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From production-based to consumption-based regional carbon inventories: Insight from spatial production fragmentation

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HIGHLIGHTS

- We analyze the link from production-based to consumption-based accounting.
- We trace carbon transfer path along production chains at the spatial level.
- The average economic length of carbon transfer within China in 2010 was 1.34.
- Spatial production fragmentation hinders the shift of carbon accounting.
- There is a negative relation between economic length and magnitude of carbon transfer.

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ABSTRACT

The key distinction between production-based and consumption-based accounting lies in the way in which trade-embodied emissions are allocated between producer and consumer regions. Yet, these two regions are not necessarily directly connected to each other in supply chains, due to spatial production fragmentation. To better understand the link from the production-based to the consumption-based regional carbon inventories, this paper defines the economic length of carbon transfer (ELCT) as the number of administrative border-crossing involved in the influence process of a region's final demand on the carbon emissions of another region. Using a multi-regional input-output analysis framework for China, we propose an approach to calculating the ELCT related to a region's production or demand for domestic consumption or international export. We find that the average ELCT in 2010 is 1.34 and that more than a quarter of interregional carbon transfer crosses provincial borders twice or more. The provincial and sectoral analysis of ELCT reveals that spatial production fragmentation is an important challenge to be conquered for successful implementation of consumption-based climate regulations.

1. Introduction

To reflect consumers' responsibility for climate change, prior research [1–8] has proposed consumption-based accounting as an appropriate alternative to production-based accounting. The crucial difference between these two accounting approaches lies in the attribution of carbon transfer through cross-border trade flows. A growing number of previous studies [6,7,9–18] has evaluated the magnitude and direction of carbon transfer through interregional trade. Yet, little attention has been paid to an important feature of the modern economy, namely that the spatial production fragmentation has been significantly reshaping interregional trade patterns in recent decades [19]. For instance, trade in intermediate products accounts for approximately two thirds of the world gross trade, and intermediate products may cross provincial or national borders multiple times before they are finally absorbed into products purchased by consumers. A region's influence power on the carbon emitter decreases gradually with increasing border-crossing frequency because of international differences in fields of politics, economy and culture. Thus, this paper attempts to fill this research gap and analyzes the link from production-based to consumption-based accounting from the perspective of spatial production fragmentation.

For the traditional "Ricardian" trade pattern, only two regions are involved, and traded products cross their border only once [20,21]. The corresponding carbon transfer route is simple and allows an easy shift from the production-based to consumption-based accounting. With the

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development of spatial production fragmentation, several regions may be involved in the production chain of traded products, and the inter-regional carbon transfer routes become more complex. As noted by Turner et al. [22], regional jurisdictions provide the main reason for the difficulty in shifting from production-based to consumption-based accounting. With a greater number of regions/countries involved in the supply chains, it is more difficult to shift from production-based to consumption-based accounting because the producer and consumer regions are not necessarily directly connected to each other in global production networks. This problems call for a thorough analysis of carbon transfer from the perspective of spatial production fragmentation. Such a task is undertaken here by an analysis on the economic length of carbon transfer (ELCT).

This paper assumes that the economic distance between any two regions is one and uses the frequency of border-crossing of traded products [23] to define an average ELCT, which essentially accounts for the number of times a product is traded across regional borders. A smaller ELCT implies a more direct economic linkage between carbon emitters (i.e., producers of raw, intermediate or finished goods) and consumers; and a greater ELCT suggest that the emitter and the consumer are connected through multiple intermediate trading parties. For instance, the ELCT for the traditional “Ricardian” trade is one; whereas the intermediate products cross national borders multiple times. The magnitude of ELCT increases with the degree of spatial production fragmentation. Furthermore, the ELCT is directional and is related to but different from the geographical distance between regions. For example, the average ELCT from region A to region B (with A being the producer and B being the consumer) is not necessarily equal to the average ELCT from region B to region A (with B being the producer and A being the consumer).

