Energy Economics 40 (2013) 967–975

Contents lists available at ScienceDirect

Energy Economics

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

The responsibility for carbon emissions and carbon efficiency at the sectoral level: Evidence from China

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ARTICLE INFO

Article history:
Received 18 September 2012
Received in revised form 31 May 2013
Accepted 31 May 2013
Available online 13 June 2013

JEL classification:
Q56
Q58
C67

Keywords:
Environmental responsibility
Emissions multiplier
Benefit principle
Input–output analysis

ABSTRACT

This work reviews benefit-based principles to measuring responsibility for carbon emissions at the sectoral level using environmental input–output analysis. Several new emissions multipliers are proposed to measure sectoral carbon efficiency. These principles are used in an empirical analysis of carbon emissions in China, and differences between the principles are compared. The results indicate that all principles considered can prevent double-counting of emissions but that different principles may lead to significantly different attributions of responsibility for carbon emissions and to different multiplier values for particular sectors. *Electricity and heat supply* is found to be the sector with the highest emissions responsibility under all but the consumer responsibility principle, as well as the highest carbon multiplier under all principles. However, this sector's responsibility under producer responsibility principles is greater than that under other principles. *Basic metals* and *transportation* and *post and telecommunication* are among the top five sectors with the greatest responsibilities under all but the consumer responsibility principle, whereas *construction* has the highest consumer responsibility among all sectors. The pros and cons and policy implications of each principle are also discussed.

1. Introduction

In recent decades, a growing number of scholars have focused on the question of environmental responsibility: "who" should be responsible for the environmental impacts of economic activity, and how should responsibility be assigned? Environmental impacts may include the consumption of energy, material and natural resources; accompanying byproduct and waste production; and emissions and energy consumption associated with consumption of the products and services that are produced (WBCSD, 2000).

Many researchers (e.g., Ferng, 2003; Gallego and Lenzen, 2005; Lenzen and Murray, 2010; Lenzen et al., 2007; Marques et al., 2012; Rodrigues et al., 2006) agree that responsibility should be assigned to agents/actors in accordance with the benefits they receive. Similar to Gallego and Lenzen (2005) and Lenzen and Murray (2010), we will categorize agents in a circular economy, as described in an input–output (IO) table, into producers (companies) and agents exogenous to the IO system, including households, investors, the government and foreign importers and exporters. On the one hand, producers in a given sector use primary inputs from households (e.g., workers providing labor), the government (providing administration services), investors (donors of capital) and foreign exporters (providing imports) to produce commodities and sell those commodities both to producers in other sectors (as purchasers of intermediate inputs) and to final consumers, including households, the government, investors (as purchasers of capital) and foreign importers. On the other hand, the primary input providers receive income from producers: households as workers are rewarded with wages; the government collects taxes; investors gain dividends and profits; and foreign exporters obtain export revenues.

Thus, benefit could be defined as income generation and maintaining or enhancing living standards. Further, the benefits flowing to a given sector can be identified as revenue (total output) from products produced by the sector; final demand[1] supplied by the sector for (households and government) consumption, capital formation and exports; and income or value added that is ascribed to the sector.

The literature proposes three primary benefit principles for assigning environmental responsibility for pollutant emissions: the producer/production responsibility (PR) principle, the consumer/consumer responsibility (CR) principle and the income responsibility (IR) principle. The shared responsibility (SR) principle, which can be regarded as a compromise of the PR, IR and CR principles, is also discussed fully in the literature in recent years.

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[1] As defined by Lenzen and Murray (2010), intermediate inputs and outputs are commodities that are traded between companies to produce something else; final demand (output) is a commodity that is not used to produce something else.

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http://dx.doi.org/10.1016/j.eneco.2013.05.025

The PR principle, which implies that a producer (e.g., a company) is responsible for all environmental impacts of its production processes, is widely applied. If we regard a country as a producer, the PR principle is equivalent to a principle of territorial responsibility (Eder and Narodoslawsky, 1999).

However, many scholars (Lenzen and Dey, 2002; Munksgaard and Pedersen, 2001) favor adoption of the CR principle, which attributes responsibility for environmental impacts to consumers (households, the government and foreign importers). Some researchers (e.g., Peters and Hertwich, 2008) suggest adopting the CR principle as a strategy to avoid carbon leakage, which under the PR principle arises from international trade.

The IR principle is presented by Lenzen and Murray (2010) and Marques et al. (2012) as a mirror concept of CR and developed on the basis of previous work (e.g., Gallego and Lenzen, 2005; Lenzen et al., 2007; Rodrigues et al., 2006).[2] The IR principle assigns responsibility for emissions to the primary input providers (workers, investors, the government and foreign exporters), whose income is generated by activities associated with emissions. Although the IR principle has been applied in several studies (e.g., Lenzen and Murray, 2010; Marques et al., 2012, 2013; Zhang, 2010), it is not as popular as the CR principle because it has not been clearly defined (Lenzen and Murray, 2010). In recent work, Lenzen and Murray (2010) conceptualized and interpreted the IR principle in a way that is consistent with the CR principle. Marques et al. (2012) argue that the IR principle can also be applied to minimize carbon leakage. Marques et al. (2013) use the IR principle to study the effect of international trade on global carbon emissions.

