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# Decomposition and forecasting analysis of China's energy efficiency: An application of three-dimensional decomposition and small-sample hybrid models

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ABSTRACT

The coordinated actions of the central and the provincial governments are important in improving China's energy efficiency. This paper uses a three-dimensional decomposition model to measure the contribution of each province in improving the country's energy efficiency and a small-sample hybrid model to forecast this contribution. Empirical analysis draws the following conclusions which are useful for the central government to adjust its provincial energy-related policies. (a) There are two important areas for the Chinese government to improve its energy efficiency: adjusting the provincial economic structure and controlling the number of the small-scale private industrial enterprises; (b) Except for a few outliers, the energy efficiency growth rates of the northern provinces are higher than those of the southern provinces; provinces with high growth rates tend to converge geographically; (c) With regard to the energy sustainable development level, Beijing, Tianjin, Jiangxi, and Shaanxi are the best performers and Heilongjiang, Shanxi, Shanghai, and Guizhou are the worst performers; (d) By 2020, China's energy efficiency may reach 24.75 thousand yuan per ton of standard coal; as well as (e) Three development scenarios are designed to forecast China's energy consumption in 2012–2020.



## 1. Introduction

Energy efficiency improvement has become one of the core objectives of China's energy policy adjustment. Since 2001, China's 10th, 11th, and 12th Five-Year Plans, as the maximum development program of this country, have all emphasized the importance of improving energy efficiency [1,2] mainly because of the following four reasons.

A. Pressure to supply fossil energies. Fossil energies have accounted for most of the proportion of the primary energies that China consumed because of natural resource endowment and technology. Since 2001, the consumption share of fossil energies has remained stable within 91.4%–92.5% [3]. There is no sign that this energy consumption structure will change greatly in the foreseeable future. More seriously, besides the enormous consumption amount (2.74 billion tonnes oil equivalent in 2012, accounts for 21.92% of the world's total), China's general energy consumption trend is still in the stage of rapid growth [4,5]. To meet the fossil energy demand, the supply of some important energy sources has to increasingly depend on import from abroad. In 2012, the degree of external dependence of oil is as high as 58.34%, much higher than 39.93% in 2001 [6]. This has not only tightened the international energy supply but also caused worry about China's energy security. The Chinese government is facing increasing pressure to supply fossil energies.

B. Pressure to control $CO_2$ emissions. At present, Global warming and its subsequent effects caused by the emissions of GHGs (greenhouse gases) are very important issues in scientific and political agenda [7]. Studies show that energy-related $CO_2$ emissions are the most important GHGs and are responsible for over two thirds of the current global warming [8]. Toward the end of 1997, the Kyoto Protocol was adopted as the first multilateral attempt to cap global energy-related $CO_2$ emissions. This international agreement is viewed as a significant step toward long-term stabilization

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of the world's climate [9]. Given its smaller emission share and lower economic level in the early 1990s, China was not listed in the “Annex I” emitters of the Kyoto Protocol, which include nearly all developed countries that should take responsibility for $CO_2$ mitigation [10]. However, with the rapid growth of fossil energy consumption, China's $CO_2$ emissions have increased significantly. Since 2008, China has become the largest emitters of the world, and its emission share has increased over the years. China's emission share in 2012 was as high as 26.72% [11]. These facts have caused strong discontent among many “Annex I” emitters. They urged China to take responsibility for emission control. In this context, the Doha Amendment to the Kyoto Protocol, which was adopted in the latter part of 2012, clearly states that “developing countries contribute adequately according to their responsibilities and respective capabilities” is a premise for many emitters to continue fulfilling their commitments [12].

C. Pressure to mitigate regional haze. Haze is an atmospheric phenomenon characterized by visibility of less than 10 km because of complex materials suspended in the air, such as dust, smoke, and other fine particles [13]. Haze not only has a negative impact on transportation, with highways closed and flights delayed or canceled, and education, with primary and middle schools and kindergartens forced to suspend classes, but is also an indicator of high concentrations of $PM_{2.5}$; it has the potential to adversely affect public health by damaging people's respiratory system, cardiovascular system, blood vessels the of the brain, and nervous system [14]. Currently, haze is China's most serious atmospheric pollution issue. Owing to this phenomenon, less than 1% of the 500 largest cities in China meet the air quality standards recommended by the World Health Organization, and 7 of these cities are ranked among the 10 most polluted cities in the world [15]. Studies show that fossil energy combustion is the single most important contributor to China's haze and accounts for approximately 70% of it [16].

