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Will the aggregation approach affect energy efficiency performance assessment?

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ABSTRACT

Aggregate energy is usually measured in the linear weighted summation of various energy types based on thermal dynamics laws. This measurement is scientific and acceptable in the physics or energy engineering world. However, it implicitly assumes that all energy types are perfectly substitutable and thus may result in distorted conclusions in energy-economy research. In economics world, production factors are usually non-linearly aggregated using Divisia approach, which is derived from microeconomic theory and considers the heterogeneity and imperfect substitutability among various energies. Using which "ruler" to measure the aggregate energy, the linear one or the others, will certainly affect the conclusions and energy saving incentives of the economic agents. Inequitable energy aggregations may bring out speculations or discouraged behaviors. According to China's current provincial energy efficiency performance assessment policy, the central government assigned the target of reducing the national aggregate energy intensity by 20% in 2006–2010 to provincial authorities in 2006. And in July 2011, the central government formally released the provincial assessment results based on conventional linear aggregation approach (coal equivalent). Our re-examination review this policy and show that the official results are quite different to that based on Divisia approach. From the perspective of economics, some local performances are overestimated and others are underestimated. To raise the equity and incentive compatibility of the assessment, we suggest the central take the imperfect substitutability or energy structure changes into consideration. We also discuss the difficulties and deficiencies when using Divisia aggregate approach.

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1. Introduction

Turvey and Nobay [1] argued that *an economic phenomenon deserves an economic approach.* However, in energy-economy research or policy practice, this is not always the case. Many national or regional energy efficiency (or energy intensity) performance assessments are such cases. For example, IEA [2] reported the aggregate energy in terms of calorific or heating value, which is not economic approach but physical one. In this paper, we will review China's provincial energy intensity reduction assessment.

During the last two decades in the 20th century, China made great achievements on energy efficiency with 63% energy intensity reduction according to the official data [3]. However, contrary

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to most of the earlier predictions, and partly due to the rapid industrialization and energy intensive fixed asset investment, its energy consumption increased dramatically with a result of 2% intensity increasing in the first five years of this century[4]. In order to reverse the trend of intensity rising, China's central government set a challenging target of reducing its aggregate energy intensity by 20% in 2010 compared with that in 2005. And it assigned this target to local provincial authorities to reduce their provincial energy intensity by 12–22%. The quantitative assignments across provinces are different according to their local economic development levels and their informal negotiations with the central government (see Fig. 1(a)). For example, Beijing was required to reduce its energy intensity by 20%, and Hainan was allocated 12% reduction. According to the central authority's declaration, if a province failed to accomplish its assignment, its provincial governors' would probably be negatively affected on political promotion, and those with excellent performance will probably be promoted. And in June 2011, the central government officially released the provincial energy efficiency performance assessment communiqué: all the provinces successfully accomplished the assignment except for Xinjiang (this region was exempted because it encountered many other social difficulties), and among the 31 provinces, 18 of them over-fulfilled their assignments by 0–2%. Beijing performed the best with a 26% intensity reduction in 2006–2010 according to the communiqué. Many researchers and public media doubt the provincial raw data reliability. In this paper, we will not discuss the raw data quality. We only re-examine the aggregation of various energy types and compare the results based on different aggregation approaches.

In July 2011, China's central government assigned its new round of provincial energy conservation target for 2011–2015 (see Fig. 1(b)). So the measurement methods of aggregate energy intensity reduction are vital: appropriate measurement methods may incentive local authorities' energy efficiency behaviors. By contrast, inappropriate measurement methods may result in discouraged or speculative behaviors, which is inequitable and not helpful to reduce the whole country's energy intensity.

