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Regional Economic Development, Energy Consumption, and Carbon Emissions in China

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Chunhua Wang

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EXECUTIVE SUMMARY

The main aim of this study is to understand the relationships between regional economic development, energy consumption and total carbon emissions in Chinese provinces by analyzing panel data from 1995-2010. The distribution of economic activity is uneven within China and population migration across regions is persistent. These factors have significant implications for understanding patterns of CO_2 emissions. We propose a framework that decomposes changes in emissions into sources attributable to:

1. the national growth rate of gross domestic product (GDP);
2. differential growth rates of gross regional product (GRP) across regions;
3. changes in energy intensity across regional economies; and
4. changes in the CO_2 emissions coefficient of energy consumption.

Uneven growth across regions was found to contribute significantly to lower CO_2 emissions in China during this time period. We calculated the changes in emissions between 1995 and each year from 1996-2010. The sum of the changes was 25048.36 million tonnes. We found that differential growth saved about 580.34 million tonnes of CO_2 from 1996-2010, which accounts for about 2.32% of the total changes. Simulations were conducted to analyze the chances of lowering energy intensity and emissions intensity in the 12th Five-Year Plan, as well as the goal of lowering carbon emissions intensity by 2020. Policy implications from this study include:

1. decreasing energy intensity by promoting technological growth, improving the technical efficiency of poor areas, and upgrading the economic structure of the Chinese economy;
2. taking into account the differential growth rates across regions when making policies; and
3. allocating energy resources more efficiently across regions by improving the transport system.

1.0 INTRODUCTION

Policymakers in many countries face the challenge of controlling greenhouse gas (GHG) emissions while trying to achieve economic growth; this is a challenge particularly in developing countries such as China. Since 1978, when economic reform was initiated, China has had a rapidly growing economy, with an average annual growth rate of 9.5%. As a result, both energy consumption and CO_2 emissions have increased at tremendous speed.

In November 2009, the Chinese government announced a target of lowering carbon emissions per unit of gross domestic product (GDP) by 40-45% by 2020 compared with the 2005 level. Measures taken to achieve this goal will influence gross carbon emissions and regional economic development within the country. In China, climate change and GHG policies mainly target CO_2 emissions intensity, i.e., CO_2 emissions per unit of GDP. To decrease the coefficient, different measures have been proposed and implemented to achieve lower energy intensity (energy-GDP ratio) and the carbon coefficient of the energy (carbon-energy ratio).

Disparities between western, central and coastal provinces in China are striking. Correcting regional disparities is an important issue for the Chinese government at all levels, which is striving to build an "all-round well-off society." Regional disparities in economic development and regional economic development policy also affect the chances of lowering emissions intensity and controlling carbon emissions because provinces have different levels of emissions intensity, energy intensity, and energy input structure. Hence, it is of great practical and scientific importance to understand the relationships between economic development, energy consumption, and carbon emissions at regional and national levels.

The majority of previous studies focus on the dynamics of carbon intensity and per capita CO_2 emissions (see, for example, Aldy 2007). A relatively small number of studies explore the factors that drive the changes in total emissions between years, though this indicator is more straightforward for predicting the future of climate change. The Kaya identity (Kaya and Keiichi 1997) offered a simple and useful framework for that purpose. It found that output growth is a main source of CO_2 emission increments in most countries and falling energy intensity contributes to declines in emissions. The findings of studies on China are consistent with those in a global context (Ang and Pandiyan 1997; Lee and Oh 2006; Liu *et al.* 2010; Wang *et al.* 2005; Wu *et al.* 2005; Zhang *et al.* 2011). Most studies in this line of literature primarily rely on sector data for specific countries and industries (Ang and Zhang 2000).

The distribution of economic activity within China is uneven and population migration across regions is persistent. If regions differ in the carbon intensity of their economies, these fundamental factors have implications for understanding trends in CO_2 emissions. These variations exist and are significant. However, the effect of differential GDP growth across regions on changes in total emissions between time periods in a country is largely neglected in literature. This paper contributes to understanding this issue.

The main objective of this study is to investigate the links between regional economic growth and trends in energy consumption and CO_2 emissions from burning fossil fuels. Specifically, we quantify the effect on changes in total emissions of differential growth across regions in China. To accomplish this, this paper proposes a framework that decomposes changes in CO_2 emissions into sources attributable to:

1. the national growth rate of GDP;
2. differential growth rates of GRP across regions;
3. changes in the energy intensity across regional economies; and
4. changes in the CO_2 emissions coefficient of energy consumption (i.e., CO_2 emissions per unit of energy consumption).

The effects of differential growth can increase or decrease CO_2 emissions. The net effects depend on the distribution of carbon intensity and economic growth rates across regions. We performed a nonparametric statistical analysis to understand the roles played by changes in energy intensity and carbon coefficient in the distribution dynamics of CO_2 intensity.

Empirical results indicate that the effects of differential growth are not minimal. Differential growth has a more important role to play than changes in carbon intensity of energy, with regard to decreasing emissions during some sub-periods in our sample. Our empirical results highlight the importance of uneven output growth for reducing CO_2 emissions in China. Differential growth across provinces in China saved about 580.34 million tonnes of CO_2 from 1996-2010.

An advantage of our framework is that it allows us to analyze regional data. This is important because CO_2 emissions and energy consumption targets in China are normally set by central government, which then informs each province of their targets. It should be noted that the decomposition analysis in this paper is an accounting exercise which generates new results regarding the sources of changes in carbon emissions. As in previous studies using sector data, our decomposition results do not provide explanations about fundamental drivers of the changes in CO_2 emissions. To show the validity of the proposed framework and for the purpose of comparison, evidence from US states is described in the Appendix. When comparing results from the two countries, one needs to note that the US data covers different years compared to the China data, and includes a structural break in the data series for GDP in the US results.

The organization of the remainder of the paper is as follows: Section 2 describes data and presents some stylized facts. Section 3 features the decomposition framework. Section 4 presents our decomposition results and discussion. Section 5 briefly analyzes China's national and regional targets for lowering energy intensity and reducing CO_2 emissions intensity for the next Five-Year Plan (2011-2015). Some simulation analyses are also presented. Section 6 presents the results of small-scale interviews regarding related policy issues, and discusses policy implications from the analyses of this project. Section 7 offers our conclusion.

2.0 DATA DESCRIPTION AND SOME STYLIZED FACTS

2.1 Data Sources

The unit of observation in the paper is provinces in China.[1] We collected data for China's provinces and decomposed changes in CO_2 emissions from fossil fuel combustion. We constructed province-level CO_2 emission estimates based on fossil fuel combustion data for 1995-2010. Data on fuel type and consumption were obtained directly from various editions of the *China Energy Statistical Yearbook* (NBS and NDRC 2000-2011).[2] Energy consumption has been converted to CO_2 emissions using fuel-specific emission factors. Similar applications of this approach have been used by many previous studies (Lutter 2000; Marland *et al.* 2008; Blasing *et al.* 2004; Aldy 2007). Data on population and GRP come directly from various editions of the *China Statistical Yearbook* (NBS 1997-2010). We also looked at statistical publications from specific provinces for more information about related variables.

2.2 Data for CO_2 Emissions

The combustion of fossil fuels is the main source of carbon emissions in China, accounting for about 70-80% of emissions. Our study is concerned with measuring carbon emissions resulting from the use of primary energy in China, including coal, coke, crude oil, gasoline, kerosene, diesel oil, fuel oil, and natural gas.

According to the fuel-based method for estimating emissions from fossil fuel combustion given by the *2006 IPCC Guidelines for National Greenhouse Gas Inventories*, carbon emissions can be estimated on the basis of the quantities of fuel burned (energy consumption in this study), average emission factors, and the emissions factor, which is the product of calorific value (CV), carbon content (CaC) and the carbon oxidation factor (COF) (Table 1). The formula is as follows:

$$EC = \sum_{i=1}^{7} EC_i = \sum_{i=1}^{7} E_i \times CV_i \times CaC_i \times COF_i \times 3.67$$

where *EC* is total emissions of all types of energy mentioned above, E_i is the consumption of energy type *i* at the provincial level and the product of $CV_i \, x \, CaC_i \, x \, COF_i \, x \, 3.67$ is the emission factor for each type of energy.

According to the *China Energy Statistical Yearbook*, three uses of energy can lead to CO_2 emissions: total final consumption, thermal power generation, and heating supply. We have data on each type of energy for each of these uses. Using the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* and *The People's Republic of China National Greenhouse Gas Inventory*, we calculated emission factors in view of specific fuels and different levels of combustion technologies across provinces in China. However, due to the different criterion used for coal classification by the IPCC and China's statistics, where coal is classified by raw coal, cleaned coal, and briquettes, to get a credible coal emissions factor, the weighting method by Du (2010) is used in this paper. Table 1 documents the CO_2 emission factors for each type of energy in this study.

