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Multiplicative structural decomposition analysis of energy and emission intensities: Some methodological issues

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ABSTRACT

Structural decomposition analysis (SDA) has been a popular tool for studying a country's energy or emission performance. At the same time, there has been an increasing use of intensity indicators, such as energy consumption and carbon emissions per unit of economic output, in energy and emission performance reporting. The ratio change of an energy or emission intensity indicator can be more conveniently handled in the multiplicative form. In the context of multiplicative SDA of intensity indicators, this study investigates three specific methodological issues. The first is about sub-aggregate decomposition which provides detailed results at the sectoral/regional level to explain the observed aggregate intensity change. The second is the possible linkages between multiplicative SDA and additive SDA when studying changes in an intensity indicator over time. Arising from the convergence between SDA and index decomposition analysis (IDA) in application, the third issue is about the conceptual and empirical linkages between these two decomposition analysis techniques in the multiplicative form. A better understanding of these three issues will help to promote the use of multiplicative SDA of intensity indicators. A case study that looks into China's energy intensity change from 2007 to 2012 is presented.

1. Introduction

Assessing performances in energy use and emission mitigation has increasingly attracted much attention [1]. Its main purposes include evaluating the effectiveness of past and existing policies, and helping make decisions regarding future courses of action. Structural decomposition analysis (SDA), which is built upon the input-output (I-O) model for an overall economic system, is one of the techniques that have been widely used for such purposes [2,3].[1] More specifically, it has been used to quantify the impacts of the driving forces on an aggregate energy or emission indicator within the I-O framework at the economy-wide level. Examples of such studies with a policy focus are Minx et al. [6], Baiocchi and Minx [7] and European Environment Agency [8].

In the SDA literature, the aggregate indicator can be the total energy consumption or carbon emissions, i.e. a quantity indicator, or the energy or emission intensity, i.e. an intensity indicator of a country. In general, the energy or emission intensity is respectively a country's total energy consumption or carbon emissions divided by its gross domestic product (GDP). A change in the aggregate indicator, either a quantity indicator or intensity indicator, from one year to another is decomposed. The change can be an arithmetic change or a ratio change, i.e. respectively the value of the second year subtracts or is divided by that of the first year. Both types of aggregate indicators have been adopted in energy and emission performance analyses or in target setting. For example, in the intended nationally determined contributions (INDCs) communicated by nearly 200 parties to the UNFCCC in 2015, Canada, European Union and the United States use total emissions, i.e. a quantity indictor, while other countries such as China, India and Mexico use the emission intensity, i.e. an intensity indicator, in their climate pledges.[2]

A quantity indicator is an absolute measure and in energy or emission studies it is often assumed to be dependent on economy

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[1] Another widely used decomposition technique for assessing energy and emission performances is the index decomposition analysis (IDA). See, for example, Ang et al. [4] and Ang [5].

[2] For the indicators used in the INDCs of world countries, refer to https://www.carbonbrief.org/paris-2015-tracking-country-climate-pledges.

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Table 1
SDA studies dealing with intensity indicator, 2010-2016. EGY: Energy, EMS: Emissions, C: Competitive imports assumption, N-C: Non-competitive imports assumption, "*": The polar version of the decomposition method.

No.	Study	Country	Period	Application area		Decomposition form		Imports assumption		Decomposition method	
				EGY	EMS	Add	Mul	C	N-C	Add D&L	Mul D&L
1	Fan and Xia [32]	China	1987–2007	x			x	x			x*
2	Xiaet al. [33]	China	1987–2005	x			x	x			x*
3	Liaoet al. [45]	Beijing, China	2002–2010	x		x		x		x*	
4	Michel [54]	Belgium	1995–2007		x	x			x	x*	
5	Zenget al. [55]	China	1997–2007	x		x			x	x	
6	Zhang and Lahr [46]	China	1987–2007	x			x	x			x*
7	Xiaet al. [47]	China	2002–2007		x		x		x		x*
8	Su and Ang [31]	China	2007–2010		x		x	x	x		x
9	Su and Ang [53]	China's 30 regions	2002		x		x	x	x		x

size. In contrast, an intensity indicator is a ratio measure with energy consumption or emissions divided by economy size and has a "productivity" or "efficiency" connotation. Take the case of energy consumption and if there is a positive relationship between a country's energy consumption and its GDP, energy consumption, the quantity indicator, is expected to increase as GDP increases (assume that all other factors that could affect energy consumption remain unchanged). However, the intensity indicator, given by energy consumption divided by GDP, may or may not increase as GDP increases. How a change in the intensity indicator will take place is determined by the growth of energy consumption relative to that of GDP. In decomposition studies, studying changes of a quantity indicator is generally more straightforward and easier to handle mathematically, and the decomposition results can be more easily presented and understood by non-experts, compared to that of an intensity indicator.

