CHANGES IN CHINA'S ENERGY INTENSITY: ORIGINS AND IMPLICATIONS FOR LONG-RUN CARBON EMISSIONS AND CLIMATE POLICIES

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ABSTRACT

Since the economic reforms that began in 1978 China has experienced a dramatic decline in energy intensity until about 2002 when it flattened out and even rose slightly. There have been considerable debates about the origins of this dramatic decline of energy intensity before year 2000: whether it is mostly due to changes in composition of economic activity (structural change) or mostly due to changes in technology (energy per ton of steel, for example). However, very few studies have examined the slightly rising energy intensity trend for the post-2000 period. In this report, we use a new time series input output data set from 1981-2007, decompose the reduction in energy use into technical change and various types of structural change, including changes in the quantity and composition of imports and exports. We conducted different SDA and IDA decomposition methodologies. Based on these estimates of changes in energy intensity, we project autonomous energy efficiency improvement (AEEI) parameters in forecasting future capital, labor and energy input shares of output for each industry. We then construct a recursive-dynamic computable general equilibrium (CGE) model of the Chinese economy to analyze both command-and-control policies and carbon taxes, and provide policy recommendations on how China would pursue a more sustainable development trajectory to deal with greenhouse gas emissions.

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Key Words: China, Energy and Carbon Intensity, Decomposition Analysis, CGE Model

INTRODUCTION

In many developing or transitional economies, energy consumption typically grows faster than GDP or final economic output during the period of industrialization, motorization, and urbanization when there are rising capital-labor ratios increasing use of commercial energy, and construction of modern infrastructure (Lin and Polenske, 1994; Lin 1994). However, China, the biggest transitional and developing economy, is following a striking opposite pattern in the pre-2000 period. China had an average annual growth rate of 9.7% over the period 1978-2005, but during the 1978-2000 period commercial energy consumption per unit of GDP declined by about two thirds. Even though the rate of energy intensity decline slowed down after year 2000 and even rose slightly (see figure 2A) the overall picture is remarkable.

In the meanwhile, some studies have show that China has surpassed US and become the biggest carbon emitter in the world[1], and such a rapid increasing trend becomes dominant thereafter. Figure 1 shows the annual carbon emissions from fossil fuel and cement production in major carbon-emitting countries. We can see that China follows the similar trend as other non-Annex I countries, but after 2002 the slope of carbon emission increase dramatically, much faster than all the developed and other non-Annex I countries. Furthermore, we sketch out the historical trend of China's carbon intensity, which is measured by the total carbon emissions from the fossil fuel combustion, divided by real GDP. Given the dominance of fossil fuels, this trend is similar to the energy intensity trend. Thus we can conclude that China has experienced a dramatic decline of both energy and carbon intensity for 1980-2000, but since then this pattern reversed and both ratios start to follow a slightly rising trend after 2002, which has an important implication for understanding future carbon emission trend.

In addition, in its 11th Five Year Plan, the Chinese government set a target to reduce the energy intensity by 20% during 2006-2010. However, as shown in Figures 1 and 2, the dramatically higher total energy use and carbon emissions after 2001 raises questions about whether China can successfully achieve this target. China has failed to reach the energy saving and environmental protection targets in the previous 10th five year plan as discussed in Cao et al (forthcoming). . Although the government has asserted that the target in the 11th Five Year Plan is a "mandatory" objective, whether it can be successful or not has attracted a lot of discussion in both academic and policy forums. To answer these questions it is necessary to understand the nature of these past changes in energy intensity. This paper examines the change in aggregate energy intensity, the energy-GDP ratio, by decomposing it into structural change and change in energy efficiency at the individual industry level. This industry level change includes substitution among variable inputs due to changes in prices and changes in energy per unit output due to technical progress. Structural change includes the reallocation of capital and labor across industries and changes in the composition of final demand (changes in consumption, investment and exports).

A comprehensive analysis of climate change policies should include some understanding of the future emissions of greenhouse gases (GHGs). Projections of long-run emissions of GHGs require a projection of the level of economic activity, the distribution of resources among the various industries and the demand for fossil fuel by these industries. Given this complexity there is little consensus on the projection of long-run emissions,. The main source of uncertainty is the modeling of technical progress, which is viewed as the major influence on the intensity of energy use.

In many climate models or environmental-economic models, the technological changes of energy use per unit output (i.e. changes over time not due to price effects) are typically represented as following some exogenous path of "Autonomous Energy Efficiency Improvement" (AEEI) . By exogenous we mean that the rate of technical progress does not depend on any variable determined within the model such as levels of

[1] http://www.pbl.nl/en/publications/2009/Global-CO2-emissions-annual-increase-halves-in-2008.html

output or prices[2]. Some models implement this by having a declining trend in the coefficients on coal, oil and gas uses in the production functions, other models specify two techniques – clean and conventional -- and change the share of the clean one over time. For example, in Edmonds and Reilly (1985) and many state-of-the-art intertemporal CGE models for climate policy analysis, the coefficients on energy use in the industrial production functions were constructed to decline according to the inverse of an index of energy-saving technological progress.

In this project, in the first step we decompose the aggregate energy intensity trend into the contributions of structural change and shifts in the intensity of energy use in individual sectors; in the second step we use the estimates of the rate of change of input intensities in the individual sectors to project the change in the AEEI parameters in our recursive dynamic CGE model. In this paper we compare two types of climate policies: Command and Control Mandates on Energy Conservation, and market based policies such as energy taxes. In the current 11th Five Year Plan, the first policy option – command-and-control energy targets – has been widely implemented by National Development Reform Commission (NDRC). However, the latter policy option is still under discussion.

Literature Review on Energy Intensity Decomposition

There is an extensive literature using decomposition analysis to study changes in Chinese energy intensity, changes in carbon dioxide intensity and related indicators in the past two decades (for example: Huang, 1993; Sinton and Levine, 1994; Lin and Polenske, 1995; Garbaccio, Ho and Jorgenson, 1999; Zhang, 2003, Fisher-Vanden *et al*., 2003; Ma and Stern, 2007). Most of these studies examine the energy intensity trend for the pre-2000 period, and concluded that the most important factor for the sharp decline of energy intensity is technical change, while there is some disagreement about the role of structural change. Many find that structural change only play a minor role in reducing energy intensity, Garbaccio, Ho and Jorgenson (1999), and Ma and Stern (2007) even found that structural change actually increased energy use. On the other hand, World Bank (1994, 1997) asserted that structural change was the major factor in the declining trend of energy intensity. That conclusion is drawn from earlier work conducted by the Energy Research Institute (ERI) of the National Development and Reform Commission (NDRC) (Wang and Xin, 1989).

Ma and Stern (2007) is the only study among those listed above that examined the energy intensity in the post-2000 period, and conclude that the increasing trend after 2000 is mainly explained by negative technological progress which is a reversal of the pre-2000 trend. However, Ma and Stern based their study only on 10 aggregate sectors, or aggregated to primary, secondary and tertiary sectors. They use the Index Decomposition Analysis (IDA) approach, due to a lack of a time-series of Input-Output tables for a more robust Structural Decomposition Analysis (SDA). In addition, as Garbaccio, Ho and Jorgenson (1999) pointed out, most of the controversies rest on the

[2] An alternative formulation would have endogenous technical progress where higher prices of energy, say, would lead to a faster rate of innovation of energy-saving processes. Another case is where research and development expenditures lead to a faster rate of progress. These effects are distinct from the more familiar substitution between capital and energy in a given period due to changes in the prices of capital and energy.

level of aggregation, which is of crucial importance in separating technical and structural factors in changes of aggregate energy intensity. Thus if the sectors are aggregated at a high level, structural changes below that level may be wrongly attributed to technical changes. Similarly, both Sinton and Levine (1994) and Fisher-Vanden *et al.* (2003) found that the explanatory power of structural change rises as the sectoral disaggregation becomes finer. To improve the study in Ma and Stern (2007), we use a more robust decomposition method based on a time-series of input-output tables for 1980-2005 for 33 sectors in China.

In addition, most of these studies only examine the declining trend of energy intensity, while for the post-2000 rising energy use era, the changes in the economy may have been of a very different nature. Quality and environmental regulations may have limited the potential for technical improvements at the industry level; improvements in household incomes may have exceeded some threshold that dramatically changed the rate of automobile and electricity use.

Thus our goal is to examine the historical trend and patterns in energy and carbon intensity, focusing carefully on the changes in the post-2000 era. We expect that this is useful information for policy analysts to parameterize their models, as well as for energy planning in the government. This should help project the trend of technical change and so shed some light on future carbon emissions and other local pollutants, such as particular matter and sulfur dioxide. Given the widespread concern about the quality of the data on output and prices from different sources, we also conduct several decomposition methods, including the Divisa-index SDA approach, and LDA approaches to see if there is a common pattern from these different methods and data sources.

Remarks on the use of "Autonomous Energy Efficiency Improvement" (AEEI)

As noted above, most top-down energy use or climate policy models have an exogenous "Autonomous Energy Efficiency Improvement" (AEEI) parameter to project exogenous improvements in energy per unit output. The value chosen is about 1% per year (Weyant, 1999). The basic idea is to sketch a declining trend in the coefficients on energy use in the production function, with the AEEI parameter being the rate of the decline (Sue Wing and Eckaus, 2005). In most of these macro-economic models the AEEI is set to one common parameter for all industries for generating the future trajectories of energy use and carbon emissions. Such an approach is understandable given the lack of estimates, however, such a "one-size-fits-all" parameter has some weaknesses.

Base-year bias: many models calibrate the AEEI parameters by retaining the characteristics of their initial conditions when forecasting the future. However, without decomposing the origins of the aggregate efficiency improvement, the fixed calibrated AEEI tends to maintain the ratio of energy use to overall economic output and the initial industry structure of the economy, this is due to the absence of mechanisms to allow different rates of improvement that we actually observe in the data.

Inappropriate use of developed countries estimates: In many climate policy modeling, the long-run energy intensity (E/GDP) is modeled to decline about 1% per year, which is roughly the average of US performance over the past 200 years (Grübler, 1998). However, the future growth of energy and emission intensities may differ significantly from the past historical time series. Actually, even for US, Manne and Richels (1990) pointed out there is no well established empirical basis for such a coefficient for energy efficiency improvement. Hogan and Jorgenson (1991) also argue that AEEI may actually be negative. It is also risky to transfer this U.S. estimate to other developing or transitional economies.

Thus, in this study we decompose the trend in aggregate energy-output ratio by sector to identify the sources of the aggregate AEEI. We want to understand the magnitude of the contributions from intra-sector intensity reductions driven by the substitution of various inputs, embodied energy-saving technologies, disembodied technological progress, and structure change. Based on our empirical decomposition results, we estimate the values of the AEEI parameter for China, and then apply these parameters in a CGE model for climate policy analysis.

As the largest developing country, and a country experiencing dramatic change and economic growth, China is expected to consume a large and rapidly rising share of world energy use. This trend is viewed with alarm by those worried about the sustainability of such economic development. China's energy intensity has been declining for 20 years since the economic reform of 1978. However, this frugal pattern may have reversed since 2002 and causing analysts to raise the previous high projection even more. How the Chinese government could reverse this rise in energy intensity, or at least lower the growth rate, i.e, how it could achieve its 20% reduction target in the 11th Five Year Plan, and reduce carbon emissions in the future, is becoming a very crucial question for the government. In particular, should it follow a command-and-control policy like the energy conservation mandates currently used in the 11th Five Year Plan, or alternatively, use economic incentive based policies – energy or carbon taxes -- is the focus of our study. We provide a methodological framework for energy intensity decomposition, and for projecting future energy use and carbon emissions using industry level estimates of improvements in energy use.. In the process we provide a new set of AEEI sectoral estimates for other analysts to use in their models.

Research Objectives

The general goal of this study is to understand the proximate reasons for the past changes in aggregate energy intensity and to use the estimates of the contribution of the various factors to project future energy consumption and emissions in the business as usual scenarios or if past policies are maintained. With these estimates of past energy use we also analyze the effects of various command and control policies and hypothetical carbon tax policies to examine their effects on energy conservation and emission reduction to meet China's sustainable development purposes.

The paper is constructed as follows. We first describe our data preparation for energy decomposition and major SDA and IDA methods. Then we construct a simple method to apply these decomposition results in estimate overall AEEI parameters for China's future energy use and carbon emissions. Finally, we apply these AEEI parameters for our policy analysis using a recursive China CGE model.

RESEARCH METHODS AND PRELIMINARY RESULTS

1. Data Preparation and Adjustments

As noted above, previous decomposition analysis of Chinese energy intensity change either use input-output tables from two benchmark years, or use annual data for gross output and energy input only. In this study, we use an annual series of input-outputtables. This data set, covering the period 1980-2005, is a preliminary version of estimates made by a group led by the National Accounts Department in the National Bureau of Statistics (NBS) and Ren Ruoen of the School of Economics and Management, Beihang University, in collaboration with Dale Jorgenson (Harvard University) and Bart van Ark (The Conference Board, New York)[3]. This is the first study to use this unique data set for energy decomposition analysis.

In this final report, our data covers a newly revised data set covering period 2000-2005 after NBS adjusted the GDP level, a new GDP series I-O table is revised upward so that the GDP adjustments in major service sectors can be incorporated. Thus the entire series is used in this report. The industries identified in this data set are given in the Appendix Table A1. Here we briefly summarize our methodology to calculate KLEM input indexes (capital, labor, energy and materials), further details are in Cao et al (2009):

a) Capital Input

We measure capital input in a way that takes into account the heterogeneity of the capital assets, from long-lived buildings to short-lived computers. Capital input for industry *j*, K_{jt}, is defined as the Tornqvist index (the Divisia method) of three types of assets: structures, equipments and auto vehicles:

$$d\ln K_{jt} = \sum_k \bar{v}^j_{Kkt} d\ln K_{jkt} \qquad (1)$$

where the value shares are given by:

$$\bar{v}^j_{Kkt} = \frac{1}{2}(v^j_{Kkt} + v^j_{Kkt-1})$$

$$v^j_{Kkt} = \frac{p^j_{Kkt} K_{jkt}}{\sum_k p^j_{Kkt} K_{jkt}} \qquad \text{(j=1, 2, …, 33; } k\text{=structure, equipment, auto vehicles)}$$

p^j_{Kkt} denotes the rental price of capital asset *k* in industry *j* and is derived from data on operating surplus and depreciation. K_{jkt} is the stock of capital of type *k* and is derived from data on investment in asset *k*. The measurement of capital input is discussed at length by Ren and Sun (2005).

b) Labor Input

[3] An earlier version of this work is described in Cao et al (2009). Van Ark and The Conference Board is also aiming to supplement these input-output estimates with data on capital and labor input in order to conform to the requirements of a large international project to study productivity, the *Productivity in the European Union* (EUKLEMS) project. This is described at www.euklems.net.