Table 1. CO_2 emission factors

Emission source	Coal	Coke	Gasoline	Kerosene	Diesel oil	Fuel oil	Natural gas
carbon content (t-C/TJ)	27.28	29.41	18.90	19.60	20.17	21.09	15.32
calorific value (TJ/million t or TJ/100 million m^3)	178.24	284.35	448.00	447.50	433.30	401.90	3893.10
carbon emission factor (t-C/t or t-C/100 million m^3)	0.449	0.776	0.830	0.865	0.858	0.835	5.905
CO_2 emission factor (t-CO_2/t or t-CO_2/100 million m^3)	1.674	2.848	3.045	3.174	3.150	3.064	21.670

[1] "Region" and "province" are used interchangeably in this paper.

[2] Tibet is excluded from the analysis because data on energy are not available. Data for Ningxia in 2000, 2001 and 2002 and for Hainan in 2002 are missing. The provinces are excluded from our analyses for these and related years.

We calculated CO_2 emissions from the combustion of each type of energy for each province in our sample. Figure 1 shows aggregates over provinces and the relative importance of the combustion of each type of energy in total emissions at a national level. These findings suggest that burning coal is the most significant source of CO_2 emissions. However, this share of emissions has declined slightly over the years. Coal accounted for 75.15% of total emissions in 1995, but only 69.51% of total emissions in 2010.

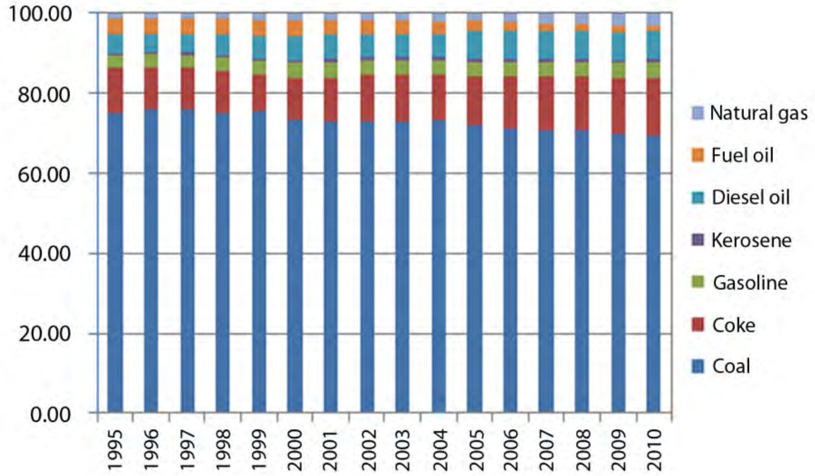

Figure 1. Sources of CO_2 emissions in China (%), 1995-2010

After China's entry into the World Trade Organization (WTO) in 2001, total CO_2 emissions soared. In 2006, China passed USA to become the largest emitter in the world (Marland *et al.* 2009).

Figure 2 shows the dynamic of China's CO_2 emissions intensity from 1995-2010 in our data sample. The intensity declined steadily before 2002 then experienced a short period of increase during 2002-2005. Emissions intensity reached its highest level in 2005. Since 2006, emissions intensity has been decreasing. CO_2 emissions intensity in 1995 at a national level was 0.435 t/CNY 1000 (1995 CNY rates). It decreased by 46.8% over the next 15 years and the level in 2010 was about 0.232 t/CNY 1000 (1995 CNY rates).

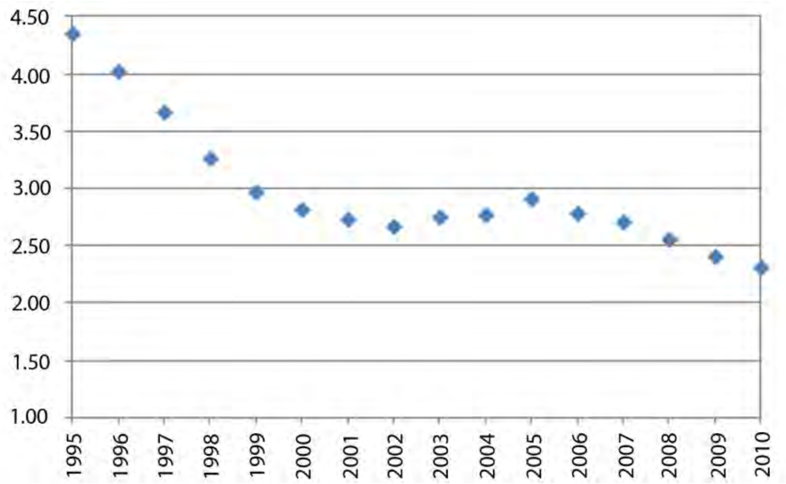

Figure 2. CO_2 intensity of China's economy (in t/CNY 10,000 1995 CNY rates), 1995-2010

Figure 3 shows statistics for per capita emissions (in 10,000 t) in China's provinces. It indicates that the mean level of per capita emissions increased steadily over the 16-year period. Variations in per capita emissions across provinces are huge. Emissions per capita in the province with the highest level are more than two times that in the province with the lowest level.

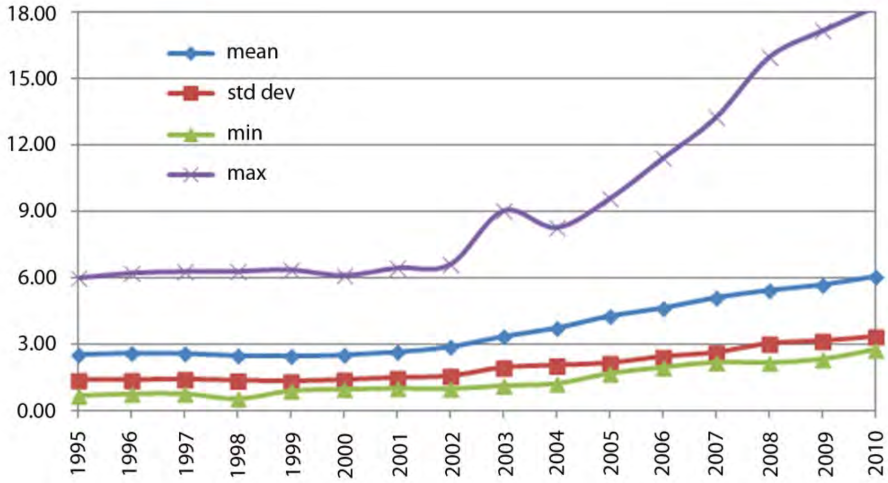

Figure 3. Per capita CO_2 emissions in China's provinces, 1995-2010

2.3 Summary of Statistics

The major objective of this paper is to understand the relationships between regional economic development, energy consumption and total carbon emissions in Chinese provinces. Table 2 provides a summary of statistics of data on key variables for this paper. We report average annual growth rates of GRP, regional CO_2 emissions, and energy consumption for two sub-periods. Absolute values for selected variables are also reported for selected years.

Table 2. Summary of statistics, Chinese provinces

Variable	Year/period	Mean	Std. dev.	Min	Max	# obs.
Annual growth rate (%)						
CO_2 emissions	1995–2004	5.677	3.317	1.389	14.960	29
	2005–2010	8.395	2.530	4.042	14.531	30
Energy consumption	1995–2004	6.587	2.844	2.583	13.229	29
	2005–2010	8.339	1.566	4.720	11.716	30
GRP	1995–2004	10.443	1.083	8.558	12.410	29
	2005–2010	13.163	1.558	10.572	17.590	30
Absolute level						
CO_2 intensity	1995	5.282	2.732	1.399	13.521	29
	2005	3.706	2.374	1.577	11.524	30
	2010	3.033	2.089	1.226	10.646	30
Energy intensity	1995	2.710	1.422	0.836	7.752	29
	2005	1.960	1.087	0.941	5.663	30
	2010	1.575	0.869	0.786	4.525	30
CO_2 coefficient	1995	1.948	0.264	1.372	2.855	29
	2005	1.857	0.321	1.101	2.511	30
	2010	1.863	0.341	1.139	2.684	30

Notes: Carbon intensity is measured in metric tonnes of CO_2 per CNY 10^4 (1995). Energy intensity is measured in metric tonnes of standard coal per CNY 10^4 (1995). The carbon coefficient is measured in metric tonnes of CO_2 per metric tonne of standard coal.