D. Expectations on economic growth. Since the founding of the People's Republic in 1949, China has considered high-speed economic growth a core evidence to justify the superiority of its governments and management system. This concept was further strengthened after the 3rd Plenary Session of the 11th CPC Central Committee in 1978. In the past several years, economic growth rate has become an important indicator to evaluate the performance of governments and, has closely related to the evaluation and promotion of government officials.

One basic characteristic of China is its dual economy. Under this economic structure, the considerable impetus to the economic growth of energy consumption has been proven by many studies [17–19]. Although faced with increasing pressures in terms of fossil energy supply, $CO_2$ emission control, and regional haze control, the Chinese government remains reluctant to limit energy consumption directly. The plan is to maintain economic growth with low energy consumption as much as possible, that is, improve energy efficiency.

The central and provincial governments in China are all important in improving the energy efficiency of the country. In most cases, energy-related macroeconomic policies are created and supervised by the central government and implemented virtually by the provincial governments. When the two levels of government have the same purpose, efficient management will ensue. Otherwise, efficient management usually cannot be realized. The energy consumption of a province usually arise the economic growth of its own, but the pressures related to fossil energy supply, $CO_2$ emission control, and regional haze caused by energy consumption mainly taken by the central government. That is, a negative external effect exists in China's provincial energy consumption. Provincial governments are reluctant to implement the energy efficiency improvement policies of the central government, especially when these policies will affect their economic growth. Therefore, how to coordinate the actions of the provincial and central governments is important in improving China's energy efficiency. Currently, researches on China's energy efficiency are mainly of two kinds. Some literatures focused on the policy design of a certain industrial sector [20–22]. Others discussed the possible measures of a certain area [23–25]. But they both didn't consider the administration environment of China. This paper will firstly discuss the relationship between the central and the provincial governments in improving the country's energy efficiency. By decomposition and forecasting empirical analysis, it will find several areas for the central government to adjust the provincial energy-related policies to promote the coordinated actions of the two levels of governments.

To quantitatively measure the relationship between the central and the provincial governments in improving the country's energy efficiency, a decomposition model is needed. In fact, there are two types of factors can promote the improvement of the country's energy efficiency. These are technological innovation and consumption share adjustment. Technological innovation refers to the phenomenon where an enterprise produces a product with less energy consumption. This phenomenon may be a result of many factors, such as application of a new technology or enlargement of the enterprise scale [26–28]. Different provinces usually differ in energy efficiency. If the energy consumption shares of different provinces change, then the energy efficiency of the country will change accordingly. This phenomenon is referred to as consumption share adjustment [29,30]. In this paper, a three-dimensional decomposition model is used to decompose the changes in China's energy efficiency from 2001 to 2011 into a summation of the quantitative influence of each province through each influence factor (technological innovation and consumption share adjustment) in each year. Analysis of the decomposition results is expected to identify the driving factors for improving China's energy efficiency and evaluating the energy sustainable development level of each province. Furthermore, a small-sample hybrid model is also utilized to forecast the changes in the influence factors and predict the future development trend of China's energy efficiency. Several suggestions on policy adjustment are also proposed based on the analysis of the decomposition and forecasting results.

This paper is organized as follows. The three-dimensional decomposition model and the small-sample hybrid model employed in this study are introduced in Section 2. The data sources, preliminary analysis and decomposition results of selected historical data are presented in Section 3. The decomposition and forecasting results are discussed in Section 4. Section 5 provides the summary conclusions and policy implications.

## 2. Methods

### 2.1. Energy efficiency decomposition model

Traditional decomposition models (e.g. classic LMDI [31] and Laspeyres index [32] decomposition algorithms) have the ability to simulate the roadmap of a simple indicator. But as a ratio indicator, the changes of the energy efficiency can not be decomposed by these models. Meng and Niu [33] have firstly proposed a complete decomposition model for ratio indicators. This paper follows their idea to design the three-dimensional decomposition model for the energy efficiency.

Energy efficiency of a country, which is defined as the GDP (gross domestic product) output per unit energy consumption, can be expressed as

$$E = \frac{G}{C} = \sum_{j=1}^{n} \frac{G_j}{C_j} \cdot \frac{C_j}{C}, \tag{1}$$