In the SDA literature, the majority of studies in energy or emissions deal with the quantity indicator. This is the choice in almost all SDA studies prior to 2010 in which changes in absolute energy consumption or emissions over time are decomposed. The methodological issues for decomposing changes in these quantity indicators are well documented [2]. Examples of some recent studies are Wood [9], Xie [10], Chang and Lahr [11], Cansino et al. [12], Supasa et al. [13] and Wu and Zhang [14] which investigate growth in individual economy's energy use and emissions, Arto and Dietzenbacher [15], Malik and Lan [16], Malik et al. [17] and Lan et al. [18] which study changes in global energy use and emissions, and Cellura et al. [19], Su et al. [20], Xu and Dietzenbacher [21], Zhang and Tang [22], Hoekstra et al. [23], Zhao et al. [24] and Su and Thomson [25] which analyze changes in emissions embedded in trade (EET). The reason for the widespread use of the quantity indicator is that its changes can be conveniently studied using additive SDA which can be easily handled. In addition, the decomposition results are expressed in the same unit as the quantity indicator studied and can be more conveniently presented, interpreted and understood.

In contrast, due to the reasons mentioned earlier, decomposing an intensity indicator using SDA was seldom used prior to 2010. Our literature survey shows only nine journal articles dealing with energy and emission intensity indicators from 2010 to 2016. These nine studies, shown in Table 1, account for only about 10% of the total number of English-language, peer-reviewed journal articles on SDA applied to energy and emissions from 2010 to 2016. The interest in decomposing an intensity indicator is therefore a recent development. This is due mainly to the advent of the use of intensity indicators in performance assessment and target setting, such as in the case of INDCs. This applies to the case of China which uses emission intensity in its climate pledge. China is also the focus of eight out of the nine studies in Table 1. A close examination shows some differences among the nine studies although intensity indicator is the aggregate indicator of choice. The studies differ in terms of the modelling and decomposition procedures used.[3] Both additive and multiplicative decomposition analysis are applied, with more studies using the latter. Both the competitive and non-competitive imports assumptions are used to build an I-O model.[4] However, all the nine studies adopt the D&L decomposition method [26,27].[5]

Our study focuses on the decomposition of the intensity indicator. A main reason is that decomposition of the intensity indicator in SDA is relatively less well documented and understood compared to the case of the quantity indicator. Another reason is that interests in studying the intensity indicator are growing. For the intensity indicator, multiplicative decomposition is generally preferred to additive decomposition due to the ease of result presentation and greater suitability for tracking purposes [4,31].[6] Our focus is therefore further narrowed down to multiplicative decomposition of intensity indicators. Decomposing an intensity indicator in SDA, unlike the case of index decomposition analysis (IDA), is still an area where further research is needed.[7] Based on the current stage of development of SDA and research gaps, we have identified three specific methodological issues related to multiplicative decomposition analysis of intensity indicators. The three issues are depicted in Fig. 1. The four boxes in the figure refer to the four decomposition analysis cases for an intensity indicator, i.e. whether SDA or IDA is used, and whether decomposition is done additively or multiplicatively.

The first methodological issue, as indicated in the bottom left box of Fig. 1, is about the decomposition results at the sub-

[3] In Table 1, the first eight studies apply the temporal SDA while the last adopts the spatial SDA. Spatial decomposition analysis refers to studying the difference between two regions for an aggregate indicator and quantifying the underlying drivers.

[4] For discussions about the differences between the competitive and non-competitive imports assumptions, see Su and Ang [20].

[5] Decomposition methods that have been used in SDA in energy and emissions studies are described in Hoekstra and van der Bergh [28] and Su and Ang [2]. Corresponding to the last two columns of Table 1, the additive D&L method is known as the Shapley/Sun method [29] while the multiplicative D&L method is the same as the generalized Fisher index method [30] in IDA.

[6] For example, in energy and emission studies, the intensity indicator is often measured in kilograms of oil equivalent per dollar or kilograms of CO_2 per dollar of output. Because of the measurement unit, a relative change of the indicator is easier to understand and handle than an absolute change.

[7] For the case of IDA much work has already been undertaken. Readers may refer to, for example, Ang [5].