Energy xxx (2014) 1–9

Contents lists available at ScienceDirect

Energy

journal homepage: www.elsevier.com/locate/energy

Attribution of changes in the generalized Fisher index with application to embodied emission studies

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ARTICLE INFO

Article history:
Received 22 June 2013
Received in revised form
15 March 2014
Accepted 18 March 2014
Available online xxx

JEL classification:
C67
P28
Q43
Q54
Q56

Keywords:
Index numbers
Generalized Fisher index
Index decomposition analysis
Structural decomposition analysis
Input–output analysis
Emissions embodied in trade

ABSTRACT

The Fisher index and its extensions have been used in multiplicative decomposition analysis applied to energy and emissions. In this study, we extend the concept of "additive decomposition of the Fisher index" in the national accounts and propose an attribution analysis of the generalized Fisher index in the context of structural decomposition analysis (SDA). The proposed attribution analysis allows changes of an aggregate index derived through the application of the generalized Fisher index decomposition in SDA to be attributed to give the contributions of the individual components at a finer level. Using the proposed approach, we attribute changes in the carbon emissions embodied in China's exports and show that valuable information at the industry sector level is revealed.

1. Introduction

Decomposition analysis has been widely used to evaluate the driving forces of the historical changes of an aggregate indicator in energy, economics, environmental and other socio-economic areas. In the literature, index decomposition analysis (IDA) and structural decomposition analysis (SDA) are two of the most popular decomposition techniques. The developments of IDA can be found in Ang [1,2], Ang and Zhang [3], and Ang et al. [4–6], while those of SDA can be found in Rose and Casler [7], Miller and Blair [8], and Su and Ang [9,10]. Especially, the comprehensive comparisons between SDA and IDA based on the latest available information are reported in Su and Ang [9]. Recent SDA publications on energy and emissions are Fan and Xia [11], Feng et al. [12], Kagawa et al. [13], Zhang [14] and Das and Paul [15].

Although IDA and SDA developed independently, they are similar in a number of aspects. For example, the multiplicative form of the D&L method [16], a widely used SDA technique, is similar to the generalized Fisher index method in IDA in concept [9,17,18]. The generalized Fisher index, as proposed in Ang et al. [17] for IDA application, can be traced back to Siegel [19]. It is an extension to the conventional two-factor Fisher index [20,21] to more than two factors. Such an extension is needed because in IDA (and also SDA) the number of factors studied is often more than two.

With the increasing interest in using indexes for policy analysis, it is useful to look beyond the information normally provided by an aggregate index through quantifying the contributions of the individual components to the changes in this index. The issue has recently been looked into in IDA by Choi and Ang [22]. In the national accounts, two forms of indexes have been advocated, i.e. the arithmetic and geometric mean indexes. Taking the price index as an example, the arithmetic and geometric mean price indexes are presented as follows:

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http://dx.doi.org/10.1016/j.energy.2014.03.074
0360-5442/

$$P = \sum_{i=1}^{m} s_i \frac{p_i^1}{p_i^0}, \quad \sum_{i=1}^{m} s_i = 1 \tag{1}$$

$$P = \prod_{i=1}^{m} \left(\frac{p_i^1}{p_i^0}\right)^{w_i}, \quad \sum_{i=1}^{m} w_i = 1 \tag{2}$$

where p_i^0 and p_i^1 are the prices of ith item at time 0 and 1, s_i and w_i are some expenditure shares of ith item. The advantage of using these two forms is that the aggregate price index can be explained as the additive decomposition in percent-changes and log-changes:

$$P - 1 = \sum_{i=1}^{m} s_i \left(\frac{p_i^1}{p_i^0} - 1\right), \quad \sum_{i=1}^{m} s_i = 1 \tag{3}$$

$$\ln(P) = \sum_{i=1}^{m} w_i \ln\left(\frac{p_i^1}{p_i^0}\right), \quad \sum_{i=1}^{m} w_i = 1 \tag{4}$$

They capture the sources of the aggregate price change and are therefore very useful to the users of price indexes. In index number theory, many indexes such as the Laspeyres index and Paasche index can be directly expressed as the arithmetic or geometric mean index [21]. Although the Fisher index cannot be directly expressed any of these two forms, recent studies show that this can be indirectly achieved through some transformations [23–26].

Choi and Ang [22] introduce the “additive decomposition of an index” concept in Eqs. (1)–(4) to the IDA literature and expand it to what they call an “attribution analysis” in IDA. They apply the analysis to the Divisia energy intensity index through which they show how changes in the aggregate energy intensity index for industry can be attributed to the individual industrial sectors. The attribution analysis is based on Logarithmic Mean Divisia Index (LMDI) methods in the context of IDA, which has been used in SDA studies, e.g. Wachsmann et al. [27], Wood [28] and Wood and Lenzen [29]. Recently, González et al. [30] apply this attribution concept to analyze the evolution of real energy efficiency in 20 European countries.

