.1 Motivation

4.1.1.1 The composition of GDP and CO_2 emissions

The reduced form of environmental Kuznets curve (EKC) is widely used as the main model specification in the studies on relationship between economic growth and carbon emissions. According to the different research concern, experts have made lots of correction and extension about the reduced form. In terms of the income inequality effects on carbon emissions, the studies mentioned before also employ the reduced form of EKC as the main part of their model and introduce the income inequality variable (Gini coefficient) into the EKC specification. Moreover, the interaction terms of inequality variable with other variables are also considered in some of these studies. Directly add income inequality variable into the EKC model indicates that the income inequality has a direct effect on the carbon emissions. However, in the real world, the direct driving forces of CO_2 emissions are economic growth, energy consumption, household consumption investment, international trade and so on, not inequality issues. It seems difficult to relate household income inequality with carbon emissions directly. Therefore, in this paper, we consider an indirect causality running from household income inequality to carbon emissions through the direct driving forces of CO_2 emissions. Since GDP as the indicator of income in the reduced form of EKC model captures only the net effect of income on CO_2 emissions, the effect composition of GDP on carbon emission are obscured. This ‘black box’ makes it difficult to explain how household income inequality will affect CO_2 emissions through the composition of GDP. Thus, the relation between the composition of GDP and CO_2 emissions, and the relation between the composition of GDP and household income inequality are two key relationships which can help us to find the link between carbon emissions and income inequality.

The relation between the composition of GDP and CO_2 emissions in China can be clearly observed in Fig. 4-1. The primary vertical axis in Fig. 4-1 denotes the percentage (unit:%), while the secondary vertical axis represents the carbon emissions (unit: metric tons). The growth rate of GDP, the household final consumption share in GDP and the investment share in GDP are reflected through the primary vertical axis, while CO_2 emissions per capita is shown via the secondary vertical axis. From Fig. 4-2, we can find that the CO_2 emissions per capita increase slowly, before year 2000, but become quickly after year 2000. Moreover, during the period 1978 to 2011, the growth rate of GDP fluctuates around 10%. Before 2000, the average annual growth rate of GDP is 9.78% and the average annual growth rate CO_2 emissions per capita is 2.41%. After 2000, the average annual growth rate of GDP is 10.38% and the average annual growth rate CO_2 emissions per capita is 8.41%. Consequently, we can find that 1% GDP growth causes 0.24% growth of CO_2 emissions per capita in the period 1978 to 2000, while 1% GDP growth leads to 0.81% growth of CO_2 emissions per capita in the period 2001 to 2011. Why the same economic growth rate causes more carbon emissions per capita after year 2000? It might be explained by the changes of the composition of GDP. Before year 2000, the household final consumption share in GDP and the investment share in GDP change not so much, and the percentage of household final consumption is higher than the percentage of investment. However, after 2000, the percentage of household final consumption decrease rapidly and the investment share increase quickly. After year 2004, investment share exceeds the household final consumption share in GDP. In the period 1978 to 2000, the household final consumption share in GDP decreases from 49% to 47%, while it decreases from 47 to 34% (from 2000 to 2011). Meanwhile, the investment share in GDP increase from 29% to 34% (from 1978 to 2000), while it increase from 34% to 46% during the period of 2000 to 2011. Therefore, the CO_2 emissions per capita increase sharply when the investment share increase quickly. The substitution of consumption by investment leads to more CO_2 emissions.

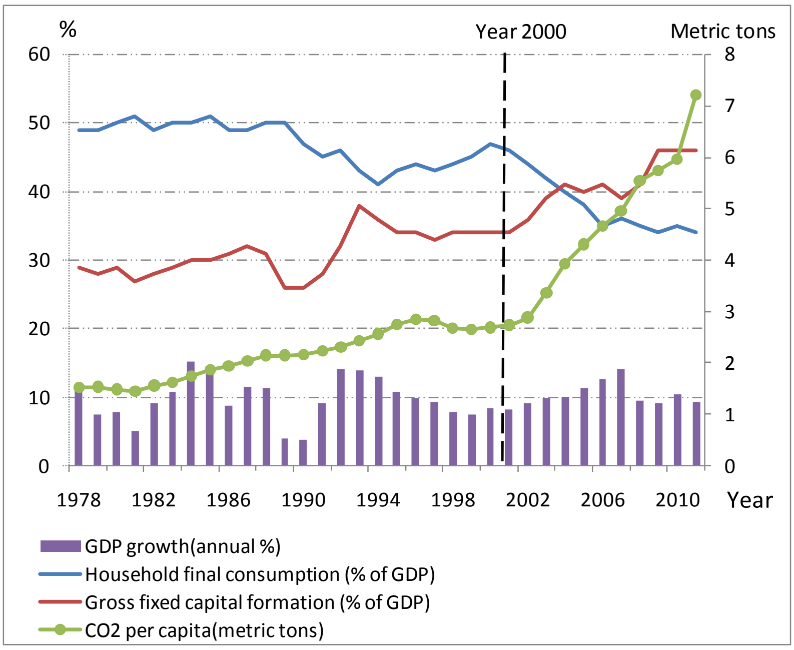


Fig. 4-1 The trend of the composition of GDP, growth rate of GDP and CO2 emissions per capita

Data source: WDI 2012

4.1.1.2 Household income inequality, composition of GDP and CO_2 emissions

As Fig. 4-1 shows that the household income consumption share in GDP has experienced a great decrease, while the investment share in GDP is increasing. As we all know, the direct cause of the China's rapid economic growth is investment growth, including domestic investment growth and international China's foreign direct investment (FDI). The high domestic investment rate comes from the high domestic savings rate which is caused by the inhibition of consumption. According to the traditional Keynesian absolute income hypothesis, the marginal propensity to consume of rich household is lower than that of poor household. Therefore, the equalization of income distribution increases aggregate consumption in the country. Similarly, consumption will decline if income inequality increases. Von Doorn (1975) finds that an increase in income inequality will have a negative effect on consumption. Blinder (1975), rejects the conventional Keynesian wisdom based on the time-series data of the United States. Della Valle and Oguchi (1976) found a significant negative relationship between the average propensity to consume and income inequality in developed countries. The findings of Khan (1987) are in accordance with the conventional Keynesian wisdom for 20 developing countries. As for China, Fig.4-2 (1) shows the scatters of household Gini index and Household final consumption share in GDP for the period 1978 to 2010. It is obviously that household income inequality (indicated by household Gini) is inversely related to aggregate household consumption share in GDP (total income), which is consistent with Keynesian wisdom.

Fig.4-2 (3) shows the scatters of CO_2 emissions per capita and household final consumption share in GDP from 1978 to 2010. The CO_2 emissions per capita decreases along with the increase of household consumption share in GDP. That is because the CO_2 emissions per capita from on unit household final consumption are less than that from on unit investment. Thus the substitution of investment by consumption leads to less CO_2 emissions. According Fig.4-2 (1) and Fig.4-2 (3) together, we can simply explain the negative relationship between household income inequality and carbon emissions observed in Fig.4-2 (4) which is the Scatters of CO_2 emissions and household Gini coefficient. The indirect impact of household income inequality on CO_2 emissions through the household consumption share in GDP is found in this way: The increase of income inequality will inhibit consumption and promote savings, thus investment. Consequently, the substitution of consumption by investment will lead to an increase of CO_2 emission.

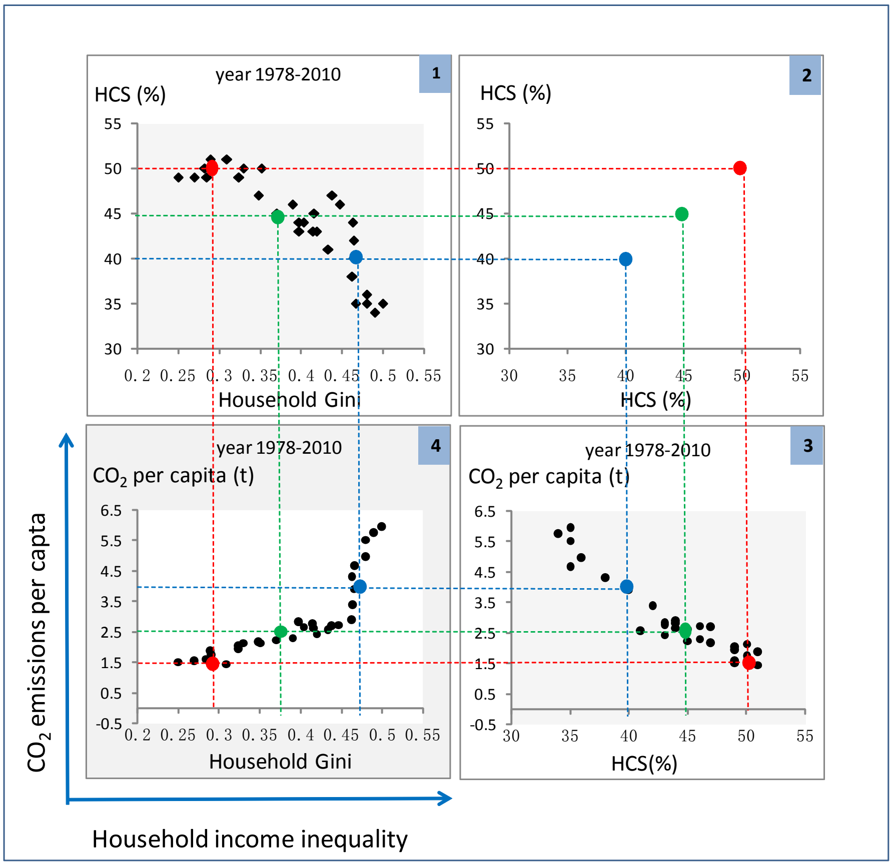


Fig. 4-2 Scatters of CO2 emissions and household Gini index

4.1.2 The model

As we have mentioned before, the limited to my knowledge, there are seldom empirical studies that estimate the relationship between carbon emissions and household income inequality by simultaneous equation model (SEM). Meanwhile, according to Kuznets (1955), income inequality is determined by a nonlinear function of GDP per capita. Thus, income inequality should be treated as endogenous. Furthermore, there are also some studies that focus on the effect of income distribution on aggregated consumption function. Consequently, we combine a single equation of GDP per capita affecting carbon emissions with an extended Kuznets curve function and an extended aggregated consumption function to establish a simultaneous equations model. The model specifications of the SEM are explained in the followings.

4.1.2.1 Carbon emissions equation

The empirical studies on carbon Kuznets curve (CKC) mainly adopt several reduced form, including quadratic, cubic, logarithmic of per capita income (GDP per capita). In this study, we employ the quadratic term of GDP per capita as the main part of carbon emissions equation. Besides per capita income, there are also many driving forces that can affect carbon emissions, such as: population size, technology progress, energy efficiency and so on. Therefore, based on the classical econometrical model proposed by Grossman and Krueger (1995), this paper introduces household final consumption share in GDP, population, R&D expenditure (indicator for technology progress), capital-labor ratio and energy efficiency into the model to describe how household final consumption share in GDP directly affects carbon emissions. The carbon emissions determined equations is shown in eq. (4-1):

$$\ln CO_2 per_{it} = a_0 GDPper_{it} + a_2 (GDPper)^2{}_{it} + a_3 HCS_{it}$$
$$+ a_4 \ln P_{it} + a_5 \ln RDG_{it} + a_6 \ln KL_{it} + a_7 \ln GE_{it} + \mu_i + e_{it} \quad (4\text{-}1)$$

where $GDPper_{it}$, $(GDPper_{it})^2$ and HCS_{it} represent the GDP per capita, the square of the GDP per capita and the household final consumption share in GDP in province i, year t, respectively. The variables $\ln CO_2 per_{it}$, $\ln P_{it}$, $\ln RDG_{it}$, $\ln KL_{it}$ and $\ln GE_{it}$ denote the natural logarithms of CO_2 emissions per capita, the population size, the percentage of the R&D expenditure in GDP (suggested by Yang et al. (2011)), the capital-labor ratio (suggested by Managi et al. (2009)) and the energy efficiency in province i, year t, respectively. Energy efficiency is GDP per unit energy consumption. In addition, according to the category of household consumption, HCS_{it} includes total household consumption share ($HCStot_{it}$), urban household consumption share ($HCSurb_{it}$)and rural household consumption share ($HCSrur_{it}$). More details of the data for each variable can be found in Table 4-2. μ_i and e_{1it} denote the individual province effect and a random disturbance, respectively. According to EKC hypothesis, a_1 is expected to be negative and a_2 is expected to be positive. Fig. 4-1 suggest that household final consumption share in GDP has a negative effect on carbon emissions per capita, thus a_3 is expected to be negative. Population size and the capital-labor ratio has been proved to have a bad effect to emissions, therefore a_4 and a_6 are expected negative. R&D expenditure and energy efficiency will help to improve the productivity, thus a_5 and a_7 are assumed to have a positive sign.

4.1.2.2 Income inequality equation

As it is well known, Kuznets hypothesis suggests that there is an “inverted-u” relationship between income distribution and economic growth. Thus, the income inequality should be treated as endogenous variable. The main model specification of income inequality is the quadratic nature logarithm function of GDP per capita. The quadratic model assumes a symmetrical curve, while the quadratic log function assumes that an asymmetrical curve which means a more gradual decrease on the downward slope once it passes the turning point. Since the speed of improvement in income inequality is not as quickly as the speed of deterioration in the real world and inequality level cannot fall at the same rate as it increased, the quadratic logarithmic function seems to reflect a more realistic situation. Thus, we select the quadratic nature logarithm function as the basic model in this paper. Meanwhile, education expense, human capital, base pension insurance and urbanization are all important factors which can affect income distribution remarkably. Therefore, this paper structures the model to describe the income distribution ($Gini_{it}$) determined equations for urban-rural household income inequality ($Tgini_{it}$), urban household income inequality ($Ugini_{it}$) and rural household income inequality ($Rgini_{it}$), as eq. (4-2) shows:

$$\begin{aligned} Gini_{it} &= b_0 \ln GDPper_{it} + b_1(\ln GDPper)^2{}_{it} + b_2 HCL_{it} + b_3 FDI_{it} \\ &+ b_4 BPIS_{it} + b_5 EduExG_{it} + b_6 Urb_{it} + b_7 \ln CO_2 per_{it} + b_8 HCS_{it} + \alpha_i + \varepsilon_{it} \end{aligned} \tag{4-2}$$

where $\ln GDPper_{it}$ and $(\ln GDPper)^2$ stand for the natural logarithms of the GDP per capita, the square of the natural logarithms of the GDP per capita in province i, year t, respectively. The variables, HCL_{it}, FDI_{it}, $BPIS_{it}$, $EduExG_{it}$ and Urb_{it}

denote human capital (the percentage of labor with College education and higher level), Foreign direct investment, base pension insurance share (the percentage of employee with basic pension insurance), the percentage of education expenditure in GDP and urbanization in province i, year t, respectively.. HCL_{it}, FDI_{it} and $BPIS_{it}$ are all suggested by Xiaolu Wang and Gang Fan (2005). Urb_{it} is suggested by Wan et al. (2006). More details of the data for each variable can be found in Table 4-2. α_i and ε_{it} denote the individual province effect and a random disturbance, respectively. In addition, the variables $\ln CO_2 per_{it}$ and HCS_{it} in the income inequality equation are used to test whether there exist the feedback effect from carbon emissions to income inequality, and whether HCS_{it} affect the income inequality.