Growth rates in GRP, energy consumption, and CO_2 emissions vary substantially across provinces in China. Between 2005 and 2010 the annual growth rate for the fastest-growing province was 17.59%, while the lowest annual growth rate was 10.57%. Disparities in carbon intensity and energy intensity across provinces are striking. Carbon intensity in the province with the highest annual growth rate is more than nine times higher than in the province with the lowest annual growth rate. It is also surprising to find that the CO_2 coefficient of energy also differs significantly across provinces.

On average, provinces experienced declines in the energy intensity and carbon intensity of their economies. The carbon coefficient did not change much during these time periods. Obviously, the patterns of differential growth of GRP across regions matter for CO_2 emissions because the carbon intensity of these regional economies is hugely disparate. If regions of the country with lower levels of carbon intensity grow faster, the country as a whole would produce fewer emissions.

2.4 Distribution Dynamics: Carbon Intensity

To describe the dynamics of carbon intensity distributions, we conduct some simple nonparametric analysis. Let $CO_2^{s,t}$ denote carbon emissions in region *s* at year *t*, $Y^{s,t}$ GRP, and $E^{s,t}$ energy consumption. Carbon intensity of the economy can be written as the product of energy intensity of the economy and carbon coefficient of energy:

$$\frac{CO_2^{s,t}}{Y^{s,t}} = \frac{E^{s,t}}{Y^{s,t}} \times \frac{CO_2^{s,t}}{E^{s,t}} \equiv e^{s,t} \times c^{s,t} \qquad \text{(Equation 1)}$$

Thus, changes in energy intensity and carbon coefficient contribute to the change in carbon intensity of the economy between years τ and *t*:

$$\frac{\frac{CO_2^{s,\tau}}{Y^{s,\tau}}}{\frac{CO_2^{s,t}}{Y^{s,t}}} = \frac{e^{s,\tau}}{e^{s,t}} \times \frac{c^{s,\tau}}{c^{s,t}} \qquad \text{(Equation 2)}$$

Climate change and GHG policies in many countries mainly target the CO_2 emissions intensity of their economy. Different measures have been proposed and implemented to lower the energy intensity of the economy and the CO_2 coefficient of energy. The above equations can help us to investigate the contributions of the two components of change in carbon intensity over time. Carbon intensity in year τ can be constructed by successively multiplying carbon intensity at year *t* by each of the two components. To isolate the effect on the distribution dynamics of carbon intensity from the change in energy intensity only, we examine the counterfactual year τ carbon intensity distribution of the variable:

$$CI^e = \frac{CO_2^{s,t}}{Y^{s,t}} \times \frac{e^{s,\tau}}{e^{s,t}} \qquad \text{(Equation 3)}$$

assuming no changes in the carbon coefficient. This counterfactual distribution for China is shown in Panel (A) of Figure 4, along with the actual distributions in 1995 and 2010.[3] Note that if energy intensity did not change for any region in China, the counterfactual distribution in this panel would be identical to the actual 1995 distribution.

With the effect of changes in energy intensity alone, the counterfactual distribution is very close to the actual 2010 distribution, which indicates that this component primarily accounts for carbon intensity distribution changes between 1995 and 2010. The effect of the changes in carbon intensity can be deduced by comparing the counterfactual distribution in Panel (A) with the 2010 actual distribution. The effect of such changes slightly shifts the distribution further to the left. However, the shape of the distribution does not change significantly. Panel (B) of Figure 4 considers the effect on distribution dynamics of carbon intensity from changes in the carbon coefficient only. The small shift of the counterfactual distribution from the actual 1995 distribution to the left in Panel (B) confirms that improvements in the carbon coefficient of energy played a minor role in the changes in carbon intensity of China's economy.

Analyses of the US data lead to similar conclusions about the distribution dynamics of CO_2 emissions intensity between 1997 and 2009. That is, energy intensity change primarily accounts for the emissions intensity distribution change.

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[3] To estimate the densities in the two years and all the other densities in this paper, we used the Gaussian kernel function and the Sheather and Jones (1991) selector to determine the "optimal" bandwidth.

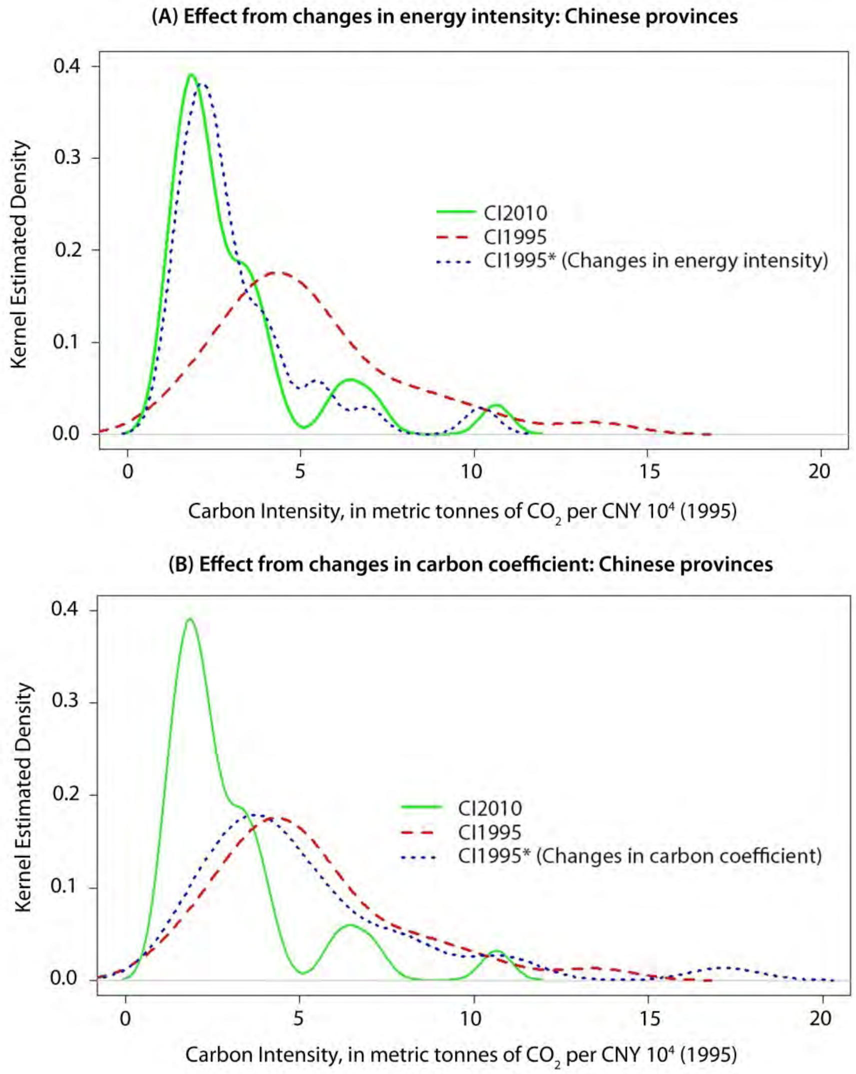

Figure 4. Counterfactual distributions of carbon intensity, Chinese provinces
Note: CI1995 is the 1995 actual distribution; CI2010 is the 2010 actual distribution.

To further examine the drivers of changing energy productivity (i.e., the inverse of energy intensity) in Chinese provinces, we (Wang 2011) constructed a framework based on production theory (Shepard 1970) and data envelopment analysis (Charnes *et al.* 1978) and decomposed the changes into five components attributable to changes in capital-energy ratio, labor-energy ratio, output structure of the economy, technical efficiency change, and technological change. Then a nonparametric analysis (Sheater and Jones 1991; Li 1996; Li 1999) was implemented to statistically test the relative contributions of the components and their roles in the distribution dynamics of energy productivity in Chinese provinces.

It was found that: a) changes in capital-energy ratio, output structure of the economy, and technological change over the time period have contributed to the declines in energy intensity of China's economy; b) an increase in capital-energy ratio caused by capital accumulation has been the primary driving force; and c) capital accumulation has contributed to energy intensity convergence between Chinese provinces over the time period.

2.5 Simple Regression Analysis

We ran a series of simple regressions of provincial output growth rates between 1995 and the later years on the 1995 carbon intensity in Chinese provinces. It was found that the level of carbon intensity in 1995 and economic growth rates in later years are negatively correlated in Chinese provinces, with the exception of the years 2008-2010. The relationship is not statistically significant.