The SR principle implies that producers, income recipients and consumers should all share environmental responsibility. Several studies in recent years have addressed the allocation of environmental responsibility under the SR principle. Ferng (2003) proposes a framework, based on an IO model for national GHG responsibility accounting that combines benefits and ecological deficits. Gallego and Lenzen (2005) develop two approaches, based on the classical Leontief and Ghosh (Ghosh, 1958) IO models, to calculate the environmental responsibilities of various agents under the SR principle. Lenzen et al. (2007) and Lenzen (2008) extend these approaches by appropriately defining sharing parameters. Lenzen (2007) and Andrew and Forgie (2008) apply these approaches to an evaluation of the GHG responsibilities of Australia and New Zealand. Rodrigues et al. (2006) recommend an alternative method of calculating responsibility under the SR principle by combining the Leontief and Ghosh IO models. These authors suggest that, under the SR principle, the average of the income and consumer responsibilities of an agent should be regarded as the agent's responsibility.[3]

It should be noted that an agent should be assigned responsibility not only for domestic emissions but also for foreign emissions (emissions embodied in imports in the case of CR and exports in the case of IR). If we focus on domestic emissions at the national level, single-region IO analysis is appropriate. However, if we account for both domestic and foreign emissions, single-regional IO analysis is inappropriate, as it cannot capture the international feedback effects in the global supply chain (Su and Ang, 2011). Thus, it is better to adopt multi-regional IO analysis to account for an agent's global responsibility. It is also worth noting that, in addition to the choice of responsibility principle used for analysis, many other factors such as sector (dis-)aggregation (Lenzen, 2007; Lenzen et al., 2007; Su et al., 2010) may affect the responsibility assignment of a particular agent. In addressing the issue of responsibility, we should keep these points in mind.

[2] Gallego and Lenzen (2005) refer to IR as “worker/investor responsibility.”

[3] In addition, Rodrigues and Domingos (2008a, 2008b) and Lenzen (2008) discuss in depth the policy implications of different approaches under the SR principle.

Table 1
Environmental-extended IO model.

	Intermediate input	Final demand	Total output
Commodities	$\mathbf{Z}$	$\mathbf{y}$	$\mathbf{x}$
Primary input	$\mathbf{v}^T$		
Total input	$\mathbf{x}^T$		
Emissions	$\mathbf{q}^T$		

The purpose of this paper is to compare principles to the evaluation of domestic sector emissions responsibility under various benefit principles. Additionally, we incorporate the SR principle into our sectoral carbon efficiency analysis. The remaining sections are organized as follows. Section 2 describes the IO techniques in sector environmental responsibility allocation; Section 3 presents an empirical study for China; Section 4 discusses the results; Section 5 concludes this work.

2. IO-formulated environmental responsibility and emissions multiplier at sectoral level

In this section, we consider seven principles to the evaluation of benefit-based sector emissions responsibility in an environmentally extended IO table, as in Table 1. Here, we define the benefit and responsibility of a sector as the total benefit and total responsibility assigned to its agents, including its producers, income recipients, and final consumers. The indicator used for sector emissions efficiency is the sector emissions multiplier, which is the ratio of responsibility to benefit. Assume there are n sectors in a nation. The meanings of the symbols in Table 1 are as follows:

- $\mathbf{x}$ is the output vector (all vectors are in column format by default), with element x_i denoting the direct output of sector i.
- $\mathbf{Z}$ is the domestic intermediate input matrix, with element Z_{ij} denoting the value of intermediate goods purchased by sector i from sector j.
- $\mathbf{y}$ is the final demand vector, with element y_i denoting the value of domestic final demand supplied by sector i.
- $\mathbf{v}$ is a vector, with element v_i denoting the primary input[4] of sector i.
- $\mathbf{A}$ is the intermediate input coefficient matrix, with element A_{ij} denoting the ratio of Z_{ij} to the total input of sector j, x_j.
- $\mathbf{B}$ is the intermediate output coefficient matrix, with element B_{ij} denoting the ratio of Z_{ij} to the total output of sector i, x_i.
- $\mathbf{q}$ is a vector, with element q_i denoting emissions directly arising from sector i.

We define a further set of variables as follows:

- Q is total emissions across all production processes.
- $\mathbf{e}$ is a vector, with element e_i denoting the direct output emissions intensity of sector i.
- $\boldsymbol{\beta}$ is the downstream sharing parameter vector, with element β_i denoting the share of responsibility, related to intermediate input Z_{ji}, that is allocated to sector i.
- $\boldsymbol{\alpha}$ is the upstream sharing parameter vector, with element α_i (which takes values in the range $0 \le \alpha_i \le 1$) denoting the share of responsibility, related to intermediate output Z_{ij}, that is allocated to sector j.

Superscript “T” denotes transpose.

The environmental IO model is a powerful tool for calculating indirect environmental impacts. Two types of IO models, the Leontief (demand-driven) model and the Ghosh (supply-driven) model, can

[4] We treat imported commodities purchased by a sector as a primary input.