4.1.2.3 Consumption equation

According Keynes (1963) more equal distribution of income will benefit to the higher levels of consumption. Blinder (1975) employ dynamic aggregated consumption equation to test this issue, by regressing the average propensity to consume (APC) and the lag term of APC on the measure of income inequality. Valle and Oguchi (1976) use the model specification of Blinder (1975), employ Gini coefficient as the measure of income inequality in order to examine whether Blinder's results also hold for cross-country dataset. Khan (1987) also use the similar function to test the inequality- consumption issue based on the developing countries panel dataset.

We also estimate Blinder's dynamic aggregated consumption equation. In a words, it requires regressing the APC on the inverse of disposable income, the income distribution variables and the lagged APC. In this study, we consider GDP as the total income, as Valle and Oguchi (1976) did. Thus, the APC can be calculated by the household consumption divide GDP, which is just the household consumption share in GDP. The consumption determined equations is shown in eq. (4-3):

$$HCS_{it} = c_0 Gini_{it} + c_1 HCS_{it\text{-}1} + c_2 (inc)^{-1}{}_{it} + c_3 \ln CO_2 per_{it} + c_4 IV_{it} + \beta_i + \omega_{it} \qquad (4\text{-}3)$$

where IV_{it} is a vector of the control variables, $Unem_{it}$, DUE_{it}, DRL_{it} CPI_{it} and IR_{it}. $Unem_{it}$, DUE_{it} and DRL_{it} represent unemployment rate, dependents per urban employee, and dependents per rural labor force, which is used to control the uncertainty of income. In China, the data on unemployment rate are not so good, therefore some literature suggest to use dependents per urban employee, and dependents per rural labor force to instead it (Hang, 2009). CPI_{it} and IR_{it} denote Consumption price index and deposit interest rate, respectively, which is suggested by Qin et al. (2009), Wan et al. (2001),Yu et al. (2000). Meanwhile, the variable $(inc)^{-1}{}_{it}$ indicates the inverse of population weighted per capita income of household. Furthermore, in the following empirical estimation, $(inc)^{-1}{}_{it}$ are replaced by $(Tinc)^{-1}{}_{it}$ $(Uinc)^{-1}{}_{it}$ and $(Rinc)^{-1}{}_{it}$ which indicate the inverse of population weighted per capita income of total household, the inverse of urban per capita disposable income and the inverse of rural per capita net income, respectively. More details of the data for each variable can be found in Table 4-2. β_i and ω_{it} denote the individual province effect and a random disturbance, respectively. In addition, the variable $\ln CO_2 per_{it}$ in the consumption equation aims to examine the the feedback effect from carbon emissions to household consumption share in GDP.

4.2 Methodologies and data

4.2.1 Carbon emission data

Since China has no official CO_2 emissions data for each province, we calculated the CO_2 emissions for 30 provinces of China from 1995 to 2010, based on the the IPCC reference approach (Intergovernmental Panel on Climate Change (IPCC), 2006). We estimate the CO_2 emissions from seven kinds of fossil fuel: coal, coke, gasoline, kerosene, diesel, fuel oil and natural gas. The consumption data of all these fossil fuels are compiled from the regional energy balance tables in China Energy Statistical Yearbook (1996-2011). The eq. (4-4) is the formula we used to estimate CO_2 emissions.

$$TE_j = \sum_{i=1}^{7} TE_{ij} = \sum_{i=1}^{7} E_{ij} \times \left(NCV_i \times CEF_i \times OC_i \right) \times \frac{44}{12} \tag{4-4}$$

where TE_j is the total CO_2 emissions from all types of energy consumption in province j; i indicates the type of fossil fuel, ($i=1,\cdots,7$). E_i represents the total consumption of the i th fossil fuel in province j. NCV_i is the net calorific values ofthe i th fuel. and CEF_i denotes the carbon emission factor of the i th fossil fuel. OC_i stands for the i th fuel's fraction of carbon oxidized. $\left(NCV_i \times CEF_i \times OC_i \right) \times \frac{44}{12}$ indicates the CO_2 emissions factors for i th fuel. The coefficients for each type of fossil fuel are provided in Table 4-1.

Table 4-1 Coefficients for fuels used in IPCC reference approach.

Fossil Fuel	Coal	Coke	Gasoline	Kerosene	Diesel	Fuel oil	Natural gas
NCV	20.52	28.2	44.8	44.67	43.33	40.19	48
CEF	24.74	29.5	18.9	19.55	20.2	21.1	15.3
OC	0.90	0.97	0.98	0.98	0.98	0.98	0.99

Source: IPCC (2006)

4.2.2 Inequality data

There are many methods to measure the income inequality. In this paper, we adopt Gini coefficient as the indicator of China's urban-rural, urban and rural household income inequality. According to China's Statistical Yearbooks of 30 Provinces, most of the urban and rural household survey data are based on the income groups with non-equal population size. Therefore, we employ the non-equal calculation method proposed by Thomaset al (2003) to calculate the Gini coefficient of urban household and rural household separately, refer to eq.(4-5) and eq.(4-6). Then we adopt the method proposed by Sundrum (1999) to calculate the Gini coefficient of urban-rural household income inequality, refer to eq. (4-7).

$$Gini = \frac{1}{\mu}\sum_{i=2}^{N}\sum_{j=1}^{i-1} p_i \left| y_i - y_j \right| p_j \tag{4-5}$$

$$Gini = \sum_{i=1}^{N} W_i Y_i + 2\sum_{i=1}^{N-1} W(1-V_i) - 1 \tag{4-6}$$

$$GINItotal = p_1 \frac{\mu_1}{\mu} Gini_1 + p_2 \frac{\mu_2}{\mu} Gini_2 + p_1 p_2 \left| \frac{\mu_2 - \mu_1}{\mu_t} \right| \tag{4-7}$$

Where $Gini$ denotes the Gini coefficient, μ represents the mean of the total income. N stands for the total number of the groups divided. y_i is the average income of the i th group. p_i is the population proportion of the i th group . W_i indicates the population proportion of the i th group and Y_i presents the income proportion of the i th group. V_i is the accumulation of Y_i from the first group to the i th group. In eq. (4-7), $GINItotal$ denotes the urban-rural Gini coefficient. $Gini_1$ is the urban household Gini coefficient; $Gini_2$ is the rural household Gini coefficient; p_1 and p_2 stand for the proportion of urban population and rural population respectively. μ_t, μ_1 and μ_2 represent the average income per capita of the whole, the average income per capita of urban and rural, respectively.

4.2.3 Data description

This paper adopts the Chinese provincial panel dataset. Because the household survey data of Tibet is not available, we delete Tibet, and finally get a dataset cross 30 provinces over 16 year. All the data we used are collected from following statistics yearbooks: 《Chinese Statistical Yearbook》(CSY), 《Educational Statistical Yearbook of China》(ESYC), 《China Population Statistics Yearbook》(CPSY), 《 China Yearbook of Rural Household Survey》(CYRHS),《China Energy Statistical Yearbooks》(CESY),《China labor Statistical Yearbook》(CLSY),《China Statistical Yearbook on Science and Technology》(CSYS&T), China Monthly Economic Indicators (CMEI) and the Statistical Yearbooks of 30 Provinces (SYP) from 1996 to

2011. The data on GDP per capita, urban per capita disposable income, rural per capita net income, GDP and consumption of household are all adjusted according to CPI (1978=100) in each province. The definitions of the variables, unit and sources of the data used in our model are presented in Table 24-. Table 3 provides the summary of descriptive statistics of the variables. We also divide the 30 provinces into 3 groups: eastern, western and central regions. The composition of each group can be found in Table A2.

Table 4-2 Definitions and data source of the variables

Variables	Definition	Unit	Source
$lnCO_2per$	CO2 per capita	ton	CESY
lnGDPper	The nature logarithms of GDP per capita	yuan	CSY
$ln(GDPper)^2$	The square of nature logarithms of GDP per capita	yuan	CSY
HCStot	Average propensity to consumption total	%*100	SYP
HCSurb	Average propensity to consumption of urban household	%*100	SYP
HCSrur	Average propensity to consumption rural household	%*100	SYP
lnGE	The nature logarithms of GDP / Energy	10000 yuan / ton of SCE	SYP, CESY
lnP	The nature logarithms of population	10000 persons	SYP
Urb	urbanization	%*100	SYP
lnKL	The nature logarithms of Fixed Capital / labor	100 million yuan / 10000persons	SYP
lnRDG	The nature logarithms of R&D / GDP	%*100	SYP, CSYS&T
Tgini	Urban-rural gini	----	SYP, CYRHS
Ugini	Urban gini	----	SYP, CYRHS
Rgini	Rural gini	----	SYP, CYRHS
HCL	Human capital / labor	%*100	ESYC, CPSY
EduExG	Education expenditure / GDP	%*100	ESYC, CSY
Unem	Unemployment	%*100	SYP
BPIS	Number of People Participating in Basic Pension Insurance / Staff	%*100	CLSY
FDI	Foreign Direct Investment	10000 us dollar $	SYP, CYRHS
Tinc	Total per capita income	yuan	SYP, CYRHS
Uinc	Urban Per Capita Disposable Income	yuan	SYP, CYRHS
Rinc	Rural Per Capita Net income	yuan	SYP, CYRHS
CPI	Consumption price index	------	SYP
DUE	Dependents Per Urban Employee	person	SYP
DRL	Dependents Per rural Labor Force	person	SYP
IR	Deposit interest rate	%	CMEI
staff	Year-end Employed Persons	10000 persons	SYP
labor	Population with the age 16-54	10000person	CPSY

Table 4-3 Summary of descriptive statistics

	Mean	Median	Maximum	Minimum	Std.Dev.	Skewness	Kurtosis	Sum
GDPper	15259.62	10666.5	78989	2048	13669.57	2.202216	8.589721	5310349
GDPper2	4.18E+08	1.10E+08	6.20E+09	4200000	8.83E+08	4.171646	22.74639	1.46E+11
HCStot	40.20972	39.81185	77.0998	23.2233	7.621763	1.174963	6.950809	13992.98
HCSrur	14.27282	13.5785	48.0724	1.95044	7.709427	1.130701	5.506324	4966.941
HCSurb	25.9369	26.1692	40.4449	12.4936	4.906424	-0.155235	3.032773	9026.041
Rgini	0.297745	0.296772	0.402	0.124433	0.050707	-0.505225	3.54559	103.6152
Ugini	0.271042	0.271775	0.383	0.165	0.042904	0.08876	2.447484	94.3225
Tgini	0.364905	0.369	0.49	0.129807	0.057746	-0.931791	5.151163	126.987
Urb	4908.196	38.0524	291174	0.734	36826.13	7.424567	56.16027	1708052
Unem	5.434856	3.82	41.2	0.58	6.000985	3.515272	16.0768	1891.33
DUE	2.40229	1.886	192	1.178	10.19473	18.56361	345.7403	835.9969
DRL	1.531003	1.49	3.06	0.44	0.306662	1.904708	14.0984	532.7891
CPI	102.178	101.7	111.6	96.4	2.978792	0.669253	3.121531	35557.93
FDI	29.54451	9.34285	284.978	0.003175	48.87269	2.627321	10.07041	10281.49
IR	3.17319	2.25	7.47	1.98	1.596755	1.634032	4.508206	1104.27
EduExg	3.82761	3.7059	7.37163	2.07385	0.90024	1.089993	4.496157	1332.008
HCL	7.715024	6.08164	36.7122	0.831249	6.059345	2.503185	10.39965	2684.828
BPIS	28.0196	20.6952	113.493	5.06128	20.18708	1.904889	6.944386	9750.819
lnGDPper	9.333085	9.27486	11.2771	7.62462	0.751141	0.387521	2.528177	3247.914
lnGDPper2	87.66907	86.02305	127.172	58.1348	14.25462	0.552139	2.732935	30508.84
lnP	8.150443	8.24918	9.2535	6.19032	0.710948	-1.047329	3.851235	2836.354
lnCO2per	1.245716	1.265055	2.77384	-0.047429	0.544322	0.075832	2.736715	433.509
lnGE	-0.406964	-0.39831	0.707813	-3.10625	0.502144	-0.662305	4.583325	-141.6235
lnRDG	-0.335946	-0.38939	1.93947	-4.8324	0.849725	-0.100737	4.871328	-116.9092
lnKL	-0.418101	-0.48634	1.52999	-2.32251	0.855636	0.164163	2.036636	-145.4991

4.3 Empirical results

Since there are endogeneity among variables and lagged dependent variables in the model specifications and heteroscedasticity among different provincial estimating equations, this paper adopts two estimation methods, generalized method of moments estimation (GMM) and system GMM to estimate the simultaneous equations

4.3.1 Household income inequality and carbon emissions

The estimation of the SEMs are performed according to three types of income inequality: urban-rural household income inequality, urban household income inequality and rural household income inequality, to see the effect of different income inequality on per capita carbon emissions in China.

4.3.1.1 Urban-rural inequality and carbon emissions

We first estimate the urban-rural inequality effects on carbon emissions using provincial panel dataset mentioned before. The results of both GMM estimators and system GMM estimators are given in Table 4-4, and the comparison of the estimation results of the two methods are in Table 4-7.