Though these administrative or incentive mechanisms on energy efficiency have some disadvantages, they come into some effects in the short run. Almost all the local governments have tried their best to achieve their aims. And in order to ensure the accuracy and reliability of the raw energy and GDP data, the central government has made great efforts to enhance the provincial data statistical regulatory. However, there are still some corners left that may have impacts on the equity of performance assessment. The energy aggregation approach is such one. According to China's current provincial statistical regulations, the linear weighted summation on various energy types is used for measuring aggregate energy, and this method is based on the first law of thermal dynamics and coal equivalent. In detail, coal, oil and gas are converted to standard thermal unit according to their heat content; hydro/nuclear/wind power, and net import/moving in power from other countries/provinces are converted to equivalent coal according to the average efficiency of thermal power generation (about 37%). We call it ***equivalent value approach***, which is one of the conventional linear aggregation approaches. However, different energy has different quality or work. Using exergy accounting, another linear aggregation approach, Chen and Chen [5,6] investigated China's energy consumption in detail based on the second law of thermodynamics. These two methods are scientific and acceptable in physics and energy engineering world. However, in economics world, linear aggregation methods implicitly assume that all the energy types are homogeneous, freely inter-convertible, and perfectly substitutable (i.e. the substitution elasticities among them are infinity). In fact, all energy types are heterogeneous and their substitution elasticities are finite. Their marginal products are unequal, which results in different market prices. The imperfect substitution elasticity assumption may result in partial or distorted conclusions in energy-economy research. The conventional linear aggregation approaches based on thermal dynamics are not good enough for energy-economic analysis. In microeconomics, aggregation theory and methodology are deeply studied and widely used in capital and labor accounting [7]. Derived from microeconomic theory, Divisia approach as well as Törnqvist or Sato-Vartia approach as its discrete types, are such super aggregations and widely used in composite price index [8] and composition analysis [9,10].

Using which "ruler" to measure the aggregate energy (the linear one, Divisia or others) will certainly affects the conclusions and energy saving incentives of the economic agents. Inequitable energy aggregations may bring out speculations or discouraged behaviors. In energy-economic empirical study, few literatures investigated the energy aggregation issue. Berndt [11] argued the advantages of Divisia. Cleveland et al. [12] illustrated three case-studies and showed that the conclusions were reversed by using the Divisia methods. And Stern [13] further investigated the energy quality issue from the perspective of economics. By investigating the aggregation approach, Liao and Wei [14] further explained China's energy intensity fluctuation in 1996–2005. In this paper, we re-examine the possible partial assessment on provincial energy efficiency performance, which have already been and will continue to be executed by China's central government.

2. Methodology and data sources

We will employ Divisia approach to account China's provincial aggregate energy intensity reduction during 2006–2010, and compare the results to that of the official "equivalent value method" (i.e. coal-equivalent method). Aggregate energy intensity is usually measured as aggregate energy consumption per unit of GDP. There are several methods to aggregate the various energy types. Divisia approach has many advantages over the conventional ones since it considers the imperfect substitutability among various energy types. Divisia approach can be described as the following:

$$d\ln E = \sum_{i=1}^{n} \frac{p_i e_i}{\sum_{i=j}^{n} p_i e_i} d\ln e_i = \sum_{i=1}^{n} s_i d\ln e_i \quad (1)$$

There are n energy types in the system. e_i represents the consumption of the ith energy type ($i=1,2,\ldots,n$), and E is the Divisia aggregate energy. p_i denotes the energy price of the ith energy type. And $s_i = p_i e_i / \sum_{i=1}^{n} p_i e_i$, represents the cost share. According to the above differential equation, the aggregate energy growth rate is equal to the weighted sum of the growth rates of various energy types, and the weights are their cost shares. If the growth rates of various energy types are equal to each other, the Divisia aggregate energy equals the linear aggregate. According to integral mean value theorem, we estimate the Divisia aggregate energy index by using the Sato-Vartia method. For more details about Divisia aggregation, please see Balk [8], Stern [13], Liao and Wei [14]. The elasticity of substitutions among energy types can also be derived based on Divisia approach.

We will re-examine China's provincial energy intensity reduction performance in 2006–2010 and compare it with the official assessment communiqué. There are 31 provincial authorities in mainland China. Unfortunately, till now only some provinces reported their energy balance in detail. Due to the data