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A spatial–temporal decomposition approach to performance assessment in energy and emissions

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ABSTRACT

There has been growing interest among researchers and policymakers in comparing or benchmarking countries on the basis of their performance in energy consumption or energy-related CO_2 emissions. Such studies allow variations among countries to be revealed, the contributing factors identified, and the scope for improvement better understood. At the same time, tracking changes or quantifying improvements in energy use or emissions over time in a country have long been a focus area of researchers and policy makers. To provide a fuller picture on country performance in a multi-country study over time, it would be of interest to integrate the above-mentioned spatial and temporal analyses in a single analysis framework. This paper deals with this issue using the technique of index decomposition analysis. A spatial–temporal approach is introduced and two application cases are presented to illustrate how the approach can be applied. The first analyzes variations and changes in the aggregate CO_2 intensity of electricity production for ten countries from 1990 to 2010, and the second deals with variations and changes in the aggregate energy intensity for eight economic regions of China from 2002 to 2012. In addition, two different ways of presenting the results are introduced. Our study shows that the proposed approach can supplement studies which are conducted purely on a spatial or temporal basis.

1. Introduction

The use of energy and its impacts on sustainability and climate change have been the focus of many researchers and policymakers. While looking for opportunities for mitigating the impacts, there has at the same time been increasing emphasis on country performance assessment, such as tracking of energy efficiency trends, studying drivers contributing to changes in energy consumption or related CO_2 emissions, and quantifying determinants contributing to variations between countries. For such purposes, index decomposition analysis (IDA) is an analytical tool that has been widely adopted.[1] To date, most of such studies can be divided into three different types in terms of the focus of performance assessment. The first deals with assessment over time in a country, i.e. single-country temporal analysis. This type accounts for the majority of the reported studies in the literature. The second type comprises studies dealing with more than one country. Temporal analysis is conducted independently for each country and the results obtained are compared to study similarities and differences between countries, i.e. multi-country temporal analysis. The third type of studies focuses on comparative analysis between countries using the data of a specific year. We shall refer to these studies as single-year spatial or cross-country analysis.

The first type of studies comprises the conventional IDA studies which have been widely reported in the literature. No further elaboration is required. The second type is a direct extension of the first. A requirement of these studies is that the same decomposition method and a consistent data format are used for all the countries so that the results obtained can be meaningful compared. Some recent studies are Voigt et al. (2014), Pothen and Schymura (2015), and Mundaca and Markandya (2016) which respectively deal with changes in energy intensity, material use, and CO_2 emissions in major global economies. Fernández González et al. (2014), Fernández González (2015), Löschel et al. (2015), and Kopidou et al. (2016) compare EU member countries' energy consumption, energy efficiency or CO_2 emissions changes. Liu et al. (2012), Wu (2012), Guo et al. (2014), and Du and Lin (2015) track changes in China's regional energy consumption, energy intensities, CO_2 emissions, or greenhouse gas emissions. Focusing on the electricity generation sector, Ang and Su (2016) and Karmellos et al. (2016) respectively examine CO_2 emission changes at the global level and for the EU countries respectively. These studies, which are representative of a much larger number of recent studies, show the growing popularity of the second type of studies where the main focus is to compare the development or performance of a group of countries over time. These comparisons are “indirect” because mathematically there are no direct linkages between the results of the countries compared.

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[1] Literature surveys on IDA can be found in Ang and Zhang (2000), Ang (2004), Xu and Ang (2013), and Ang (2015).

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Table 1
A summary of spatial IDA studies in the literature.

Study	Time period	Countries	Aggregate indicator	Decomposition method	Model	Reference region selection strategy
Ang and Zhang (1999)	1993	OECD and global regions	CO_2 emissions, total and per capita	LMDI-I	B-R	–
Sun (2000a)	1995	Finland and Sweden	CO_2 emission intensity	S/S	B-R	–
Sun (2000b)	1995	15 EU countries	CO_2 emission intensity	S/S	R-R	A-2
Schipper et al. (2001)	1994	14 countries	CO_2 emissions	Laspeyres	Modified R-R	B-2
Zhang and Ang (2001)	1993	3 world regions	CO_2 emissions	Laspeyres, S/S, AMDI & LMDI-I	B-R	–
Lee and Oh (2006)	1996	APEC countries	CO_2 emissions	LMDI-I	B-R	–
Bataille et al. (2007)	2002	G7 countries	GHG emissions	LMDI-I	Modified R-R	B-2
Bartoletto and Varas (2008)	1870–2000	Italy and Spain	CO_2 emissions	LMDI-I	B-R	–
Gingrich et al. (2011)	1920–2000	Austria, Czechoslovakia	CO_2 emissions	LMDI-I	B-R	–
Ang et al. (2015)	2002	30 provinces in China	Energy consumption	LMDI-I	M-R	B-1
Li et al. (2016)	1990–2010	9 provinces in China	CO_2 emissions per capita, CO_2 emissions per unit of GDP	LMDI	B-R	–

The third type of studies is very different from the first two. Using the data of a specific year, the spatial analysis conducted is static and the results obtained are valid for the year of analysis (Ang and Zhang, 1999; Ang et al., 2015). In the simplest form, for example, differences in the aggregate energy intensity, i.e. total energy consumption divided by GDP, between two countries or regions can be studied by quantifying contributions arising from variations between them in terms of activity structure and activity energy intensities.[2] In the case of aggregate carbon emission intensity comparisons, additional factors such as fuel mix and fuel emission coefficients are often included in the decomposition analysis. In the literature 11 such journal articles can be found and they are shown in Table 1. Also shown in the table are the regions and aggregate indicator compared and the IDA method used.