We first discuss the GMM estimators in the urban-rural SEM. (1)As for carbon emission equation, the GMM estimators suggest that the coefficient of squared GDP per capita term is negative and the coefficient of GDP per capita is positive and statistically significant at 1% level, which provides the evidence for an inverted-U relationship between CO_2 emissions per capita and income per capita. Meanwhile, the sign of coefficient of HCStot (total household consumption share in GDP) is also found to be negative and significant at 1% level, which indicates that the decrease in percentage of consumption in GDP will lead to an increase of CO_2 emission due to the substitution of consumption by investment. That is just the case in China, the economic growth in China is mainly depends on the investment. The percentage of consumption in GDP is decreasing while investment share is increasing. Moreover, both population size and capital-labor ratio have the significant positive effects on carbon emission, which are consistent with most of the other studies. The province with a higher capital-labor ratio tends to have higher emissions because capital-intensive goods are associated with higher emissions. Furthermore, the effect of energy efficiency is negative, as expected. Higher energy efficiency will reduce the CO_2 emissions. (2) As for urban-rural income inequality equation, all the variables are statistically significant except FDI, $\ln CO_2$per and HCStot. We find a U relationship between urban-rural income inequality and economic growth. Meanwhile, the increase in HCL (human capital) will benefit to reduction of urban-rural income inequality, while the education expenditure is bad for the urban-rural income inequality due to the unbalanced education expenditure between urban and rural area. In addition, basic pension insurance and urbanization will help to reduce urban-rural income inequality. $\ln CO_2$per and HCStot do not have a feedback effect on urban-rural inequality. (3) As to consumption equation, we focus on the effect of urban-rural income inequality on total household consumption share in GDP. The coefficient of urban-rural income inequality is negative and statistically significant at 1% level. In addition, the coefficient of CO_2 emissions per capita is not significant, which means the carbon emissions have no feedback effect on the total household consumption share in GDP. Consequently, the induce elasticity of urban-rural income inequality on carbon emissions is positive via HCStot.

Then, we discuss the system GMM estimators in the urban-rural SEM. (1) As for carbon emission equation, compared with the GMM estimators, The sign of coefficients of all the variables are the same with the GMM estimators and statistically significant. (2) As to urban-rural income inequality equation, all the variables are statistically significant except HCI and FDI, and have the same signs compared with GMM estimators. (3) In the consumption equation, the coefficient of urban-rural income inequality is negative and statistically significant at 1% level, which is consistent with the conventional Keynesian wisdom that equalization of income distribution increases aggregate consumption. Therefore, according to the bothe GMM and system GMM estimators , the induce elasticity of urban-rural income inequality is positive via HCStot.

4.3.1.2 Urban inequality and carbon emissions

Table 4-5 provides the estimation results of urban income inequality effects on carbon emissions. The comparison of the estimation results of the two methods are in Table 4-8. (1)As for carbon emission equation, the GMM estimators suggest that the coefficient of the squared GDP per capita term is negative and the coefficient of GDP per capita is positive and statistically significant, which provides the evidence for an inverted-U relationship between CO_2 emissions per capita and income per capita. Meanwhile, the sign of coefficient of HCSurb (urban household consumption share in GDP) is also found to be negative and significant at 10% level, which indicates that the decrease in percentage of consumption in income will lead to an increase of CO_2 emission due to the substitution of consumption by investment. That is just the case in China, the economic growth in China is mainly depends on the investment. The percentage of consumption in GDP is decreasing while investment share is increasing. Meanwhile, population size and capital-labor ratio have the significant positive effects on carbon emission, which are consistent with most of the other studies. The province with a higher capital-labor ratio tends to have higher emissions because capital-intensive goods are associated with higher emissions. Furthermore, the effect of energy efficiency is negative, as expected. Therefore, the signs of the coefficients of all the variables are same compared with the carbon emission equation in urban-rural SEM except variable lnRDG. (2) As for urban income inequality equation, the coefficient of the squared GDP per capita is not significant. urban inequality is linear related with economic growth. Meanwhile, the sign of the coefficients of variables HCL, and education expenditure are the same compared with the income inequality equation in urban-rural SEM. (3) As to consumption equation, we also focus on the effect of urban income inequality on urban household consumption share in GDP. The coefficient of urban income inequality is negative but not statistically significant, which means the effect of urban income inequality on urban household consumption share.. The system GMM estimators in the urban inequality SEM are similar with the GMM estimators. Consequently, the induce elasticity of urban income inequality on carbon emissions are lack of evidence.

4.3.1.3 Rural inequality and carbon emissions

The results of both GMM estimators and system GMM estimators are given in Table 4-6 for the rural inequality effects. The comparison of the estimation results of the two methods are in Table 4-9. (1) As for carbon emission equation, both GMM and system GMM estimators suggest that the coefficient of squared GDP per capita term is negative and the coefficient of GDP per capita is positive and statistically significant, which provides the evidence for an inverted-U relationship between CO_2 emissions per capita and income per capita. Meanwhile, the sign of coefficient of HCSrur (rural household consumption share in GDP) is also found to be negative and significant at 1% level, which indicates that the decrease in percentage of rural consumption in income will lead to an increase of CO_2 emission due to the substitution of rural consumption by investment. Meanwhile, both population size and capital-labor ratio have the significant positive effects on carbon emission, which are consistent with most of the other studies. Furthermore, the effect of energy efficiency is negative, as expected. To summary, all the variables in rural SEM have the same effect on carbon emissions compared with urban-rural SEM (2) As to consumption equation, The coefficient of rural income inequality is also negative and statistically significant at 1% level. In addition, the variable of CO_2 emissions per capita is not significant, which means the carbon emissions have no feedback effect on the total household consumption share in GDP. Consequently, the induce elasticity of rural income inequality is positive via HCSrur.

Table 4-4 Urban-rural inequality and emissions

Variables	GMM			System GMM		
	EQ1($lnCO_2per$)	EQ2(Tgini)	EQ3(HCStot)	EQ1($lnCO_2per$)	EQ2(Tgini)	EQ3(HCStot)
GDPper	0.0000436***			0.0000346***		
	(5.05e-06)			(9.27e-06)		
GDPper2	-3.10e-10***			-2.61e-10**		
	(5.47e-11)			(1.19e-10)		
HCStot	-0.0153018***			-0.0170334**		
	(0.0021376)			(0.0068713)		
lnP	0.0991229***			0.0708376*		
	(0.0175064)			(0.0371397)		
lnRDG	0.0234477			0.0323226		
	(0.0150939)			(0.0304283)		
lnKL	0.2491929***			0.302291***		
	(0.0388279)			(0.0804501)		
lnGE	-0.7734931***			-0.7012854***		
	(0.0298321)			(0.1230253)		
lnGDPper		-0.3105189***			-0.4177809*	
		(0.1162798)			(0.2338168)	
lnGDPper2		0.0186432***			0.0248167*	
		(0.0062443)			(0.0122471)	
HCI		-0.0027192**			-.0023567	
		(0.0012384)			(0.0024113)	
FDI		0.0000862			-0.0000169	
		(0.0000768)			(0.0002468)	
BPIS		-0.0008592***			-0.0008364**	
		(0.0002613)			(0.0003869)	
EduExG		0.0227725***			0.0270087***	
		(0.0042823)			(0.0095245)	
Urb		-1.74e-07**			-1.34e-07**	
		(7.70e-08)			(6.39e-08)	
$lnCO_2per$		-0.0064051			-0.0356719	
		(0.0093966)			(0.0255006)	
HCStot		0.0003862			-0.0013586	
		(0.0007301)			(0.0027716)	
Tgini			-12.93206***			-9.820897***
			(3.697362)			(2.952294)
HCStot (t-1)			0.947432***			0.9470936***
			(0.0574038)			(0.0240792)
$(Tinc)^{-1}$			-1084.435			2185.064
			(1345.622)			(1470.979)
$lnCO_2per$			-0.7632013			0.1349166
			(0.5609691)			(0.5620251)
_cons	0.3150466*	1.57722***	7.262891*	0.7998357*	2.120341*	4.305121*
	(0.1856872)	(0.5575022)	(3.730612)	(.4264478)	(1.174066)	(2.154007)
Obs	348	348	348	478	378	349
F-test				103.75***	6.53***	1728.48***
Hansen's J	5.78101			28.11	25.62	22.14
	[p=0.4482]			[p=0.999]	[p=1.000]	[p=0.998]
A-B test for AR(1)				-0.95	-1.54	-3.32
				[p=0.340]	[p=0.124]	[p=0.001]
A-B test for AR(2)				-0.82	-0.43	-0.30
				[p=0.411]	[p=0.665]	[p=0.768]

Notes: The values in parentheses are standard errors. * indicates the rejection of the null hypothesis at a 10% level of significance. ** indicates the rejection of the null hypothesis at a 5% level of significance. *** indicates the rejection of the null hypothesis at a 1% level of significance. A-B test for AR(1) is Arellano-Bond test for AR(1); A-B test for AR(2) is Arellano-Bond test for AR(2)
GMM
Instruments for equation 1: gdpper gdpper2 lnp lnrdg lnfkl lnge apctotlag _cons
Instruments for equation 2: lngdpper lngdpper2 hcl fdi bpis eduexg urb apctotlag lnco2perlag1 _cons
Instruments for equation 3: hcl fdi bpis eduexg urb otinc cpi unem ir L.lnco2pert _cons

Table 4-5 Urban inequality and emissions

Variables	GMM			System GMM		
	EQ1lnCO2per	EQ2Ugini	EQ3HCSurb	EQ1lnCO2per	EQ2 Ugini	EQ3HCSurb
GDPper	0.0000455***			0.0000488***		
	(5.33e-06)			(0.0000144)		
GDPper2	-3.60e-10***			-4.16e-10***		
	(5.71e-11)			(1.45e-10)		
HCSurb	-0.0222095***			0.0402019		
	(0.0038753)			(0.0275924)		
lnP	0.0412908**			0.150435		
	(0.0175632)			(0.1058238)		
lnRDG	0.0525327***			-0.1179999		
	(0.0193828)			(0.0998593)		
lnKL	0.3550762***			0.426821***		
	(0.0373662)			(0.0784629)		
lnGE	-0.778497***			-.7799827***		
	(0.0285749)			(0.154172)		
lnGDPper		0.1235458**			0.0101716	
		(0.0552824)			(0.013689)	
lnGDPper2		-0.0039274			0.0021718	
		(0.0030384)			(0.0014382)	
HCL		-0.003045***			-0.0038811*	
		(0.0007232)			(0.002014)	
FDI		0.0001287***			0.0001422	
		(0.0000481)			(0.0001693)	
BPIS		-0.0002543			0.0000802	
		(0.0001651)			(0.0004425)	
EduExG		0.0128084***			0.0216436***	
		(0.0025119)			(0.007255)	
Urb		6.45e-08**			6.98e-08	
		(2.89e-08)			(6.64e-08)	
lnCO2per		-.0002578			-.0001847	
		(0.004943)			(0.0225275)	
HCSurb		0.0000167			-0.0028658	
		(0.0004189)			(0.0022701)	
Ugini			-1.956247			0.7395369
			(4.556078)			(4.823972)
HCSurb			0.9742822***			0 .9356156***
(t-1)			(0.0282824)			(0.0226036)
$(Uinc)^{-1}$			-601.03			295.9979
			(2492.519)			(3270.366)
$lnCO_2per$			-0.3641273**			-0.4379116
			(0.1680872)			(0.3094446)
_cons	0.8043091***	-0.5588606**	1.734681	-1.756269		1.961998
	(0.2178615)	(0.2516043)	(1.814671)	(1.597824)		(1.5874)
Obs	421	421	421	478	451	420
F-test				47.74***	398.62***	650.18***
Hansen's J	8.46077			28.81	35.79	28.48
	[p = 0.2063]			[p=0.370]	[p=0.660]	[p=1.000]
A-B test for				-1.15	-3.77	-3.42
AR(1)				[p=0.250]	[p=0.000]	[p=0.001]
A-B test for				-1.21	1.31	-0.22
AR(2)				[0.225]	[p=0.189]	[p=0.827]

Notes: The values in parentheses are standard errors. * indicates the rejection of the null hypothesis at a 10% level of significance. ** indicates the rejection of the null hypothesis at a 5% level of significance. *** indicates the rejection of the null hypothesis at a 1% level of significance. A-B test for AR(1) is Arellano-Bond test for AR(1); A-B test for AR(2) is Arellano-Bond test for AR(2)

Instruments for equation 1: gdpper gdpper2 lnp lnrdg lnfkl lnge apctotlag _cons

Instruments for equation 2: lngdpper lngdpper2 hcl fdi bpis eduexg urb lnco2perlag1 apcurblag _cons

Instruments for equation 3: hcl fdi bpis eduexg urb ouinc due cpi100 ir L.lnco2pert _cons

Table 4-6 Rural inequality and emissions

Variables	GMM			System GMM		
	EQ1lnCO2per	EQ2Rgini	EQ3HCSrur	EQ1lnCO2per	EQ2Rgini	EQ3HCSrur
GDPper	0.0000404***			0.0000339***		
	(4.86e-06)			(7.99e-06)		
GDPper2	-2.86e-10***			-2.59e-10**		
	(5.27e-11)			(9.48e-11)		
HCSrur	-0.0210999***			-0.023218***		
	(0.0024102)			(0.0068844)		
lnP	0.1535007***			0.0880449*		
	(0.0165458)			(0.0440891)		
lnRDG	-0.0208714			-0.0212834		
	(0.0146803)			(0.0429811)		
lnKL	0.2617414***			0.2820791***		
	(0.0361397)			(0.0661686)		
lnGE	-0.7975871***			-0.6884684***		
	(0.0280524)			(0.1515231)		
lnGDPper		0.125133			0.1010274***	
		(0.130869)			(0.0251622)	
lnGDPper2		-0.0079892			-0.006163**	
		(0.0069175)			(0.0027597)	
HCL		-0.0005763			-0.0002041	
		(0.001016)			(0.0013338)	
FDI		0.0001028			0.0000633	
		(0.0000627)			(0.0001767)	
BPIS		0.0009993***			0.0005778	
		(0.0002544)			(0.0004441)	
EduExG		0.0144909***			0.0078897	
		(0.003445)			(0.0060303)	
Urb		8.54e-08			2.05e-07**	
		(6.01e-08)			(7.69e-08)	
lnCO2per		-0.021952**			-0.072775*	
		(0.0087237)			(0.0372581)	
HCSrur		-0.001904*			-0.0049915**	
		(0.0010873)			(0.0019873)	
Rgini			-27.05046***			-20.45575***
			(10.30451)			(4.847547)
HCSrur(t-1)			0.6891317***			0.7576292***
			(0.1087789)			(0.0904534)
$(Rinc)^{-1}$			7819.263***			6300.678**
			(2782.578)			(2682.923)
$lnCO_2per$			-1.820826**			-1.199979
			(0.7897908)			(0.8310647)
_cons	-0.4205662***	-0.2001045	11.20799**	0.2970564		7.984245***
	(0.1434255)	(0.6363782)	(4.521698)	(0.3747716)		(2.551617)
Obs	361	361	361	478	389	362
F-test				153.49***	836643.54***	598.04***
Hansen's J	6.79173			27.02	21.14	26.74
	[p = 0.3405]			[p=0.999]	[p=1.000]	[p=0.992]
A-B test for AR(1)				-1.02	-1.96	-2.06
				[p=0.306]	[p=0.051]	[p=0.040]
A-B test for AR(2)				-2.12	-1.06	-0.74
				[p=0.034]	[p=0.290]	[p=0.461]

