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Empirical study on the environmental pressure versus economic growth in China during 1991–2012

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ABSTRACT

Since adoption of the policy of reform and opening-up in 1978, China has achieved spectacular success in economic growth, which mainly driven by abundant consumption of natural resources and resulted in serious environmental problems. Based on Emergy approach and Rescaled Range analysis, this paper aims to examine the decoupling condition in economic growth nexus environmental pressure both at specific and aggregate level and track the changing trend and the corresponding socio-economic cost in decoupling process. The results show that: the decoupling performance of waste emission (includes waste water, SO_2 and solid waste) is better than energy consumption at a specific level which implies that the policies focused on end-of-pipe treatment has been succeeded in meeting the targets of emission reduction. But at aggregate level, the situation is opposite which suggest that China need more efforts in life-cycle management. The weak decoupling condition of resource use and waste water discharge may continue in the future, so as the strong decoupling condition of SO_2 and solid waste, but for the aggregate environmental pressure induced by waste emission, the decoupling performance may be getting worse in the future. The investment cost of decoupling increased, whilst the job-cost of decoupling decreased. The decoupling performance can be influenced by environmental policies substantially, such as the polices of circular economy, rigorous emission reduction and waste recycling which have brought about the strong decoupling of SO_2 emission and solid waste discharge from economic growth, whereas the less rigorous policies on resource exploitation and waste water discharge didn't achieve the same result. Therefore, China needs to intensify the unity among various environmental policies.

1. Introduction

China has experienced spectacular economic growth mainly indicated as gross domestic product (GDP) which has increased more than 22-fold since 1978. The remarkable growth has made China the second largest economy, and also the largest energy consumer (Zhang et al., 2011a), the biggest energy-related CO_2 emitter (IEA, 2006), the largest solid waste generator (Chen et al., 2014) and the largest single contributor to global SO_2 emission (Li et al., 2013) in the world. Therefore, China's economic growth "coupled" with the increase in resources consumption and waste emission. The coupling between resources consumption and economic growth as well as pollution emissions are central to the debates (Xue et al., 2010). China's serious environmental challenges call for disclosing the relationship between economic growth and environmental pressure, which is important for achieving environmental sustainability for both China and the world (Liang et al., 2013; Liu and Diamond, 2008, 2005). It is generally agreed that resources use and waste emission should be "decoupled" from economic growth (Wang et al., 2013).

Currently, decoupling has been defined by several organizations and academic groups, such as decoupling is "breaking the link between environmental bad and economic goods" by Organization for Economic Co-operation and Development (OECD) (OECD, 2002); is "the reduction of the negative environmental impacts generated by the use of natural resources in a growing economy" by European Union (EU) (Mudgal et al., 2010), and is "reducing the amount of resources used to produce economic growth and delinking economic development from environmental deterioration" by

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United Nation Environmental Program (UNEP) (UNEP, 2011). Two main kinds of decoupling are in general taken into account, defined as relative and absolute decoupling. Relative decoupling refers to a decrease of emissions intensity per unit of economic output. Absolute decoupling refers to an overall decrease of emissions as GDP increases (Andreoni and Galmarini, 2012). Thus, decoupling has been the overall goal of environmental sustainability (Kovanda and Hak, 2007), and the process of decoupling is generally considered to be crucial for sustainable development strategies such as the *factor 4* or *factor 10* in resource use (Hanssen et al., 2007; Pretty, 2013; Reijnders, 1998; Weizsäcker et al., 1997). For example, decoupling has been proposed as one of five inter-linked objectives for enhancing cost-effective and operational environmental policy of OECD in the context of sustainable development for the first decade of the 21st century (Moldan et al., 2012; OECD, 2001; Wang et al., 2013).

