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Exploring the characteristics of production-based and consumption-based carbon emissions of major economies: A multiple-dimension comparison

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HIGHLIGHTS

- Time-series multi-regional input-output models are constructed for accounting emissions.
- We compare consumption-based and production-based CO_2 emissions for 14 economies.
- Four categories of economies with significant different dynamic features are summarized.
- The relationships between per capita emissions and per capita GDP are analyzed.
- Consumption-based emissions are more obviously correlated with per capita GDP.

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ABSTRACT

Addressing climate change requires the efforts of all countries with common but differentiated responsibilities. The mitigation responsibilities one country takes greatly depends on its national emission inventories. As a good complement to the production-based accounting (PBA) principle, consumption-based accounting (CBA) principle has been widely concerned. However, few studies focus on emissions equity issues temporally and spatially. In this paper, we explore the characteristics of production-based and consumption-based CO_2 emissions for 14 major economies through multiple-dimension comparisons to get insight into the emissions equity comparisons among major emitters. In particular, four categories of economies with different dynamic features are divided based on their percentage differences between PBA and CBA emissions. Demographical and economic variables are additionally taken into consideration. The results indicate that France and Russia hold extreme characteristic on evaluating the emission difference between two principles, while China and Chinese Taiwan reveal uniquely increasingly larger gaps between two principle emissions. Besides, the per capita CBA emissions grows more prominently and possesses a more obviously positive correlation with their own per capita GDP which confirms that CBA principle is potentially attractive for estimating national emissions.

1. Introduction

1.1. Background

Climate change has become a great concern for the whole world, the main cause for which is greenhouse gas (GHG) emissions produced by human activities. Thus, accounting the national emission inventories (NEIs) for each country is not only essential to understand the source of GHG emissions but also helpful to provide a premise for carrying out climate negotiation agreements and mitigation actions. For this purpose, the Intergovernmental Panel on Climate Change (IPCC) has released guidelines for national GHG inventory since 1995 [1], and published several revised and updated versions continuously [2,3]. The United Nations Framework Convention on Climate Change (UNFCCC) requests the States Parties to report their annual territorial-based NEIs in accordance with the IPCC guidelines [3]. The territorial-based NEIs used by the UNFCCC are considered to be equivalent to the

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production-based NEIs, apart from the fact that the UNFCCC inventories do not allocate international transportation [4].

1.2. Production-based accounting (PBA) and consumption-based accounting (CBA) principle

Existing studies whether regarding national emissions [5,6], regional emissions [7,8] or sectoral emissions (e.g. residential sector [9–11], transportation sector [12], cement sector [13,14], steel industry [15,16]) are in the scope of production-based accounting (PBA) circumstance. However, the production-based accounting (PBA) system has received much criticism and questioning due to its ignorance of carbon leakage issues in the international trade [17–19]. Given that the carbon leakage is defined as the increase in emissions outside a region as a direct result of the policy to cap emissions in the region [20], under the PBA method, Annex B countries can achieve their emissions reduction commitment not only through improving energy efficiency, technical progress and other energy policies, but also easily by transferring high energy-consuming industries abroad and importing high emission-embodied products to meet domestic demand, thereby causing carbon leakage problems. Therefore, many scholars have proposed that the adoption of consumption-based NEIs is more reasonable compared with the production-based accounting NEIs [21–24].

The consumption-based accounting (CBA) principle calculates carbon emissions in accordance with the principle that *people who consume bear responsibility*. Under this scheme, even if the consumers do not directly produce CO_2 emissions, they should take responsibility for those emissions generated in the production processes of the goods they purchase (such as clothing, cars, housing, etc.); hence, it is known as the CBA principle. When applying CBA principle for estimating sectoral emissions within one country, it is usually called indirect emissions, for instance, some studies estimated indirect carbon emissions of residential sectors in China [9,25] and Baltic States [24]. Thus, two systems have been formed in connection with the accounting of NEIs: PBA and CBA principles.