Notes: The values in parentheses are standard errors. * indicates the rejection of the null hypothesis at a 10% level of significance. ** indicates the rejection of the null hypothesis at a 5% level of significance. *** indicates the rejection of the null hypothesis at a 1% level of significance. A-B test for AR(1) is Arellano-Bond test for AR(1); A-B test for AR(2) is Arellano-Bond test for AR(2)

Instruments for equation 1: gdpper gdpper2 lnp lnrdg lnfkl lnge apcrurlag _cons

Instruments for equation 2: lngdpper lngdpper2 hcl fdi bpis eduexg urb lnco2perlag1 apcrurlag _cons

Instruments for equation 3: hcl fdi bpis eduexg urb orinc drl cpi100 ir L.lnco2pert _cons

Table 4-7 Comparison of the estimation result (urban-rural inequality)

Method	Variables								
	Carbon emission equation								
	GDPper	GDPper2	HCStot	lnP	lnRDG	lnKL	lnGE		
GMM	+	-	-	+		+	-		
System GMM	+	-	-	+		+	-		
	Income inequality equation								
	lnGDPper	lnGDPper2	HCI	FDI	BPIS	EduExG	Urb	lnCO2per	HCSot
GMM	-	+	-		-	+	-		
System GMM	-	+			-	+	-		
	Consumption equation								
	Tgini	HCStot(t-1)	$(Tinc)^{-1}$	lnCO2per					
GMM	-	+							
System GMM	-	+							

Table 4-8 Comparison of the estimation result (urban inequality)

Method	Variables								
	Carbon emission equation								
	GDPper	GDPper2	HCSurb	lnP	lnRDG	lnKL	lnGE		
GMM	+	-	-	+	+	+	-		
System GMM	+	-				+	-		
	Income inequality equation								
	lnGDPper	lnGDPper2	HCI	FDI	BPIS	EduExG	Urb	lnCO2per	HCSurb
GMM	+		-	+		+	+		
System GMM			-			+			
	Consumption equation								
	Ugini	HCSurb (t-1)	$(Uinc)^{-1}$	lnCO2per					
GMM		+							
System GMM		+							

Table 4-9 Comparison of the estimation result (rural inequality)

Method	Variables								
	Carbon emission equation								
	GDPper	GDPper2	HCSrur	lnP	lnRDG	lnKL	lnGE		
GMM	+	-	-	+		+	-		
System GMM	+	-	-	+		+	-		
	Income inequality equation								
	lnGDPper	lnGDPper2	HCI	FDI	BPIS	EduExG	Urb	lnCO2per	HCSrur
GMM					+	+		-	-
System GMM	+	-					+	-	-
	Consumption equation								
	Rgini	HCSrur(t-1)	$(Rinc)^{-1}$	lnCO2per					
GMM	-	+	+	-					
System GMM	-	+	+						

4.3.2 Regional comparison

Table A2 lists the classification of the 30 provinces in China. Eastern region includes 11 provinces, central region contains 8 provinces and western region is composed of 12 provinces. In order to see whether income inequality effects on carbon emissions are different regions, we add the region dummy variables to the SEM for both the urban-rural and rural income inequality. Since the indirect effect of urban income inequality on carbon emissions is not found, we ignore the urban inequality SEM and test only the urban-rural and rural SEMs. Table 4-10 shows the estimation results of the SEM with regional dummy variables. The eastern region is considered as the basic group, thus we get two dummy variables: D2 denotes central region and D3 stands for western region. D2 *HCS indicates the interaction variable of D2 and HCS and D3 *HCS represents the the interaction variable of D2 and HCS. Similarly, D2*Gini and D3*Gini stand for the interaction variable of D2 and Gini and Gini interacted with D3, respectively. The estimated results in Table 4-10 shows that the Gini variable interacted with central and western region dummy are significant, which suggests that the urban-rural income inequality in both central and western region inhibit the total household consumption and thus lead to an increase CO_2 emissions per capita. Meanwhile, the coefficients of Gini interacted with western region dummy are bigger than that interacted with central region dummy, therefore the urban-rural income inequality in western has a greater positive effect on CO_2 emissions per capita. As to rural income inequality effects on carbon emissions, the rural income inequality effects on rural household consumption share in GDP are the same in all the regions, since the dummy variables in consumption determined equation is not statistically significant.

Table 4-10 SEM with regional dummy variables

Variables	Urban-rural income inequality			rural income inequality		
	EQ1($lnCO_2per$)	EQ2(Gini)	EQ3(HCS)	EQ1($lnCO_2per$)	EQ2(Gini)	EQ3(HCS)
GDPper	0.0000372***			0. 000039***		
	(5.32e-06)			(4.84e-06)		
GDPper2	-2.52e-10***			-2.69e-10***		
	(5.64e-11)			(5.25e-11)		
HCS	-0.0107277***			-0147739***		
	(0.0025045)			(0. 0034733)		
D2* HCS	-0.0007406			-0.0023943		
	(0.0007548)			(0.0019254)		
D3* HCS	-0.0027695***			-.0058549***		
	(0.0008036)			(0.0020679)		
lnP	0. 0951597***			0. 1390719*		
	(0.0181502)			(0. 0171906)		
lnRDG	0.0097596			-0.01716		
	(0.0151593)			(0. 0148234)		
lnKL	0.3207317***			0. 2850593***		
	(0.0429163)			(0. 037127)		
lnGE	-0. 8044545***			-0. 8205897***		
	(0.0309819)			(0. 0287642)		
lnGDPper		-0. 3089682***			0.0964592	
		(0. 1165813)			(0. 1310581)	
lnGDPper2		0. 0186267***			-0.0066128	
		(0. 0062559)			(0.0069082)	
HCI		-0. 0029105**			-0.0005202	
		(0. 0012752)			(0.0010443)	
FDI		0. 000091			0.0001387*	
		(0. 0000798)			(0.000072)	
BPIS		-0. 0007494***			0.0010498***	
		(0. 0002746)			(0.0002699)	
EduExG		0. 0238932***			0.012715***	
		(0. 0043582)			(0.0036303)	
Urb		-2.01e-07**			8.52e-08**	
		(7.88e-08)			(6.11e-08)	
$lnCO_2per$		-0. 0082199			-.0221377**	
		(0. 009491)			(0.0086577)	
HCS		0. 000461			-0.0019673*	
		(0. 0007327)			(0.0010805)	
Gini			6.047533			-25.02175**
			(5.372826)			(10.48223)
D2*Gini			-2.541469**			-2.373739
			(1.26044)			(2.560016)
D3*Gini			-4.271194**			-2.73172
			(1.855141)			(1.686534)
HCS (t-1)			1.210035***			0. 7150055***
			(0.0949303)			(0.1074615)
$(inc)^{-1}$			-125.8825			8736.477***
			(1679.403)			(2783.4)
$lnCO_2per$			1.719256*			-1.543439*
			(0.8854053)			(0.7927356)
_cons	0.3012564	1.557697***	-12.84192**	-0.03317513**	-0.0477358	10.03449**
	(0.1861162)	(0.5593876)	(6.181274)	(0.1461479)	(0.6388887)	(4.609022)
Obs	347	347	347	360	360	360
F-test						
Hansen's J	4.27431			3.35879		
	[p=0.6396]			[p=0.4997]		

Notes: The values in parentheses are standard errors. * indicates the rejection of the null hypothesis at a 10% level of significance. ** indicates the rejection of the null hypothesis at a 5% level of significance. *** indicates the rejection of the null hypothesis at a 1% level of significance. A-B test for AR(1) is Arellano-Bond test for AR(1); A-B test for AR(2) is Arellano-Bond test for AR(2)
GMM
Instruments for equation 1: gdpper gdpper2 lnp lnrdg lnfkl lnge apctotlag _cons
Instruments for equation 2: lngdpper lngdpper2 hcl fdi bpis eduexg urb apctotlag lnco2perlag1 _cons
Instruments for equation 3: hcl fdi bpis eduexg urb otinc cpi unem ir L.lnco2pert _cons

However, the effects of rural household consumption share on CO_2 emissions per capita are different between eastern and western China. The western area has a higher negative impact on the CO_2 emissions per capita. These results indicate that the household income inequality in less developing region, like western region, has a greater positive impact on CO_2 emissions per capita. Therefore, the poor and unequal economy tends to face more pollution problems.

4.4 Discussion and implications

The empirical study in this paper has proved that the household income inequality has an indirect positive effect on carbon emissions per capita through its effect on household consumption share in GDP. This indirect positive effect can be summarized in the following two ways.

(1) The first way caused an increase in carbon emissions is the excess capacity in manufacturing, which leads to the waste of energy and more pollutions. The expanded household income inequality continues to suppress purchasing power of residents and encourage the savings, which promotes the investment. The prevalent investment “Wave” phenomenon in developing countries has led to excess capacity (Lin Justin Yifu et al., 2007, 2010). In China, the excess capacity in manufacturing has attracted a wide attention. The "Twelfth Five Year Plan" of China has proposed the policy to inhibit the six industries with excess capacity, including iron and steel, cement, plate glass, polysilicon, wind power equipment and Coal chemical industry. The data in 2012 show that the excess capacity of some industries are 21% in iron and steel industry, 12% in automotive industry, 28% in cement industry, 35% in

electrolytic aluminum industry, 60% in stainless steel industry, 60% in pesticides industry, 95% in photovoltaic industry, 93% in glass industry. Even so, the investment of high energy consumption industries is accelerating. In January-October 2012, the investment of high energy consumption industries grew 21.7%, continuing a trend of accelerated growth since the beginning of 2011. Therefore, the increase in household income inequality results in the lower consumer demand and higher scale of investment. Consequently, after the investment transform into productive capital, the gap between supply and final consumption demand will be further expanded, and thus excess capacity occurs at the rise of the waste of energy consumption and increase in carbon emissions.

(2)When income inequality is widening, the large proportion of the society is poor people, while only a small proportion is high-income people. The high-income people will not spend too much on the same product due to the diminishing marginal utility. However the poor people cannot afford the high quality and innovative product due to the high price. They are more sensitive to the price of the product than the quality. Therefore, the low quality and high energy-intensive products will occupy the large market. The new innovative products will be faced with the problem of lack of market demand, and innovation cannot be guaranteed with a reasonable return. Thus, enterprises no longer willing to carry out innovation activities. Meanwhile, the energy-saving technologies may increase the cost of the product, thus reduce the competitiveness of products in the price-sensitive market. The enterprises do not have incentive to innovate or adopt energy-saving technologies. Consequently, not only the total consumption amount is inhibited but also the consumption structure is influenced by the household income inequality. The energy-intensive and low quality preferred consumption structure will become the obstacle to upgrade for industrial structure and technological innovation from the demand side. Because low value-added products always have market demand, and backward production capacity cannot be eliminated by spontaneous consumption upgrade, the development of tertiary industry will be restricted due to the limitations of the market capacity, and upgrading of industrial structure would be difficult to successfully achieve. The way to reduce carbon emissions through upgrading of industrial structure and develop energy-saving technologies will face a stress from the consumption structure.

According to above analysis, our policy implications mainly focus on how to reduce income inequality for promoting consumption and the upgrade of consumption structure and how to curb excess capacity in the manufacturing industry.

(1)Promote the reform of the income distribution system and expand consumer demand, adjust the structure of consumption demand to reduce national savings rate and gradually change the situation of over-reliance on investment for economic development. Focus on narrowing the income gap between urban and rural residents, especially migrant workers, and pay special attention to low-and middle-income class, continue to increase the real income of residents, especially the real income of low- and middle-income residents to promote the upgrading of consumption demand structure.

(2) Deepen the reform of factor markets and strengthen the ability of market for allocating resources. Due to the pricing mechanism of production factors (such as land, water and electricity) include government subsidies, the prices of production factors are distorted and thus lead to the distortion of the investment activities of the enterprises. Therefore the manufacturing enterprises with backward production capacity get a "comparative advantage" and considerable profit. To fundamentally eliminate backward and excess production capacity, the government should deepen the reform of factor markets, so that the environment, resources and other external costs can be incorporated into the cost of all enterprises to reflect the scarcity of resources and eliminate the profit of backward production capacity.

(3) The industries with excess capacity are mostly high-polluting and energy-intensive industries. Therefore, the government should gradually improve environmental emission standards, establish pollutant emissions market mechanism, impose the taxes from the high-pollution industries with excess capacity, so that the industries with excess capacity have to bear the economic responsibility for the pollution, rationalize the cost of investment and regulate their investment behavior.

(4) Develop the market-oriented financial resource allocation mechanism. Use financial leverage to regulate the enterprises' behavior of investment in fixed capital, control business loans for investment in the high pollution, high energy consumption and overheated investment enterprises.

(5) Establish statistical monitoring system for the capacity utilization of industries. The government should announce the capacity utilization information to the public regularly and guide the enterprises to make investment and production decision and prevent the irrational investment and blind expansion.

4.5 Concluding remarks

This paper analyzes the relationship between household income disparity and CO_2 emissions based on panel dataset in China over the period of 1995 to 2010, by employing GMM and system GMM estimation methods to estimate the SEM. Compared with previous studies, the main features of this study include the following. 1) The impact of income distribution on carbon emissions is studied at a household level within in an individual country, whereas other studies primarily focus on the effect of household income inequality on emissions using cross-country data. 2) The SEM are employed in this study, whereas other studies adopt single model specification. 3) This paper chooses three types of household income inequality to make comparisons (urban-rural, urban and rural inequality), whereas other studies use only the total household income inequality. 4) An induced effect that household income inequality affects CO_2 emissions through the HCS is observed, whereas other studies primarily focus on the direct relation between household income inequality and CO_2 emissions.