Labor input is measured in a way that also accounts for the heterogeneity of workers, from high-wage, educated, experienced workers to young, less educated, workers. The details are in Yue *et al.* (2005), briefly, the workers are cross-classified by sex, age and educational attainment. The labor data is compiled from the 1982, 1990 and 2000 Population Censuses, and the 1987 and 1995 Sample Population Surveys. Labor costs are estimated from household surveys of income distribution, the China Household Income Project (CHIP) survey. Our index of labor input in industry j , L_{jt}, is a Tornqvist index over the various types of labor:

$$d\ln L_{jt} = \sum_l \bar{v}^j_{Llt} d\ln L_{jlt} \tag{2}$$

where the value shares are:

$$\bar{v}^j_{Llt} = \frac{1}{2}(v^j_{Llt} + v^j_{Llt-1})$$

$$v^j_{Llt} = \frac{p^j_{Llt} L_{jlt}}{\sum_l p^j_{Llt} L_{jlt}}$$ (j=1,2,…, 33; l=cross classification of sex, age, education)

p^j_{Llt} denotes the price of labor of type *l* in industry *j*, and L_{jlt} denotes the hours worked by type *l*.

c) Output and Intermediate Inputs

Ren *et al.* (2005) describe how they constructed a time-series of input-output tables for 33 industries in nominal terms covering the period 1981-2000. These are derived by revising the benchmark tables for 1981, 1987, 1992 and 1997 to the latest definitions based on the *System of National Accounts* (SNA). They also constructed price indices for the output of these 33 industries since they are not compiled by any statistical agency in China. These value and price data are then used to construct indexes of sectoral output and intermediate inputs.

The IO tables give us the value of each of 33 intermediate inputs, and capital and labor inputs, into each of the 33 industries. The energy input index for industry *j*, E_{jt}, is the Tornqvist aggregate over the 5 energy commodities (e = coal mining, oil and gas mining, petroleum and coal products, electric utilities, gas utilities) while the material input index, M_{jt}, is an aggregate over the remaining *i*=1,..28 commodities:

$$d\ln E_{jt} = \sum_e \bar{v}^j_{Eet} d\ln E_{jet}$$
$$d\ln M_{jt} = \sum_i \bar{v}^j_{Mit} d\ln M_{jit} \tag{3}$$

where

$$\bar{v}^j_{Eet} = \frac{1}{2}(v^j_{Eet} + v^j_{Eet-1}) \qquad \bar{v}^j_{Mit} = \frac{1}{2}(v^j_{Mit} + v^j_{Mit-1})$$

$$v_{Eet}^{j}=\frac{p_{Eet}^{j}E_{jet}}{\sum_{e}p_{Eet}^{j}E_{jet}} \qquad v_{Mit}^{j}=\frac{p_{Mit}^{j}M_{jit}}{\sum_{i}p_{Mit}^{j}M_{jit}}$$

2. Decomposition Analysis of the Change in Energy Intensity (1981-2005)

Decomposition analysis has been extensively applied in energy research, in particular interpreting the factors affecting aggregate energy intensity, or energy-related carbon emissions. However, there is little consensus on a decomposition methodology, and results vary depending on the methods, in addition to the differences due to data source and sample period. Here we use three decomposition techniques on the Chinese data to shed some light on these methodological issues , and try to look for a convenient approach to use the decomposition results to adjust AEEI parameters in our CGE model.

Up to now, two major types of decomposition methods are extensively used : Structural Decomposition Analysis (SDA) and Index Decomposition Analysis (IDA). The SDA is based on input-output tables, so it captures both direct and indirect effects. (An increase in the demand by households for motor vehicles has a direct effect on the output of motor vehicles, but producing more vehicles requires more steel and the production of steel requires motor vehicles, thus there is an indirect effect due to the increase in household demand). Given the structural details in the input-output table that allow us to distinguish between GDP (the sum of value added) and the sum of industry gross output, SDA is able to distinguish between a range of technical effects and structural effects that are not possible in the IDA model (Ma and Stern, 2007). Index Decomposition Analysis usually considers only industry gross output and defines aggregate output as the sum of these industry output. . More specifically, the IDA analyzes effects from changes in the structure of production, while the SDA typically analyze the technology effects in production that arise from changes in the input requirement matrix and the structural effects from the changes in the composition of GDP (final demand). (Wadeskog and Palm, 2003). SDA almost exclusively work with levels, while IDA can work with level, intensities, or elasticities. In terms of time frame, SDA typically corresponds to the availability of IO tables which are only available for benchmark years, while IDA is less demanding in terms of data, and easier to implement for time-series analysis (Wadeskog and Palm, 2003).

Another important key issue is the choice of index, such as the Laspeyres index (with fixed base year weights) or the Divisia Index with moving weights. In this study, our preferred methodology is using SDA approach based on input-output tables, similar to the I-O based studies introduced by Lin and Polenske (1995) and Lin (1996), but following Garbaccio, Ho and Jorgenson (1999) we do not use fixed base year weights, but use the Divisia index.

2.1 Method 1: Structural Decomposition Analysis (SDA)

Our method is similar to that used in Garbaccio, Ho and Jorgenson (1999) and Liu, Ang, and Ong (1992), and we give a summary description here[4].. Unlike those

[4] Our discussion and notation follows Miller and Blair (1985), however, here we only use the activity matrix A instead of the "use" and "make" matrices separately.

studies we are able to apply the methodology to a sequence of annual tables, rather than two sporadic base and end years. This is especially useful to match our decomposition results with the actual policies implemented in particular years or particular energy saving strategies, so we can have a sharper estimate of the impact of the past policies. This would allow a better discussion of future energy saving programs or policy options. It is also helpful to further divide the whole period into sub-period based on structural breaks.

Let $\mathbf{A_t}$ denote the input-output matrix at time t (with n sectors), $\mathbf{y_t}$ the vector of final demand and $\mathbf{x_t}$ the vector of industry gross output (both of length n). The sum of intermediate demand and final demand equals the supply of the output:

$$\mathbf{A_t x_t} + \mathbf{y_t} = \mathbf{x_t} \tag{5}$$

The sum of the values of the n commodities in the final demand vector gives us GDP. From eq. (5) we get the well known Leontief inverse which gives us the level of industry output required to supply the vector $\mathbf{y}$:

$$\mathbf{x_t} = (\mathbf{I} - \mathbf{A_t})^{-1}\mathbf{y_t} \tag{6}$$

It is useful to decompose final demand to the main components:

$$\mathbf{y_t} = \mathbf{c_t} + \mathbf{v_t} + \mathbf{g_t} + \mathbf{e_t} - \mathbf{i_t} = \mathbf{y_t^d} - \mathbf{i_t} \tag{7}$$

where $\mathbf{c_t}$ is household consumption, $\mathbf{v_t}$ is investment, $\mathbf{g_t}$ is government consumption, $\mathbf{e_t}$ is exports and $\mathbf{i_t}$ is imports. The second equality in equation (7) expresses net final demand as the difference between the gross domestic demand and imports.

In addition, the use of commodities (u_t) can be written as domestic production plus imports less exports:

$$\mathbf{u_t} = \mathbf{x_t} + \mathbf{i_t} - \mathbf{e_t} \tag{8}$$

We can also rewrite $\mathbf{y_t}$ as a share vector of total demand, or GDP, (Y_t):

$$\mathbf{y_t} = \gamma_t Y_t \qquad \text{where } \gamma_t = (\gamma_{1t}, \ldots, \gamma_{nt})' \tag{9}$$

The output equation (6) can thus be rewritten as:

$$\mathbf{x_t} = \mathbf{G_t y_t} = \mathbf{G_t}\gamma_t Y_t \tag{10}$$

where $\mathbf{G_t} = (\mathbf{I} - \mathbf{A_t})^{-1}$ is the Leontief inverse, the “commodity total requirements matrix”.

Writing this out explicitly for the output of industry j:

$$x_{jt} = \sum_i G_{jit}\gamma_{it}Y_t \tag{11}$$

Combining this with eq. (8), the rate of change in the use of commodity j is:

$$\dot{u}_{jt} = \sum_i \dot{G}_{jit}\gamma_{it}Y_t + \sum_i G_{jit}(\dot{\gamma}_{it}^d - \dot{\gamma}_{it}^m)Y_t + \sum_i G_{jit}\gamma_{it}\dot{Y}_t + \dot{i}_{jt} - \dot{e}_{jt} \tag{12}$$

The Tornqvist discrete time approximation of the integral of equation (12) gives (see Garbaccio, et al (1999) eq. 20):

$$\ln\frac{u_{jt}}{u_{j,t-1}} = \sum_i \tfrac{1}{2}(w_{i,t-1}+w_{i,t})\ln\frac{G_{jit}}{G_{ji,t-1}} + \sum_i \tfrac{1}{2}(w_{i,t-1}\frac{\gamma^d_{i,t-1}}{\gamma_{i,t-1}} + w_{it}\frac{\gamma^d_{it}}{\gamma_{it}})\ln\frac{\gamma^d_{it}}{\gamma^d_{i,t-1}}$$
$$+\left[-\sum_i \tfrac{1}{2}(w_{i,t-1}\frac{\gamma^m_{i,t-1}}{\gamma_{i,t-1}} + w_{it}\frac{\gamma^m_{it}}{\gamma_{it}})\ln\frac{\gamma^m_{it}}{\gamma^m_{i,t-1}}\right] + \sum_i \tfrac{1}{2}(w_{i,t-1}+w_{it})\ln\frac{Y_t}{Y_{t-1}}$$
$$+\tfrac{1}{2}(w^m_{j,t-1}+w^m_{jt})\frac{i_{jt}}{i_{j,t-1}} - \tfrac{1}{2}(w^e_{j,t-1}+w^e_{jt})\frac{e_{jt}}{e_{j,t-1}} + R_u \tag{13}$$

where the *d* superscript denote domestic, and *m* denotes import, and the shares are:

$$w_{it} = \frac{G_{jit}\gamma_{it}Y_t}{u_{jt}}, \quad w^m_{jt} = \frac{i_{jt}}{u_{jt}}, \quad w^e_{jt} = \frac{e_{jt}}{u_{jt}},$$

and R_u is the approximation residual. When *j*=coal, for example, we may interpret the above equation as expressing the change in coal use as the sum of the change in technique, the change the composition of domestic demand, the change in the composition of imports, the growth of GDP, and the change in the level of coal imports and exports. Note that the GDP term on the right hand side may be simplified using eq. (11) to:

$$\sum_j \tfrac{1}{2}(w_{j,t-1} + w_{jt})\ln\frac{Y_t}{Y_{t-1}} = \tfrac{1}{2}(\frac{x_{j,t-1}}{u_{j,t-1}} + \frac{x_{jt}}{u_{jt}})\ln\frac{Y_t}{Y_{t-1}}$$

We also want to decompose the change in the intensity of energy use (energy per unit GDP). Rewrite equation (13) by moving the GDP term to the left hand side, and denoting the change in intensity of commodity j by Δu_{jt}, we get:

$$\Delta u_{jt} = \ln\frac{u_{jt}}{u_{j,t-1}} - \tfrac{1}{2}(\frac{x_{j,t-1}}{u_{j,t-1}} + \frac{x_{jt}}{u_{jt}})\ln\frac{Y_t}{Y_{t-1}}$$
$$= \sum_i \tfrac{1}{2}(w_{i,t-1}+w_{it})\ln\frac{G_{jit}}{G_{ji,t-1}} + \sum_i \tfrac{1}{2}(w_{i,t-1}\frac{\gamma^d_{i,t-1}}{\gamma_{i,t-1}} + w_{it}\frac{\gamma^d_{it}}{\gamma_{it}})\ln\frac{\gamma^d_{it}}{\gamma^d_{i,t-1}}$$
$$+\left[-\sum_i \tfrac{1}{2}(w_{i,t-1}\frac{\gamma^m_{it}}{\gamma_{i,t-1}} + w_{it}\frac{\gamma^m_{it}}{\gamma_{it}})\ln\frac{\gamma^m_{it}}{\gamma^m_{i,t-1}}\right] \tag{14}$$
$$+\tfrac{1}{2}(w^m_{j,t-1}+w^m_{jt})\frac{i_{jt}}{i_{j,t-1}} + \left[-\tfrac{1}{2}(w^e_{j,t-1}+w^e_{jt})\frac{e_{jt}}{e_{j,t-1}}\right] + R_u$$

When *j*=coal, for example, eq. (14) may be interpreted as saying that the change in the intensity of coal use can be attributed to the following five factors[5]:

1) changes in technology as represented by changes in the **G** matrix

[5] See the discussion in Garbaccio, Ho and Jorgenson (1999) for their eq. 27.

2) changes in final demand patterns for domestic goods as represented by changes in the share vectors (γ^d)

3) changes in the pattern of imports (γ^m)

4) changes in the level of imports of commodity *j*

5) changes in the level of exports of commodity *j*

Before applying the above decomposition equation let us summarize the main features of Chinese energy use. Table 1 gives an overview of the domestic output of China's primary energy and secondary energy sectors. We can see that China has kept a real GDP growth rate at about 10% during the 1981-2005 period, while coal, crude petroleum and gas, refining petroleum only increased at 5%, giving the famous decline in energy intensity. Electricity growth is slightly slower than the GDP growth, 9.1% per year compared to 10.1%. However, in the most recent period (2000-2005), overall the growth rate of coal, oil and gas, electricity is close to real GDP growth, in some cases like natural gas and electricity, even exceeded the GDP growth rate. Thus the overall energy intensity did not go down as in the earlier period, being flat or slightly increasing. Using the SDA method, we would need to collect more data in addition to the IO tables – industry output prices, export and import prices and quantities for all energy commodities.

As equation (14) suggests, we conduct a decomposition analysis for each of the energy types: coal, crude petroleum and gas, hydroelectricity, electric power (non-hydro), and refined petroleum. The hydroelectric sector is part of the power generation sector in the input-output tables described in the Data section above, and we disaggregated it so that we have an explicit hydro industry. We do this in order to be able to isolate the contribution of the main sources of primary energy – coal, crude oil, natural gas, and hydro. Nuclear power and biomass were still very small sources of electricity during 2000-2005, so we did not separate them.

The results of our decompositions of changes in energy use per *yuan* of GDP, are reported in Table 2. The decompositions are performed using the input-output tables from 1981 to 2007 described above. The first column of numbers is the overall change in the use of each type of energy per *yuan* of GDP for each year. The next six columns of numbers correspond to the terms on the right-hand side of equation (14), breaking down the change in the energy-output ratio into the five components and the approximation residual. Since China has substantially revised its GDP value, so the data set we have has a gap before and after 2000, where NBS has a consistent national account measurement after 2000 based on NBS 2002 official 2002 benchmark IO table definition and 2004 census data. For the period before 2000, NBS also revised the whole time series and adjusted the service sector based on 2004 census information, however all the pre-2000 are based on 1997 IO benchmark, so there is still a gap between the 1981-1999 and 2000-2007 data, so we divide our sample into two sub-samples for analysis (see table 2).

Consistent with the overall energy intensity trend in Figure 1, there is a general intensity decline between 1981 and 1999 for the fives types of primary energy, and then rising intensity between 2001 and 2005. In the following discussion we will try to understand the linkages between actual macroeconomic and energy policy changes and our energy intensity decomposition factors.

A) Coal

In terms of coal, technical change is the main factor to explain the overall intensity changes during our samples. Except the period 1992 to 1996 when Chinese macroeconomic expand with inefficient investment, overall coal mining industry improved its technology progress over the whole period from 1982-2002, however during 2002-2005 the trend reverse until 2005-2007 when China implement its 20% energy intensity reduction target in the 11th Five Year Plan Policy. For the special term 2002-2005, part of the reason is that in the 10th Five Year Plan, China faces huge demand from the infrastructure development, thus with the high profit in iron&steel, cement, chemical industries, small-scale inefficient firms were built up quickly to meet the demand surge, but the technology level actually declines substantially, this eventually led to the failure of reaching the environmental target set for 10th Five Year Plan. After 2005, China imposed some stringent policies in energy-intensive sectors, mainly coal mining and electricity sectors, for example shutting down inefficient coal mine and power plants, and listing achieving energy saving and environmental target as important performance indicator for local governments, thus we observe substantial improvement after 2005.