Similar regressions were run for the US data in 1997 and later years (see Appendix for empirical results). Negative correlations are also found and they are statistically significant in most of the years. Generally, the estimated coefficient for the US case is greater (in absolute value) than that for China's, which indicates that regional growth in the US is more responsive to carbon intensity in base years.

3.0 THE DECOMPOSITION FRAMEWORK

Changes in GRP, energy intensity, and carbon coefficients affect total CO_2 emissions at a national level. Data presented in the previous section suggests that regions across China differ hugely in GRP growth rate, levels of energy intensity, and carbon coefficients. To quantify the effects of differential growth, we propose a framework which decomposes a change in CO_2 emissions between years into its sources.[4]

Note that CO_2 emissions in region *s* at time period *t* can be seen as the product of three factors: GRP $Y^{s,t}$, energy intensity of the regional economy $e^{s,t}$, and CO_2 coefficient of the energy consumption in the region $c^{s,t}$,

$$CO_2^{s,t} = Y^{s,t} \times e^{s,t} \times c^{s,t} \qquad \text{(Equation 4)}$$

A simple aggregation over the regions in the above equation leads to a representation for the whole country:

$$CO_2^{t} = \sum_s \left(Y^{s,t} \times e^{s,t} \times c^{s,t}\right) \qquad \text{(Equation 5)}$$

Then the changes in CO_2 emissions in the country between two time periods *t* and τ can be decomposed into three components: growth across regions, changes in carbon intensity, and changes in energy intensity.

$$\frac{CO_2^{\tau}}{CO_2^{t}} = \frac{\sum_s (Y^{s,\tau} \times e^{s,\tau} \times c^{s,\tau})}{\sum_s \left(Y^{s,t} \times e^{s,t} \times c^{s,t}\right)} \qquad \text{(Equation 6)}$$

To isolate the effects on CO_2 emissions changes between time periods *t* and τ, we can decompose it in six different ways with three factors in each of them. Each of the 18 factors measures the effect of the change in one of *Y*, *e* and *c* with two others fixed. For example,

$$\frac{CO_2^{\tau}}{CO_2^{t}} = \frac{\sum_s (Y^{s,\tau} \times e^{s,t} \times c^{s,t})}{\sum_s \left(Y^{s,t} \times e^{s,t} \times c^{s,t}\right)} \times \frac{\sum_s (Y^{s,\tau} \times e^{s,\tau} \times c^{s,t})}{\sum_s (Y^{s,\tau} \times e^{s,t} \times c^{s,t})} \times \frac{\sum_s (Y^{s,\tau} \times e^{s,\tau} \times c^{s,\tau})}{\sum_s (Y^{s,\tau} \times e^{s,\tau} \times c^{s,t})} \qquad \text{(Equation 7)}$$

The first term in the right-hand side of Equation 7, where only GRP changes and the other two factors are fixed between the two time periods, measures the sole effect of national economic growth trends on changes in total emissions. The second term quantifies the sole effect of changes in the energy intensity of regional economies. The last one singles out the sole effect of changes in CO_2 coefficients of energy consumption in the regions.

We took the geometric mean of the six decompositions and rearranged them into three groups, resulting in the following equation:[5]

$$\frac{CO_2^{\tau}}{CO_2^{t}} = \left\{ \left[\frac{\sum_s (Y^{s,\tau}\, e^{s,t}\, c^{s,t})}{\sum_s \left(Y^{s,t}\, e^{s,t}\, c^{s,t}\right)}\right]^2 \left[\frac{\sum_s (Y^{s,\tau}\, e^{s,\tau}\, c^{s,\tau})}{\sum_s \left(Y^{s,t}\, e^{s,\tau}\, c^{s,\tau}\right)}\right]^2 \frac{\sum_s (Y^{s,\tau}\, e^{s,t}\, c^{s,\tau})}{\sum_s \left(Y^{s,t}\, e^{s,t}\, c^{s,\tau}\right)} \frac{\sum_s (Y^{s,\tau}\, e^{s,\tau}\, c^{s,t})}{\sum_s \left(Y^{s,t}\, e^{s,\tau}\, c^{s,t}\right)} \right\}^{\frac{1}{6}} \qquad \text{(Equation 8)}$$

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[4] A similar decomposition framework has been proposed in the regional literature to investigate the importance of differential growth. For example, Overman *et al.* (2008) used an additive model to decompose the growth in land occupied by residences in the US and found that the shift of population across states made significant contributions to the increase in residential land.

[5] See Seigel (1945) for a general mathematical discussion. Ang *et al.* (2004) gives an example of application in energy studies.

$$\times\left\{\left[\frac{\sum_s\left(Y^{s,t}e^{s,\tau}c^{s,t}\right)}{\sum_s\left(Y^{s,t}e^{s,t}c^{s,t}\right)}\right]^2\left[\frac{\sum_s\left(Y^{s,\tau}e^{s,\tau}c^{s,\tau}\right)}{\sum_s\left(Y^{s,\tau}e^{s,t}c^{s,\tau}\right)}\right]^2\frac{\sum_s\left(Y^{s,t}e^{s,\tau}c^{s,\tau}\right)}{\sum_s\left(Y^{s,t}e^{s,t}c^{s,\tau}\right)}\frac{\sum_s\left(Y^{s,\tau}e^{s,\tau}c^{s,t}\right)}{\sum_s\left(Y^{s,\tau}e^{s,t}c^{s,t}\right)}\right\}^{\frac{1}{6}}$$

$$\times\left\{\left[\frac{\sum_s\left(Y^{s,t}e^{s,t}c^{s,\tau}\right)}{\sum_s\left(Y^{s,t}e^{s,t}c^{s,t}\right)}\right]^2\left[\frac{\sum_s\left(Y^{s,\tau}e^{s,\tau}c^{s,\tau}\right)}{\sum_s\left(Y^{s,\tau}e^{s,\tau}c^{s,t}\right)}\right]^2\frac{\sum_s\left(Y^{s,t}e^{s,\tau}c^{s,\tau}\right)}{\sum_s\left(Y^{s,t}e^{s,\tau}c^{s,t}\right)}\frac{\sum_s\left(Y^{s,\tau}e^{s,t}c^{s,\tau}\right)}{\sum_s\left(Y^{s,\tau}e^{s,t}c^{s,t}\right)}\right\}^{\frac{1}{6}}$$

This decomposition leads to several Fisher ideal indexes (Fisher 1921).

Furthermore, GRP in region s can be rewritten as $Y^{s,t}=Y^t\times\frac{Y^{s,t}}{Y^t}$, which is the product of national output Y^t and the share of this region's output in the national economy. Then we have the following representation of this region's growth between the two time periods,

$$\frac{Y^{s,\tau}}{Y^{s,t}}=\frac{Y^\tau}{Y^t}\times\frac{\frac{Y^{s,\tau}}{Y^\tau}}{\frac{Y^{s,t}}{Y^t}}\equiv\frac{Y^\tau}{Y^t}\times\frac{y^{s,\tau}}{y^{s,t}},\qquad\text{(Equation 9)}$$

where the first part denotes the growth rate of the national economy. The second part is a measure of differential change of this region's GRP. Equation 9 allows us to further single out the effect of differential growth across regions on national CO_2 emissions.

Combining Equations 8 and 9, we find that

$$\frac{CO_2^\tau}{CO_2^t}=\frac{Y^\tau}{Y^t}\times\left\{\left[\frac{\sum_s(y^{s,\tau}e^{s,t}c^{s,t})}{\sum_s(y^{s,t}e^{s,t}c^{s,t})}\right]^2\left[\frac{\sum_s(y^{s,\tau}e^{s,\tau}c^{s,\tau})}{\sum_s(y^{s,t}e^{s,\tau}c^{s,\tau})}\right]^2\frac{\sum_s(y^{s,\tau}e^{s,t}c^{s,\tau})}{\sum_s(y^{s,t}e^{s,t}c^{s,\tau})}\frac{\sum_s(y^{s,\tau}e^{s,\tau}c^{s,t})}{\sum_s(y^{s,t}e^{s,\tau}c^{s,t})}\right\}^{\frac{1}{6}}\qquad\text{(Equation 10)}$$

$$\times\left\{\left[\frac{\sum_s(y^{s,t}e^{s,\tau}c^{s,t})}{\sum_s(y^{s,t}e^{s,t}c^{s,t})}\right]^2\left[\frac{\sum_s(y^{s,\tau}e^{s,\tau}c^{s,\tau})}{\sum_s(y^{s,\tau}e^{s,t}c^{s,\tau})}\right]^2\frac{\sum_s(y^{s,t}e^{s,\tau}c^{s,\tau})}{\sum_s(y^{s,t}e^{s,t}c^{s,\tau})}\frac{\sum_s(y^{s,\tau}e^{s,\tau}c^{s,t})}{\sum_s(y^{s,\tau}e^{s,t}c^{s,t})}\right\}^{\frac{1}{6}}$$

$$\times\left\{\left[\frac{\sum_s(y^{s,t}e^{s,t}c^{s,\tau})}{\sum_s(y^{s,t}e^{s,t}c^{s,t})}\right]^2\left[\frac{\sum_s(y^{s,\tau}e^{s,\tau}c^{s,\tau})}{\sum_s(y^{s,\tau}e^{s,\tau}c^{s,t})}\right]^2\frac{\sum_s(y^{s,t}e^{s,\tau}c^{s,\tau})}{\sum_s(y^{s,t}e^{s,\tau}c^{s,t})}\frac{\sum_s(y^{s,\tau}e^{s,t}c^{s,\tau})}{\sum_s(y^{s,\tau}e^{s,t}c^{s,t})}\right\}^{\frac{1}{6}}$$

$$\equiv: NG\times DG\times EI\times CC$$

The four factors in the above decomposition describe the sources for the change in CO_2 emissions across the whole country between time periods t and τ. The four factors are:

1. the national growth rate of GDP;
2. the differential growth rates across regions;
3. changes in the energy intensity of regional economies; and
4. changes in the CO_2 emissions coefficient of energy consumption.

If $DG < 1$, then differential growth in regional economies can help lower national CO_2 emissions. If it is equal to one, which means all regions grow at the same rate, then this factor does not have an effect on emissions in China.

It can be verified that the indexes from the above decomposition framework satisfy perfect decomposition of the index for the change in national carbon emissions. The framework also passes three major tests for desirable properties of decomposition analysis: time-reversal, factor-reversal, and zero-value robust (Ang and Zhang 2000). Obviously, the last three components in Equation 10 are the contributors to changes in the CO_2 emissions intensity of the economy at a national level.

This method of decomposing a change in CO_2 emissions into contributing factors provides an advantage over previous techniques because it has more flexible data requirements that permit the analysis of cross-regional data. It should be noted that the decomposition analysis in this paper is an accounting exercise which generates new results regarding the sources; the decomposition results do not provide explanations about fundamental drivers of the change.

4.0 DECOMPOSITION RESULTS AND DISCUSSION

In this section, we apply the proposed decomposition framework to quantify the sources of changes in total CO_2 emissions and emissions intensity in China. We focus on the effects of differential output growth across provinces on the changes in total emissions.

4.1 Decomposition Results

Table 3 reports the sources of changes in CO_2 emissions between year pairs in China. The upper panel uses 1995 as the base year and decomposes changes in CO_2 emissions between 1995 and each of the following years.[6] The first row decomposes emissions growth between the years of 1995 and 1996 into four sources: national pattern of output growth, differential growth across provinces in China, changes in energy intensity, and changes in carbon coefficient.

Table 3. CO_2 emissions growth and its sources in China, 1995-2010

Year pairs	Changes in emissions	National GDP growth	Differential GDP growth	Change in energy intensity	Change in carbon coefficient
1995-1996	1.0337	1.1185	0.9990	0.9117	1.0147
1995-1997	1.0462	1.2415	0.9968	0.8324	1.0157
1995-1998	1.0212	1.3615	0.9950	0.7613	0.9902
1995-1999	1.0081	1.4812	0.9922	0.7120	0.9633
1995-2000	1.0556	1.6239	0.9893	0.6986	0.9406
1995-2001	1.1223	1.7800	0.9886	0.6534	0.9761
1995-2002	1.2144	1.9745	0.9872	0.6694	0.9308
1995-2003	1.4006	2.2144	0.9867	0.6839	0.9373
1995-2004	1.6032	2.5161	0.9883	0.6983	0.9232
1995-2005	1.9058	2.8485	0.9897	0.7048	0.9592
1995-2006	2.0763	3.2437	0.9900	0.6853	0.9434
1995-2007	2.3141	3.7175	0.9895	0.6554	0.9599
1995-2008	2.4481	4.1637	0.9919	0.6194	0.9570
1995-2009	2.5763	4.6508	0.9915	0.5868	0.9522
1995-2010	2.7991	5.2623	0.9929	0.5639	0.9500
1995-1996	1.0337	1.1185	0.9990	0.9117	1.0147
1996-1997	1.0121	1.1099	0.9979	0.9131	1.0009
1997-1998	0.9761	1.0967	0.9979	0.9151	0.9747
1998-1999	0.9871	1.0879	0.9968	0.9343	0.9763
1999-2000	1.0475	1.0963	0.9977	0.9785	0.9787
2000-2001	1.0631	1.0961	0.9993	0.9364	1.0365
2001-2002	1.0831	1.1085	0.9992	1.0270	0.9522
2002-2003	1.1421	1.1225	0.9994	1.0121	1.0059
2003-2004	1.1495	1.1362	1.0004	1.0188	0.9925
2004-2005	1.1887	1.1321	1.0025	1.0055	1.0417
2005-2006	1.0895	1.1388	1.0002	0.9691	0.9870
2006-2007	1.1145	1.1461	1.0006	0.9579	1.0145
2007-2008	1.0579	1.1200	1.0017	0.9440	0.9989
2008-2009	1.0524	1.1170	1.0006	0.9466	0.9947
2009-2010	1.0865	1.1315	1.0014	0.9620	0.9968

[6] Chongqing City, which received provincial status in 1997, is treated as a part of Sichuan province when 1995 is used as the base year for decomposition. In later parts of the paper, Chongqing City is treated as a separate region when 1997 and later years are used as base years.

In 1996, the level of total emissions in China was about 3.37% higher than that of the previous year. Had all provinces followed the national pattern of economic growth in China between the two years, CO_2 would have been 0.10% (i.e., 2.71 million tonnes) higher than its actual 1996 level. Differential output growth contributes much more to reducing emissions in the following years until 2003, when this factor lowered emissions by 49.20 million tonnes (i.e., 1.35% of the actual 2003 level). We calculated the changes in emissions between 1995 and each year from 1996-2010. The sum of the changes between 1995 and those years is 25,048.36 million tonnes. Decomposition results from our framework suggest that differential growth saved about 580.34 million tonnes of CO_2 from 1996-2010, which accounts for about 2.32% of the total changes.

The results shown in the lower panel of Table 3 were obtained by using the earlier year in each pair of consecutive years as the base year for decomposition analysis. A clear pattern of the effects of differential growth on the changes in CO_2 emissions was observed – it decreases emissions during each pair of consecutive years before 2003. Comparing the magnitudes of the four factors reveals that differential growth is a more important factor than changes in carbon coefficient with regards to reducing CO_2 emissions in the years 1996, 1997, 2001 and 2003.

4.2 Discussion

China has set itself the goal of reducing the CO_2 intensity of its economy by 40-45% from the level of 2005 by 2020. This requires an annual rate of 3.35% to 3.91% between 2005 and 2020. Table 3 shows that CO_2 emissions intensity has declined faster than that in most of the years in our sample (especially in the years before 2003). While decreases in energy intensity are widely regarded as the key to achieving the reduction in CO_2 intensity that has been set, we find that differential growth can also play an important role. Experience between 1995 and 2003 suggests that differential growth across regions can contribute much to achieving the reduction in CO_2 intensity goal. For example, differential growth lowered emissions intensity by 0.32% between 1998 and 1999.

Figure 5 shows the contributions to changes in the CO_2 emissions intensity of China's economy from differential growth, changes in energy intensity across provinces, and changes in carbon coefficient. The year 1995 is used as the base year in this figure. Decreasing energy intensity (EI in the figure) is the most important source of the decline in CO_2 emissions intensity in China over the years. While the contribution from changes in the CO_2 coefficient (CC in the figure) of energy consumption is becoming more and more significant in the years before 2000, its level remained largely steady after 2000. Differential growth across regions (DG in the figure) helped lower CO_2 emissions intensity during this period.

