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Economic development and carbon dioxide emissions in China: Provincial panel data analysis

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ABSTRACT

This paper investigates the driving forces, emission trends and reduction potential of China's carbon dioxide (CO_2) emissions based on a provincial panel data set covering the years 1995 to 2009. A series of static and dynamic panel data models are estimated, and then an optimal forecasting model selected by out-of-sample criteria is used to forecast the emission trend and reduction potential up to 2020. The estimation results show that economic development, technology progress and industry structure are the most important factors affecting China's CO_2 emissions, while the impacts of energy consumption structure, trade openness and urbanization level are negligible. The inverted U-shaped relationship between per capita CO_2 emissions and economic development level is not strongly supported by the estimation results. The impact of capital adjustment speed is significant. Scenario simulations further show that per capita and aggregate CO_2 emissions of China will increase continuously up to 2020 under any of the three scenarios developed in this study, but the reduction potential is large.

1. Introduction

Scientific evidence overwhelmingly indicates that greenhouse gas emitted by human activity is the main cause of global warming. Stern (2007) warns that, if no action is taken to reduce emissions, the overall costs and risks of climate change will be equivalent to at least a 5% of global GDP loss each year. With progress in industrialization and urbanization, China's energy consumption and carbon dioxide (CO_2) emissions have increased rapidly in the past few years. In 2009, the total energy consumption of China reached 2.9 billion tons of standard coal, with the total CO_2 emissions reaching 7.7 billion tons.[1] As one of the largest emitters, China has become the focus of global reduction of CO_2 emissions. Thus the following questions need to be addressed. What are the main factors affecting China's CO_2 emissions? What are the emission trends for the foreseeable future? How large is the reduction potential?

Almost all of the studies on modeling and forecasting China's CO_2 emissions are based on national level time series data or industrial level cross-sectional data, and only a few of them are based on panel data models. It is widely recognized that panel data sets for economic research possess several major advantages over conventional cross-sectional or time series data sets. Panel data usually give the researchers a larger number of data points. More importantly, panel data models are able to capture the individual heterogeneity by introducing an individual specific effect term in the regression model, thus improving the estimation performance (Baltagi, 2005; Hsiao, 2003). A number of previous studies on international CO_2 emissions based on cross-country panel data models have taken advantage of panel data econometric models, such as Holtz-Eakin and Selden (1995), Tucker (1995),

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[1] The data of China's energy consumption are derived from China Energy Statistical Yearbook 2010. The data of CO_2 emissions are derived from EIA, http://www.eia.gov/environment/data.cfm.

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Schmalensee, Stoker, and Judson (1998), Lantz and Feng (2006), Maddison (2006), Aldy (2007). Most recently, Auffhammer and Carson (2008) attempt to forecast China's CO_2 emission path for the foreseeable future by using provincial panel data models, and they find evidence of underestimation in previous studies which are conducted based on time series or cross-sectional data. Their estimation results, however, are not based on a panel data set of CO_2 emissions but are based on a panel data set of waste gas emissions.

This paper investigates the driving forces, emission trends and reduction potential of China's CO_2 emissions over the next decade, based on a provincial panel data set of CO_2 emissions covering the years 1995–2009. Our results show that economic development, technology progress and industry structure are the most important factors affecting China's CO_2 emissions, while the impacts of energy consumption structure, urbanization level and trade openness are negligible. The inverted U-shaped relationship between per capita CO_2 emissions and economic development level is not strongly supported by the estimation results. The impact of capital adjustment speed on China's CO_2 emissions is significant. Scenario simulations further show that per capita and aggregate CO_2 emissions of China will increase continuously up to 2020 even with active policy interventions, but the reduction potential is large.

This paper makes two contributions to the literature on investigation of China's CO_2 emissions. First, we construct a novel provincial panel data set of CO_2 emissions covering the years 1995–2009 for China. This data set not only allows us to capture the advantages of panel models in this study, but also provides a database for future research, such as the allocation of emission rights and reduction obligations among provinces. Second, using this newly constructed panel data set, we investigate the driving forces, emission trends and reduction potential of China's CO_2 emissions based on both static and dynamic panel models. We find some interesting results that are different from previous studies.