The main findings of this study reveal that there is an inverted-U relationship between per capita CO_2 emissions and income in China. The indirect effect that household income inequality affects CO_2 emissions through the HCS is positive in both urban-rural case and rural case. The reasons for this positive effect are: (1) the increase in household income inequality results in the lower consumer demand and higher scale of investment. The prevalent investment "Wave" phenomenon in developing countries has led to excess capacity with rise of the waste of energy consumption and increase in carbon emissions.(2) Not only the total consumption amount is inhibited but also the consumption structure is influenced by the household income inequality. The energy-intensive and low quality preferred consumption structure will become the obstacle to upgrade for industrial structure and technological innovation from the demand side. Thus, the way to reduce carbon emissions through upgrading of industrial structure and develop energy-saving technologies will face a stress from the consumption structure.

Our policy implications are: (1) promote the reform of the income distribution system and expand consumer demand, adjust the structure of consumption demand to reduce national savings rate and gradually change the situation of over-reliance on investment for economic development. (2) The government should deepen the reform of factor markets, so that the environment, resources and other external costs can be incorporated into the cost of all enterprises to reflect the scarcity of resources and eliminate the profit of backward production capacity. (3) The government should gradually improve environmental emission standards, establish pollutant emissions market mechanism, impose the taxes from the high-pollution industries with excess capacity. (4) Develop the market-oriented financial resource allocation mechanism to control business loans for investment in the high pollution, high energy consumption and overheated investment enterprises. (5) Establish statistical monitoring system for the capacity utilization of industries to guide the enterprises to make investment and production decision and prevent the irrational investment and blind expansion.

The weakness of this study stems from the estimation problems. Meanwhile, this study could also be improved by analyzing the interaction effects between GDP and regional income disparity and their effects on carbon emissions. Furthermore, the income (GDP) in the model of this study is treated as exogenous, however, it should be endogenous. The work to improve this study is currently underway.

5 Income inequality, Consumption pattern and Carbon Emissions

5.1 Model specification and methodologies

5.1.1 Input-output approach

In this paper, we employ the input-output approach to estimate the carbon emissions from household consumption including indirect and direct emissions.

This paper firstly calculates the energy consumption for each sector production process and its related carbon emissions. Then, base the Chinese input-output table 2007, we use Leontief inverse matrix to get the total input coefficients of energy consumption. Finally according to the total input coefficients of energy consumption, we can estimate carbon emissions factors of the household indirect consumption.

According to the Input-output table structure,

$\boldsymbol{X=(I-A)^{-1}Y}$

$$\begin{bmatrix} X_1 \\ X_2 \\ \vdots \\ X_n \end{bmatrix} = \left(\begin{bmatrix} 1 & 0 & \cdots & 0 \\ 0 & 1 & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & 1 \end{bmatrix} - \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix} \right)^{-1} \bullet \begin{bmatrix} Y_1 \\ Y_2 \\ \vdots \\ Y_n \end{bmatrix} \quad (5\text{-}1)$$

where X_i denotes the gross output of the ith sector. Y_{ir} stands for the final use and $a_{ij} = \frac{x_{ij}}{X_j}$ is the direct input coefficients. $(I-A)^{-1}$ is the Leontief inverse matrix which is the total input coefficients. Therefore, we can get the emissions input-output table.

$$E=eX=e(I-A)^{-1}Y \quad (5\text{-}2)$$

$$E=\begin{bmatrix} e_1 & e_2 & \cdots & e_n \end{bmatrix}\bullet\left(\begin{bmatrix} 1 & 0 & \cdots & 0 \\ 0 & 1 & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & 1 \end{bmatrix}-\begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix}\right)^{-1}\bullet\begin{bmatrix} Y_1 \\ Y_2 \\ \vdots \\ Y_n \end{bmatrix} \quad (5\text{-}3)$$

Where e is the energy consumption coefficient matrix (1 × n), e_i denotes the direct energy consumption coefficient, namely the direct energy consumption for production of per unit product ($e_i=\frac{EN_i}{X_i}$, ENi is the energy consumption of the sector i). E is the total carbon emissions embodied in household final consumption. Therefore, we can get $e'= e(I\text{-}A)^{-1}$, which is the total input coefficients matrix of energy consumption(1×n), which indicates the total energy consumption for production of per unit product, including direct and indirect energy consumption.

Then we should calculate the carbon emissions embodied by the embodied energy consumption.

To calculate the carbon emissions embodied by the embodied energy consumption by different sector, we need to estimate the carbon emission factor for each sector. Carbon emission factor of energy consumption depends on the total consumption of energy structure and the carbon emission factors of various fuels.

Due to the difference of the energy consumption structure in different sector, we assume that the carbon emission factor of the j sector is. α_j .

$$\alpha_j=\sum_{k=1}^{n}\frac{\omega_k\cdot EN_{jk}}{EN_j}=\sum_{k=1}^{n}\omega_k\cdot\lambda_{jk} \quad (5\text{-}4)$$

whereω_k denotes the carbon emission factor of the fuel k. EN_{jk} denotes the consumption amount of fuel k in sector j，EN_j represents the total energy consumption. λ_{jk} is the weight of the consumption amount of fuel k in total energy consumption amount in sector j.

Thus, we can get the carbon emissions embodied in final product of sector j is,

$$C_j = \alpha_j \cdot E_{Tj} \tag{5-5}$$

Where C_j is the carbon emissions embodied in final product of sector j

In this paper, we consider eight kinds of goods refer to the household survey data avaiable. The consumer behavior related sectors are list in Table 5-1. We tranform the 42 sector input-output table to this eight sector input-output table, then caculate the emissions following above approach.

Table 5-1 Consumer behavior related sectors.

Goods	Sectors
Food	Food manufacturing; Agro-food processing industry; Beverage manufacturing
Clothing	Manufacture of Textile, Wearing
Residence	Production and Supply of Electric, Power, Heat Power and Water; Manufacture of Nonmetallic; Manufacture and Processing of Metals and Metal Products
Household Facilities and Articles	Manufacture of Machinery and Equipment; Manufacture of furniture; Wood processing and wood, bamboo, rattan, brown, grass products industry; Electrical machinery and equipment manufacturing
Transport and Communications	Communications equipment; Computers and other electrical equipment manufacturing; Transportation equipment manufacturing
Education, Culture and Recreation	Paper and paper products industry; Educational and Sports Goods; Printing and Reproduction of Recording Media
Health Care and Medical Services	Pharmaceutical manufacturing
Others	Accommodation, food and beverage industry; wholesale, zero good, tobacco

5.1.2 The econometric model

In order to generate a relation from income to expenditure and then carbon emissions, we need to consider the appropriate framework for the goods consumption demand model. The demand theory serves our purpose better. Demand theory study the demand for goods based on the behavior of consumers references. The cornerstone of the theoretical and empirical research is to analyze the demand model. A demand for certain goods should be based on the reasonable requirements of the choice of functional form, so that the impact of different factors change in consumer demand can be captured to master the structure of demand, to predict the behavior of consumer demand, and to fully aware the impact of the change in price and income on the behavior of consumer demand. The earliest demand model is proposed by Working (1943). After development and improvement in the following decades, we have the Stone's "Linear expenditure systems" (Stone, 1954), Lluch's "extended linear expenditure system"(Lluch, 1973), Cragg's "bimodal model"、Rotterdam model (Theil, 1955; Barten, 1969), MinflexLaurent model (Barnett ,1983) and logarithmic utility function (Christensen, 1975)。The popular model is the double logarithmic demand model (Leser, 1963) and Almost Ideal Demand System (AIDS) (Deaton, 1980).

In the analysis of influence factors to changes in demand, impact of changes in the factors. Therefore, the demand model needs to be able to reveal the correct Engel curve of commodity consumption, in order to ensure an accurate estimation of the income effect and the income elasticity of the goods. Due to the differences in individual income and commodities, the income effect of income in the different overall income distribution may correspond to different value. Thus, the income elasticity changes with the changes in income levels. For example, certain commodities are necessity at lower income levels, gradually show luxury properties with the increase in income, but become inferior goods after a further increase in income. Because of Engel curve of come commodities have a nonlinear characteristics, the above demand model cannot accurately analysis the income effect of the goods with multiple properties. Therefore, Bank et al. (1997) proposed the so-called quadratic almost ideal demand systems QUAIDS model as the extension of the AIDS model.

In this paper, we employ the QUAIDS model as our econometric model to estimate the marginal propensity to budget share of each good. Because the data we used here is a cross sectional dataset in year 2007. Thus, we ignore the price effect in the QUAIDS model. Then, our model specification takes the form:

$$W_{ijt} = \alpha_{jt} + \sum_{m=1}^{k} \gamma_{jm} \ln p_{jt} + \beta_{jt} \ln\left[\frac{y_{it}}{p_t}\right] + \lambda_{jt} \left\{\ln\left[\frac{y_{it}}{p_t}\right]\right\}^2 + \varepsilon_{ijt} \quad j = 1, \ldots, k \tag{5-6}$$

where W_{ijt} denote the budget share for good j in household i and period t. p_{jt} is the price of good j. y_{it} represents the total expenditure on all the goods of household i. Since we consider the household survey data in 2007, the price effect is constant in the regressions. Therefore, we ignore the price effect in the following estimation.

5.1.3 Data source

To caculate the carbon emission factor for each good, we use the 2007 Chinese input-output Table. The energy consumption data by sectors are collected from China

Energy Statistical Yearbook (2007). The carbon emission factors for each fossil fuel come from the "2006 IPCC Guidelines for National Greenhouse Gas Inventories". The carbon emission coefficients for each fossil fuel are listed in Table 5-2.

The household survey data used in this study are provided by the National Bureau of Statistics of China (NBSC), named "Urban household survey data", covering 5000 households.

Table 5-2 Coefficients for fuels used in IPCC reference approach.

Fossil Fuel	Coal	Coke	Gasoline	Kerosene	Diesel	Fuel oil	Natural gas
NCV	20.52	28.2	44.8	44.67	43.33	40.19	48
CEF	24.74	29.5	18.9	19.55	20.2	21.1	15.3
OC	0.90	0.97	0.98	0.98	0.98	0.98	0.99

Source: IPCC (2006)

5.2 Income distribution, expenditure structure and CO_2 emissions

5.2.1 Data description

The urban household survey is conducted by National Bureau of Statistics of China (NBSC) in 2007. This survey data we used in this study covers 5000 household with their household size, income and consumption information. Because we aim to find the effect of household income distribution on carbon emissions through its effect on consumption pattern, the consumption structure data and income data are the main dataset we needed. In order to get the income distribution pattern, we need household disposable income and disposable income per capita. For consumption structure and consumption related carbon emissions, we need the specific consumption items and the total expenditure of the household. According to the survey dataset, the household expenditure for daily life is divided into eight types of goods, including food, clothing, household facilities and articles, health care and medical services, transport and communications, education, culture and recreation, residence and others goods. The descriptive statistics of these variables are provided in Table 5-3. The disposable income of the richest household is 499000 yuan, which the poorest household only has 402 yuan. Similarly, the household has the largest expenditure 507450.3 yuan, while the poorest household only spends 1538.4 yuan. Also see, the mean value of the disposable income and expenditure for the household are 41385.02 yuan and 29324.43 yuan, which is still far more below the highest value. The large gap between rich and poor household indicates that the income distribution is unequal in the survey data. As to the expenditure structure, we can find that the food consumption account for the largest part. The second largest contributor of consumption is transport and communications and the third largest is the expenditure of education, culture and recreation. The minimize expenditure is zero except the food consumption. We find that the highest food expenditure is 118563.1 yuan in the richest household, while the poorest one only spend 616.9 yuan in food. It is shows that given the household size is similar (around 3 person per household), the large difference in food expenditure indicate the high difference in food quality.

Table 5-3 Summary of the household survey data

Variable	Obs	Mean	Std. Dev.	Min	Max
Total Expenditure	4969	29324.43	25103.78	1538.4	507450.3
Food	4969	10425.52	6406.195	616.9	118563.1
Clothing	4969	3102.149	2945.794	0	38903
Household Facilities and Articles	4969	1699.928	2997.861	0	52509.9
Health Care and Medical Services	4969	2129.64	3836.169	0	51849
Transport and Communications	4969	4054.591	14135.21	0	378139
Education, Culture and Recreation	4969	3921.161	5623.358	0	120132
Residence	4969	2923.943	6303.79	0	160656.3
Others	4969	1067.499	1897.226	0	33684
Household disposable income	4969	41385.02	27797.86	402	499000
Disposable income per capita	4969	15085.39	10729.08	100.5	249500

Base on the China Input-output Table 2007 mentioned above, the energy consumption data provide in the China Energy Statistical Yearbook (2007) and the emission factors by IPCC, we calculate the carbon emissions intensity of the eight types of goods: food (0.093), clothing (0.121), household facilities and articles (0.156), health care and medical services (0.179), transport and communications (0.168), education, culture and recreation (0.162), residence (0.195) and others goods (0.061). Finally, according the carbon emissions intensity of the eight types of goods and the household expenditure data for the goods, we get the emissions for each good in each household.

5.2.2 Income inequality and carbon emissions inequality

As Table 5-3 suggests a great income inequality in the survey data, we sort the household by the disposable income per capita, then divide the household into five groups with equal size (994 household) and calculate the total income share of each group and total CO_2 emissions share of each group: first quintile group (income share 8.88%, emission share 10.44%), second quintile group (income share 13.67%, emission share 14.88%), third quintile group (income share 17.59%, emission share 17.83%), fourth quintile group (income share 22.6%, emission share 22.38%) and fifth quintile group (income share 37.26%, emission share 34.47%). Fig. 5-1 shows the difference between household income share and carbon emissions share by household income groups. It is clear that both income share and carbon emissions of the first quintile group are very low and the highest income group (fifth quintile group) has the largest income share and carbon emissions. However, the carbon emissions share is bigger than the income share in the first quintile group, second quintile group and third quintile group, while it is smaller than the income share in the fourth quintile group and fifth quintile group. Thus, the emission inequality is accordance with the income inequality but smaller than the income inequality. Why the poorer group emit more than their expenditure ability? We can find the reason through the analysis of emission shares of different types of goods by different household income groups.