Ang et al. (2015) classify spatial IDA models into bilateral-region (B-R), radial-region (R-R), and multi-region (M-R). In the B-R model every pair of regions in a study group are compared. The results obtained are easy to understand but the approach is impractical if the number of regions is large. To overcome this difficulty, the R-R and M-R models may instead be used. In the R-R model, each region is compared with a reference region. In the M-R model, two regions are compared indirectly after direct comparisons have been made between each individual region with the reference region. In Table 1, the specific spatial IDA model used in each study is indicated in the second last column. The last column refers to the reference region selection strategy which is an important step in spatial IDA and the strategies will be discussed in the next section.

In spatial IDA, determinants contributing to performance gaps between regions in a specific year are quantified. From the results obtained, the regions can be ranked. Due to different development paths among regions, the relative performance of regions in a subsequent year can be different and a separate static spatial analysis is needed to establish the new ranking. The same spatial analysis is often repeated year by year and this is the approach used in Bartoletto and Varas (2008), and Gingrich et al. (2011). An advantage of this approach is ease of understanding. The comparison base, however, varies between comparison years. As a result, changes in regional disparities over time cannot be traced analytically since the spatial analyses conducted are different for different years.

The objective of this paper is to develop an IDA procedure that integrates the key features of type 2 and type 3 studies, where both spatial differences between regions and temporal developments in individual regions are captured simultaneously. This calls for an integrated approach which we shall refer to as spatial–temporal index decomposition analysis (ST-IDA). ST-IDA represents a two-dimensional analysis, i.e. both spatially and temporally. The approach provides formal linkages for the results of spatial comparisons obtained for different years. It may be used to supplement existing type 2 and type 3 studies.

An important step in applying the proposed model is the selection of a reference region for comparisons, as in the case of a conventional spatial analysis. We first review the various reference region selection strategies. We then introduce the proposed ST-IDA model. Two case studies are then presented, one deals with analyzing variations in the aggregate CO_2 intensity of electricity production for ten countries from 1990 to 2010, while the other deals with variations in the aggregate energy intensity for eight economic regions of China from 2002 to 2012. A number of recent studies dealing with the problem in each of these two cases can be found in the IDA literature. They are either temporal or spatial decomposition analysis. The choice of the two cases serves not only to illustrate the various underlying concepts of ST-IDA but also to show the wide scope of its application. In addition, two different ways of presenting the results are explained. Finally, some methodological and application issues are discussed.

2. Approaches to reference region selection

When conducting a spatial IDA study, except for the B-R model, a reference region which serves as a benchmark for comparisons needs to be first selected. The common strategies are shown in Fig. 1. The reference region can be an existing region (Group A strategies) or a hypothetical region (Group B strategies). Since the main objective of spatial IDA is to study regional disparities, it often makes sense to compare each region with a region that is representative or meaningful. Strategy A-1 allows policymakers to select a region that can best accommodate their specific needs, while strategies A-2 and A-3 facilitate comparisons with the extreme case, i.e. the best or worst player in the study group. If a comparison with the regional average level is of interest, Group B strategies can be adopted. A hypothetical region can be constructed whose attributes or indicators are given by the simple or weighted average of those of all the regions studied, i.e. strategy B-1. Alternatively, to eliminate the impact of the region under evaluation in the average, strategy B-2 can be adopted where the hypothetical region is constructed from averaging all the regions in the dataset except the region to be compared. Since the region under evaluation is compared with the average of all the remaining regions, a hypothetical region is to be constructed in each comparison case in strategy B-2.

As shown in Table 1, seven out of the 11 listed studies apply the B-R model. In these seven studies, the number of regions under evaluation is generally small (either two or three), which makes direct bilateral comparisons easy to implement. As to the remaining four studies, Sun (2000b) considers 15 European countries and applies strategy A-2. France is chosen as the reference region since it had the lowest CO_2 emission intensity among the countries studied. Using strategy B-2, Schipper et al. (2001) compare the CO_2 emissions of several IEA member countries and Bataille et al. (2007) compare the greenhouse gas emissions of the G7 nations. More recently, Ang et al. (2015) adopt strategy

[2] For simplicity, we shall use the term "regions" to represent the geographical units compared. The geographical units can be world regions, countries, or specific regions, states or provinces in a country.