The rest of the paper is organized as follows. Section 2 reviews existing literature briefly. In Section 3 we estimate CO_2 emissions for 29 provinces of China in detail. Section 4 focuses on the econometric model and data description. Section 5 presents the estimation results and specification search. In Section 6, we forecast per capita and aggregate CO_2 emissions up to 2020 under three different scenarios. The last section is devoted to conclusion.

2. Literature review

The existing literature on modeling and forecasting China's CO_2 emissions mainly falls into four categories from methodological perspectives. The first category is the index decomposition analysis based on national level time series data, including Ang and Pandiyan (1997), Zhang (2000), Wang, Chen & Zou (2005), Wu, Kaneko, and Matsuoka (2005), Fan, Liang, Wei & Okada (2007), Liu, Fan, Wu & Wei (2007), Feng, Hubacek & Guan (2009), Zhang, Mu, & Ning (2009) and Zhang, Mu, Ning & Song (2009), etc. A variety of index decomposition methods are used in these previous studies according to the usage of the decomposition formulations and index numbers.[2] Typically, CO_2 emissions are decomposed into population size, per capita GDP, energy intensity and carbon intensity of energy consumption, which is called Kaya Identity. Almost all of the index decomposition analyses find that energy intensity and economic activity are the main contributors to the decrease and increase of China's CO_2 emissions respectively, whereas the impact of economic structure, emission coefficient and fuel switching is much smaller.

The second category is bottom-up sector-based analysis. Typically, this method takes one year of data as the baseline and then forecast future trends by scenario simulations, based on detailed sectoral analysis. Using the method of bottom-up sector-based analysis, He, Huo, Zhang, He, An & Wang, et al. (2005) and Wang, Cai, Lu & Chen (2007) try to forecast the future trends of oil consumption and CO_2 emissions in road transport sector of China, and Wang, Wang, Lu & Chen (2007) and Cai, Wang,Wang, Zhang & Chen (2007) attempt to analyze the iron and steel industry and electricity industry, while Cai, Wang, Chen, Wang, Zhang & Lu (2008) further analyze five energy intensive industries of China (including electricity, cement, iron and steel, pulp and paper, transportation). They all find that China's energy demand and CO_2 emissions will increase continuously for the next decade, but the reduction potential of the emissions is large.

The third category is system optimization. The Energy Information Administration (EIA) of the US Department of Energy and the International Energy Agency (IEA) publish the outlook of world energy markets every year, based on World Energy Projection System and World Energy Model respectively.[3] The Energy Research Institute (ERI) of the National Development and Reform Commission of China has published a series of analyses on China's energy demand and CO_2 emissions based on a system model, i.e. the Integrated Policy Assessment Model for China (ERI, 2009; Jiang & Hu, 2006; Jiang, Masui, Morita & Matsuoka, 1999). Chen, Gao, and He (2004) also construct their own system model, MARKAL-MACRO, to analyze China's energy demand and CO_2 emissions. The main idea of systems optimization is to simulate the dynamics of the energy markets via linear or non-linear mathematical programming. Once the simulated system is constructed, researchers are able to project the energy demand and CO_2 emissions by scenario simulations. It is worth noting that, although the analyses of the system models are based on mathematical systems of equations, the parameters used in these equations are sometimes econometrically estimated using historical data.

The fourth category is the input–output analysis and the computable general equilibrium (CGE) model. Typically, both input-out analysis and CGE model are based on Social Accounting Metrics, which update every five years in China. Using the method of the input–output analysis, Fan, Liu, Wu, Tsai & Wei (2007b) and Liang, Fan & Wei (2007) find that China's energy demand and CO_2 emissions will grow exponentially even with many energy efficiency improvements, and it will be hard for China to maintain its advantage of low per capita emissions in the next 20 years. Garbaccio, Ho, and Jorgenson (1999) evaluate the possible impact of carbon taxes on China's economy based on a dynamic CGE model. They find that the use of carbon taxes can decrease CO_2

[2] Ang and Zhang (2000) provide a more comprehensive survey of the index decomposition analysis in energy and environment studies. Metcalf (2008) provides an analysis of energy intensity of the U.S. by Fisher Ideal Index, which has the property of exact decomposition.

[3] For more detailed descriptions of the system models of EIA and IEA, i.e. World Energy Projection System and World Energy Model, please refer to EIA (1997) and IEA (2007).