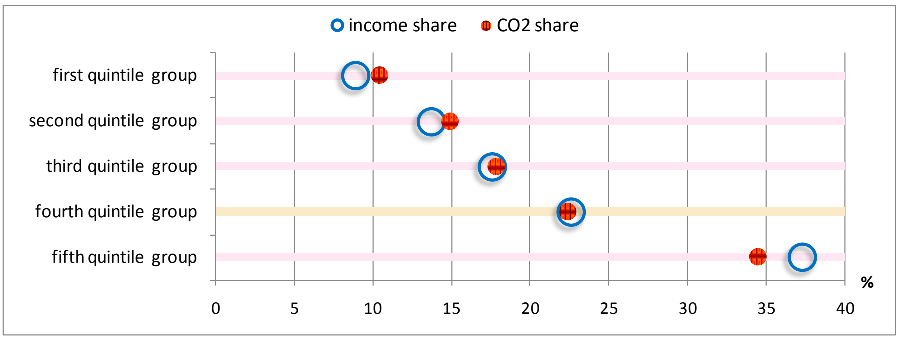


Fig.5-1 Income share vs CO_2 emissions share by income group

Fig. 5-2 gives the details about the comparison of income share and CO_2 emissions share by different household group and goods type. For the first quintile group, the emission share of food, clothing and residence excess its income share. For the second quintile group, the emission share related to food, clothing, health care and medical services and residence excess its income share. For the third quintile group, the emission share caused by food, clothing, household facilities and articles, health care and medical services consumption excess its income share. As to the fourth quintile group, the emission share of health care and medical services excess its income share, while the emission share of transport is smaller than its income share. As for the fifth quintile, all the emission shares are smaller than its income share except emission share of transport and other goods. Therefore, the lower income groups (first quintile and second quintile) emit more than their income share because they have a larger emission share of food, clothing and residence. Meanwhile, the higher income groups (fourth quintile and fifth quintile) emit less than their income share since they account for a smaller emission share of all goods except transport.

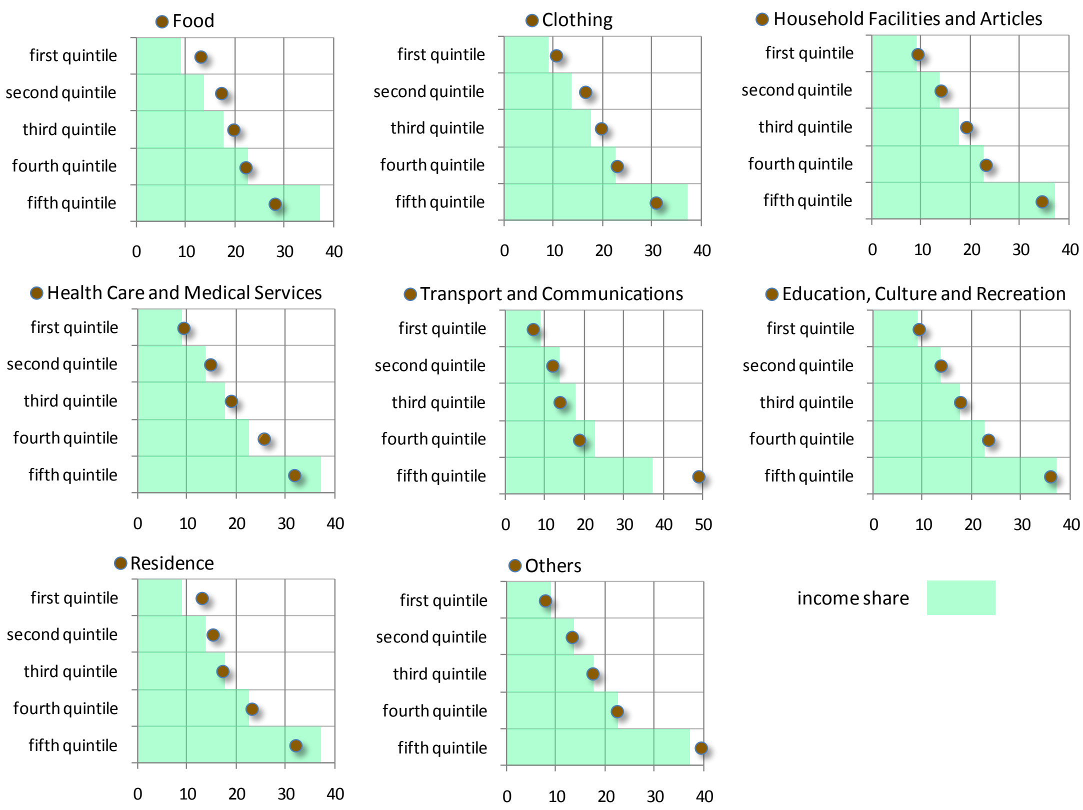


Fig.5-2 Income share vs CO_2 emissions share by goods type and income group

To summarize, the smaller CO_2 emissions inequality than income inequality is explain by the greater expenditure in low income groups compared with their income level.

5.2.3 Expenditure share and carbon emissions share

Table 5-4 shows the expenditure share and carbon emissions share by goods. The carbon emissions share from food consumption is smaller than expenditure share of food. The carbon emissions share from clothing is also smaller than its budget share. Meanwhile, the emission share from other goods is lower than its budget share as well. However, the emission share from household facilities and articles, health care and medical services, transport and communications, education, culture and recreation and residence are all larger than their expenditure share. That is because the emission intensity of food, clothing and other goods are lower, while the emission intensity of other types of goods are higher, see the last column of Table 5-4. Furthermore, we can easily find that food, transport and communications, education, culture and recreation and residence account for the largest four emission shares.

Table 5-4 Expenditure share vs. carbon emissions share by goods

		Comparison	Emission Intensity
Food	emission share	25.21	0.093 kg/yuan
	expenditure share	35.55	
Clothing	emission share	9.95	0.121 kg/yuan
	expenditure share	10.58	
Household Facilities and Articles	emission share	6.84	0.156 kg/yuan
	expenditure share	5.8	
Health Care and Medical Services	emission share	9.6	0.179 kg/yuan
	expenditure share	7.26	
Transport and Communications	emission share	16.41	0.168 kg/yuan
	expenditure share	13.83	
Education, Culture and Recreation	emission share	15.97	0.162 kg/yuan
	expenditure share	13.37	
Residence	emission share	14.29	0.195 kg/yuan
	expenditure share	9.97	
Others	emission share	1.73	0.061 kg/yuan
	expenditure share	3.64	

Table 5-5 provides the budget share and emission share within each household income group corresponds to different types of goods. In the first quintile group, emissions of food consumption take 31.51% of the total emissions. Residence related emissions account for the second largest part of the total emissions (17.65%). Education, culture and recreation emissions are the third largest emission share. Transport and communications emissions and clothing related emissions are 10.64% and 10.07%, respectively. As to the second quintile group, food emissions also generate the largest emissions, but smaller than the first quintile group. The emissions caused by clothing consumption increase to 10.91 compared to the first quintile group. The residence related CO_2 emissions become smaller with 14.47%. The emissions from transport and communications increase 3.23% comparing with first quintile group. The emissions of health care and medical services increase about 1%. For the third quintile group, emissions from clothing changes little. Emissions from both education, culture and recreation and health care and medical services increase more than 1%. However, the emissions from residence decrease to 13.37%. In the higher income groups, the emissions from clothing, health care and medical services, transport and residence change little in the fourth quintile group, while the emissions of education, culture and recreation and household facilities and articles grow about 1% comparing with the first quintile group. As for the fifth quintile group, the food consumption related CO_2 emissions decrease to 20%, while the emissions from transport and communications increase to 23.3%. The clothing generates lower percentage of carbon emissions. To summarize, the food triggered emissions decrease in the richer income groups, while the emissions from transport and communications increase in the richer income groups. Different household income groups have different consumption pattern, thus lead to various carbon emissions structure.

Table5-5 Expenditure share vs. carbon emissions share by goods and household group

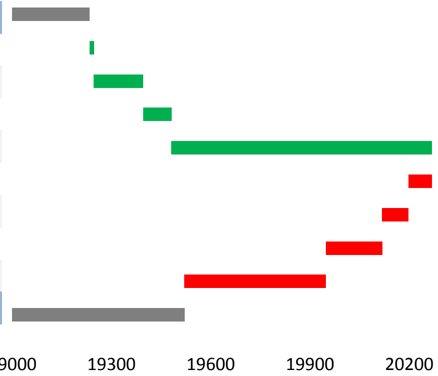
Expenditure items	First quintile		Second quintile		Third quintile		Fourth quintile		Fifth quintile	
	Budget share	CO_2 share	Budget share	CO_2 share	Budget share	CO_2 share	Budget share	CO_2 share	Budget share	CO_2 share
Food	43.29	31.51	40.15	29.09	38.55	27.80	35.38	25.02	29.51	20.41
Clothing	10.43	10.07	11.36	10.91	11.48	10.98	10.81	10.14	9.628	8.834
Household Facilities and Articles	4.952	5.996	5.343	6.437	6.129	7.350	6.026	7.089	5.939	6.833
Health Care and Medical Services	6.294	8.536	7.0215	9.476	7.520	10.10	8.287	10.92	6.861	8.843
Transport and Communications	8.734	10.64	10.91	13.23	10.40	12.56	11.50	13.62	20.12	23.30
Education, Culture and Recreation	11.66	14.29	12.14	14.82	12.97	15.76	14.06	16.75	14.22	16.56
Residence	11.99	17.65	9.885	14.47	9.421	13.73	10.28	14.70	9.450	13.21
Others	2.6328	1.291	3.158	1.541	3.498	1.699	3.627	1.728	4.262	1.986

5.2.4 Income distribution and carbon emissions

According to Table 5-5, household groups with various income level have different budget share, which might lead to different emissions share and the total emissions level. Here, we consider the effect of the change in income distribution on the budget share, then lead to the change in carbon emissions. As we have mentioned above, current income distribution of the sample household is unequal. Holding the mean disposable income of the household unchanged, we assume that all the household has the same disposable income which equal to the current mean disposable income. Then, the consumption patterns for all the households are similar to the middle income group (the third quintile group). Therefore, we can adopt the budget share of the third quintile group to redistribute the total expenditure of all the sample households. Finally, we get the CO_2 emissions in an equal distribution economy with total expenditure and mean disposable income fixed. Table 5-6 provides the information of CO_2 emissions predicted and its changes in different goods. Given the total expenditure unchanged, we only change the budget share to the budget share in equal distribution, the CO_2 emissions decrease from 19521 ton to 19234 ton. The details for how this decrease happen can be found through the emissions changes in different goods. From the unequal distribution scenario to the equal scenario, the emissions from food consumption, clothing, household facilities and articles, and health care and medical services are all increase at different level (refer to the red bars). However, the emissions from transport and communications decrease a large amount which can over all the increased emissions from previous 4 goods (refer to the longest green bar). Furthermore, the emissions from education, culture and recreation, residence and other goods decline (refer to the green bars). Consequently, the emissions decreased excess the increased amount, and lead to a decrease of total carbon emissions.

Table 5-6 Change in CO_2 emissions in an equal income distribution scenario

Consumption structure	CO_2 emissions
Equal distribution	19234
Others	-13
Residence	-149
Education, Culture and Recreation	-85
Transport and Communications	-787
Health Care and Medical Services	70
Household Facilities and Articles	79
Clothing	171
Food	427
Current distribution	19521



Unit: ton

5.3 Estimation results

The estimation of the QUAIDS model is performed according to total sample and five types of household income group to see the effect of household income group on different goods budget shares.

The estimation results of the QUAIDS models are displayed in Table5-7. The variables W1 to W7 indicate food, clothing, household facilities and articles, health care and medical services, transport and communications, education, culture and recreation and residence, respectively. Since other goods take little part of the total emissions change, the QUAIDS model of other goods is not estimated in this paper. We mainly concentrate on the other main goods.

Table 5-7 Estimation results of QUAIDS model

Dep.Var.		Total sample	By income 0ercentile group				
			First	Second	Third	Fourth	Fifth
W1	lnE	0.0586907	0.3899306***	0.3673783*	-0.1271878***	0.4893126**	-0.1175652***
		(0.0535177)	(0.1435975)	(0.2190401)	(0.0085102)	(0.1989388)	(0.0062479)
	lnE2	-0.0086793***	-0.0267563***	-0.024912**		-0.030173***	
		(0.0026337)	(0.007608)	(0.0110362)		(0.009664)	
	cons.	0.7015319 **	-0.815297	-0.7614744	1.694808***	-1.448363	1.59531
		(0.2716582)	(0.677919)	(1.086628)	(0.0859345)	(1.023343)	(0.0662789)
W2	lnE	0.3062084***	0.5054806***	0.3347835**	0.7195616***	0.6756457***	0.4212335***
		(0.0318387)	(0.0926934)	(0.1439442)	(0.1234395)	(0.1260819)	(0.0785954)
	lnE2	-0.0152058***	-0.0267143***	-0.016994**	-0.0353266***	-0.0333016 ***	-0.0201913***
		(0.0015668)	(0.0049133)	(.007254)	(0.0061436)	(0.0061249)	(0.0036573)
	cons.	-1.424718***	-2.278083***	-1.530399**	-3.541968***	-3.306041***	-2.081675***
		(0.1616147)	(0.4369686)	(0.7136609)	(0.6198906)	(0.6485291)	(0.4217254)
W3	lnE	0.0850416***	-0.1179224*	0.0158381***	-0.2960181***	0.0102735**	0.1544647**
		(0.0251437)	(0.063359)	(0.0039936)	(0.10461)	(0.004446)	(0.0654536)
	lnE2	-0.0034863***	0.0072886**		0.0159792***		-0.0068964**
		(0.0012373)	(0.0033585)		(0.0052071)		(0.0030459)
	cons.	-0.4482821***	0.5042545*	-0.1067099***	1.411909***	-0.0469461	-0.8010046**
		(0.1276308)	(0.2986523)	(0.0396316)	(0.5251455)	(0.0457574)	(0.3511758)
W4	lnE	0.199736***	0.0200194***	0.0175033***	0.0157322**	0.0154847**	0.2453322**
		(0.0410925)	(0.0051507)	(0.0063973)	(0.0064988)	(0.0072136)	(0.1077347)
	lnE2	-0.0092558***					-0.0121057**
		(0.0020222)					(0.0050133)
	cons.	-0.9984489**	-0132741***	-0.1067339*	-0.0864397	-0.079788	-1.157416**
		(0.2085874)	(0.0492267)	(0.0634843)	(0.0656235)	(0.0742401)	(0.5780784)
W5	lnE	-0.6382751***	0.012137***	-0.3960534***	0.0093976**	-0.6892816***	-1.467827***
		(0.0345929)	(0.0035724)	(0.1398571)	(0.0042879)	(0.1281967)	(0.118172)
	lnE2	0.0334784***		0.021406***		0.0343005***	0.0725196***
		(0.0017023)		(0.0070481)		(0.0062277)	(0.0054989)
	cons.	3.126049***	-0.0309358	1.920156***	0.0069217	3.559357***	7.521328***
		(0.1755952)	(0.0341423)	(0.693385)	(0.0432981)	(0.6593893)	(0.6341046)
W6	lnE	0.3769479***	0.0721352***	0.0819323***	0.5553561***	0.7717249**	0.9297553***
		(0.0467042)	(0.0067776)	(0.0072076)	(0.1632333)	(0.1835832)	(0.1194424)
	lnE2	-0.015763***			-0.0237012***	-0.0331481***	-0.0415474***
		(0.0022984)			(0.0081235)	(0.0089181)	(0.0055579)
	cons.	-2.075844***	-0.5885886***	-0.705748***	-3.069774***	-4.299155***	-5.034184***
		(0.2370726)	(0.0647744)	(0.0715262)	(0.8199438)	(0.9443415)	(0.6409604)
W7	lnE	-0.4247527***	-0.9240366***	-0.5652377***	-0.9183745***	-1.386761***	-0.3754733***
		(0.0367277)	(0.1057029)	(0.1388172)	(0.1312537)	(0.1645509)	(0.1015686)
	lnE2	0.0202544***	0.0482954	0.0275436***	0.0445912***	0.0675601***	0.0176089***
		(0.0018074)	(0.0056023) ***	(0.0069957)	(0.0065334)	(0.0079941)	(0.0047265)
	cons.	2.316284***	4.525567***	2.992308***	4.813208***	7.19854***	2.084295***
		(0.1864314)	(0.4984744)	(0.6882141)	(0.6588636)	(0.8462835)	(0.5449467)
Obs		4969	994	994	993	994	994
B-P test		3363.122***	742.231***	691.723***	714.184***	667.748***	694.795