In terms of changes in demand patterns for coal sector, we can see that except some periods like 87-89, 92-93, and 97-98, demand pattern in general shift positively toward cleaner consumption structure. Coincidently these special periods all correspond to special periods with major reforms, such as Deng's south trip which foreshadow the starting point of SOE reform in 1992 and Asian economic crisis in 1997 and big Yangtze flooding in 1998. So we can see that inefficiencies before these historical moments and big improvements following the major events. Similarly, for the period 2001-2005 even the demand side we can see the inefficiencies arise due to huge demand surge for housing and real estate development, and the 11th FYP energy policy also reverse the negative trend in demand as well.

The factor of import and export play important roles after 1991, though not as important as technology change and demand patterns. For the sub-period 1994-98 and 01-05 we can see import patterns play positive role in energy intensity reduction, however after 2005 although overall energy intensity decline the trend of coal import reverse, thus dragging down the progress in energy conservation. On the opposite, China's coal export increase substantially during 2002-2004, while contracts again after 2004, this reflects changes in both domestic and world coal market.

B) Crude Petroleum and Gas

We can see that in the pre-2000 period, crude petroleum and gas has similar effects as coal, however after 2002 the trend reverse reflected by inefficiencies in technology change and demand change, partly due to the surging demand for automobile consumption in China. We also find big changes in 92-93 and 97-98, part of the reason may due to the big macro event, though data issue could be another reason for the outliner estimates. During 2000-2002, we observe big efficiency improvement, however this trend reverse after 2002, and get even worse after 11th Five Year Plan, since there is only overall energy efficiency target which encourage shifting coal to oil use, and no other policies to curb automobile usages in China. Imports and export patterns and level changes are key important factors affecting the overall energy intensity for crude oil, and import plays much important role than export, this trend becomes more prominent in the post-2000 period, thus shed some lights on the challenges in improving oil efficiencies and curbing vehicle emissions in the near future

The panel C) D) E) in table 2 also shows the decomposition results for hydroelectricity, electricity power (non-hydro) and refined petroleum. Except for hydroelectricity, both electricity (non-hydro) and refined petroleum results suggest that intensity in 2005-2007 basically follows the trend in 2002-2005, and such a post-2000 trend is quite different from the pre-2000 trend. Since 2004, the electricity demand face a shortage with a two digit GDP growth, meanwhile the coal price and electricity price are managed by NDRC, thus a low electricity price leads to excess demand, in some area like Guangdong province inefficient oil-fired power plants were observed to put into production again, to support for the electricity shortage with local government subsidy. These partly offsets government's efforts in terms of small unit power plants shutdown policy and energy saving target policy.

2.2 Method 2: Index Decomposition Analysis (IDA)

The second method used is the Index Decomposition Analysis (IDA) described in Ma and Stern (2007). This uses a time series data set from the NBS's final energy use by sector data, and the sector gross output and price data from the IO dataset. In the NBS framework, the aggregate economy is first divided into Primary, Secondary and Tertiary Industries. Within the Secondary Industry are the Mining, Manufacturing, Utilities and Construction sectors. Then within Manufacturing, for example, there are the sub-sectors like Food Manufacturing, Tobacco, Textiles, etc.

Instead of calculating separate decompositions for coal, oil and gas as in the previous SDA method, here we add the units of energy (in Standard Coal Equivalents, SCE) from all the primary sources to give total energy consumption of the target of interest. The target may be the total economy, however, here we focus on the Mining, Manufacturing and Utilities only since they have the most reliable data. Let E_{mk} denote the energy in SCE from fuel m used in the k-th sub-sector, and Q_k the output. The total energy used in the sub-sector is:

$$E_k = \sum_m E_{mk}$$

and its energy intensity is:

$$I_k = E_k / Q_k$$

Aggregate energy use is $E = \sum_k E_k$, aggregate output is $Q = \sum_k Q_k$ and the overall, or total, energy intensity is thus $I_{tot}=E/Q$. The IDA method expresses the overall energy intensity as a function of the fuel shares in each sector and sector output shares of aggregate output:

$$I_{tot}=\sum_{i}\sum_{j}\sum_{k}\sum_{m}F_m I_k S_k S_j S_i \tag{15}$$

I_{tot}——Overall energy intensity

F_m——Share of fuel m in total energy consumption of the *ijk*-th sub-sector (E_{mk}/E_k);

m = coal, oil, gas, hydro

I_k——Energy intensity in the *ijk*-th sub-sector

S_k——Output share of the *ijk*-th sub-sector in the *ij*-th sector

S_j——Output share of the *ij*-th sector in the *i*-th industry

S_i——Output share of the *i*-th industry in the overall economy

The overall energy intensity can be decomposed as a summation of each of the sub-sectors of the major sector in the economy. As Ma and Stern (2007) suggest, a logarithmic mean Divisa index (IMDI) would avoid the unexplained residual in the SDA methods, and is not path dependent so that one can choose any two years for comparison. Differentiating equation (15) with respect to time, and using the logarithmic mean weight scheme, we have:

$$\begin{aligned}\Delta I_{tot} &= \sum_{i}\sum_{j}\sum_{k}\sum_{m}L(w_{ijkm_{t-1}},w_{ijkm_t})\ln(\frac{F_{m_t}}{F_{m_{t-1}}})+\sum_{i}\sum_{j}\sum_{k}\sum_{m}L(w_{ijkm_{t-1}},w_{ijkm_t})\ln(\frac{I_{k_t}}{I_{k_{t-1}}})\\ &+\sum_{i}\sum_{j}\sum_{k}\sum_{m}L(w_{ijkm_{t-1}},w_{ijkm_t})\ln(\frac{S_{k_t}}{S_{k_{t-1}}})+\sum_{i}\sum_{j}\sum_{k}\sum_{m}L(w_{ijkm_{t-1}},w_{ijkm_t})\ln(\frac{S_{j_t}}{S_{j_{t-1}}})\\ &+\sum_{i}\sum_{j}\sum_{k}\sum_{m}L(w_{ijkm_{t-1}},w_{ijkm_t})\ln(\frac{S_{i_t}}{S_{i_{t-1}}})\\ &=\Delta I_{fls}+\Delta I_{tec}+\Delta I_{strss}+\Delta I_{strs}+\Delta I_{stri}\end{aligned} \tag{16}$$

where $w_{ijkm}=F_m I_k S_k S_j S_i$, and $L(w_{ijkm_{t-1}},w_{ijkm_t})$ is the "logarithmic mean weight":

$$L(w_{ijkm_{t-1}},w_{ijkm_t})=\frac{w_{ijkm_t}-w_{ijkm_{t-1}}}{\ln(w_{ijkm_t})-\ln(w_{ijkm_{t-1}})}. \tag{17}$$

That is, the aggregate intensity change, ΔI_{tot} , is decomposed to five factors：

ΔI_{fls}——intensity change due to fuel substitution

ΔI_{tec}——technological change

ΔI_{strss}——structural shift at sub-sector level

ΔI_{strs}——structural shift at sector level

ΔI_{stri}——structural shift at industry level

Our analysis focus on the industrial sector only, this includes mining, manufacturing, and electric power and hot water utilities; we ignore agriculture and services here. That is, the overall energy intensity in this section is not the economy-wide energy intensity in the previous section using the SDA, but merely the Secondary Industry. In terms of equation (15) we do not need the S_i term, and in equation (16) there is no ΔI_{stri} term. We also just focus on total energy use in each sub-sector, ignoring the reallocation among fuel types. The fuel substitution effect is folded into the technological change term. Thus, we focus on the three factors:

ΔI_{tec} ——technological change
ΔI_{strss} ——structural shift at sub-sector level
ΔI_{strs} ——structural shift at sector level

The IO dataset described earlier includes a version with 62 sub-sectors, of these 52 are in the mining-manufacturing-utilities group. This gives us the output of the 52 sub-sectors for each year 1993-2005. The Chinese Energy Statistical Yearbook gives final energy use for 39 sub-sectors in Industry (Table 5-3 of CESY 2007). Final energy use includes the combustion of fossil fuels and electricity but excludes biomass and energy embodied in intermediate inputs. Combining the output and energy use data gives us information for 39 sub-sectors.

Table 3 gives the results of the above IDA method of decomposing energy intensity changes in mining, manufacturing and electricity power sectors. We can see the industrial energy intensity drops very quickly during 1982-1987 and 1990-1994. Overall, due to the data difference, the IDA decomposition results in some years are quite different from the SDA methods. But for 2005-2007, the general trend is consistent for all the sectors using both methods. We can see that for coal sector there is inefficiencies during 2000-2005 but with the 11th FYP there is an efficiency improvement in 05-07. However for other energy sectors, we did not observe this effect, which suggest that our energy conservation mostly focus on coal use only, thus overall the intensity decline from 2005 to 2007 is still very limited.

The caveats for the IDA methods rely on its decomposition of sector classifications at different layers, and data is extracted from very different sources, so its results are less reliable as SDA method. In sum, when we conclude the total energy intensity change, we can see both methods shows that after 2000 there is a reverse trend, technology change and demand pattern change both play important roles here, and sometimes the both effects have opposite effects.

2.3 Method 3: Simple Index

Most energy decomposition studies use the SDA or IDA methods implemented here. However, the results from these decomposition techniques are difficult to use to specify AEEI parameters that could be incorporated into CGE models. We thus also use a simple decomposition technique suggested by Wing and Eckaus (2004) and Wing and Eckaus (2005) to apply a simpler index for linking with our CGE model.

Let the energy used in industry i in period t be E_{it}, the output be Y_{it}, and the aggregate energy use be E_t^*. Aggregate energy intensity is a weighted sum of the sectoral intensities::

$$\frac{E_t^*}{Y_t^*} = \frac{1}{N}\sum_{i=1}^{N}\phi_{i,t}\left(\frac{E_{it}}{Y_{it}}\right) \tag{18}$$

where $\frac{E_t^*}{Y_t^*}$ is the overall energy intensity, N is the total number of sectors which include the primary, manufacturing and tertiary sectors, and $\phi_{i,t}$ is the weight of industry *i* given by the ratio of its share of GDP to its share of total energy use ($\frac{Y_{it}/Y_t^*}{E_{it}/E_t^*}$), and $\left(\frac{E_{it}}{Y_{it}}\right)$ is the energy intensity of each sector *i*. Taking the time derivative of equation (18) in logarithms, we have:

$$\frac{\partial}{\partial t}\ln\left(\frac{E_t^*}{Y_t^*}\right) = \underbrace{\frac{1}{N}\sum_{i=1}^{N}\frac{\partial}{\partial t}\ln\phi_{i,t}}_{\Phi^*} + \underbrace{\frac{1}{N}\sum_{i=1}^{N}\frac{\partial}{\partial t}\ln\left(\frac{E_{it}}{Y_{it}}\right)}_{\Psi^*} \tag{19}$$

Therefore, the change in overall energy intensity can be decomposed as two parts:

1) Structural change effects: the average of changes in industries' contributions to aggregate energy intensity, denoted as Φ^*;

2) Intensity change effects: the average of changes in energy intensity within industries, such as input substitution, pure technology progress with fixed amounts of inputs, denoted as Ψ^*.

We combine our time series 1981-2007 IO tables with the physical units of energy use by five energy types: coal, oil & gas mining, hydro, refine, and electricity. Figure 3 presents the estimated structural change effects (Φ^*) and intensity change effects (Ψ^*) of coal use, crude oil and natural gas in China. For the coal use, we can see that the overall change in energy intensity ($\Phi^* + \Psi^*$) are negative in most years except 2003-2005. The improvement of energy efficiency is mostly contributed to technology change, we can see that out of 24 years only 6 years the intensity change effects are positive, while about half of the years the structural change effects are positive. Although this is only the energy change for coal use, considering coal use accounts about 70% of total energy use in China, it is not surprising that the coal result alone coincides with the total energy intensity trend in figure 2. For crude oil and natural gas, we see similar overall trend changes, though structural change and technology change are more volatile than coal use except for period 2005-2007.

In addition, the detail results of coal intensity decomposition in the mix of industries within the large sectors are shown in figure 4 and 5, both are in terms of coal consumption. We can see that structural composition changes and energy intensity changes vary substantially across different sectors. For example, in most energy intensive industries and service industries, the origins of coal intensity decline can be attributed to within industry coal intensity changes. In fact, we can also see that for energy intensity sectors and service sectors, the effects of changing industrial composition actually increase the use of energy. However, for agriculture and other manufacturing, the effects of changing industrial composition may exceed the within industry energy intensity changes, and both effects are working in the same direction, thus reinforcing the decline in overall energy intensity. From 2003-2005, the within industry energy intensity changes are smaller for all the four major sectors: agriculture, energy intensive sectors, other manufacture and service sectors, this explains why the overall energy intensity is flat out after 2003, especially the improvement from the structural change is almost flat for most sectors, when compared to their 1981 level. From 2005 to 2007, we can see that within sector intensity change improve substantially for coal use, however this is most part offset by the structural change in the opposite direction. Therefore overall the aggregate intensity change is still quite limited.

In sum, our paper obtained the similar results as in many previous energy intensity decomposition literatures for China for the pre-2000 era. For example, using a discrete SDA method, Lin and Polenske (1995) suggest that the origin of the energy intensity decline during 1981-87 attributed to the technology change, rather than the final demand changes. In addition, with an improved SDA method and updated IO data of 1987 and 1992 tables, Garbaccio and Ho (1999) also suggest that technology change within sectors accounted for most of the fall in the energy-output ratio, and points out structural change actually increased the use of energy. Zhang (2003) used Laspeyres index to calculate the energy intensity decomposition for China’s manufacturing sectors for 1990-1997, and suggest that technology change is the most important reason. Ma and Stern (2006) used Logarithmic Mean Divisia Index (LMDI) studies energy intensity trend for 1980-2003, they focus on post-2000 period, and suggest the increased energy intensity attributed to the negative technology change, within sector energy input substitution and structural change play very minor roles. In this study, we applied three decomposition techniques, all suggesting that the real technology change after 2002 is limited, however for 2005 to 2007 the trend seems reverse to some degree, most prominently in coal sector.

4. Energy Intensity Decomposition, Energy Use Projections and Environmental Policy Analysis

We now turn to the question of what these results imply for the projection of future energy use, and carbon emissions into the long-term future, especially how would these energy intensity decomposition results for the historical data can be of some use to the CGE model analysis and policy simulations. Right now most CGE models normally assume a one-size-for-all AEEI parameters to indicate the autonomous energy efficiency improvement, that is, all the countries and most models use the same common parameter, that is assuming AEEI is 1% improvement very year.

It has long been realized that AEEI is not a simple factor, rather a short-hand approximation for several complicated processes, such as energy-saving technological progress that is to use less energy with given other inputs fixed, shifts in the composition of energy mix, the shift in the composition of economy that demand less quantities of energy use (i.e. structural change), or other relevant policy effects such as environmental policies that restricting use of fossil fuel, R&D and technological diffusion, or simply removing the "market barriers" to more advanced energy-saving technologies (Williams 1987, 1990; Williams *et. al* 1987, Weyant, 2000, Wing and Eckaus, 2005).

