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A multi-fuel, multi-sector and multi-region approach to index decomposition: An application to China's energy consumption 1995–2010[☆]

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ABSTRACT

Index Decomposition Analysis (IDA) has been extensively applied in studies of energy consumption and energy-related emissions. Most have focused on the impacts of industrial structural change and technology progress and a few have also looked at inter-fuel substitution. There has been no study examining spatial aspects within an IDA setting. This paper first describes an analytical framework analyzing driving forces behind a country's changing energy consumption with special highlights on the spatial dimension and then develops an IDA model to operationalize the analytical framework. The model is applied to a panel of 29 Chinese provinces over the period of 1995–2010. It is shown that the model not only captures the impact of changes of economic and human geography but also provides valuable insights and richer information on spatial variations of other contributing factors than conventional country-level analysis.

1. Introduction

The past couple of decades have seen a significant number of studies applying the decomposition method to analyze the driving forces behind changes of an aggregated indicator over time. The majority of these studies appear in the field of energy research where the objective is to obtain a well-informed understanding of the drivers of energy use and energy-related emissions for an industry, a country or the global economy. This fast-growing body of literature has been facilitated by ease of application, good data availability, straightforward policy implications and well-documented methodological advancement. Most applied research in this field select one of the two most popular decomposition techniques: the structural decomposition analysis (SDA) or the index decomposition analysis (IDA). SDA relies on input–output (IO) tables which for many countries are only updated every few years. IDA uses annual statistics which allows the analysis to be conducted in a time-series form. Reviews of applied IDA studies can be found in Ang (1995, 2004), Ang and Zhang (2000), and Liu and Ang (2007). Similar reviews for applied SDA studies are also available in Rose and Casler (1996), Miller and Blair (2009), and recently Su and Ang (2012a). Both techniques have advantages and disadvantages, as well as similarities and differences. Hoekstra and van den Bergh (2003) did a comprehensive comparison of the two techniques. A recent update on the methodological developments of SDA can be found in Su and Ang (2012a,b). Advancements of IDA methods have been more systematically documented in Ang (2004) and Ang et al. (2009, 2010).

There has been an increased popularity of using IDA in applied research which is evidenced by a large number of published works and gray literature. This is primarily due to more frequent annual data updates (compared to IO tables required for SDA studies which is typically updated every few years), well-documented methodological developments as well as ease of application. Among the vast number of applied IDA studies, China appears to be one of the focal subjects of research. For instance, Ma et al. (2010) review 36 IDA studies on China up to 2009, all of which examine industrial energy consumption. Most studies find a dominant contribution of technology progress to a reduced energy consumption or intensity while the contribution from industrial structure change is mixed depending on the level of sector disaggregation under study. This highlights the need for IDA studies to go beyond

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pure time series analysis using aggregated economy-wide data and decompose at the sector level using more disaggregated data wherever it is available. More recently, IDA has also been used to study China's residential energy consumption. Zha et al. (2010) examined residential CO_2 emissions in urban and rural China. Zhao et al. (2012) studied impacts of lifestyle changes and fuel substitution on urban residential energy consumption. Yao et al. (2012) and Zhang and Guo (2013) analyzed residential energy consumption and corresponding carbon emissions in rural areas. Another line of research aims to address the spatial variations in energy consumption and its decomposed effects across China's provinces. These studies basically follow the analytical approach used by Metcalf (2008) which combines the decomposition method and the econometric technique. Typically, such studies involve a decomposition analysis of a regional energy indicator at the first step followed by a regression analysis to explain the spatial variations. Examples of this line of research include He and Wang (2007), Zhang (2009), Wang (2011), Wu (2012) and Song and Zheng (2012).

The large-scale population migration observed in the past couple of decades in China shares a similar pattern with that in other developing countries at a comparable stage of socio-economic development. People are migrating from the rural areas of less developed inland provinces to the urban areas of more developed coastal provinces. This migration pattern has significant bearings on provincial as well as national energy consumption due to changing resource endowments, lifestyles, economic activities and technology transfer. In this study, I show that this spatial dimension can be captured within an IDA framework. The conventional IDA approach can be extended to capture two spatial effects: 1) a shift of economic geography — i.e. geographical change of economic activities which contributes to unequal economic growth across provinces and 2) a shift of human geography — i.e. migration of population across provinces.