Our present study is in the same vein except that we introduce the attribution analysis to the SDA literature and focus on the generalized Fisher index (since the popular multiplicative D&L method in SDA is similar to the generalized Fisher index). In the literature, most SDA studies applied to energy and emissions use the additive decomposition technique [9]. Very few use the multiplicative form, although both additive and multiplicative forms are widely used in the IDA literature [3,9]. An important and possible reason is that traditional multiplicative SDA can only give decomposition results in aggregate and these aggregate results are difficult to be attributed to the sectoral level. Moreover, the number of factors considered in SDA studies is generally larger than that in IDA studies. This paper is an attempt to introduce the attribution analysis to multiplicative SDA studies to fill the gap.

Analyzing emissions embodied in trade has been a popular research area. Wiedmann et al. [31] give a comprehensive review of the studies on emissions embodied in trade. The methodology developments can be found in Lenzen et al. [32], Peters [33], Peters et al. [34], Su et al. [35,36] and Su and Ang [37–40]. Most previous embodied emission studies focus on estimating a country’s emissions embodied in its international trade and the resulting “consumption-based” emissions. Recently, some studies, such as Su and Ang [9,10], Edens et al. [41], and Xu et al. [42], apply the additive SDA to analyze the driving forces behind the absolute changes of national and sectoral embodied emissions in trade. To our knowledge, there is no study using the multiplicative SDA to investigate the relative changes of national and sectoral emissions embodied in trade. We therefore use the proposed attribution analysis technique to estimate and analyze the contributions of various industrial sectors to the changes of carbon emissions embodied in China’s exports.

2. Generalized Fisher index decomposition

In decomposition analysis, the aggregate measure of interest is expressed as the summation of sub-categories. For ease of explanation, we assume that the sub-categories are given at the industry sector level as is often the case in SDA. We assume that the sub-category $y(x_1,x_2,\cdots,x_n)$ is a function of n factors and $y(x_1,x_2,\cdots,x_n) = x_1 \cdot x_2 \cdots x_n$. The identity can then be formulated as

$$V = \sum_{i=1}^{m} V_i = \sum_{i=1}^{m} y_i(x_1, x_2, \cdots, x_n) = \sum_{i=1}^{m} x_{i,1} x_{i,2} \cdots x_{i,n} \tag{5}$$

where V is the aggregate value, $V_i = y_i(x_1,x_2,\ldots,x_n)$ is the sub-category of the aggregate at the ith sector level, $x_{i,j}$ is the value of jth factor at the ith sector level, and m is the number of sub-categories.

A change of the aggregate measure from V^0 at the starting time 0 to V^1 at the ending time 1 can be measured in terms of the ratio D_{tot}:

$$D_{\text{tot}} = V^1 \big/ V^0, \quad V^1 = V(t = 1), \quad V^0 = V(t = 0) \tag{6}$$

In multiplicative decomposition, we decompose D_{tot} to give the contribution to the change from each of the n factors:

$$D_{\text{tot}} = \prod_{j=1}^{n} D_{x_j} \quad \text{or} \quad \ln D_{\text{tot}} = \sum_{j=1}^{n} \ln D_{x_j} \tag{7}$$

The subscript tot denotes the total or overall change and the terms on the right-hand side give the aggregate effects associated with the respective factors in Eq. (5).

For illustration purposes, we refer to the three-factor case. From Ang et al. [17], the generalized Fisher index for the first factor can be formulated as:

$$D_{x_1} = \left[\frac{\sum_{i=1}^{m} x_{i,1}^1 x_{i,2}^0 x_{i,3}^0}{\sum_{i=1}^{m} x_{i,1}^0 x_{i,2}^0 x_{i,3}^0} \cdot \left(\frac{\sum_{i=1}^{m} x_{i,1}^1 x_{i,2}^1 x_{i,3}^0}{\sum_{i=1}^{m} x_{i,1}^0 x_{i,2}^1 x_{i,3}^0} \cdot \frac{\sum_{i=1}^{m} x_{i,1}^1 x_{i,2}^0 x_{i,3}^1}{\sum_{i=1}^{m} x_{i,1}^0 x_{i,2}^0 x_{i,3}^1}\right)^{\frac{1}{2}} \cdot \frac{\sum_{i=1}^{m} x_{i,1}^1 x_{i,2}^1 x_{i,3}^1}{\sum_{i=1}^{m} x_{i,1}^0 x_{i,2}^1 x_{i,3}^1}\right]^{\frac{1}{3}}$$
$$= \left[\frac{V_{100}}{V_{000}} \cdot \left(\frac{V_{110}}{V_{010}} \cdot \frac{V_{101}}{V_{001}}\right)^{\frac{1}{2}} \cdot \frac{V_{111}}{V_{011}}\right]^{\frac{1}{3}} = \left(\frac{V_{100}}{V_{000}}\right)^{\frac{1}{3}} \left(\frac{V_{110}}{V_{010}}\right)^{\frac{1}{6}} \left(\frac{V_{101}}{V_{001}}\right)^{\frac{1}{6}} \left(\frac{V_{111}}{V_{011}}\right)^{\frac{1}{3}} \tag{8}$$