In this study, we conduct a number of numerical experiments, which would shed some light on various scenarios of future energy use and carbon emissions. The scenarios are described in table 4. First, we consider a scenario as control experiment to assume no AEEI at all, that is only the benchmark IO table is used in our simulations. Then we adopt the most common assumption in energy modelling, that is to assume AEEI is 1 percent improvement for each sector every year. Third, following Wing and Eckaus (2005) study, based on our energy intensity studies above, we assume that AEEI parameters incorporate both structural and intensity change factors, and we use different sample period 1981-2007, 2000-2007 and 2000-2005 results for our sensitivity analysis of forecasting carbon emissions using our CGE model. Note different from other carbon emission forecast, which focus on empirical estimation techniques, rather here we conduct sensitivity analysis on AEEI parameters, then run our CGE model to get the forecast on carbon emissions. From 2000-2005, our overall intensity (1.77%) change only slightly higher than one-size for all AEEI (1%). If we incorporate the 11th FYP period after 2005, then overall 2000-2007 is about 2.29%, and if we consider the overall AEEI for 1981-2007, then the technology progress is about 4.76%.

Figure 6 shows our forecast of China's future energy use and carbon emissions till 2030. Without any improvement in AEEI, we can see that energy use and carbon emissions will increase by 6 times in 2030. If we adopt the common AEEI assumption – 1% per year, then both energy use and carbon emissions will be cut by more than half. If we based on our AEEI assumption from using 2000-2005 data, our carbon emissions forecast is similar to EIA (2008), Zou Ji's group at Renmin University, and ERI Jiang Kejun's group results. If we assume 2000-2007 and 1981-2007 results, our forecasted results are much lower than most other groups at the business as usual case. Considering that during the period of 2000-2005 there is no important energy policy in place, rather after 2005 China imposed a very stringent energy intensity target policy. Therefore, we think that overall AEEI = 1.7% is more reliable in the business-as-usual case, and mostly consistent with other modeling groups' results, so we use his as our central estimate in the following policy analysis, while using other scenarios to test for sensitivity and robust checks[6].

4.1 An Overview of the Chinese Economy-Energy-Environment CGE Model

To have a better forecast and reasonable forecast on future energy use and carbon emissions in China, we incorporate the results of the previous section into a recursive-dynamic CGE model of the Chinese economy. In the following section, we will first describe its economic module and environmental module respectively.

A) Economic Module

a) Production**:** The production technology is a nested Cobb-Douglas production

[6] Scenario I assumes no efficiency improvement and structural shift, so is not realistic, in the uncertainty analysis on environmental policies we drop this scenario as upper bound but pick 1% AEEI assumption as upper bound for energy use and carbon emissions.

function:

$$QI_{jt} = g(j,t)KD_{jt}^{\alpha_{Kj}} LD_{jt}^{\alpha_{Lj}} TD_{jt}^{\alpha_{Tj}} E_{jt}^{\alpha_{Ej}} M_{jt}^{\alpha_{Mj}} \tag{20}$$

where $g(j,t)$ is the technical progress term that is assumed to have rapid technology progress in the beginning, and then the growth rate decrease, and eventually stabilize at the steady state.

***b) Household*: **The representative household drives utility from his consumption of commodities, supplies an inelastic supply for labor input in productions, and owns a share of the capital stock; it also receives lump-sum transfers and interests on its public debts. For the recursive property, the representative household makes exogenous savings decisions that are transformed into investment in the subsequent period.

***c) Capital and Investment*: **The Chinese capital stock is modeled in two parts, the first part is a plan share of capital since some state-owned enterprises might receive favorable investment funds directly from the state budget, and the second part is market capital, the rental price of which is equal to the marginal product of capital input. Both types of capital are evolved with investment accumulation and depreciation.

***d) Pre-existing taxation*: **The model includes a variety of pre-existing taxes, such as taxes on production, consumption; subsidies in production and consumption; tariffs and subsidies on exports. With a recent tax reform in 1994, the Chinese taxation system has moved to one with a broader tax base, a value-added tax cover all the industrial sectors and commerce, enterprise profits tax, and sales tax.

***e) International Trade*: **This model assumes imperfect substitution among goods originating from China and those from the rest of the world. Imported demand of goods is derived from a CES aggregation of domestic and imported goods. The current account and government debts are set as exogenous. Though in this stage of our CGE model development, such a strong assumption is not quite realistic but we focus on calibrating 2005-08 current account, and we only care a short-medium run simulation results, thus we can mitigate the effects of such modeling weakness for our purpose. Note our policy is focused on domestic ones, so the import and export changes are not quite important for our purpose. In addition, our domestic policy changes only bring second-order bias when we compare with the benchmark case.

***f) Market Clearing*: **All market prices in the model are endogenous and adjust to clear the market for goods and factors. In addition, the government debt balance, trade balance, and savings-investment balance are combined in order to complete the model. The Walras Law is checked to test the market clearing.

***g) Calibration*: **To improve the robustness of the model, a critical step after setting up the model is to calibrate parameters in the recursive CGE model so that it can successfully "replicate" the benchmark year 2002 for China. But different from the previous version, the energy input share parameters are based on our empirical work on energy intensity decomposition.

B) Environmental Module

One advantage of our CGE model lies in its integrated structure of both economics and energy-pollution-health module for analyzing the benefits and costs of environmental policies. More specifically, the China CGE model has developed a methodology and data base that provide a tractable link between emissions and human exposures, which is incorporated into an environmental damage model that estimates health damages by industry. In estimating for cost and benefit of environmental policies, many previous studies have dealt only with direct costs of pollution control such as the costs of scrubbers. In contrast, our CGE modeling approach also identified the indirect, general equilibrium costs. The overall flowchart of this integrated approach is summarized in Table 5 follows.

Step 1. From economic activity and fossil fuel use to pollutant emissions

In our integrated economy-environment model for China, the economic component generates the level of output for 33 industries and the household sector. The input demand functions of the model generate the consumption of fossil fuels – coal, oil and gas –for each industry, which in turn generates emissions of pollutants. The focus is on three pollutants: TSP, SO_2 and NO_x. Emissions may come from either combustion of fossil fuels or from production processes. Only NO_x emissions from the transportation sector were considered, because there were no estimates for the other sectors at the time of either study. The emissions of the three pollutants are linked to fossil fuel combustion by emission coefficients (e.g., tons of TSP per ton of coal). The damage due to particulate matter depends crucially on the size of the particles, with fine particles going deep into the lungs, such as PM_{10} to denote particles smaller than 10 microns, and $PM_{2.5}$ for those finer than 2.5 microns. However, comprehensive data for China were only available for TSP. Therefore the emission coefficients were calibrated to the official national TSP data, and converted to PM_{10} equivalents.

Step 2. From emissions to concentrations.

Although different industries clearly produce different levels of emissions and emissions per dollar of output, it may be less obvious that each ton of emissions from the different industries produces a different level of damages. This is due to numerous factors, including differences in meteorology, smokestack characteristics, proximity to dense populations, and distributions of particle size. The modeling of atmospheric transport is a large field of study involving complex atmospheric chemistry. In this interim report, we use our previous Harvard-Tsinghua study to calibrate our emission-concentration relationships. The detail of this work is explained in Ho and Jorgenson (2007a, 2007b). Our results are calibrated to two basic air dispersion models. The first was to use a relatively simple model for dispersion within 50 km, and the second was to use a more sophisticated model for regional dispersion up to 3000 km. We used this model to calculate the dispersion of pollutants for a sample of sources and, as explained in Step 3 below, the concentration estimates were combined with population maps.

Step 3. From Concentrations to Human Exposures.

In this step, we apply an "intake fraction" (*iF*) methodology described by Levy and Greco (2007), which allowed the Harvard-Tsinghua study to estimate human exposures for all national sources. The *iF* from a particular source is the fraction of a pollutant emitted that is eventually inhaled by people before it is dissipated. This method calculates the *iF*s using the air dispersion models and population maps for a small sample of sources and then extrapolates to other emission sources. This extrapolation is done using regressions of the *iFs* on a small set of key characteristics, such as a source's stack height and emission characteristics, average wind speed, population within 10 km and total population in the domain. The *iF* estimates for China were obtained by running the air dispersion models over a fine population grid for a sample of sources. The resulting pollution concentrations were then regressed on the key characteristics described above. We then turned to national data sets for the four highly polluting industries and selected a national sample of plants.

Step 4. From Exposures to Health Impacts.

This part of the analysis relies on air pollution epidemiology to identify the concentration-response coefficients (e.g., the percent increase in death rates per $\mu g/m^3$ increase in the PM_{10} concentration). Levy and Greco (2007) summarize the few epidemiological studies for China and compare them to estimates for other countries. They describe how most of the studies for the U.S., which has much lower levels of pollution, attribute most of the health effects to PM concentrations and a statistically insignificant amount to SO_2 (Levy and Greco 2007, Table 4.5). However, because the Chinese studies also find statistically significant contributions from SO_2, we include effects from both types of pollutants. After considering all the studies, we used concentration-response estimates for "acute mortality" of 0.03 percent per $\mu g/m^3$ of PM_{10} and 0.03 percent per $\mu g/m^3$ of SO_2. Based on the mortality rate in China, we estimated that these values of the concentration-response are equivalent to 1.92 deaths per million people per year per $\mu g/m^3$ increase in concentration of PM_{10} and SO_2.

Step 5. Valuation of Health Effects.

After the health impacts have been estimated, the health effects need to be monetized in order to compare the benefits of pollution reduction with the cost of pollution reduction policies. The central concept in this analysis is the value of a statistical life (VSL), which is the WTP divided by the change in risk. We express the value of the change in the number of cases of illness and mortality in terms of *yuan*, the Chinese currency. The VSL ranges from modest 0.26-0.51 million *yuan* figure from Hammit and Zhou (2005) to over 1.4 million *yuan* figure in World Bank (2008). In our study we will conduct sensitivity analysis to compare various environmental policies due to the uncertainty on VSL estimations.

The estimated valuations for the other health effects listed in Table 6, which are based on the World Bank (1997) and ECON (2000), are mostly from studies of Western countries. The top two values of morbidity risks are for chronic bronchitis and respiratory hospital admissions

4.2 Environmental Policy Analysis (Command-and-Control vs. Economic Incentive Based Instruments)

In reconciling economic growth and environmental protection, Chinese government usually spent too much effort in hope to achieve a certain rate growth target, such as 8% this year. However in recent years, environmental concerns are increasingly being incorporated into China's planning process at both the national and local levels, and targets for pollution control is set parallel with the growth target. For example, the National Economic and Social Development 11th Five-Year Plan in the area of environmental protection, such as 20% energy intensity reduction, 10% SO2 and COD reduction, ratified by the Fourth Plenary Session of the Tenth National People's Congress in March 2006, can be seen as an attempt to maintain rapid growth while incorporating increased concern for environmental sustainability.

The 11th Five Year Plan, covering the years 2006-2010, assumes that China's economy is now market driven, and targets are now specified as either "expected" or "compulsory." Expected targets are those that are anticipated to be achieved through the workings of market forces, with the government providing overall macroeconomic stability and the necessary regulatory institutions. Compulsory targets are those that are imposed by the central government, with enforcement the responsibility of central government agencies and local governments (Fan 2006; You 2007). Of the compulsory targets, half are directly related to energy and the environment. This plan contains only five targets: three for water quality and two for air, including a 10% reduction in SO_2 emissions and a 20% reduction in energy intensity. The sulfur target is modest, maybe due to the poor performance under the 10th Environmental Protection Plan, which covered the years 2001-2005, which was set at 10% below the 2000 level of emissions, was exceeded by more than 40%. The energy efficiency target is very ambitious, reflecting a number of growing concerns of the central government. Among these concerns is energy security, as China has been forced to import increasing amounts of oil and natural gas and more recently has also been a net importer of coal (Oster and Davis 2008).

In this study we focus on two typical command-and-control policy under the 11th Five Year Plan – a technological mandate policy that requires to add FGD equipments in the electricity sector, and a mandate policy to shut down small-scale coal-fired power plants. More specifically, the first policy is the installation of 167 GW of new fluidized gas desulphurization (FGD) equipment on existing power generation units.[7] The installation of this equipment is expected to result in a reduction of 5.4 million tons of emissions. The second policy is a shutdown of 50 GW of small-scale power generation units during the time span of the Plan, 2006-2010. The expected net reduction in SO_2 emissions from this policy is 2.1 million tons. Base year (2005) emissions levels, 2010 business as usual (BAU) emissions projections, and the 2010 Five-Year Plan targets are shown in Table 7.

Alternatively, we think China is also ready for imposing new market incentive-based tax or cap-and-trade instruments. In our model, we use a carbon tax to represent this portfolio of policies. We assume the tax is imposed on the carbon contents

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[7] All new power plants are required to install FGD equipment.

of fossil fuel consumption. Based on a new recent Ministry of Finance Carbon Tax study, such a tax on fossil fuel is very likely to be implemented in the forthcoming 12th Five Year Plan or the 13rd Five Year Plan. In fact, energy tax in the Chinese name "resource tax" is already under major reforming process to substantially raise its current tax rate to reflect the environmental externality cost. In our study, we assume a fiscal neutral carbon tax, that is the revenue is either lump-sum transferred to the households, or used to reduce other pre-existing distorted taxes in the current fiscal structure.

In sum, we want to compare two different policies: Command and Control policies (FGD, shut down, and combined 11th FYP FGD and shut down policy), and Carbon Tax (recycled with lump-sum transfer, or recycling other distorted taxes). In comparison, we assume both kind of policies has been imposed from the first year of 11th five year plan 2006 and then compare their cost-effectiveness and economic-wide impacts, with regard to each carbon emission scenarios that we specified in the previous sections.

1) FGD Installation Policy under the 11th Five Year Plan

At the end of 2005, FGD equipment had been installed on 46.2 GW of coal-fired electricity generation capacity – 12 % of the total. In order to meet the SO_2 reduction target of the 11th Five-Year Plan, an additional 167 GW of FGD equipment is scheduled to be installed on existing power generation units by 2010. Moreover, all new power generation units constructed during the 11th Five-Year Plan – estimated in the JES (2007) at 250 GW of capacity – are mandated to have FGD equipment. Thus, if the FGD policy is fully implemented, there will be a total of 463.2 GW of FGD equipment installed on coal-fired power plants by the end of 2010. The IEA's reference scenario (IEA 2007) projects total coal-fired electricity generation capacity at 547 GW in 2010. This means that FGD would be installed on almost 85% of total coal-fired capacity.