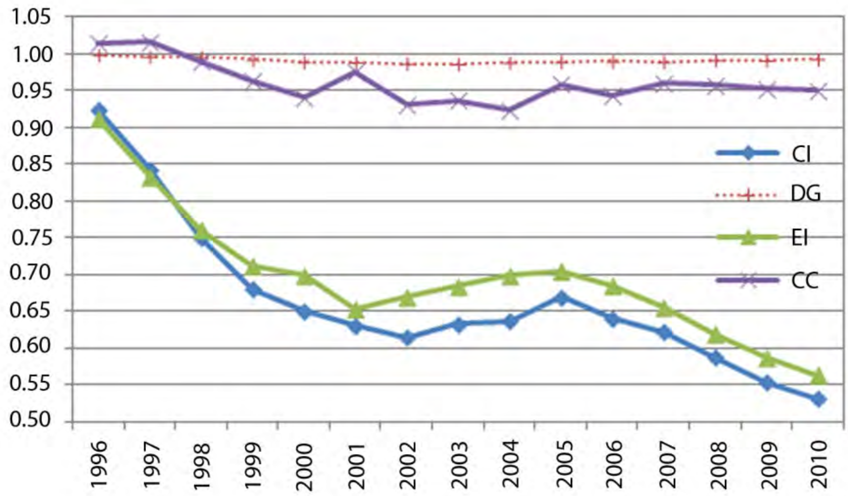

Figure 5. China's CO_2 intensity indexes, 1995-2010

5.0 SIMULATION ANALYSIS

This section collects relevant data from the national and provincial 12th Five-Year Plans and also contains some simulation analysis. We are interested in the following questions: *Can the goal of lowering emissions intensity be achieved? How can differential growth across regions contribute to the chances of success?* Goals for reducing emissions intensity by 2020 are also examined.

5.1 Goals of the 12th Five-Year Plan (2011-2015)

In September 2011, China's central government announced in the national 12th Five-Year Plan that energy consumption per unit of GDP should be reduced by 16% and CO_2 emissions per unit of GDP by 17% in the five years until the end of 2015. National GDP growth is planned to grow at a rate of 7% annually. Specific targets for energy intensity and CO_2 emissions intensity have also been set for each province. Most of the provinces state clearly in their own provincial 12th Five-Year Plans that the targets set by central government for the province should be achieved. Also, each province has its own plan for economic growth. Table 4 documents the targets for each province.

Table 4. China's 12th Five-Year Plan targets for lowering energy intensity and CO_2 emissions intensity (%)

Region	GDP (+) annual growth rate	Energy intensity (-)	CO_2 intensity (-)
Beijing	8	17	18
Tianjin	12	18	19
Hebei	≈8.5	17	18
Shanxi	13	16	17
Inner Mongolia	≥12	15	16
Liaoning	11	17	18
Jilin	≥12	16	17
Heilongjiang	≥12	16	16
Shanghai	≈8	18	19
Jiangsu	≈10	18	19
Zhejiang	8	18	19
Anhui	≥10	16	17
Fujian	≥10	16	17.5
Jiangxi	≥11	16	17
Shandong	9	17	18
Henan	≥9	16	17
Hubei	≥10	16	17
Hunan	≥10	16	17
Guangdong	≥8	18	19.5
Guangxi	10	15	16
Hainan	≈13	10	11
Chongqing	≈12.5	16	17
Sichuan	≈12	16	17.5
Guizhou	≥12	15	16
Yunnan	≥10	15	16.5
Tibet	≥12	10	10
Shaanxi	≥12	16	17
Gansu	≥12	15	16
Qinghai	12	10	10
Ningxia	≈12	15	16
Xinjiang	≥10	10	11

Note: Targets for energy consumption and CO_2 emissions are for the whole period.

Sources: Targets for economic growth are from the respective provincial 12th Five-Year Plans. Information for the energy intensity and CO_2 intensity columns comes from the national 12th Five-Year Plan.

We used the energy intensity and emissions intensity reduction targets for each province set by the national plan and the provincial targets for regional economic growth to examine the impacts on CO_2 emissions. Then we can look at whether the target for emissions intensity for the national economy can be achieved.

Forecasts for GRP for a province in the years 2011-2015 were obtained by multiplying GRP in 2010 and the planned annual growth rate set by the provincial government in its Plan. Forecasts for energy intensity in a province were obtained by using the energy intensity for 2010 and the annual rate of decline set by the central government in the national Plan. Then the forecasted total energy consumption by the province was calculated. Forecasted CO_2 emissions for each province in 2011-2015 were obtained in a similar way.

With the forecasted values of GRP, energy consumption, and CO_2 emissions, we found that the energy intensity of the national economy will decrease by 15.12% between 2010 and 2015 and CO_2 emissions intensity by 15.81%. The planned targets are about 16% and 17%, respectively. This suggests that the national goals for lowering energy intensity and reducing CO_2 emissions intensity cannot be achieved even if individual provinces can achieve their own specific targets set by the central government and their own economic growth targets. The reason for these shortfalls is quite simple; in their own Plans, some of the low-income provinces anticipate relatively higher economic growth rates for the next five years, while the central government has set relatively lower rates of decreases in both energy intensity and CO_2 emissions intensity for these provinces.

We then applied our proposed decomposition framework from Section 3 to the forecasted data. Using 2005 as the base year, the decomposition results reported in Table 5 show that planned regional economic growth patterns will increase emissions intensity if they are realized by 2015. The decomposition results in Table 5 also document the results for the years between 2005 and 2010. It seems that the results from 2005-2010 are slightly inconsistent with those reported earlier in the lower panel of Table 3. The reason for this is that we treat Chongqing as an independent region in Table 5, while it is merged with Sichuan province in Table 3.

Table 5. Decomposition results and emissions intensity change for 2005-2015 with forecasted data

Year pairs	Changes in emissions	National GDP growth	Differential GRP growth	Change in energy intensity	Change in carbon coefficient	Emissions intensity change
2005-2006	1.0895	1.1388	1.0002	0.9691	0.9870	0.9567
2005-2007	1.2143	1.3051	1.0005	0.9283	1.0017	0.9304
2005-2008	1.2846	1.4617	1.0023	0.8764	1.0005	0.8788
2005-2009	1.3519	1.6327	1.0027	0.8298	0.9951	0.8280
2005-2010	1.4688	1.8474	1.0039	0.7983	0.9920	0.7950
2005-2011	1.5586	2.0294	1.0073	0.7703	0.9898	0.7680
2005-2012	1.6543	2.2296	1.0108	0.7433	0.9876	0.7420
2005-2013	1.7564	2.4501	1.0143	0.7172	0.9854	0.7169
2005-2014	1.8653	2.6929	1.0179	0.6921	0.9833	0.6927
2005-2015	1.9815	2.9602	1.0215	0.6679	0.9811	0.6694

Notes: Results for 2011 and after are based on forecasted data on energy consumption, CO_2 emissions, and GRP in the associated years.

The last column of Table 5 calculates changes in CO_2 emissions intensity between 2005 and associated years. It indicates that China's CO_2 emissions intensity in 2015 will be about 33.06% lower than the level of 2005 if all targets for 2011-2015 are achieved. The results in Table 5 also suggest that the intensity will be about 34.47% lower if the provinces grow at the same rates between 2010 and 2015.

The results in Table 2 for years 1995-2010 show that the index for differential growth across regions takes values in the range between 0.9968 and 1.0017. However, the simulated results for 2011-2015 give much higher values, at about 1.0036. If economic growth patterns across provinces in China do not have such a high variation, the planned 17% decrease in emissions intensity during this period will have a better chance of being achieved.

5.2 The 2020 Goal

China aims to lower the CO_2 emissions intensity of its economy by 40-45% by 2020 (compared with the level of 2005). Assuming that the targets for decreasing emissions intensity for 2015 could be achieved (as outlined in Table 4) if differential growth across regions does not increase intensity, the 2020 goal of 40% could be achieved if China's energy intensity reduces by 10.17% in the next five-year period (2015-2020), even if carbon coefficients do not change.

If differential growth across regions can help lower the emissions intensity, as it did between 1995 and 2000 when it had an index of 0.9893, energy intensity needs to be lowered by 9.19% between 2015 and 2020. If there is an additional contribution from decreasing carbon coefficient, and it decreases by 0.80% (the same change as from 2005 to 2010), energy intensity should be lower by 8.46% in 2020, compared with its forecasted level in 2015.

6.0 POLICY IMPLICATIONS

This section starts with a summary of the results of a small number of interviews on the subjects of regional economic development policies and climate change policies. Then we outline policy implications.

6.1 Interview Results

To help with drawing feasible policy implications from the analyses, we conducted small-scale and informal interviews with government officials, scholars working for government organizations at central and local levels, and management personnel at large state-owned enterprises.

During our conversations, two main questions were asked and related issues discussed. The first question was *"Do you think policies to reduce GHG emissions conflict with economic development policies? If so, how can there be better coordination between the two?"* The second set of questions was as follows: *"China has proposed a target of reducing CO_2 emissions per unit of GDP in 2020 by 40-45% compared with the level of 2005. Do you think that this target is achievable? Would achieving this target influence economic growth in your region?"*

The majority of the interviewees thought that the target for lowering emissions intensity is achievable with considerable effort, and policies and actions may negatively affect economic growth in Chinese provinces and in some industrial sectors. Several interviewees argued that policies to reduce GHG emissions are essentially consistent with long-term economic development policies.

