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An axiomatic approach to decoupling indicators for green growth

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ABSTRACT

The concept of decoupling was introduced to measure and analyze the controversial trade-off between economic development and environmental sustainability; in particular, several empirical studies concern the construction and use of decoupling indicators. We elaborate on a descriptive comparison by Conte Grand (2016) of the three main ones, respectively D_O by OECD (2002), D_ϵ by Tapio (2005), and D_t by Lu et al. (2011), and introduce an axiomatic approach into the subject that articulates in the identification of some properties that appear indispensable or at least desirable for any decoupling indicator and in the assessment of their validity for the indices under scrutiny and/or in the construction of new indices that satisfy them. A graphical examination of the aggregation function level sets in the Cartesian plane is a relevant part of the method. Under such analysis, the index D_O turns out to show milder defects than D_ϵ and D_t. We then propose a suitable modification D_N in order to remove the defects and fulfill all the given compatible axioms; in particular, D_N is cumulative over sub-periods.

It may also be opportune for a decoupling index to differentiate the treatment of the case when, during economic growth, environmental stress (e.g., polluting emissions) decreases from the case when it increases, although less than economy (the so-called absolute and relative decoupling, respectively), as well as to capture the rebound effect phenomenon, whereby the efforts to reduce environmental intensity may eventually result in a smaller overall environmental improvement than predicted or intended. To this end we build another index D_P by applying to D_N a correction (that can be calibrated via a global parameter) for the distance from what we define symmetric decoupling, the case when the variations of economy and of environmental pressure are inversely proportional.

We conclude by testing the novel indices D_N and D_P against D_O on data from OECD (2017) of 103 world countries for the most recent completely available decade 2003–2013.

1. Introduction

Since its introduction by Zhang (2000) in the study of environmental costs of China's economic take-off, the term *decoupling* refers to the breaking of the link between economic development and ecological unsustainability. Sometimes also referred to as *delinkage* or *delinking* (de Bruyn, 2000), the concept is now widespread in the political and institutional context as a desirable goal in view of the ever increasing challenges posed by climatic change. Indeed an intense debate is in progress on the implementation of effective strategies to reduce the potential trade-off between economic progress and environmental protection (Selin, 2016).

The environmental stress caused by economic activities can be assessed by focusing either on the consumption of primary raw materials such as water, minerals, and fossil fuels, or on the environmental impact of water, land or air pollutants. Correspondingly (UNEP, 2011) one speaks about *resource decoupling*, respectively *impact decoupling*.

In a situation of economic growth, another distinction (OECD, 2002) is between *absolute* (or *strong*) *decoupling* and *relative* (or *weak*) *decoupling*, according if the environmental stress decreases or it increases, although less than economy. In the economic growth literature the former alternative is also referred to as *green growth* to emphasize a sustainable path for economic development.

A phenomenon to be taken into account when dealing with decoupling is the *rebound* (or *take-back*) *effect* (Sorrell, 2009), according to which the efforts to reduce energy intensity may eventually result in a smaller overall energy saving than predicted or intended. For instance, the diminution of energy cost per production unit of a certain good can reduce its price and thereby stimulate the demand either of that good, now less expensive, or of other goods with the saved money. The additional energy consumption thus generated may partially or totally compensate—or even overcompensate (the so-called Jevons' paradox)—the initial decrease.

Several factors are involved in the above-mentioned issues, such as

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consumer behavior (Huang and Rust, 2011), innovation (Rennings, 2000), and market regulation (Porter and van der Linde, 1995), and such complexity requires a careful study of the quantification of decoupling. To this end there are contributions about the estimation of the environmental Kuznets curve (Vehmas et al., 2007), a decomposition analysis of the environmental pressure (Diakoulaki and Mandaraka, 2007), and decoupling indicators, which are the object of the present investigation.

The three most popular decoupling indicators, respectively D_O by OECD (2002), D_ϵ by Tapio (2005), and D_t by Lu et al. (2011), are compared in a recent descriptive analysis by Conte Grand (2016). In the present article we change the methodological perspective by adopting an axiomatic approach. As happened in the debate on the operationalization of the human development concept through the study and revision of the United Nations' HDI Index (UNDP, 2010), see for instance Klugman et al. (2011), Zambrano (2014), and Casadio Tarabusi and Guarini (2016), the normative characterization of an index may enable to better assess its measurement capability, coherence with the intended characteristics of the phenomenon under scrutiny, correct interpretation, and practical usability. Consequently such an approach tends to be all the more useful as the phenomenon is theoretically complex and politically sensitive, as is the case with decoupling; in particular, it permits to detect relevant features and possible defects of existing indicators and propose new ones that better satisfy the identified axioms. A relevant part of the method followed here consists in the graphical examination of level sets of the aggregation function in the Cartesian plane.