The costs of the FGD installation policy can be divided into two types: direct and economy-wide. The direct costs of the FGD policy include the capital costs of the FGD equipment and operation and maintenance costs, which include additional electricity for the operation of the equipment and thus an increase in fuel inputs. Capital costs for FGD units manufactured in China have fallen by more than half since the 1990s as domestic firms have learned to produce the new technology. These costs now range from 150 *yuan*/kW for a 600 MW plant to 180 *yuan*/kW for a 100 MW plant. As the cost of constructing a 600 MW plant without FGD is approximately 4000 *yuan*/kW, the addition of FGD equipment represents about a 3.8% increase in capital costs. The unit operating cost of the FGD equipment (per ton of SO_2 removed) depends on the size of the plant and sulfur content of the coal used, and ranges from 1,244 *yuan*/ton of SO_2 for a 100 MW plant to 800 *yuan*/ton for a 1000 MW plant (for coal with a sulfur content of 1%). Low sulfur coal raises the cost per ton removed, from 1,020 *yuan*/ton for 1% sulfur coal to 1,840 *yuan*/ton for 0.5% sulfur coal. The Chinese Academy for Environmental Planning (CAEP 2007) reports that coal with a sulfur content of less than 0.5% makes up 30 percent of coal combusted in the power sector, with coal having a sulfur content of 0.5-1% making up another 35 percent. Averaging over plant sizes and coal types, CAEP estimates that running FGD equipment raises operating costs by 2.4 percent. In terms of the price of delivered electricity, which includes transmission costs, the additional cost of running FGD equipment is only 1.5 percent.

Using our CGE model, we model the impact of FGD policy as a negative productivity shock in the production function, that is, to raise electricity prices, by 0.25 percent in 2006, rising to 0.94 percent in 2010. Given our unit elasticity assumption, this reduces overall electricity use by approximately the same (absolute) percentage as the rise in price. The higher cost of electricity leads to a small decline in the output of energy intensive industries such as chemicals, non-metal mineral products, and primary metals. The use of FGD also increases the amount of coal required to generate a kWh of deliverable electricity. However, this is offset by the reduction in the demand for electricity and the reduction in the demand for coal by energy intensive industries, which leads to a small net decline (0.08 percent) in coal consumption in 2010.

As table 9 shows, this small negative productivity shock results in a slight decline in GDP, with corresponding reductions in the consumption and investment components of GDP. The negative shock give rise to a larger impacts on consumption, while most other indicators such as impacts on CO_2, TSP, SO_2 and NOx are similar in the first year or last year. The GDP loss ranges from -0.10% in 2010, corresponding to central AEEI assumption specified in the previous sections. The impacts on CO2 and PM are less significant, and there is no revenue collected for the government so as to reduce other distortions.

2) Shutting Down Small-Scale Power Plants under the 11th Five Year Plan

At the end of 2005, almost one third of China's thermal power generation capacity was provided by small scale power generation units, where small scale is defined as a unit with capacity less than 100 MW.[8] Most of these small scale units are coal-fired, but some are oil and diesel units serving localities which had in the past experienced severe electricity shortages. These small units are generally inefficient in their use of energy and highly polluting. However, as they have been seen as providing local benefits, they have continued to operate. With the emphasis on energy efficiency and pollution control in the 11th Five-Year Plan, 50 GW of small scale power plants have been targeted for closure by the end of the plan period in 2010.

Table 8 shows the cost structure for thermal power plants. The average total cost per kilowatt hour for small plants is almost three times higher than for large plants. The greatest contributor is the higher fuel requirements to produce a kilowatt hour of electricity. Diesel-fired plants are particularly inefficient.

Implementing the small unit shutdown policy requires that replacement capacity be built, although as this policy is being implemented gradually over the five years of the plan, the individual units shut down are proportionately small and widely spread geographically, and electricity connected to the grid is fungible, the actual cost of replacement capacity is an average of all new capacity installed over the plan period. The direct cost of the shutdown policy would then be equal to the cost of producing the replacement electricity, less the operating and maintenance costs that would have been incurred by operating the small units and decommissioning costs.[9]

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8 The NDRC's Energy Research Institute estimates that in 2006 there was about 115 GW of capacity provided by coal and oil fired units under 100 MW, out of a total of 391 GW of thermal-fired capacity.

9 The location of the replacement plants may also mean higher transmission costs.

The decommissioning costs could include the shutdown of the small plants themselves and perhaps the retraining and relocating of displaced workers. The value of any scrap materials and the land the plant was located on should be accounted for as negative costs. Although estimation of the total direct costs of the shutdown of these very heterogeneous units is difficult, limited analysis indicates that when high fuel costs and the value of freed up land are fully accounted for, total direct costs of the shutdown policy are negative – even without taking into account the environmental benefits. The environmental benefits of the small unit shutdown policy are substantial. Based on a previous study, it is estimated that the shutdown of the 50 GW of small units would save almost 30 million tons of coal over the 11th Five-Year Plan period. The annual reduction in SO_2 emissions from the policy would be about 2.1 million tons.

The second column in table 9 shows the effects of such a shut down policy on the economic and environmental variables. We can see that the effects on SO2 are higher than the FGD mandates, in fact due to the inefficient small-scale and higher fuel use, we can see that the positive impacts are the biggest of all policies. This shows that in some circumstances, C&C policies are important for these can prevent market's myopia perspectives on investment, encouraging investments on larger and more environmental friendly technologies, thus requiring government intervention to mitigate such a market failure. Column 3 shows the effects of the combined FGD and shutdown policy, which can be used to approximate China's 11^{th} FYP measures on SO2 controls. Therefore the impact on SO2 emissions are very significant, while impacts on CO2, TSP, NOx is quite limited.

3) Hypothetical Carbon Tax Policies

An alternative policy instrument we pick is to impose a carbon tax on energy use. The carbon tax policy is currently still debated in China as compared to emission trading policy, and currently not implemented yet by the Chinese government, except the new installation of gasoline tax to replace road tolls starting in January 2009. So it is interesting to ask the potential role of this alternative economic incentive based tax policy, whether it is more cost-effective than the current implemented command-and-control options listed above, and how this alternative tax policy differ in terms of influence on energy use, technology choices within and across sectors. In particular, whether the alternative tax policy should be recommended to reach a new energy-intensity target in the next 12^{th} Five Year Plan?

In this report, we experiment with a carbon tax policy, at 100 yuan/tC on coal, crude oil and natural gas, depending on their carbon contents. The carbon tax encourages a switch from polluting coal to cleaner oil and gas, and a substitution of capital for energy. Although it is not a first-best policy, such a tax in general can still generate substantial reductions in pollution.

The model was first simulated with the existing tax rates to obtain a base case growth path. We then simulated the carbon tax in the counterfactual case to be compared to the base case. In this experiment, we assume revenue neutral carbon tax reform, that is, the collected carbon tax revenue will be returned back to industries by cutting their VAT and business taxes and other fees.

As shown in the fourth and fifth column in Table 9, the carbon causes coal use to fall by about 14 percent in 2010 and crude oil use to fall by 2.4-2.6 percent. Because the policy raises coal prices and petroleum products prices, the major users of these fossil fuels raise their output prices, causing a reduction in demand for energy-intensive goods. The imposition of fuel taxes causes changes in output mix and fuel switching that reduce both primary combustion PM emissions by 12.4-12.5 percent and SO_2 emissions by 12.9-13.1 percent in 2010. The modest tax on oil reduces transportation output and NO_x emissions by only 1.9-2.3 percent. So compared with C&C policies, we can see that carbon tax can deal with multiple pollutants and more effective in reducing overall health damages, at similar macro costs. We can see that, in the carbon tax case, the impacts on GDP are overall small, though the magnitude depends on how revenue is recycled. The GDP impacts are positive in the reduced distorted tax scenario, however this slightly hurt the households but compensate firms with capital tax and VAT tax reductions. For recycling with lump-sum transfer to households, households are better off while slightly decline in investment. In our simulations, carbon tax at 100 yuan/tC can bring 2.4-2.9% revenue, which is a modest tax revenue sources for the government to spend on compensating negatively affected coal-mining workers, or reduce pre-existing capital and VAT taxes, or investment on low-carbon R&D technologies and etc.

In our study, we also conduct a sensitivity robust check using different AEEI assumptions, we find that our policy simulations is not sensitive to the changes in the benchmark cases due to various AEEI results, the sign and magnitudes of the policy impacts on GDP, consumption, investment and environmental performances are quite similar in all scenarios.

5. Conclusion

In this study, we used a time-series input output tables and corresponding physical energy use statistics by sector to decompose China’s sectoral energy intensities, by adopting several decomposition techniques. Then based on the energy intensity decomposition, we forecast the future energy use and carbon emissions based on various AEEI assumptions, then we compare with other studies and use a central AEEI estimate for China to conduct climate policy analysis. The main results of this study may be summarized as follows.

First, during 80s and 90s, the technological changes play a very important role in explaining the sustained decline in overall energy intensities, while structural shifts play very limited roles. In many industries, China’s productivity and technological progress are quite lower than that of developed countries, so after economic reform it is easier to catch up on the productivity frontier, so accompanying a sustained efficiency improvement within industries. However, with the improvements sustained for 20 years, after year 2000, we observe a steadily decline in the role of technology progress in energy intensity decomposition, structure shift hasn’t yet become dominant role as well. The stringent energy intensity policy after 2005 seems again revert the trend of energy intensity, but most of the efforts are mainly in the coal sector.

Second, based on our energy intensity decomposition using different decomposition techniques, we extract some useful information for specifying AEEI parameter assumptions. We use the common AEEI assumption for comparison, that is, to assume a “one-size-fits-all” parameter that assume all sectors have 1% improvement in energy efficiency improvement each year. Our studies suggest that, for transitional economy like China, such a parameter sets at 1% is neither to be accurate nor to generate trajectories of energy use and carbon emissions that are consistent with the historical trend. Thus based on our energy intensity decomposition studies focusing on the past, we can try different AEEI scenarios, then using our CGE model we can forecast the future energy use and carbon emissions. In general , our model projection range is also consistent with several other modeling groups in China, especially using the low AEEI parameter at 1.7%. These carbon emission and low-carbon pathway studies are conducted by Tsinghua Zhang Xiliang’s group, ERI’s modeling group, and Renmin University Zouji’s modeling group. Though all three are based on bottom-up technology models, similar to MARCO model, our projections are linking historical energy intensity decomposition to derive AEEI parameters then using a top-down CGE model to simulate for future carbon emission trends.

Third, based on the different AEEI estimates and different energy use and carbon emission projections, we use a recursive CGE model to analyze the economy-wide impacts of two alternative policies: 1) an existing command-and-control policy used widely in the 11th Five Year Plan, FGD policy in the electricity sector and shutdown policy for small-scale power plant; 2) a carbon tax of 100 yuan/tC imposed on fossil fuel uses with two different revenue recycling regimes. Our model shows that, the assumptions on future energy use and carbon emissions only slightly affect the model results, however in general the sign and magnitude of policy effects hold in all the simulations. Thus the changes in the projections of base case model will only bring second order bias, thus we can trust the robustness of the CGE model on policy analysis even with various AEEI parameter assumptions.

Finally, by comparing the command-and-control policies and carbon tax, we found that carbon tax is more cost-effective in terms of reducing a wide range of pollutants, while command-and-control technology mandates usually only impose big cuts in one pollutants. Our model shows that a technology mandates will bring negative macro costs, however sometimes command and control policies such as shutting down inefficient small-scale power plants and replaced with big-scale efficient power plants, can bring both economic and environmental effects, such a policy can correct the myopia investment distortions and market failures. Although in both command and control policies, no revenue can be utilized for reducing other distortions, for example fiscal distortions in the pre-existing world or R&D investment on low-carbon technologies. In addition, our experiments show that carbon tax is more efficient in carbon emissions, and has great potential to bring other co-benefits in public health damages. Thus, in general it is superior than the command-and-control policies if we take into account both economic and environmental net benefits, and can be applied to reconcile both local environmental protection and climate change challenges.

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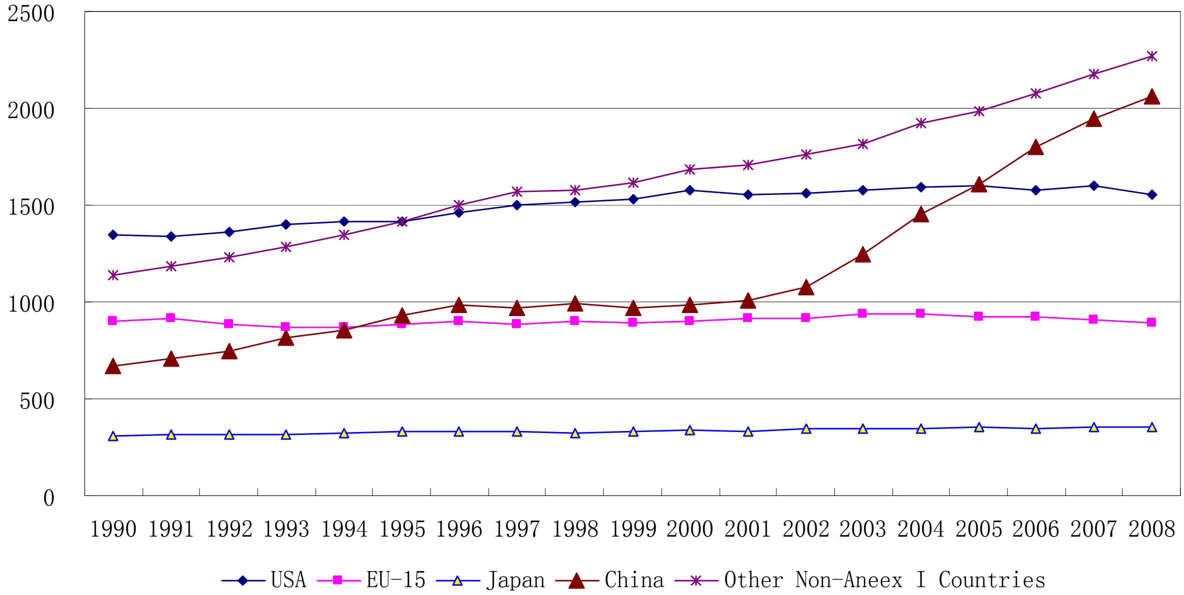
Figure 1. CO_2 emissions from Fossil Fuel Use and Cement Production in Major Countries from 1990 to 2008

(in million tons of carbon)

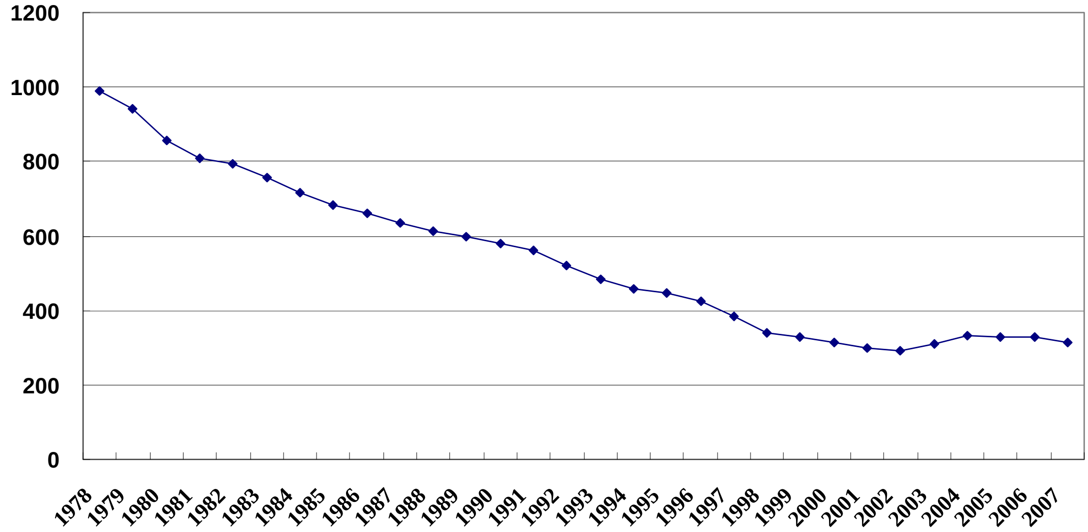


Source: EDGAR 4.0 (JRC/PBL, 2009) (1990-2005); Energie/energy: IEA, 2008 (1990-2006); BP, 2009 (2006-2008 trend);