1.3. Comparison of PBA and CBA principles

Both accounting principles have their own advantages and disadvantages. The PBA principle is simple and easy to calculate so that massive existing studies have focused on PBA principle are in the scope of PBA circumstances. But it ignores the factor of international transport and potential carbon leakage. The CBA principle not only calculates carbon emissions in international trade, but also has many other advantages, such as covering more global emissions with limited participation, increasing mitigation options, naturally encouraging cleaner production, and making policies such as the Clean Development Mechanism (CDM) as a natural element of the NEI [18]. However, this principle also has some disadvantages, including the complexity of its calculation, uncertainty, from one extreme to the other extreme measurement (which can be solved through shared responsibility), and the need to transcend the arena of geographical politics in order to make political decisions [4]. Even so, the CBA principle is still a strong complement to the PBA system [26,27].

These two principles account CO_2 emissions under different assumptions and from different perspectives. For example, Japan imports electronic equipment from China for end use. Assuming that the device is produced completely in China (from raw material inputs to final products), the emissions produced in the production of the device will be included in the NEI of China under the PBA principle, whereas they will be included in that of Japan under the CBA principle.

Therefore, when accounting national emissions, due to the existence of international trade, the PBA emissions for a country usually do not equal its CBA emissions. In other words, the CO_2 emissions generated in the production of a certain exported product in one country (PBA emissions) will transfer to the consumers of the importing country (CBA emissions); in contrast, the result for the imported goods is just the opposite. For example, China exports high energy-consuming and high emission products (such as cement, steel, etc.) while it imports high-tech products (mobile phones, computer chips, etc.) from the US, thus making its PBA emissions much larger than its CBA emissions; for the US, it is the opposite case. In 2007, China's exports to the US added 304.75 Mt extra CO_2 emissions onto its inventory, whereas the exports from the US to China only generated 25.53 Mt CO_2 emissions; as a result, 279.22 Mt (million tons) net CO_2 emissions added to China's inventory which accounts for 5.8% of China's total CO_2 emissions for that year [28].

1.4. Existing literature

Of the existing studies that calculate CBA emissions or embodied emissions in trade, most have paid attention to a specific country/region for individual years. For example, Feng et al. [23] calculated China's interprovincial and interregional CO_2 emissions outsourcing in 2007 by connecting China's provincial IO tables with Global Trade Analysis Project (GTAP) data, and found that 57% of China's emissions were driven by the consumption of other provinces. Liu et al. [29] also compared China's regional CO_2 emissions in 2002 and 2007, both under PBA and CBA principles. Muñoz and Steininger [30] employed the multi-regional input-output (MRIO) model and GTAP data to calculate Australia's PBA and CBA emissions, and the results showed that the emissions under the latter principle were 36% higher than those under the former in 1997; for the year 2004, the figure was 44%. However, few researchers have divided the world into several regions, such as Asia and EU areas and calculated emissions of regional consumptions [31,32].

In spite of the importance of equity issues across time and space [33], few of these studies focused on the international comparison analysis among multiple countries under a continuous time series, and even rare studies introduced the population and economic variables into the CBA and PBA emissions comparison. Apart from the difficulty in calculating, this may also lie in data scarcity, because the global time-series multi-regional input-output (MRIO) data is not always available. Until the World Input Output Database (WIOD) was openly accessed, related works began to emerge but unfortunately, most of them did not involve the CBA emissions with only a few exceptions. For example, the reports of Global Resources Use and Pollution, volume 1 [34] and volume 2 [35] did cover some emission indicators, but they just reported the consumption-based greenhouse gas (GHG) emissions in years 1995 and 2008 for individual economies and thus lacked the deep international comparison under time-series analysis framework.

Therefore, to make a contribution to filling the gap in the existing studies, this paper conducted arduous calculations of production-based and consumption-based national CO_2 emissions for many countries in terms of long-time series. This paper shed light on emissions accounting in the following aspects: (1) it explores the emissions differences between the two principles temporally and spatially, offering new insights for the future emissions accounting purpose; (2) it investigates the clustering characteristics for 14 large emission countries during the period of 1995–2009 and makes international comparison under the two principles, which provides scientific proof for the emissions reduction allocation with equity; (3) it examines the relationship between per capita emissions and per capita GDP under both the PBA and CBA principles, further exploring the emissions characteristics of different countries from perspectives of development

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