The indices D_ϵ and D_t, mutual algebraic complements to 1, turn out to suffer from several significant defects, among which the instability of index values in case of economic stagnation, the incomplete monotonicity with respect to input variables (greater economic growth coupled with greater environmental improvement may yield worse index values), and the impossibility for index values to yield meaningful rankings because they are unable to distinguish what may be called *brown degrowth* (economic decline with increasing environmental pressure—the least desirable combination) from green growth (the most desirable one); numerical values need to be complemented, and were indeed introduced, with categorical labels in order to separate various types of decoupling situations. These and other structural problems make the two indices unfit for further consideration in our axiomatic approach.

The index D_O does not present the same defects, yet it shows some less severe weaknesses such as metric inhomogeneity (the significance of a difference between index values depends on the values location on the real line) or non cumulativeness (the index values of consecutive periods do not add up for the overall period). We illustrate the analyzed defects of each index with examples from OECD (2017).

By suitably modifying D_O we propose a novel decoupling index D_N that overcomes these and other disadvantages and fulfills the corresponding axiomatic properties; in particular, while yielding the same meaningful rankings as D_O, it is both metrically homogeneous and cumulative.

In the aforementioned literature on HDI and, in particular, on the trade-offs among its input variables it was proposed to adjust the original synthetic index, a simple arithmetic mean, with a penalization that increases with the disequilibrium among input variables. In the same vein, we propose another decoupling indicator D_P obtained by applying to D_N the larger correction, the farther the situation from what we define as *symmetric decoupling*, the case where economy varies in inverse proportion to environmental pressure. The amount of the correction can be overall adjusted by means of a real parameter c (the value $c = 1$ is recommended); in the limit case $c = 0$ the index D_P reduces to the simpler, uncorrected D_N. The index D_P, unlike D_O, manages to take into account the duality of absolute versus relative decoupling, penalizing the former less than the latter, as well as the rebound effect described above, that similarly results in less symmetric decoupling than intended or expected, thence in stiffer index penalization. The indicators D_N and D_P may constitute an improvement in terms of policy relevance and analytical soundness, "key principles in selecting indicators to monitor progress with green growth" (OECD, 2011, Box 1 in §1).

Finally we test the novel indices D_N and D_P against D_O and the resulting rankings on data again from OECD (2017) for 103 world countries in the period 2003–2013, the most recent decade for which the data are presently complete.

The contribution of the present article to the study of decoupling indicators is manifold: an axiomatic approach is introduced, with an important graphical examination side; a list of desirable properties is compiled; their validity is tested for the three most used indices; two novel indices are proposed that better fulfill such properties. The structure is the following: in Section 2 the three indicators are defined and analyzed critically; in Section 3 some axiomatic properties are introduced and new indices are proposed; in Section 4 various indicators are compared by applying them to real data; the conclusions are in Section 5.

2. The main decoupling indicators

2.1. Definitions

All the sequel may indifferently be applied to either impact or resource decoupling. For a given country at time j, let Y_j be the Gross Domestic Product (or a similar index related to economic progress), H_j the level of environmental pressure, and $T_j = H_j/Y_j$ the resulting environmental intensity. The three quantities are all intrinsically positive. The respective variation rates with respect to time $j - 1$ are

$$y = \frac{Y_j}{Y_{j-1}} - 1, \quad h = \frac{H_j}{H_{j-1}} - 1, \qquad t = \frac{T_j}{T_{j-1}} - 1 = \frac{h+1}{y+1} - 1. \tag{2.1}$$

The pair (y, h) (in terms of which the variable t can be uniquely obtained) can be represented on a Cartesian plane as in Fig. 2.1 , which shows a subdivision corresponding to the list of thirteen cases described in Conte Grand (2016, Table 5, where the two variables are denoted by g, e respectively):

- six open regions into which the plane is divided by the two coordinate axes and by the line $y = h$ of *perfect coupling*, where the two variation rates coincide;
- six half-lines into which those three lines are parted by the axes origin;
- the origin itself (where $y = h = 0$).

The figure depicts the yearly variations y of real GDP and h of production-based CO_2 emissions of 103 world countries in the year 2009 (with respect to the preceding year) according to OECD (2017). The cloud of points extends for a substantial number of units over each of the six open plane regions (and some points may be located arbitrarily close to each of the six half-lines as well as to the origin), showing that each theoretically possible combination of signs for y, h and their difference $y - h$ may actually occur and cannot be neglected. The variables y and h are only bound by the constraints

$$y, h > -1 \tag{2.2}$$

following by (2.1).

We now present three of the main decoupling indicators used in the literature. The first was introduced in OECD (2002) and widely used thereafter, e.g., in Lu et al. (2007), de Freitas and Kaneko (2011), Yu et al. (2013), and Conrad and Cassar (2014):

$$D_O = -t = 1 - \frac{h+1}{y+1}, \tag{2.3}$$

therefore subject to the constraint

$$D_O < 1.$$