Figure 2. China's Energy Intensity and Carbon Intensity, 1978-2007

A) Energy Intensity

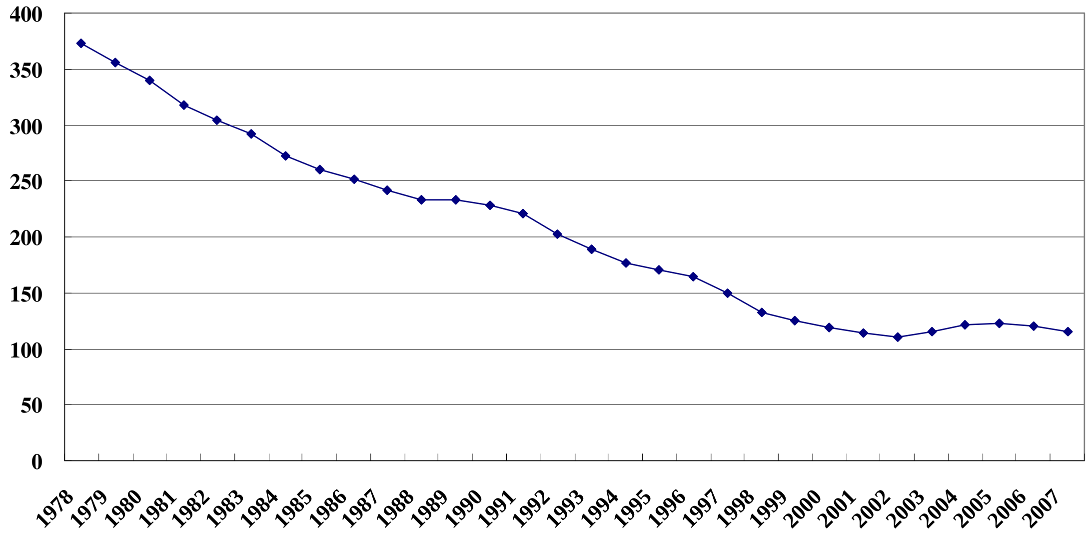
(measured in kg coal equivalent/thousand 2005 *yuan*)



Sources: Sinton (2005) *China Energy Databook* (version 6) and *China Energy Statistical Yearbook*; *Data of Gross Domestic Product of China: 1952-2004*, and *China Statistical Abstract: 2007* (GDP data reflects the national revision in 2006). Note: energy consumption here only include commercial energy and excludes biomass and firewood.

B) Carbon Intenstiy

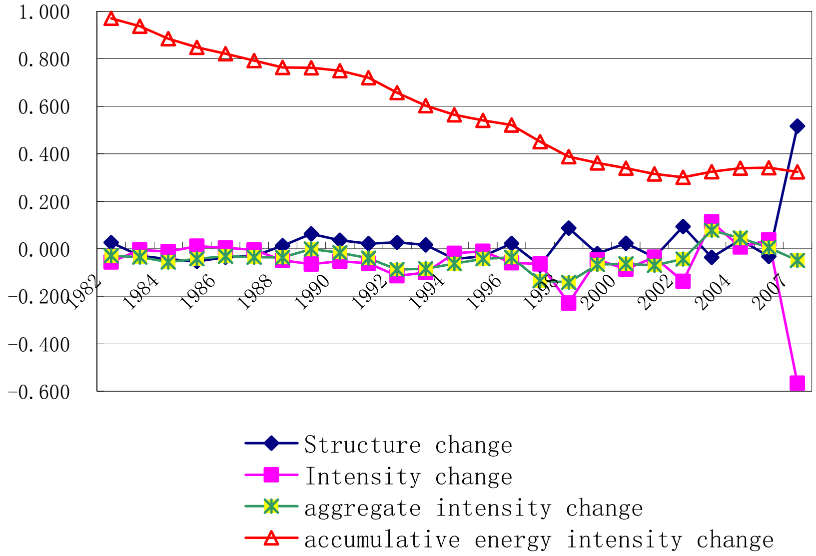
(Measured in tons of carbon dioxide per thousand 2005 *yuan*)



Sources: carbon emission data is collected from ERI, NDRC, originally based on IEA estimates.

Figure 3. Contribution of Structural Change (Φ^*) and Intensity Change (Ψ^*) to Change in Aggregate Energy Intensity in Coal Sector $d\ln\left(\frac{E_t^*}{Y_t^*}\right)$, (1981-2007)

A) Coal



B) Crude Oil and Natural Gas

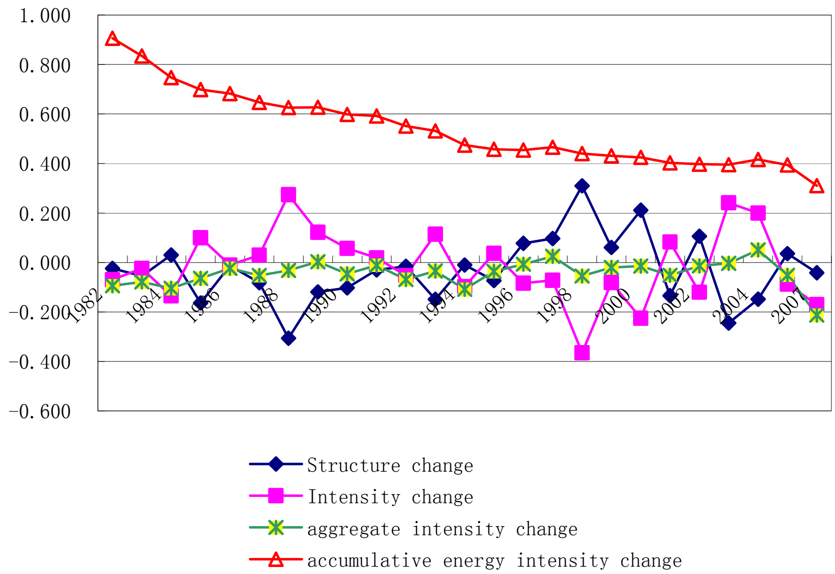


Figure 4. Effects of Changing Industrial Composition by Sectors (Φ^*_j), (1981-2007, Coal Use)

(percent change from 1981 level)

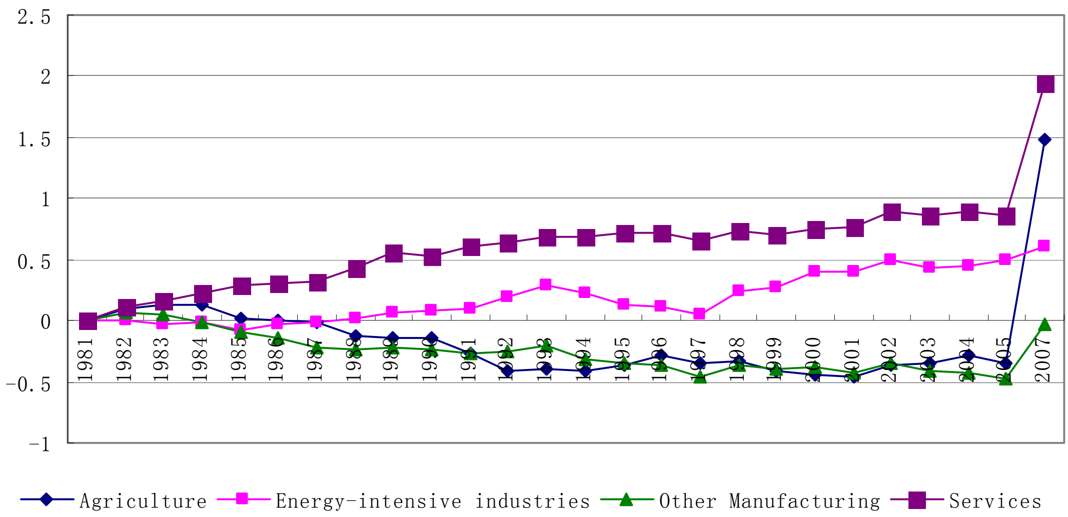


Figure 5. Within Industry Energy Intensity Change (Ψ^*_j), (1981-2007, Coal Use)

(percent change from 1981 level)

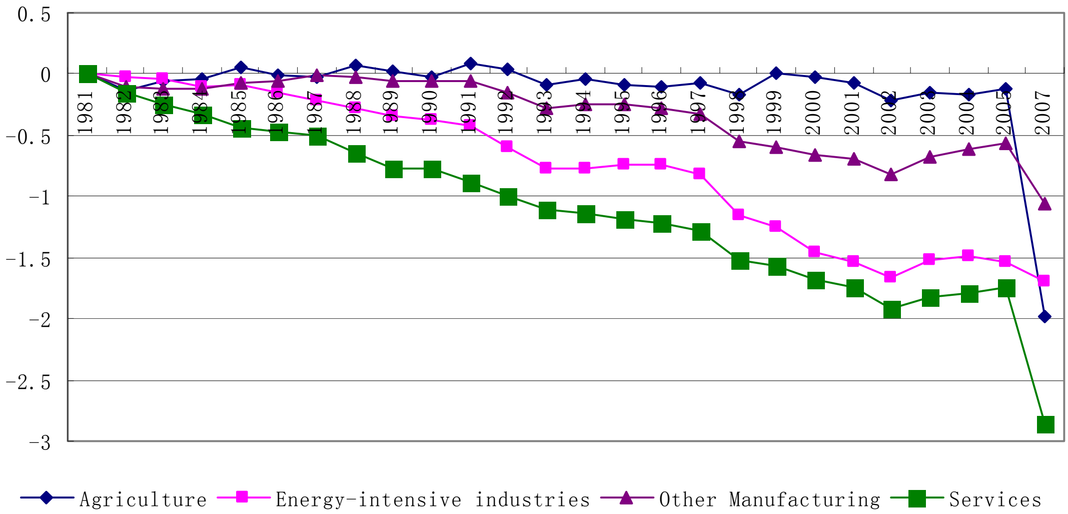
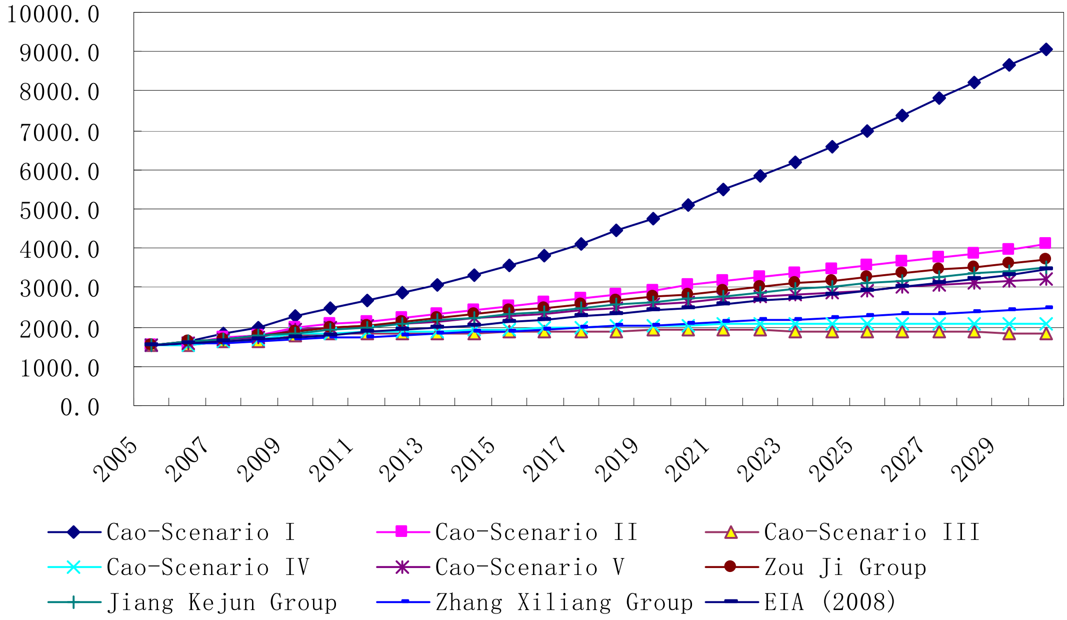


Figure 6. Range of Uncertainties in Model Projections (Carbon Emission Forecasts)



Carbon Emissions (in Million tC)

Figure 7. GDP, Energy and Emissions Projected in the Base Case (Scenario VI)

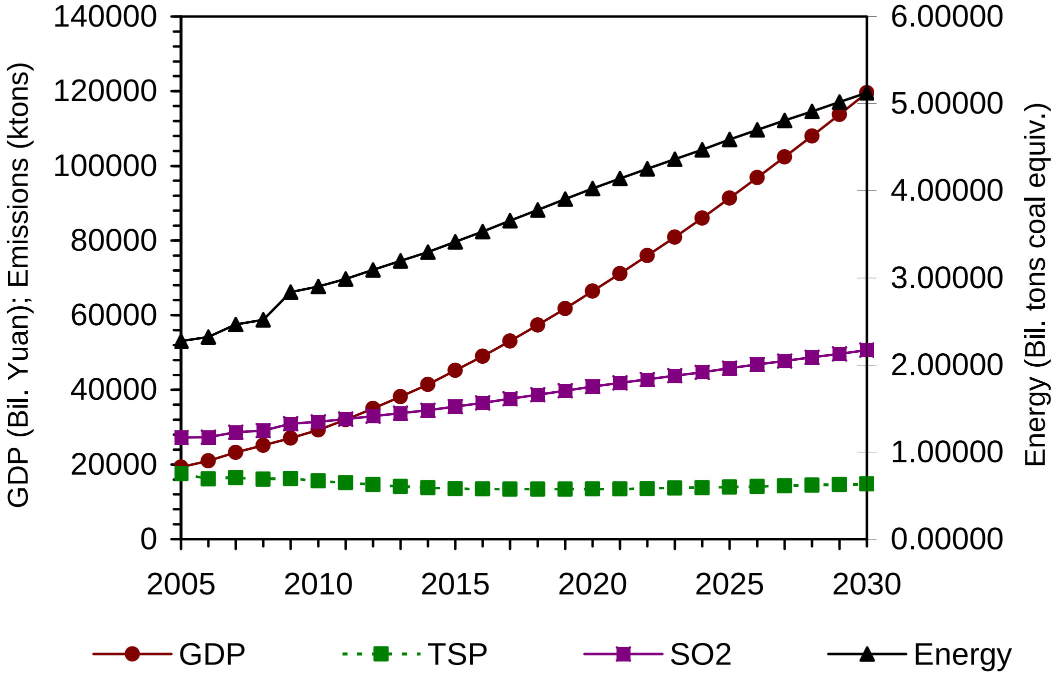


Table 1 Domestic Output of Energy Sectors (1981-2005)