Notes: The values in parentheses are standard errors. * indicates the rejection of the null hypothesis at a 10% level of significance. ** indicates the rejection of the null hypothesis at a 5% level of significance. *** indicates the rejection of the null hypothesis at a 1% level of significance. “B-P test” is the Breusch-Pagan test of independence

Meanwhile, we have adopted seemingly unrelated regressions (SURE) to estimation the model. The Breusch-Pagan tests of independence of all the models are statistically significant at 1% level, which indicates it that the system is suitable for seemingly unrelated regressions. In addition, for some of the goods in certain household income group, the estimation results for QUAIDS model are not statistically significant. In that case, we use AIDs model. The following models are AIDs model: food function in the fourth and fifth quintile groups, the function of household facilities and articles in the second and fourth quintile groups, the function of health care and medical services in the first, second, third and fourth quintile groups, The function of transport and communications in the first and third quintile groups, the function of education, culture and recreation in the first and second quintile groups.

According to the parameters estimated in Table 5-7, we can predict the marginal propensity to budget share for each goods by different household income groups. Fig. 5-3 is the marginal propensity to budget share for total sample. It is interesting that the marginal propensity to budget share of clothing, health care and medical services, household facilities and articles, and education culture and recreation are decreasing from positive to negative, while the marginal propensities to budget share of residence and transport and communication are increasing from negative to positive. Meanwhile, the marginal propensity to budget share of food is negative and is continue to decline. It indicates that the goods with lower emissions intensity decline along with the growth of expenditure, while the goods with higher emissions intensity (transport and residence) rise along with the increase of expenditure. In addition, the value of the marginal propensity to budget share of transport and residence is bigger than the other's. Therefore, the household with a higher expenditure has a higher marginal propensity to budget share of high emissions intensity and thus higher emissions propensity. Consequently, reduce income inequality can reduce the carbon emissions of household with higher expenditure and increase the carbon emissions from household with lower expenditure. Since the value of marginal propensity to budget share of the high emissions intensity (transport and residence) is bigger, the emissions reduced are larger than the emissions increased. As a result, the reducing household income inequality leads to a decrease in carbon emissions. That is the reason for the reduction shown in Table 5-6.

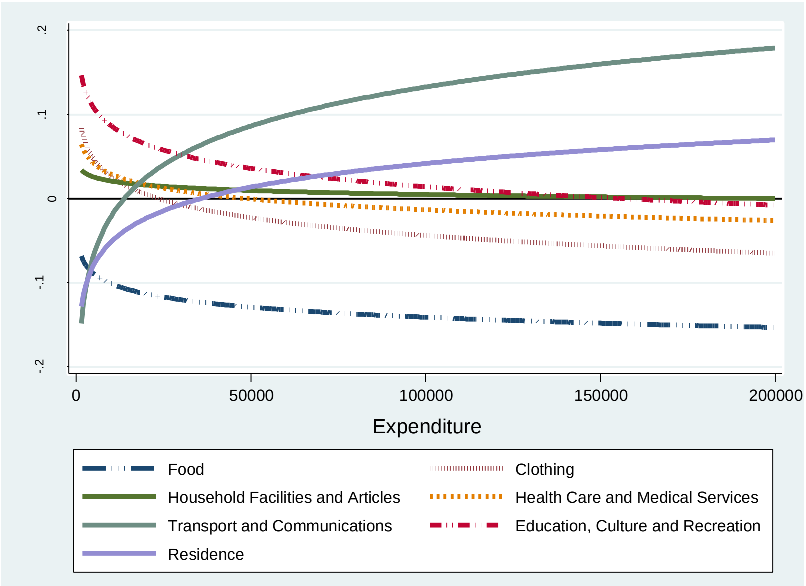


Fig.5-3 Marginal propensity to budget share (Total sample)

To see the marginal propensity to budget share by different household group, we draw Fig. 5-4. Firstly, we discuss the marginal propensity to budget share of food. The figure shows that, given same expenditure, the high income groups (fourth and fifth quintile group) have a smaller marginal propensity to budget share of food, which indicates a smaller decrease in food share. As to clothing share, the second and fifth quintile group has a smaller marginal propensity to budget share of clothing share. For the budget share household facilities and articles, the second and fourth quintile has a constant positive marginal propensity, while first and third quintile groups' marginal propensity increase from negative to positive. The marginal propensity to budget share of household facilities and articles decreases from positive to negative in the fifth quintile group. As for the marginal propensity to the budget share of health care and medical services, all the household group has a constant positive marginal propensity, while the marginal propensity to the budge share of the fifth quintile group decrease from positive to negative. When it comes to the marginal propensity to the budge share of transport and communications, the marginal propensity to the budge share of the fifth quintile group rises from negative to positive with the largest value. The marginal propensities to the budge share of the first and third quintile groups keep positive and unchanged. With the respect to the marginal propensity to the budge share of the education, culture and recreation, the marginal propensities of the first and second group are positive and the other three groups' marginal propensities decline from positive to negative. Finally, we come to the marginal propensity to the budge share of residence, it has a similarly characteristics with the marginal propensity to the budge share of transport and communications. The poorer group has a higher positive marginal propensity to the budge share of residence, while the richer group has a lower one. However the richest group (fifth quintile group) has the smallest positive marginal propensity the budge share of residence.

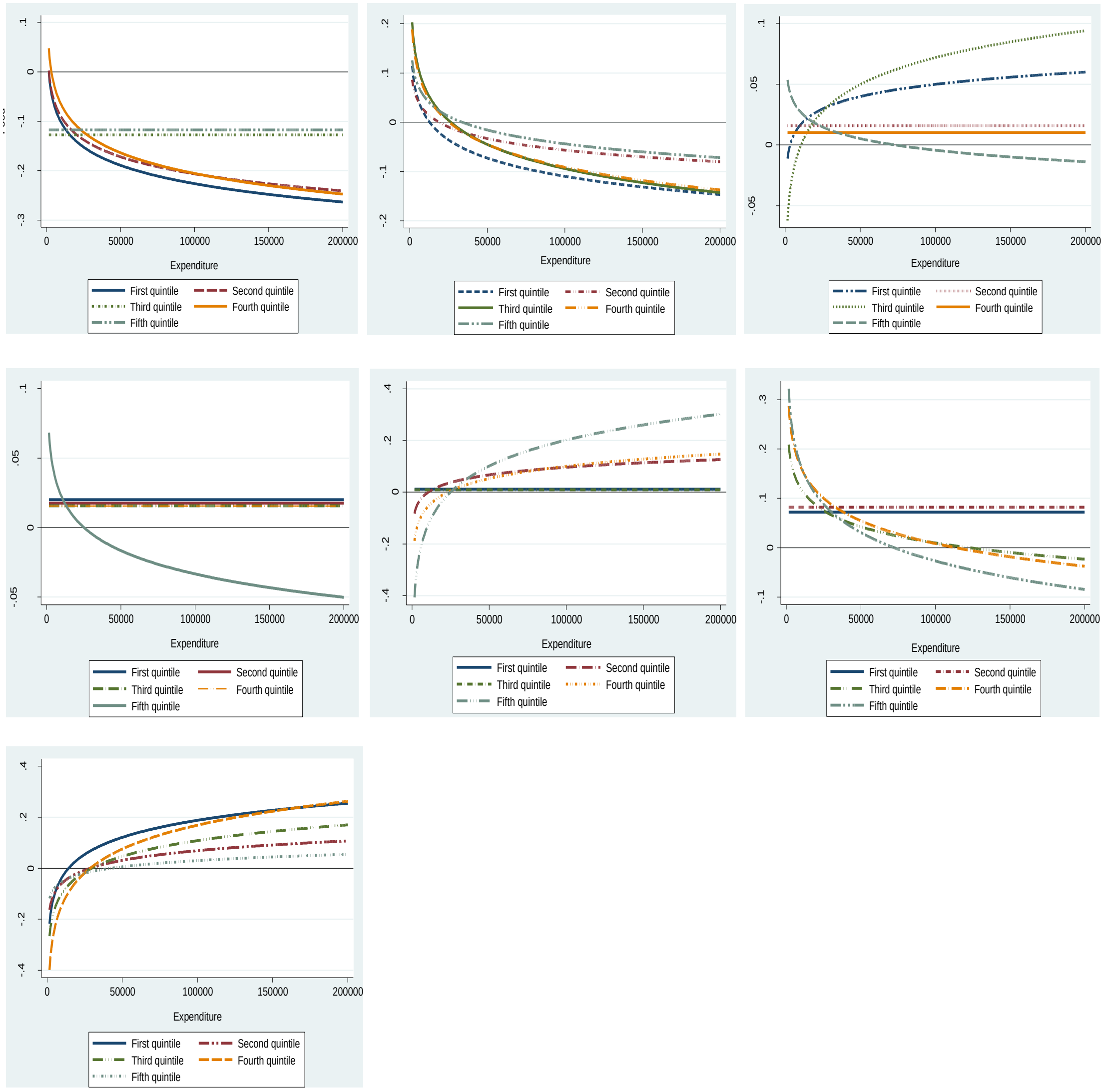


Fig.5-4 Marginal propensity to budget share by household income group

According our calculation, the mean expenditure of the five groups are: first quintile group (15694.06 yuan), second quintile group (22261.55 yuan), third quintile group (26574.68 yuan), fourth quintile group (32687.32 yuan), fifth quintile group (49401.74 yuan). Therefore, the marginal propensities to the budget share of transport and residence (high emission intensity goods) are negative in the poor household groups refer to their mean expenditure, while the marginal propensities to the budge share of transport and residence are positive. Therefore, the reduction of income distribution can help to reduce the marginal propensities to the budget share of high emission intensity goods, thus reduce the carbon emissions level. That is the reason for the income distributive effect on carbon emissions observed in the input-output analysis.

5.4 Policy implications

Our analysis suggests that the high income group (fifth quintile group) contribute to 33 % CO_2 emissions of the total emission with only 20% of population share. The income groups with high income tend to expenditure more, thus lead to a larger emissions. With China's rapid economic growth, the level of residents' living consumption will continue to improve, the living energy consumption and carbon emissions will continue to grow, so the implementation of energy-saving and emission reduction in household life field is an important aspect of carbon emission reduction. Meanwhile, the CO_2 emissions inequality is caused by income inequality and smaller than income inequality. Due to the inequality in CO_2 emissions, the population with lower income has little encouragement to reduce carbon emissions, and it is difficult to allocate the reduction responsibility. In addition, the consumption structure is another important factor to carbon emissions.

Therefore, we propose some policy suggestions as follows: (1) according to Table 5-4, the carbon emissions generated from food consumption takes the largest part of the total emissions. The emissions from residence, transport and education also account for a great part of total emissions in the sample. Food, residence, transport and education are all basic survival commodities. Especially for the poor income group, food, residence and education take a large percentage of total emissions. Therefore, it is difficult to reduce the consumption of these kinds of goods. The best way is to improve the energy efficiency of the industries related with these kinds of goods. These industries are food manufacturing; agro-food processing industry; beverage manufacturing; production and supply of electric, power, heat power and Water; manufacture of nonmetallic; manufacture and processing of metals and metal products; paper and paper products industry; printing and reproduction of recording media. (2) According to our analysis, the CO_2 emissions in an equal income distribution scenario has a lower level of total CO_2 emissions comparing with the current unequal distribution of the sample, given the mean disposable income and total expenditure unchanged (refer to Table 5-6). This indicates that the same expenditure can lead to different carbon emissions due to the different consumption structure in different income distribution economy. Thus, reduce income inequality can help to create a low-carbon consumption pattern. Given that we cannot restrain the income growth and expenditure growth with the economic development and urbanization, we can control the income inequality to lead to a low-carbon consumption structure to limit the carbon emissions as much as possible. (3) Table 5-6 also suggests that the emissions reduction from transport, residence and education contribute to the reduction of the total emissions when reducing the income inequality. Meanwhile, the estimation results of the demand model suggest that the budget shares of transport and residence with higher emission intensity have positive marginal propensities in the household groups with high expenditure. Therefore, the emissions reduction from inequality reduction mainly comes from the decrease of transport and residence in the expenditure budget in the high income households. Thus, impose the tax of the transport and residence related industry or energy consumption activities in transport and residence can help to increase the cost and price of these goods, and thus inhibit the consumption of these goods. The related industries are production and supply of electric, power, heat power and water; manufacture of nonmetallic; manufacture and processing of metals and metal products; communications equipment; computers and other electrical equipment manufacturing; transportation equipment manufacturing

5.5 Concluding remarks

This paper analyzes the relationship between household income disparity, consumption structure and CO_2 emissions based on China urban household survey dataset in 2007, by employing input-output analysis and QUAIDS models to estimate marginal propensity to the budget share of the goods. Compared with previous studies, the main features of this study include the following. (1) The impact of income distribution on carbon emissions is studied at a household level using the household survey data, whereas other studies primarily focus on the effect of household income inequality on emissions using cross-country data. (2) The input-output analysis and QUAIDS models are employed in this study, whereas other studies adopt single model specification. (3) This paper focus on the impact on household income inequality on carbon emissions through its impact on consumption structure. whereas other studies haven't go into the micro data to analysis the demand patterns influenced by income inequality, thus to emissions. (4) The emissions factors of eight kinds of goods are estimated by restructured input-output table, while the other studies use the aggregated carbon emissions at country level.