The study makes a second contribution to the analysis of inter-fuel substitution effect. While Ma and Stern (2008a) study the inter-fuel substitution effect among five fuels, this study extends it to nineteen fuels. The paper begins with a brief review of some of the key methodological developments in the IDA literature. Building on previous advancements, I introduce a conceptual framework to encapsulate all major effects that could explain the change in a region's energy consumption where the spatial dimension is highlighted. A model is then developed by extending the logarithmic mean Divisia index decomposition method to operationalize the conceptual framework. As an illustration of the model, I conduct an empirical analysis using China's provincial fuel consumption data by industrial sector over the period of 1995–2010.

2. Methodological developments in the IDA literature

IDA has been widely used to identify and quantify various driving forces underlying a change in energy or energy-related indicator over a specified period. The method treats the overall change as a weighted sum of the underlying forces. As the comparison is often made between two points in time, the decomposition is of a discrete nature. An appropriate weighted scheme needs to be selected (Ang and Liu, 2001; Ang et al., 1998; Liu et al., 1992). Researchers also need to address an unexplained residual effect for some variations of IDA (Sun, 1998) and handle zero values which make some weighting schemes undefined (Ang and Liu, 2007; Ang et al., 1998; Wood and Lenzen, 2006). Methodological advancements have also been made with regard to hierarchy decomposition which aims to obtain a better proxy for energy efficiency change (Ma and Stern, 2008a; Petrick, 2013) as well as correct choice of deflators which aims to address unbalanced economic growth across industrial sectors (Ma, 2010; Petrick, 2013). Another important methodology issue is aggregation including sector aggregation, spatial aggregation and temporal aggregation. Often there is a trade-off among these aggregation issues. The aggregation dimension is also dictated by data availability and purpose of the study. Detailed discussions on these aggregation issues can be found in Su and Ang (2012a,b). Although they have discussed these issues under a SDA context, many aspects apply to an IDA context as well. Early methodological advancements are well documented in Liu et al. (1992). Recent updates on the methodological developments of IDA have been systematically documented in Ang (2004), Ang et al. (2009, 2010), and Su and Ang (2012a,b).

As mentioned earlier, this paper builds on the previous literature and makes an original contribution by extending the conventional decomposition practice to investigate the spatial aspects — the impacts of shifts of human geography and economic geography. This is particularly valuable for a country that has been experiencing rapid economic transitions, where shifts of economic activities across provinces and large-scale inter-provincial population migration are observed. The paper differs from other studies that examine spatial variations in that it provides an alternative approach which is built on the IDA framework. I now turn to the analytical framework and the model.

3. Analytical framework and model

An IDA approach decomposes the change of an aggregated indicator into impacts of several contributing factors. The number of factors considered often depends on the purpose of the study. For example, Sorrell et al. (2009) develop an IDA model including 11 factors to analyze the changes in road freight transport energy consumption in UK. In this paper, I describe an analytical framework and an IDA model that allows multi-sector, multi-fuel and multi-region investigation. Specifically, China's changing energy consumption could be ascribed to the following factors:

1. Changes in total population — other things being equal, more energy is needed for a larger population.
2. Changes in per capita income — higher income level may create higher demand for energy.
3. Shifts in the industrial structure towards more or less energy intensive production.
4. Advancement in energy-efficient production technologies.
5. Substitution between fuels of different qualities.[1]
6. Changes in the economic or human geography — that is, economic production shifting or population migrating across regions that have different income levels and energy intensities.

Many studies focus on the first four channels while a few others also looked at inter-fuel substitution.[2] There has been no study so far to examine the implications of geographical shift of economic activities and population on overall energy consumption. Such analysis is particularly informative for a country that has been experiencing rapid economic transitions with substantial spatial heterogeneity. China has significant inter-provincial variations in terms of industrial structure, resource and technology endowments, income levels etc. Fig. 1.1 and 1.2[3] shows large inter-provincial differences in industrial structure, energy intensity as well as per capita income. More importantly, there are also substantial variations in terms of growth rate over the studied period. Other things being equal, shifts of economic activities across provinces and large-scale inter-provincial population migration are expected to have significant impacts on energy consumption. Provinces with economic production shifting out will have lower energy

[1] The concept of energy quality refers to the differences in economic productivity of different fuels and electricity. There are different ways of defining and measuring energy quality. The relevant concept here is the different marginal productivities of the fuels (Cleveland et al., 2000). Typically electricity has a higher marginal product per joule than oil and natural gas, which in turn have higher marginal products than coal. Therefore, substituting a joule of electricity for a joule of oil, or a joule of oil for a joule of coal will reduce energy intensity.

[2] See Ma and Stern (2008a) for a discussion of the inter-fuel substitution effect in the context of IDA.

[3] Note that provinces in Fig. 1.1 and 1.2 are all ranked by corresponding 2010 indicators.