Production-based and consumption-based accounting are two ways of handling carbon allocation along the supply chain [24]; the former allocates emissions occurring in the regional territory where production takes place while the latter allocates emissions to the region where consumption occurs. We believe a new insight into the nature and complexity of the gap between these two extremes from the perspective of spatial production fragmentation could also help in understanding the shared responsibility proposed by the literature [24,25]. Despite its importance, the shared responsibility is not the primary focus of this paper. In addition, the policy implications of this approach also lie in providing an important basis for trade-related climate regulations [26,27]. Considering the difficulty involved in the worldwide cooperation in carbon reduction, it is more feasible for the implication of the consumption-based accounting within a country’s territory boundary. Therefore, this paper distinguishes between provincial and national borders and focuses mainly on sub-national ELCT. The major contribution of this paper lies in remapping carbon transfer among different provinces in China from both perspectives of magnitude and ELCT. The paper is organized into five sections. Section 2 reviews the relevant literature. Section 3 describes the methodology used to calculate the ELCT. Section 4 presents the simulation results. Conclusions and policy implications are presented in Section 5.

2. Literature review

Production-based and consumption-based accountings are the two most common carbon accounting methods. Peters [5] proposes two approaches to shift from the production-based accounting to the consumption-based accounting. The first approach considers bilateral trade (EEBT) and does not distinguish between final and intermediate product trade. As the EEBT approach focuses on carbon emissions embodied in bilateral direct traded flows, its ELCT is always one. The second approach uses multi-regional input-output analysis (MRIOA), and intermediate product trade is endogenously determined, as are the effects of spatial production fragmentation on the allocation of carbon responsibility. In order to reveal the effects of spatial production fragmentation on the allocation of carbon reduction responsibility, this study decomposes the trade flow of all (intermediate and finished) products and derives the ELCT based on the MRIO data.

The present paper is closely related to the literature that evaluates the environmental effects of production fragmentation [18,19,23,28–39]. Dean and Lovely [28] find that production fragmentation reduces the pollution intensity of China’s exports while Meng et al. [36] have been able to trace carbon emissions along global value chains and thus to evaluate the environmental effects of cross-country production sharing. Lin et al. [33] evaluate the role of China’ international exports in that country’s air pollution, and their later works [34,39] analyze the impacts of global multi-lateral trade on climate forcing and public health and thus promote the idea of globalizing air pollution. Zhang et al. [19] test the pollution haven hypothesis from the perspective of global production fragmentation. The existing studies focus mainly on a country’s incorporation into the global supply chain [40], but the scale of interregional trade within some large countries, such as China [41], may be significantly greater than that of international trade. In particular, China’s rapid economic development in recent years has promoted the production fragmentation among different provinces [42,43].

The differences in regional carbon responsibility between a consumption-based and a production-based accounting can be explained from the perspective of carbon transfer. A growing literature exists on carbon transfer within China [4,9,35,44]. It is found that approximately half of China's emissions are induced by interprovincial trade and the net carbon transfer direction is from the central and western regions to the coastal region [4]. The central and western regions are China's important resource bases for raw materials that may be processed sequentially by several different regions. This means that the traded products may cross provincial borders multiple times, and thus the carbon transfer becomes much more complex. The existing studies focus mainly on the magnitude and direction of carbon transfer [6,7,14–17] and less on the inter-regional routes of carbon transfer. To the best of our knowledge, no studies have analyzed the carbon transfer within China from the perspective of the border-crossing frequency associated with traded products. Thus the present paper embraces the perspective of production fragmentation to provide new insight on carbon transfer within China.

The input-output model is also widely used to measure the production fragmentation by the number of production stages [45–50]. Dietzenbacher et al. [46] define the average production lengths (APL) to identify the production chains. Antràs et al. [45] propose the expression upstreamness to measure the position in production networks. The differences between APL and ELCT are summarized below. (1) The APL measures the economic distance between two sectors [46], and the ELCT measures the economic distance between the carbon emitting region and the final consuming region. (2) APL reflects the average number of production stages it takes a stimulus in one industry to affect another industry. ELCT is related to the number of regions that are involved in the interregional carbon transfer and focuses mainly on the transnational production stages. (3) APL could be adopted to analyze the production chains in a certain country (Dietzenbacher et al., 2005) based on single region input-output analysis framework. However, the calculation of ELCT is based on multi-regional input-output analysis framework.

Two approaches exist to calculate border-crossing frequencies associated with trade products. The first approach decomposes the intermediate input matrix [49,51]. Zhang et al. [23] propose a second approach that decomposes the Leontief inverse matrix. Zhang and Zhu [52] use this method to evaluate the effects of border-crossing frequencies on the effectiveness of trade-related climate regulations. This present paper extends Zhang et al.’s study [23] by highlighting another important policy implication of border-crossing frequencies associated with carbon footprints from the perspective of regional carbon accounting. From the methodological perspective, this present study