Decoupling was first introduced to analysis the nexus between industrial materials and energy and economic growth in advanced countries (Marin and Mazzanti, 2013). In 1990s, researches on decoupling were extended to air pollutants and greenhouse gas emissions, and Environmental Kuznets Curve (EKC) hypothesis was proposed to elaborate the relationship between pollution and economic growth, which was based on general reasoning around relative or absolute delinking in income–environment dynamics relationships (Grossman and Krueger, 1995; Marin and Mazzanti, 2013). To date, many different methods and indicators have been used to estimate the degree of decoupling (Tapio, 2005; Van Caneghem et al., 2010; Wang et al., 2013). There are two main indicators for quantifying the decoupling degree: one is the decoupling factor introduced by the OECD (OECD, 2002); another one is elasticity measured by the ratio of change in environment indicator to the percent change in economic indicator (Tapio, 2005). The two indicators have been used successfully in decoupling for resource use, energy consumption, and waste emission both in industrialized countries (Andreoni and Galmarini, 2012; Bringezu et al., 2004; Gan et al., 2013; Jorgenson and Clark, 2012; Kovanda et al., 2008; Steinberger et al., 2013) and China (Liang et al., 2013; Yu et al., 2013; Zhang and Wang, 2013; Zhang, 2000). Previous studies mostly focused on the particular source of environmental pressure, and only few studies conducted decoupling analysis at aggregate level based on Material Flow Analysis (MFA) framework. However, the MFA-based analysis has placed emphasis on the weight (quantities) of resource flows and ignored the varied qualities of material flows. Moreover, comparing with numerous case studies on decoupling in the past, few studies focused on exploring the development trend of decoupling degree. This might be due to the non-linear characteristic of decoupling degree dynamics in long time series (Zhang et al., 2014a), which made it unable to simulate the trend of decoupling degree by using linear regression analysis. And, few researches have been done to investigate the social–economic cost for sustaining decoupling process. Therefore, a set of unified indicators should be developed and employed for advancing the current studies. In this study, we investigated the decoupling of environmental pressure from economic growth in China during 1991–2012, not only from the perspective of the particular source of environmental pressure (specific level), such as energy consumption, waste water discharge, SO_2 emission and solid waste discharge, but also the aggregate environmental indicators based on emergy analysis (aggregate level), which is a technique of quantitative analysis that determines the values of resources, services and commodities in a common unit of solar energy, which allows all resources to be compared on a fair basis and thus can overcome the limits of MFA-based analysis (Huang et al., 2006) and provides strong and consistent evidence of the increasing consumption of resources in most economies, even in those economies that have focused their policies on dematerializing economic growth (Hoang, 2014; Zhang et al., 2014b). The paper also analyzed the trend of decoupling degree based on rescaled range analysis (R/S) method and socio-economic costs for meeting the goal of decoupling. Section 2 in this paper presents the methodology applied in this research, and then Section 3 presents the results, followed by Section 4 focusing on the policy implications and discussions.

2. Methods and data

2.1. Decoupling

The definition of decoupling environmental pressures (E) from economic growth (take GDP for example) is shown as in Fig. 1 (Tapio, 2005). Decoupling status could be estimated by the GDP elasticity values of environmental pressure which shows in Eq. (1):

$$\text{GDPelasticityofE} = \frac{\%\Delta \text{E}}{\%\Delta \text{GDP}} \quad (1)$$

When using economic output per capita as the X-axis and environmental impact as the Y-axis, eight logical possibilities can be distinguished. In order to not over-interpret slight changes as significant, a ± 20% variation of the elasticity values around 1.0 (0.8–1.2) is still regarded as coupling (Chen et al., 2014; Tapio, 2005). Compared to this diagram, actually, our results fell in the right part, which is indicated as zone 1 to zone 4 in Fig. 1.

2.2. Emergy analysis

Emergy analysis is an environmental accounting method, which considers the energy system as a thermodynamics of an open system, to characterize all natural resources, capitals and services in equivalents of solar energy (i.e., how much emergy would be required to provide products and services if the solar radiation were the only input) (Brown and Ulgiati, 2011; Geng et al., 2013; Zhang et al., 2011b) and thus to evaluate the contributory value of different material flow to the ecological economic system (Mu et al., 2011; Odum and Peterson, 1996). Generally, the unit of emergy analysis is solar embodied joules, abbreviated sej, and the key parameter is the emergy transformity (Trf.). The transformity of solar radiation is assumed equal to one by definition (1.0 sej/J), while the transformities of all of the other materials, energy and services are calculated based on their convergence patterns through the biosphere hierarchy. The value of the certain emergy transformity is from the corresponding references: (a) (Cuadra and Rydberg, 2006), (b) (Lan and Lu, 2002), (c) (Brown and Ulgiati, 2010), (d) (Bastianoni et al., 2009), (e) (Riposo, 2008), (f) (Lan and Odum, 1994), (g) (Brandt-Williams, 2001), (h) (Brown et al., 2011), (i) (Zhang et al., 2009), and (j) (Vega-Azamar et al., 2013) as shown in Table 1. The major steps of emergy analysis include identifying the system boundary, collecting eco-economic data, establishing emergy flow accounting, calculating a set of indices and ratios and using them to conduct the analysis.

Because our research mainly focused on the decoupling of environmental pressures induced by resources consumption and wastes emission, only two main economic activities which are agricultural and industrial activities and three main wastes include waste water, waste gas and solid waste were taken in count in the emergy analysis. The components of emergy accounting for resource consumption in agricultural sector and industrial sector are shown in Table 1. The other non-renewable resources, such as mineral resources, were not considered due to the shortage of database. The emergy accounting is simplified as three aspects consisting of non-renewable resources (NRR) consumption in agricultural system, energy consumption (ECI) in industrial activities, and waste emissions (W). Based on standard emergy transformity, the emergy accounting for NRR, ECI and W in 2012 are given in Table 1. The paper applied all the indicators in Table 1 to conduct