Interviewees thought that the targets can be achieved but that an influence on economic growth is inevitable. If China can coordinate the relationship between GHG emissions and economic growth at a national level, the influence could be minimized. Interviewees also mentioned that China can learn from the experiences of some developed countries. The impact of reducing emissions on economic growth could be minimized if measures pertaining to capital accumulation, management skills, and technological progress are undertaken.

6.2 Policy Implications

One of the constraints faced by policymakers when making climate change policy decisions is uneven economic growth across regions in China. Also, it is technically difficult to change energy input structure in a relatively short period of time (Lin *et al.* 2010).

As discussed earlier, decreasing energy intensity is an important way to lower emissions intensity. China has great potential to decrease energy intensity to a much lower level. We have found that capital accumulation, changes in output structure, and technological change contribute positively to lower energy intensity at national and provincial levels. Capital played the most important role in the process of energy intensity decline over the time period. It not only drove the decline in the provinces, but also contributed to convergence of the level of energy intensity between provinces. As China's macroeconomic policies continue to focus on economic growth in the foreseeable future, with aggressive aims to cut energy consumption per unit of GNP in a national plan for energy conservation, capital accumulation would still play an important role in increasing energy productivity. However, the observed growth in energy productivity was found to be largely driven by capital accumulation, thus questioning its sustainability. Related policies should place emphasis on promoting technological growth and improvements in technical efficiency (especially in those poor and interior provinces).

China's climate change policy is focused on CO_2 emissions intensity. As shown in earlier parts of this paper, differential growth across provinces plays an important role in determining emissions intensity at a national level. When setting targets for reducing the intensity of each province, growth patterns should be taken into account.

The allocation of energy resources across regions should consider regional variations in energy efficiency (Shi 1999). Regions with more efficient energy use or lower CO_2 emissions intensity should be able to receive more energy resources. The central government and the provincial governments need to improve transportation systems to make it easier and more efficient to transport energy resources across regions. In the transport industry, coordination between policies to reduce GHG emissions could be achieved through creating low-carbon transport and green transport, which is energy-efficient and produces less pollution and lower emissions, with the aim of improving energy efficiency and optimizing the development of transportation.

7.0 CONCLUSION

To understand the effect on CO_2 emissions of differential output growth across regions within China, this paper decomposes changes in CO_2 emissions into sources that are attributable to changes in: a) the national growth rate of GDP; b) differential growth rates of GRP across regions; c) changes in energy intensity across regional economies; and d) changes in the CO_2 emissions coefficient of energy consumption. We also performed a nonparametric statistical analysis to understand the roles played by changes in energy intensity and CO_2 coefficient in the distribution dynamics of CO_2 emissions intensity. This study also conducted a simulation analysis for the goals set for reducing emissions intensity in the next decade. Policy implications are drawn from the study.

Consistent with previous studies, our decomposition results found that output growth is a major source of increases in CO_2 emissions, while a decline in energy intensity is the main contributor to the reduction of emissions. Several findings about the role of the differential growth of regions' economic output are noteworthy. First, the effects of differential growth can increase or decrease CO_2 emissions. The net effects depend on the distribution of carbon intensity and economic growth rates across regions. Uneven growth across regions is found to contribute to reducing CO_2 emissions in our data. Second, the effects of differential growth are not minimal. Differential growth plays a more important role than changes in the carbon coefficient of energy with regards to decreasing emissions during some sub-periods in our sample.

The findings of this study have significant policy implications. Decision-makers considering climate change policies will benefit from information about spatial distributions of carbon emissions and the sources of changes in emissions. It is important to note that, to achieve a specific amount of reduction in CO_2 emissions at a national level, the distribution of the reduction across regions and the effects of uneven output growth are critical. A policy is optimal only if it fully considers regional variations in economic growth rate, energy intensity and carbon intensity. The results of the study can provide valuable information to policymakers at central and local levels to realize the value of different sources, especially balanced/unbalanced growth for controlling carbon emissions. Policy implications include:

1. decreasing energy intensity by promoting technological growth, improving the technical efficiency of poor areas, and upgrading the economic structure of the Chinese economy;
2. taking into account the differential growth rates across regions when making policies; and
3. allocating energy resources more efficiently across regions in China by improving the transport system.

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APPENDIX

Evidence from the United States

Data on energy consumption and CO_2 emissions for US states come directly from the US Energy Information Administration[7] and the Environmental Protection Agency[8]. Real GDP by state in chained (2005) US dollars are published by the US Department of Commerce, Bureau of Economic Analysis, beginning in 1977. Note that GDP by state has a structural break in 1997 due to the shift from the Standard Industrial Classification (SIC) system to the North American Industry Classification System (NAICS) in that year. We collected the 1997 data from both systems. Table A1 presents summary statistics.

Table A1. Summary statistics, US states

Variable	Year/period	Mean	Std. dev.	Min.	Max.	# obs.
Annual growth rate (%)						
CO_2 emissions	1990-1997	1.677	1.318	-2.072	6.267	51
	1997-2009	-0.214	1.034	-2.969	2.293	51
Energy consumption	1990-1997	1.730	1.222	-2.276	4.695	51
	1997-2009	0.203	0.983	-1.361	3.275	51
GRP	1990-1997	3.479	1.767	-0.602	7.833	51
	1997-2009	2.239	0.987	-0.348	4.482	51
Absolute level						
CO_2 intensity	1990	0.840	0.618	0.065	3.246	51
	1997	0.734	0.528	0.065	2.852	51
	2009	0.552	0.368	0.036	1.788	51
Energy intensity	1990	12.458	4.935	2.582	24.803	51
	1997	10.996	4.333	2.740	23.673	51
	2009	8.655	3.364	2.078	17.528	51
CO_2 coefficient	1990	0.063	0.023	0.025	0.144	51
	1997	0.063	0.023	0.024	0.149	51
	2009	0.060	0.020	0.017	0.124	51

Notes: Carbon intensity is measured in metric tonnes of CO_2 per USD 1000 (2000 USD rates). Energy intensity is measured in 1000 Btu per USD (2005 USD rates). Carbon coefficient is measured in metric tonnes of CO_2 per million Btu.

Figure A1 illustrates the actual and counterfactual distributions for the US. It demonstrates that decrease in energy intensity is also a driving force behind lowering carbon intensity in the US.

Using our proposed decomposition framework, Table A2 presents decomposition results for changes in CO_2 emissions in the US. In the upper panel of Table A2, we use 1997 as the base year and decompose changes in CO_2 emissions between 1997 and each of the following years. Aggregate CO_2 in 1998 was about 0.09% lower than its level in 1997. Had all states followed the national pattern of economic growth between the years 1997 and 1998, total CO_2 in the US would have been 0.11% (i.e., 6.41 million tonnes of CO_2) more than its actual 1997 level. A decomposition of the changes in emissions between 1997 and 2006 finds that the 2006 emissions would be 2.13% more than its actual level if GRP in all states grew at the national level. Without the effects of differential growth, the 1998 emissions would be more than the 1997 level. The decomposition results show the contributions of differential growth across states to declines in the carbon intensity of the US economy. Nearly 10% of the declines since 1997 have come from it. For example, carbon intensity in 2000 was 8.79% lower than its level in 1997. The effect of differential growth lowered it by about 1.35%.