	Primary Energy				Secondary Energy		
	Coal	Crude Petroleum	Natural Gas	Hydro-electricity	Total Electricity	Refined Petroleum	GDP* (bil. 2000
Year	**(mil.sce)**	**(mil.sce)**	**(mil.sce)**	**(Twh)**	**(Twh)**	**(mil. sce)**	***yuan*)**
1981	432.2	118.9	16.9	65.6	309.3	105.8	1613.0
1982	457.4	117.3	15.9	74.4	327.7	106.8	1759.8
1983	490.0	119.5	16.2	86.4	351.4	113.9	1951.6
1984	533.9	123.4	16.5	86.8	377.0	117.0	2248.2
1985	581.2	131.1	17.2	92.4	410.7	121.1	2551.7
1986	612.8	139.1	18.3	94.5	449.5	130.2	2776.3
1987	660.1	147.3	18.5	100.0	497.3	137.2	3098.3
1988	708.6	159.0	19.0	109.2	545.2	143.6	3448.4
1989	736.7	165.8	20.0	118.4	584.8	149.8	3589.8
1990	752.1	163.8	20.3	126.7	621.2	152.4	3726.2
1991	789.8	177.5	21.4	125.1	677.6	162.2	4069.1
1992	826.4	191.0	21.0	132.5	753.9	171.9	4646.9
1993	866.5	211.1	22.3	151.8	837.3	182.3	5297.4
1994	920.5	213.6	23.4	167.4	928.1	183.5	5991.4
1995	978.6	229.6	23.9	190.6	1007.7	199.1	6644.5
1996	1037.9	250.1	26.8	188.0	1080.0	212.4	7308.9
1997	988.0	281.1	30.2	196.0	1134.5	231.9	7988.6
1998	920.2	284.3	31.0	208.0	1166.2	232.5	8611.7
1999	924.8	302.5	29.0	203.8	1239.3	251.3	9266.2
2000	939.4	321.4	32.0	222.4	1355.6	279.8	10044.6
2001	955.1	327.9	36.3	277.4	1480.8	282.8	10958.7
2002	1006.4	355.2	39.2	288.0	1654.0	295.6	12054.5
2003	1196.9	388.5	44.1	283.7	1910.6	326.9	13272.0
2004	1381.9	453.2	51.9	353.5	2203.3	379.3	14652.3
2005	1552.6	471.8	61.6	397.0	2500.3	398.3	16381.3
Growth (81-05)	*5.47%*	*5.91%*	*5.53%*	*7.79%*	*9.10%*	*5.68%*	*10.14%*
Growth (81-00)	*4.17%*	*5.37%*	*3.40%*	*6.64%*	*8.09%*	*5.25%*	*10.10%*
Growth (00-05)	*10.57%*	*7.98%*	*14.01%*	*12.29%*	*13.02%*	*7.32%*	*10.28%*

Sources: Chinese Statistical Yearbook, Chinese Energy Yearbook, and author's calculations.
GDP*: computed from our time-series input-output table,so there is some discrepancies compared with the official NBS yearbook statistics.
Sce: standard coal equivalent.

Table 2 Decomposition of Change in Energy Use per Unit of GDP (SDA Method)

A) Coal

Type of Energy	Overall Change per yuan of GDP	Of which: Technical Change	Change in Demand Patterns	Change in Import Patterns	Change in Quantity of Imports	Change in Quantity of Exports	Residual
Coal Pre-2000							
1981-1982	0.1237	0.1301	0.0153	-0.0029	-0.0013	-0.0049	-0.0127
1982-1983	-0.0043	-0.0485	0.0472	0.0136	0.0003	0.0040	-0.0209
1983-1984	-0.0926	-0.0849	-0.0180	0.0297	-0.0011	-0.0058	-0.0125
1984-1985	-0.1679	-0.1875	0.0045	0.0445	-0.0099	-0.0087	-0.0109
1985-1986	-0.0473	-0.0625	-0.0004	-0.0081	0.0039	-0.0107	0.0305
1986-1987	-0.0834	-0.0876	-0.0345	-0.0048	0.0002	0.0017	0.0416
1987-1988	0.0734	0.0454	0.0298	-0.0098	-0.0007	-0.0044	0.0130
1988-1989	0.1578	0.1288	0.0598	0.0027	-0.0030	0.0064	-0.0369
1989-1990	-0.0302	0.0503	-0.0289	0.0161	-0.0007	-0.0182	-0.0487
1990-1991	-0.0590	-0.0291	-0.0206	0.0044	0.0036	-0.0088	-0.0085
1991-1992	-0.1021	-0.0885	-0.0176	0.0168	-0.0016	-0.0120	0.0008
1992-1993	0.1138	0.1185	0.0138	-0.0045	0.0036	0.0246	-0.0422
1993-1994	-0.1096	0.0274	-0.0934	0.0314	-0.0022	-0.0122	-0.0606
1994-1995	0.0206	0.0348	-0.0006	-0.0225	-0.0005	0.0027	0.0067
1995-1996	0.1472	0.1563	0.0279	-0.0085	-0.0052	-0.0003	-0.0231
1996-1997	-0.0578	-0.0093	-0.0606	-0.0178	0.0066	-0.0002	0.0234
1997-1998	0.0121	-0.0544	0.0704	-0.0138	0.0009	0.0013	0.0077
1998-1999	-0.1210	-0.0645	-0.0545	0.0164	0.0002	-0.0010	-0.0177
Post-2000							
2000-2001	-0.0659	-0.0318	-0.0141	0.0053	0.0005	-0.0228	-0.0030
2001-2002	0.0142	-0.0739	0.1057	-0.0231	0.0060	0.0033	-0.0039
2002-2003	0.0585	0.2064	-0.1236	-0.0617	0.0005	-0.0022	0.0390
2003-2004	0.0613	0.1612	0.0856	-0.0602	0.0083	-0.0109	-0.1227
2004-2005	0.0962	0.1521	-0.0364	-0.0092	0.0057	0.0013	-0.0174
2005-2007	-0.1391	-0.2615	-0.1225	0.0552	0.0078	0.0012	0.1806

B) Crude Petroleum and Gas

Of which:

Type of Energy	Overall Change per yuan of GDP	Technical Change	Change in Demand Patterns	Change in Import Patterns	Change in Quantity of Imports	Change in Quantity of Exports	Residual
Crude Petroleum and Gas							
Pre-2000							
1981-1982	-0.0585	-0.0762	-0.0286	-0.0083	0.0000	-0.0076	0.0622
1982-1983	-0.0954	-0.0550	-0.0180	0.0071	0.0000	-0.0274	-0.0022
1983-1984	0.0393	0.1213	0.0298	0.0273	0.0000	-0.0698	-0.0693
1984-1985	-0.4092	-0.2353	-0.1600	0.0500	0.0000	-0.0121	-0.0519
1985-1986	0.0192	-0.0235	-0.0080	-0.0024	0.0000	0.0599	-0.0069
1986-1987	-0.0517	-0.0024	-0.1157	-0.0033	0.0000	0.0780	-0.0083
1987-1988	-0.0679	-0.1213	-0.0638	0.0083	0.0000	0.0585	0.0504
1988-1989	0.0897	0.0495	0.0486	0.0095	-0.0041	0.0158	-0.0298
1989-1990	0.0427	0.0750	0.0818	0.0477	-0.0173	-0.0474	-0.0972
1990-1991	0.0977	0.0300	0.0657	0.0553	-0.0491	0.0109	-0.0150
1991-1992	0.0600	0.1311	-0.0373	0.0391	-0.0556	0.0042	-0.0215
1992-1993	0.1472	0.2754	-0.0776	-0.0141	-0.0129	0.0201	-0.0437
1993-1994	0.0757	0.1858	-0.0077	0.0886	-0.0708	-0.0075	-0.1126
1994-1995	-0.0964	-0.1805	0.0320	0.0158	-0.0245	-0.0134	0.0741
1995-1996	-0.0240	-0.1175	0.0448	-0.0536	0.0340	-0.0128	0.0812
1996-1997	0.0459	0.0997	0.0238	0.0477	-0.0514	-0.0404	-0.0335
1997-1998	0.4860	0.5364	0.1083	-0.0935	0.0490	0.0332	-0.1474
1998-1999	0.0668	0.1130	-0.0162	0.0324	-0.0205	0.0151	-0.0570
Post-2000							
2000-2001	-0.1225	-0.0245	-0.1519	0.0893	-0.0383	0.0145	-0.0117
2001-2002	-0.0684	-0.0376	0.0017	-0.0030	-0.0121	0.0017	-0.0191
2002-2003	0.1377	0.1621	0.0754	-0.2177	0.1604	-0.0039	-0.0386
2003-2004	0.1174	0.1175	0.0556	-0.2112	0.1541	0.0050	-0.0036
2004-2005	0.1391	0.1145	-0.0078	-0.0568	0.0865	-0.0110	0.0137
2005-2007	0.2729	0.2032	-0.1082	0.0301	0.1612	0.0039	-0.0173

C) Hydroelectricity

Type of Energy	Overall Change per yuan of GDP	Of which: Technical Change	Change in Demand Patterns	Change in Import Patterns	Change in Quantity of Imports	Change in Quantity of Exports	Residual
Hydroelectricity Pre-2000							
1981-1982	0.0499	0.1277	-0.0624	-0.0047	0.0000	0.0000	-0.0107
1982-1983	0.0390	0.0405	0.0281	0.0155	0.0000	0.0000	-0.0452
1983-1984	-0.2041	-0.2133	-0.0352	0.0368	0.0000	0.0000	0.0076
1984-1985	-0.1059	-0.1336	0.0377	0.0486	0.0000	0.0000	-0.0587
1985-1986	-0.1435	-0.2078	-0.0089	-0.0036	0.0000	0.0000	0.0767
1986-1987	-0.0555	-0.0735	-0.0162	-0.0039	0.0000	0.0000	0.0382
1987-1988	-0.0443	-0.1124	0.0119	-0.0161	0.0000	0.0000	0.0723
1988-1989	0.1336	0.1731	0.0073	-0.0009	0.0000	0.0000	-0.0458
1989-1990	0.0945	0.2118	-0.0291	0.0211	0.0000	0.0000	-0.1093
1990-1991	-0.0584	-0.0477	-0.0064	0.0141	0.0000	0.0000	-0.0184
1991-1992	-0.0191	0.0008	0.0021	0.0241	0.0000	0.0000	-0.0460
1992-1993	0.0205	0.0234	0.0246	-0.0032	0.0000	0.0000	-0.0243
1993-1994	0.0652	0.1306	-0.0251	0.0398	0.0000	0.0000	-0.0801
1994-1995	0.0526	0.0508	0.0233	-0.0274	0.0000	0.0000	0.0059
1995-1996	-0.0557	-0.1061	-0.0043	-0.0162	0.0000	0.0000	0.0709
1996-1997	0.0472	0.0458	0.0079	-0.0134	0.0000	0.0000	0.0069
1997-1998	0.3030	0.4625	0.0175	-0.0131	0.0000	0.0000	-0.1640
1998-1999	-0.1031	-0.1980	0.0733	0.0197	0.0000	0.0000	0.0020
Post-2000							
2000-2001	0.1151	0.1385	-0.0274	0.0046	0.0000	0.0000	-0.0007
2001-2002	-0.0948	-0.0762	-0.0051	-0.0174	0.0000	0.0000	0.0039
2002-2003	0.0819	0.0087	0.1410	-0.0615	0.0000	0.0000	-0.0064
2003-2004	0.2990	0.2754	0.0815	-0.0479	0.0000	0.0000	-0.0100
2004-2005	-0.0504	-0.0207	-0.0151	-0.0061	0.0000	0.0000	-0.0084
2005-2007	-0.2630	-0.2067	-0.1546	0.0491	0.0000	0.0000	0.0491

D) Electricity Power (non-hydro)

Of which:

Type of Energy	Overall Change per yuan of GDP	Technical Change	Change in Demand Patterns	Change in Import Patterns	Change in Quantity of Imports	Change in Quantity of Exports	Residual
Electricity Power (non-hydro)							
Pre-2000							
1981-1982	0.2012	0.2433	0.0137	-0.0055	-0.0004	-0.0309	-0.0191
1982-1983	-0.0267	-0.0056	-0.0108	0.0093	-0.0014	0.0042	-0.0223
1983-1984	-0.0374	0.0557	-0.0538	0.0274	-0.0053	-0.0192	-0.0422
1984-1985	-0.4301	-0.4095	-0.0602	0.0679	-0.0409	-0.0206	0.0333
1985-1986	0.0305	0.0882	0.0063	0.0014	-0.0050	0.0110	-0.0715
1986-1987	-0.1782	-0.1408	-0.0647	-0.0025	-0.0048	0.0018	0.0330
1987-1988	0.0543	-0.0539	0.0031	0.0331	-0.0490	0.0185	0.1026
1988-1989	0.0854	0.0521	0.0627	0.0092	-0.0066	0.0033	-0.0353
1989-1990	0.0578	-0.0612	0.1544	0.0458	-0.0408	-0.0270	-0.0135
1990-1991	0.1813	0.1340	0.0835	0.0163	-0.0234	-0.0066	-0.0224
1991-1992	-0.0825	-0.0228	-0.0608	-0.0191	0.0177	0.0003	0.0021
1992-1993	0.1704	0.2632	-0.0412	-0.0042	-0.0062	0.0204	-0.0616
1993-1994	-0.0922	0.0379	-0.0768	0.0160	0.0041	-0.0203	-0.0530
1994-1995	-0.0064	-0.0173	-0.0022	0.0039	-0.0295	0.0017	0.0370
1995-1996	-0.0250	-0.0801	0.0226	0.0007	-0.0178	-0.0063	0.0559
1996-1997	0.0368	0.0714	-0.0168	0.0126	-0.0291	-0.0145	0.0132
1997-1998	0.3179	0.4482	0.0388	-0.0532	0.0366	0.0097	-0.1624
1998-1999	0.0541	0.1269	-0.0287	0.0194	-0.0077	-0.0027	-0.0531
Post-2000							
2000-2001	-0.0784	0.0016	-0.0873	0.0180	-0.0088	-0.0007	-0.0013
2001-2002	0.0092	0.0017	0.0144	-0.0586	0.0540	0.0000	-0.0024
2002-2003	0.0796	0.1574	0.0776	-0.0722	0.0134	-0.0205	-0.0760
2003-2004	0.0991	0.0964	0.0894	-0.0920	0.0492	-0.0148	-0.0292
2004-2005	0.1075	0.1369	-0.0209	-0.0169	0.0237	-0.0127	-0.0026
2005-2007	0.1853	0.0920	-0.0668	0.0768	0.0002	-0.0011	0.0842

E) Refined Petroleum

Of which:

Type of Energy	Overall Change per yuan of GDP	Technical Change	Change in Demand Patterns	Change in Import Patterns	Change in Quantity of Imports	Change in Quantity of Exports	Residual
Refined Petroleum							
Pre-2000							
1981-1982	-0.0310	0.0271	-0.0623	-0.0047	-0.0005	0.0000	0.0093
1982-1983	-0.0345	-0.0518	0.0281	0.0155	-0.0002	0.0000	-0.0260
1983-1984	-0.1631	-0.1604	-0.0351	0.0367	-0.0005	0.0000	-0.0038
1984-1985	-0.0767	-0.0978	0.0376	0.0484	-0.0041	0.0000	-0.0608
1985-1986	-0.0660	-0.0962	-0.0088	-0.0035	0.0001	0.0001	0.0423
1986-1987	-0.0031	0.0080	-0.0162	-0.0039	0.0000	0.0000	0.0090
1987-1988	-0.0389	-0.1048	0.0119	-0.0161	0.0000	0.0000	0.0702
1988-1989	0.1210	0.1560	0.0073	-0.0009	0.0000	0.0000	-0.0413
1989-1990	0.0847	0.1981	-0.0291	0.0211	0.0000	0.0000	-0.1055
1990-1991	0.0205	0.0665	-0.0064	0.0141	0.0000	0.0000	-0.0537
1991-1992	0.0289	0.0726	0.0021	0.0241	0.0000	0.0000	-0.0699
1992-1993	0.0041	-0.0014	0.0246	-0.0032	0.0000	0.0000	-0.0159
1993-1994	0.0666	0.1328	-0.0251	0.0398	0.0000	0.0000	-0.0809
1994-1995	-0.0013	-0.0335	0.0233	-0.0274	0.0000	0.0000	0.0363
1995-1996	0.0278	0.0205	-0.0043	-0.0162	0.0000	0.0000	0.0277
1996-1997	0.0440	0.0571	0.0080	-0.0135	0.0000	0.0000	-0.0077
1997-1998	0.2702	0.4145	0.0176	-0.0132	0.0000	0.0002	-0.1490
1998-1999	0.0139	-0.0242	0.0739	0.0198	0.0000	-0.0017	-0.0538
Post-2000							
2000-2001	-0.0185	0.0045	-0.0275	0.0046	0.0000	-0.0007	0.0006
2001-2002	-0.0213	-0.0002	-0.0051	-0.0175	0.0002	0.0002	0.0012
2002-2003	0.2419	0.1664	0.1416	-0.0617	0.0002	-0.0002	-0.0045
2003-2004	0.2216	0.1973	0.0816	-0.0480	0.0001	0.0006	-0.0101
2004-2005	-0.0428	-0.0187	-0.0151	-0.0061	0.0004	-0.0004	-0.0029
2005-2007	0.1865	0.2491	-0.1540	0.0490	-0.0002	-0.0003	0.0429

Note: change in import pattern and change in quantity of export are calculated as $\sum_i \frac{1}{2}(w_{i,t-1}\frac{\gamma_{it}^m}{\gamma_{i,t-1}} + w_{it}\frac{\gamma_{it}^m}{\gamma_{it}})\ln\frac{\gamma_{it}^m}{\gamma_{i,t-1}^m}$ and $\frac{1}{2}(w_{j,t-1}^e + w_{jt}^e)\frac{e_{jt}}{e_{j,t-1}}$, respectively.

Table 3 Decomposition of Change in Energy Use per Unit of GDP (IDA Method)

	Energy intensity change	Technical Change	Structural Change	Residual	Energy intensity change	Technical Change	Structural Change	Residual	Energy intensity change	Technical Change	Structural Change	Residual
	Coal				Crude Petroleum				Refined Petroleum			
1981-1982	0.108	1.236	-1.128	-0.001	-0.030	0.150	-0.184	0.004	0.238	0.654	-0.416	0.000
1982-1983	-0.042	-1.124	1.083	0.000	-0.064	-0.126	0.061	0.000	-0.009	-0.537	0.528	0.000
1983-1984	-0.115	-0.108	-0.006	0.000	0.059	0.195	-0.136	0.000	0.009	-0.029	0.038	0.000
1984-1985	-0.197	-0.319	0.122	0.000	-0.321	-0.116	-0.204	-0.001	-0.352	-0.382	0.029	0.001
1985-1986	-0.043	0.068	-0.111	0.000	-0.043	0.534	-0.577	0.000	0.069	0.072	-0.003	0.000
1986-1987	-0.074	0.109	-0.163	-0.020	-0.058	0.100	-0.058	-0.099	-0.129	-0.071	-0.056	-0.002
1987-1988	0.086	0.055	0.027	0.005	-0.079	-0.019	-0.016	-0.044	-0.022	-0.027	0.004	0.002
1088-1989	0.129	-0.075	0.204	0.000	0.073	-0.230	0.303	0.000	0.032	-0.048	0.080	0.000
1989-1990	0.000	-0.063	0.062	0.000	0.097	-0.391	0.488	0.000	-0.080	-0.130	0.049	0.000
1990-1991	-0.036	0.106	-0.142	0.000	0.075	-0.067	0.141	0.000	0.105	0.131	-0.026	0.000
1991-1992	-0.098	-0.005	-0.093	0.000	0.052	0.245	-0.193	0.000	-0.041	-0.013	-0.028	0.000
1992-1993	0.128	0.182	-0.059	0.005	0.201	0.483	-0.281	-0.001	0.237	0.276	-0.051	0.013
1993-1994	-0.033	-0.097	0.035	0.028	0.050	0.109	-0.063	0.004	-0.051	-0.043	-0.013	0.005
1994-1995	0.038	0.086	-0.047	0.000	-0.143	-0.164	0.022	0.000	0.009	0.075	-0.066	0.000
1995-1996	0.150	0.230	-0.080	0.000	-0.068	-0.133	0.065	0.000	-0.037	-0.055	0.018	0.000
1996-1997	0.010	0.083	-0.073	0.000	0.069	0.081	-0.012	0.000	0.075	0.080	-0.005	0.000
1997-1998	-0.041	0.628	-0.669	0.000	0.494	1.053	-0.558	-0.001	0.334	0.699	-0.364	0.000
1998-1999	-0.057	-1.015	0.958	0.000	0.061	0.090	-0.028	0.000	0.067	-0.295	0.363	0.000
2000-2001	-0.045	0.075	-0.121	0.000	-0.087	0.871	-0.958	0.000	-0.004	0.023	-0.027	0.000
2001-2002	-0.083	-0.023	-0.050	-0.010	-0.080	-0.027	-0.004	-0.049	0.013	0.000	0.011	0.002
2002-2003	0.256	0.051	0.205	0.000	0.129	-0.610	0.738	0.000	0.155	0.146	0.009	0.000
2003-2004	0.173	-0.089	0.257	0.005	0.111	-0.320	0.430	0.001	0.093	-0.134	0.224	0.003
2004-2005	0.123	0.210	-0.096	0.008	0.129	-0.043	0.154	0.017	0.126	0.114	-0.009	0.021
2005-2007	-0.240	0.502	-0.818	0.076	0.189	0.929	-0.788	0.048	0.122	0.396	-0.364	0.090

	Energy intensity change	Technical Change	Structural Change	Residual	Energy intensity change	Technical Change	Structural Change	Residual
			Electricity Utilities				Gas Utility	
1981-1982	0.019	1.032	-1.012	-0.001	0.014	0.937	-0.921	-0.001
1982-1983	-0.037	-1.215	1.178	0.000	-0.036	-1.087	1.051	0.000
1983-1984	-0.146	-0.297	0.151	0.000	-0.112	-0.244	0.132	0.000
1984-1985	-0.093	-0.187	0.093	0.000	0.156	0.067	0.089	0.000
1985-1986	-0.054	-0.057	0.003	0.000	0.035	0.031	0.005	0.000
1986-1987	0.017	0.046	-0.028	-0.002	-0.019	0.001	-0.019	-0.001
1987-1988	-0.032	-0.118	0.086	0.000	0.163	0.088	0.073	0.002
1088-1989	0.115	0.004	0.111	0.000	0.119	0.004	0.115	0.000
1989-1990	0.086	0.079	0.007	0.000	0.097	0.096	0.001	0.000
1990-1991	0.037	0.011	0.025	0.000	0.058	0.037	0.021	0.000
1991-1992	0.033	0.065	-0.032	0.000	-0.057	-0.061	0.003	0.000
1992-1993	0.036	0.113	-0.080	0.003	0.146	0.191	-0.051	0.006
1993-1994	0.020	-0.051	0.065	0.005	-0.155	-0.205	0.053	-0.002
1994-1995	-0.009	0.085	-0.094	0.000	-0.044	0.050	-0.094	0.000
1995-1996	0.042	0.010	0.032	0.000	0.060	0.027	0.033	0.000
1996-1997	0.059	0.083	-0.024	0.000	0.066	0.060	0.006	0.000
1997-1998	0.284	0.736	-0.452	0.000	0.201	0.656	-0.456	0.000
1998-1999	-0.041	-0.383	0.342	0.000	0.021	-0.341	0.362	0.000
2000-2001	0.007	-0.026	0.033	0.000	0.006	0.016	-0.010	0.000
2001-2002	0.010	0.006	0.003	0.001	-0.013	-0.045	0.028	0.004
2002-2003	0.197	0.231	-0.034	0.000	0.111	0.017	0.094	0.000
2003-2004	0.238	-0.059	0.282	0.016	0.137	-0.038	0.174	0.001
2004-2005	-0.019	-0.024	0.002	0.003	0.068	0.060	0.001	0.007
2005-2007	0.275	0.886	-0.534	-0.077	0.274	0.538	-0.441	0.177

Table 4. Experiments with the CGE Model AEEI Scenarios

Scenarios	Growth Rate of AEEI
I	No AEEI improvements
II	1 percent per year
III	Average Annual rate of overall energy intensity change ($\Phi^{*}+\Psi^{*}$) =0.0476, 1981-2007
IV	Average Annual rate of overall energy intensity change ($\Phi^{*}+\Psi^{*}$) =0.0229, 2000-2007
V	Average Annual rate of overall energy intensity change ($\Phi^{*}+\Psi^{*}$) =0.0177, 2000-2005

Table 5. Pollution Impact Pathway and Analysis.

1	Economic activity and fossil fuel use to pollutant emissions
2	Emissions to concentrations
3	Concentrations to human exposures
4	Exposures to health impacts
5	Valuation of health impacts
6	Marginal damages by industry and fuel type
7	Benefit-cost analysis of Command-and-Control and Energy Taxes based on marginal damages

Table 6. Estimates of the Value of a Statistical Life in Chinese Studies

Study	***Million Yuan***
Wang and Mullahy (2006)	0.3-1.25
Zhang Xiao (2002)	0.24-1.7
Hammitt and Zhou (2005)	0.26-0.51
Krupnick et al. (2006)	1.4

Source: World Bank (2007)

Table 7. SO_2 Emissions Targets for 11th Five Year Plan

	2005	2010 BAU Baseline		2010 Target		
	mil. tons	mil. tons	Change from 2005	mil. tons	Change from 2005	Change from BAU
Power Sector	13.3	18	+35%	10	-25%	-44%
All Other Sectors	12.2	13	+6%	13	+6%	0%
Total	**25.5**	**31**	**+19%**	**23**	**-10%**	**-26%**

Source: JES (2007).

Table 8: Cost Structure for Thermal Power Plants, 2005 (yuan/kWh)

	Large	Small Plants		
Costs	**Plants**	**Total**	**Coal**	**Diesel**
Average Total Cost	0.250	0.704		
Operating & Maintenance Cost	0.057	0.068		
Fuel Costs	0.153	0.596	0.230	2.520

Source: Energy Research Institute.

Table 9. Effects of Environmental Policies on Economy and Environment Performance (in percentage)

	Assumption: Reform Starts in 2006 and Effects in Year 2010				
	C&C - FGD Policy	**C&C - Shutdown Policy**	**C&C - combined Policy**	**Carbon Tax with lump sum transfer (100 Yuan/tC)**	**Carbon Tax with reduced distorted tax (100 Yuan/tC)**
GDP	-0.100	0.732	0.656	-0.129	0.025
Consumption	-0.094	0.479	0.436	0.169	-0.086
Investment	-0.083	1.114	1.137	-0.162	0.379
Coal Use	-0.159	-5.478	-5.558	-14.402	-14.167
Oil Use	-0.062	-0.447	-0.475	-2.577	-2.368
CO_2 Emissions	-0.143	-4.567	-4.638	-12.199	-11.970
Primary TSP from Combustion	-0.138	-1.057	-1.162	-12.458	-12.381
SO_2 Emissions	-9.184	-16.096	-16.164	-13.077	-12.884
NO_x Emissions (Transportation)	-0.080	0.353	0.313	-2.231	-1.931
Premature Deaths	-4.234	-6.784	-6.891	-11.482	-11.657
Value of Health Damages	-3.943	-5.718	-6.277	-11.763	-11.574
Change in Other Tax Rates	0.000	0.000	0.000	0.000	3.030
Reduction in Damages/GDP	-0.002	-0.0021	-0.002	-0.004	-0.004
Pollution tax/Total tax revenue	0.000	0.000	0.000	2.390	2.880

Appendix Table A1. Gross Output, Factor Input and Energy Use by Sector (2005)

Sector	Output bil. Yuan	Capital Input bil. Yuan	Labor input bil. Yuan	Energy input bil. Yuan	Non-energy input bil.Yuan	Energy in million tce
Agriculture	2491.6	133.2	2176.2	100.1	1535.6	64.2
Coal mining	253.5	212.7	126.6	143.1	383.0	106.1
Metal & nonm. mining	335.5	131.3	47.7	104.4	270.9	50.9
Oil and gas extraction	578.3	387.5	41.4	170.5	133.3	45.6
Construction	2202.5	533.2	555.1	140.9	3027.2	66.2
Food products	1612.8	587.3	154.4	53.7	1801.7	35.6
Textile mill products	1045.4	209.0	132.0	62.7	1197.9	43.5
Apparel	448.2	93.3	85.1	10.2	523.8	5.9
Lumber and wood	100.8	31.4	25.1	15.5	169.8	11.7
Furniture and fixtures	179.3	60.4	25.1	13.3	257.4	10.0
Paper and allied	306.3	94.8	36.3	37.2	399.0	29.3
Printing, publishing	92.2	55.8	28.2	6.8	204.4	5.3
Chemicals	1556.9	446.7	172.4	497.6	1633.1	330.5
Petroleum, coal prod	818.3	204.0	54.4	795.4	256.1	459.3
Leather	238.9	67.2	56.9	4.8	356.8	2.8
Stone, clay, glass	999.8	287.7	137.7	255.1	845.3	267.8
Primary metal	1277.3	512.4	165.4	406.0	2126.2	412.4
Fabricated metal	535.6	147.6	78.7	62.8	734.1	43.4
Machinery, non-elect	1055.2	375.9	204.2	107.9	1725.5	85.5
Electrical machinery	2036.9	509.9	299.8	93.4	3579.2	22.8
Motor vehicles	453.4	200.7	107.2	40.0	1019.4	27.6
Transportation equip	267.8	59.3	31.2	10.2	334.8	7.0
Instruments	106.9	37.2	23.5	4.0	143.2	3.0
Rubber and plastics	565.2	156.2	79.4	45.4	783.1	17.0
Misc. manufacturing	421.1	28.1	26.9	4.9	149.1	1.8
Transportation	682.7	793.3	263.6	476.5	912.4	147.1
Communications	378.6	8.4	22.1	2.6	32.4	23.7
Electric utilities	606.6	483.9	132.4	642.5	551.2	959.5
Gas utilities	36.9	11.1	5.5	31.7	14.9	40.6
Trade	1238.6	926.8	329.3	116.7	1007.9	54.9
Finance, Insur, RE	956.8	1106.6	349.5	29.1	565.9	19.6
Other private service	2353.7	1790.7	1449.8	284.3	3755.5	152.0
Public service	543.0	82.1	436.5	52.4	859.5	23.9
Total	26776.2	10765.7	7859.9	4821.5	31289.2	3576.7