The main findings of this study reveal that (1) the CO_2 emissions inequality is caused by income inequality and smaller than income inequality. (2) The carbon emissions generated from food consumption takes the largest part of the total emissions. The emissions from residence, transport and education also account for a great part of total emissions in the sample. (3) The CO_2 emissions in an equal income distribution scenario has a lower level of total CO_2 emissions comparing with the current unequal distribution of the sample, given the mean disposable income and total expenditure unchanged. (4) The emissions reduction from inequality reduction mainly comes from the decrease of transport and residence in the expenditure budget in the high income households.

Our policy implications are: (1) to improve the energy efficiency of the industries related with basic survival goods. These industries are food manufacturing; agro-food processing industry; beverage manufacturing; production and supply of electric, power, heat power and Water; manufacture of nonmetallic; manufacture and processing of metals and metal products; paper and paper products industry; printing and reproduction of recording media. (2) Given that we cannot restrain the income growth and expenditure growth with the economic development and urbanization, we can control the income inequality to lead to a low-carbon consumption structure to limit the carbon emissions as much as possible. (3) Impose the tax of the transport and residence related industry or energy consumption activities in transport and residence can help to increase the cost and price of these goods, and thus inhibit the consumption of these goods. The related industries are production and supply of electric, power, heat power and water; manufacture of nonmetallic; manufacture and processing of metals and metal products; communications equipment; computers and other electrical equipment manufacturing; transportation equipment manufacturing

The weakness of this study stems from the estimation problems of carbon emissions due to the limitation of the data. Meanwhile, this study could also be improved by detailed goods expenditure and comparison between two or three years of household survey data.

6 Conclusions

6.1 Comparison with the literatures

The comparison between this study and the existing studies are summarized as followings.

Chapter 3 analyzes the relationship between regional income disparity and CO_2 emissions based on time series data in China over the period of 1978 to 2010, by employing the VECM, the Granger causality test and GIRF analysis. The motivation of this paper is from recent literature that emphasizes the important role that income distribution plays in the environmental Kuznets curve. Compared with previous studies, the main features of this chapter include the following. 1) The impact of income distribution on carbon emissions is studied at a regional level in an individual country, whereas other studies primarily focus on the effect of household income inequality on emissions using cross-country data. 2) The VECM, the Granger causality test and GIRF analysis are employed in this study, whereas other studies adopt fixed effects and random effects methods based on panel data. 3) This paper chooses three measures of income inequality to make comparisons, whereas other studies use only the Gini coefficient as the measure. 4) An indirect causal relation that regional income disparity affects CO_2 emissions through the MEP of GDP is observed, whereas other studies primarily focus on the direct correlation between income inequality and CO_2 emissions.

Chapter 4 analyzes the relationship between household income disparity and CO_2 emissions based on panel dataset in China over the period of 1995 to 2010, by employing GMM and system GMM estimation methods to estimate the SEM.

Compared with previous studies, the main features of this study include the following. 1) The impact of income distribution on carbon emissions is studied at a household level within in an individual country, whereas other studies primarily focus on the effect of household income inequality on emissions using cross-country data. 2) The SEM are employed in this study, whereas other studies adopt single model specification. 3) This paper chooses three types of household income inequality to make comparisons (urban-rural, urban and rural inequality), whereas other studies use only the total household income inequality. 4) An induced effect that household income inequality affects CO_2 emissions through the HCS is observed, whereas other studies primarily focus on the direct relation between household income inequality and CO_2 emissions.

Chapter 5 analyzes the relationship between household income disparity, consumption structure and CO_2 emissions based on China urban household survey dataset in 2007, by employing input-output analysis and QUAIDS models to estimate marginal propensity to the budget share of the goods. Compared with previous studies, the main features of this study include the following. (1) The impact of income distribution on carbon emissions is studied at a household level using the household survey data, whereas other studies primarily focus on the effect of household income inequality on emissions using cross-country data. (2) The input-output analysis and QUAIDS models are employed in this study, whereas other studies adopt single model specification. (3) This paper focus on the impact on household income inequality on carbon emissions through its impact on consumption structure. whereas other studies haven't go into the micro data to analysis the demand patterns influenced by income inequality, thus to emissions. (4) The emissions factors of eight kinds of goods are estimated by restructured input-output table, while the other studies use the aggregated carbon emissions at country level.

6.2 Main findings and policy implications

The findings of this study in each chapter are:

Chapter 3 reveals that there is an inverted-U relationship between per capita CO_2 emissions and income in China, and the regional income disparity has a negative effect on the average level of CO_2 emissions through the decreasing MEP of the GDP. Meanwhile, the Granger causality test and the GIRF analysis show that energy intensity has a negative impact on GDP, which results in higher energy intensity that may restrain economic growth and does not promote sustainable development. Therefore, the policymakers of the central government should be conscious of this potential trade-off between narrowing the income gap and reducing CO_2 emissions. The policy implications include accelerating the transformation of the industrial structure in low-income regions, setting different targets of saving energy and reducing carbon for different regions, improving energy efficiency, refusing the transfer of heavy and energy intensive industries from wealthy regions, making higher emission assessment criteria for new project investments, encouraging capital and labor mobility, imposing eco-taxes or carbon-taxes and developing a market for emissions trading.

Chapter 4 indicates that there is an inverted-U relationship between per capita CO_2 emissions and income in China. The indirect effect that household income inequality affects CO_2 emissions through the HCS is positive in both urban-rural case and rural case. The reasons for this positive effect are: (1) the increase in household income inequality results in the lower consumer demand and higher scale of investment. The prevalent investment "Wave" phenomenon in developing countries has led to excess capacity with rise of the waste of energy consumption and increase in carbon emissions.(2) Not only the total consumption amount is inhibited but also the consumption structure is influenced by the household income inequality. The energy-intensive and low quality preferred consumption structure will become the obstacle to upgrade for industrial structure and technological innovation from the demand side. Thus, the way to reduce carbon emissions through upgrading of industrial structure and develop energy-saving technologies will face a stress from the consumption structure. Our policy implications are: (1) promote the reform of the income distribution system and expand consumer demand, adjust the structure of consumption demand to reduce national savings rate and gradually change the situation of over-reliance on investment for economic development. (2) The government should deepen the reform of factor markets, so that the environment, resources and other external costs can be incorporated into the cost of all enterprises to reflect the scarcity of resources and eliminate the profit of backward production capacity. (3) The government should gradually improve environmental emission standards, establish pollutant emissions market mechanism, impose the taxes from the high-pollution industries with excess capacity. (4) Develop the market-oriented financial resource allocation mechanism to control business loans for investment in the high pollution, high energy consumption and overheated investment enterprises. (5) Establish statistical monitoring system for the capacity utilization of industries to guide the enterprises to make investment and production decision and prevent the irrational investment and blind expansion.

The main findings of chapter 5 suggest that (1) the CO_2 emissions inequality is caused by income inequality and smaller than income inequality. (2) The carbon emissions generated from food consumption takes the largest part of the total emissions. The emissions from residence, transport and education also account for a great part of total emissions in the sample. (3) The CO_2 emissions in an equal income distribution scenario has a lower level of total CO_2 emissions comparing with the current unequal distribution of the sample, given the mean disposable income and total expenditure unchanged. (4) The emissions reduction from inequality reduction mainly comes from the decrease of transport and residence in the expenditure budget in the high income households. Our policy implications are: (1) to improve the energy efficiency of the industries related with basic survival goods. These industries are food manufacturing; agro-food processing industry; beverage manufacturing; production and supply of electric, power, heat power and Water; manufacture of nonmetallic; manufacture and processing of metals and metal products; paper and paper products industry; printing and reproduction of recording media. (2) Given that we cannot restrain the income growth and expenditure growth with the economic development and urbanization, we can control the income inequality to lead to a low-carbon consumption structure to limit the carbon emissions as much as possible. (3) Impose the tax of the transport and residence related industry or energy consumption activities in transport and residence can help to increase the cost and price of these goods, and thus inhibit the consumption of these goods. The related industries are production and supply of electric, power, heat power and water; manufacture of nonmetallic; manufacture and processing of metals and metal products; communications equipment; computers and other electrical equipment manufacturing; transportation equipment manufacturing

6.3 Subjects for further study

The assumptions of the theoretical analysis in chapter 3 is restrictive. Meanwhile, the time period in China needs to be extended, and the other driving forces of CO_2 emissions, such as industrialization and urbanization, should be introduced in the model. Further research in this field should include these variables and use a longer time series dataset. This study could also be improved by analyzing the interaction effects between GDP and regional income disparity and their effects on carbon emissions. The work to improve this study is currently underway.

Chapter 4 can be improved by analyzing the interaction effects between GDP and regional income disparity and their effects on carbon emissions. Furthermore, the income (GDP) in the model of this study is treated as exogenous, however, it should be endogenous. The work to improve this study is currently underway.

There are some estimation problems of carbon emissions due to the limitation of the data in chapter 5. Meanwhile, this study could also be improved by detailed goods expenditure and comparison between two or three years of household survey data.

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Appendix A

Table A1. Summary statistics of data

	LCO_2per	LGDPper	$LGDPper^2$	LEG	Gini	Theil	Kakwani
Mean	0.952914	6.383694	41.39329	6.252591	0.303526	0.176762	0.088034
Median	0.941527	6.396605	40.91655	6.190205	0.303131	0.170200	0.086780
Maximum	1.783221	7.770516	60.38092	7.142120	0.350400	0.280820	0.123860
Minimum	0.377914	5.105636	26.06752	5.567202	0.262965	0.114820	0.063550
Std. Dev.	0.410622	0.813511	10.44655	0.515251	0.019611	0.035920	0.013059
Skewness	0.536884	0.066512	0.221272	0.260615	-0.011090	1.185331	0.741393
Kurtosis	2.397731	1.829749	1.883672	1.680259	3.014847	4.295845	3.736237
Jarque-Bera	2.084098	1.907376	1.982798	2.768423	0.000980	10.03647	3.768458

Table A2. Composition of the subgroups

Subgroups	Provinces
Eastern region (11 provinces)	Beijing; Tianjing; Hebei; Liaoning; Shanghai; Jiangsu; Zhejiang; Fujian; Shandong; Guangdong; Hainan;
Central region (8 provinces)	Shanxi; Jilin; Heilongjiang; Anhui; Jiangxi; Henan; Hubei; Hunan;
Western region (12 provinces)	Inner Mongolia; Guangxi Zhuang; Chongqing; Sichuan; Guizhou; Yunnan; Shaanxi; Gansu; Qinghai; Ningxia Hui; Xinjiang Uygur; Tibet

Table A3 Empirical studies on income inequality and environmental quality

Authors	Countries, periods	pollution	Func. form	Inequality variables	Control variables	Estimation methods	Data source
Torras and Boyce (1998)	Air pollution (52 cities in 42 countries) Water pollution(C87 SSTATIONS IN 58 countries) 1977-1991	Seven indicators of air and Water pollution,	Cubic Level	Gini, Literacy rate and political ights	City dummy, Coastal zones and urbanization	OLS (cross sectional data)	GEMS data set, United Nations Development Programme (1994) GINI ratios by World Development Report.1992 Literacy by United Nations Development Programme(1994) Political rights by Finn(1996);
Scruggs (1998)	29 countries 1992	Fecal coliforms Dissolved oxygen Sulfur Dioxide, Particulates	Quadratic Level	Gini and Democracy	Period, industrialization Population density Nuclear,	OLS (cross sectional data)	World Development Report1992 Gini data by Deininger and Squire(1996)
Ravallion et al. (2000)	42 countries 1975-1992	CO_2 emission	Quadratic Log Cubic log	Gini index; GDP per capita interacted with Gini variable	Population size Time trend	Fixed effect model (panel data)	ORNL, UNSTAT Gini data by Deininger and Squire(1996)
Magnani (2000)	OECD countries 1980 to 1991	Public R&D expenditure for environmental protection	Quadratic Log	Gini index;	Time trend	Random effect, Fixed effect and PCS(Pooled cross section corrected for serially correlated residuals)	OECD environmental Data(1993) Gini data by Deininger and Squire(1996)
Heerink et al. (2001)	46 countries 1992	$CO_{2,}$ SO_2 SPM	Quadratic Log	Gini index;	NA	OLS	World Development Report.1992
Nugent and Sarma (2002)	India SAM (1988-1989)	Air pollution (Total suspended particulates (TP) and fine particulates (PM10): SO2, NOX, NO2, CO, Volatile organic compounds (VOC):) Water pollution	CGE model	The relative incomes of various groups	NA	CGE model	SAM(NAS published by the Central Statistical Organization; IOT prepared by the Planning Commission; Household expenditure surveys by NSSO, income survey of applied economic research(NCAER,1996)

		(Biological oxygen demand (BOD), Suspended solids:) Toxic waste (Toxic chemicals, Bio accumulative metals)					
Duro and Padilla (2006)	114 countries 1971,1980, 1990,1999	CO_2	NA	Theil index	NA	Decomposition methodology by Kaya Factors	International Energy Agency IEA(2001)
Padilla and Serrano (2006)	113 countries 1971-1999	CO_2	NA	Theil index Pseudo-gini index of CO_2	NA	Decomposition methodology of Theil index and Gini index	World Development Report.2002
Coondooa and Dinda (2008)	88 countries 1960-1990	CO_2	Quadratic Log	Gini index	NA	Random effect, Fixed effect (cross-country panel data set at the level of country-group)	CO_2 from Penn WORLD table and Oak Ridge National Laboratory USA
Yang et al. (2011)	China provincial data (30 provinces) 1996-2008	Industrial Wastewater Emission; Industrial Waste Gas Emission	simultaneous equations (including the environmental quality determined equation and the income distribution determined equation,)	Gini index	technology advancement, human capital, industry structure, urbanization rate, education expense	3SLS Simultaneous equations model	Chinese Statistical Yearbook, Chinese Statistical Yearbook on Environment, Chinese Population and Employment Statistics Yearbook, China Yearbook of Rural Household Survey.
Clarke-Sather et al.(2011)	China provincial data(27 provinces) 1997-2007	CO_2	NA	NA	NA	Inequality Measures: the coefficient of variation, Gini index, Theil index, Kakwani index	China Energy Statistical Yearbooks1997–2007; China Statistical Yearbooks1997–2007