[7] The website is http://www.eia.gov/state/seds
[8] The website is http://www.epa.gov/statelocalclimate/resources/state_energyco2inv.html

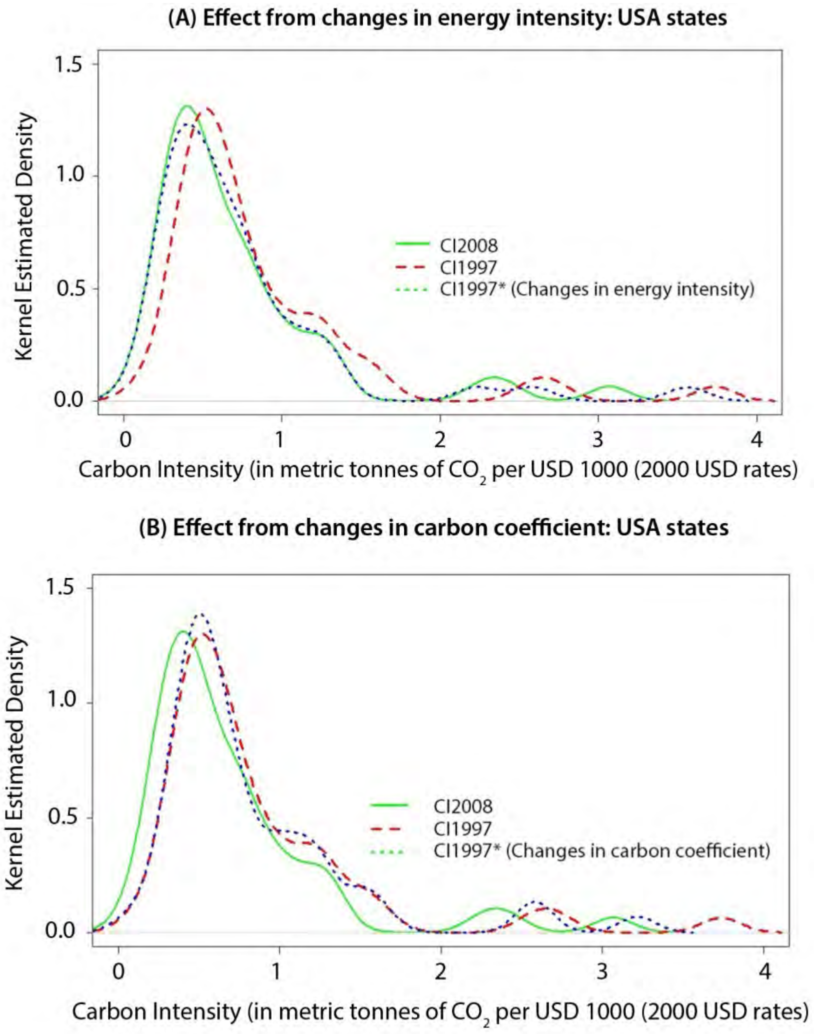

Figure A1. Counterfactual distributions of carbon intensity, US states

Table A2. CO_2 emissions growth and its sources in the US, 1990-2009

Year pairs	Changes in emissions	National GDP growth	Differential GRP growth	Change in energy intensity	Change in carbon coefficient
1997-1998	0.9991	1.0434	0.9989	0.9619	0.9967
1997-1999	1.0092	1.0929	0.9939	0.9385	0.9899
1997-2000	1.0386	1.1387	0.9865	0.9273	0.9970
1997-2001	1.0207	1.1533	0.9859	0.8946	1.0035
1997-2002	1.0286	1.1732	0.9875	0.8919	0.9954
1997-2003	1.0376	1.1982	0.9871	0.8764	1.0010
1997-2004	1.0573	1.2394	0.9864	0.8657	0.9990
1997-2005	1.0611	1.2741	0.9812	0.8489	1.0000
1997-2006	1.0477	1.3087	0.9792	0.8223	0.9942
1997-2007	1.0653	1.3339	0.9793	0.8219	0.9922
1997-2008	1.0318	1.3295	0.9802	0.8075	0.9805
1997-2009	0.9610	1.2968	0.9864	0.7815	0.9613
1990-1991	0.9917	0.9984	1.0057	0.9942	0.9933
1991-1992	1.0190	1.0300	1.0035	0.9831	1.0029
1992-1993	1.0199	1.0200	1.0039	0.9969	0.9991
1993-1994	1.0144	1.0466	1.0059	0.9678	0.9956
1994-1995	1.0105	1.0343	1.0015	0.9870	0.9883
1995-1996	1.0366	1.0437	0.9997	0.9893	1.0042
1996-1997	1.0164	1.0523	0.9993	0.9568	1.0102

Table A2 continued

Year pairs	Changes in emissions	National GDP growth	Differential GRP growth	Change in energy intensity	Change in carbon coefficient
1997-1998	0.9991	1.0434	0.9989	0.9619	0.9967
1998-1999	1.0101	1.0475	0.9953	0.9755	0.9933
1999-2000	1.0291	1.0419	0.9924	0.9881	1.0072
2000-2001	0.9828	1.0128	0.9993	0.9647	1.0066
2001-2002	1.0077	1.0173	1.0019	0.9968	0.9919
2002-2003	1.0087	1.0213	0.9996	0.9826	1.0056
2003-2004	1.0190	1.0344	0.9993	0.9878	0.9980
2004-2005	1.0036	1.0280	0.9952	0.9802	1.0009
2005-2006	0.9873	1.0272	0.9980	0.9688	0.9941
2006-2007	1.0168	1.0193	1.0001	0.9995	0.9980
2007-2008	0.9686	0.9967	1.0010	0.9824	0.9882
2008-2009	0.9313	0.9754	1.0057	0.9686	0.9802

Data on emissions indicate that total changes between 1997 and later years are 2017.85 million tonnes. Further calculation from our decomposition analysis finds that differential growth across states lower total emissions in the US by 994.38 million tonnes of CO_2. The numbers suggest that, compared to the 1996 national level of emissions, total changes during 1997-2009 will be 49.28% more. In China, the contribution from differential growth from 1995-2009 is only about 2.59%.

The lower panel in Table A2 shows the decomposition results for each pair of consecutive years from 1990-2008. It is found that the effects of differential growth have a more important role than changes in carbon intensity of energy with regards to decreasing emissions during 1996-2001, with the exception of 1999. The effects increased emissions from 1990-1995, and then decreased emissions for the next 12 years, with the exception of 2001-2002. The pattern reversed again during 2006-2007, when differential growth across states increased CO_2 emissions.

Aggregate CO_2 in 1991 was about 0.83% lower than its level in 1990. Had all states grown at the same rate as the national GDP between the years 1990 and 1991, CO_2 would have been 0.57% (i.e., 28.56 million tonnes of CO_2) lower than its actual 1991 level. It suggests that the reduced amount of CO_2 between 1990 and 1991 would have been 67.69% more had all states followed the national pattern of economic growth.

Since 1996, states with a higher level of carbon intensity of the economy have grown at lower rates. The decomposition results in Table A2 suggest that, had all states followed the national pattern of economic growth between the years 1995 and 1996, CO_2 would have been 0.03% higher than its actual 1996 level. The number is 0.76% for the year 2000, which indicates that differential growth helped save about 44.71 million tonnes of CO_2. The increment of emissions between 1999 and 2000 would have been 27.02% higher had all states grown at the same rate as the national GDP between the two years.

We repeated the exercise using a different series of data on emissions, which were compiled by Blasing *et al.* (2004) who provide estimates of annual CO_2 emitted in each state for each year from 1960 through 2001. Qualitatively, the same conclusion is reached as before. It shows that the effects of differential growth have a more important role to play than the carbon intensity of energy with regards to decreasing emissions during 1983-1988. The effects decreased emissions during 1977-1989, with the exception of 1980-1981, and then increased emissions for the next six years. This trend was again reversed in 1996 when differential growth helped lower emissions.

Figure A2 shows the indices for carbon intensity of the US economy (year 1997=100) and the contributions to changes in carbon intensity from differential growth, changes in energy intensity across provinces, and changes in carbon coefficient.

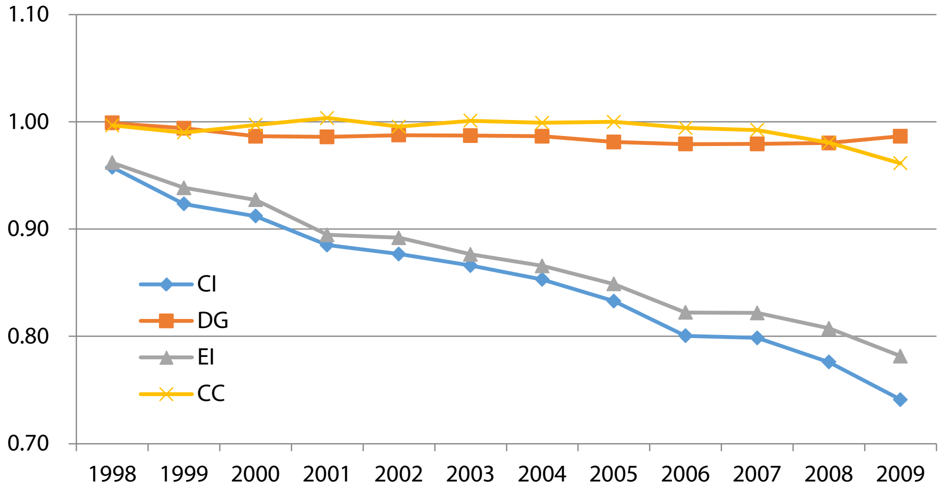

Figure A2. US Carbon intensity indices, 1998-2009

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