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Embodied cultivated land use in China 1987–2007

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ABSTRACT

The recent trend of rapid urbanization draws more and more concerns on the land use pattern in China. This study employs an ecological input–output model to reveal the impact of domestic consumption and international trade on cultivated land distributions in China during 1987–2007. According to the high-sectoral-resolution dataset, *Agriculture* and *Food Processing* are identified as the two key sectors which contribute the largest volumes of embodied cultivated land to meet household food demand in 2007. The indicators of production- and consumption-based cultivated land are highly correlated during the research period: both experience a phase of stability during 1987–1995, then a boom from 1995 to 1997, and a steady decrease afterward. Although the total cultivated land use in China is fluctuating, the embodied intensity shows a declining trend from 7.12 ha/thousand Yuan in 1987 to 0.43 ha/thousand Yuan in 2007, with an annual decrease rate of 13.09%. With respect to trade pattern, the *Agriculture* sector is China's largest net importer of cultivated land, in contrast to the *Textile* sector as the largest net exporter. When China is shown to be a net embodied cultivated land exporter throughout the concerned years, the variation of embodied cultivated land balance is closely related to the country's international trade pattern.

1. Introduction

As a populous country with about one fifth of the population but only 7% of the land area of the world, China is facing a severe food security situation (Chen, 2007). To cope with this, the Chinese government employs legislative measures to impose a "red line" restriction, i.e., 120 million hectares, for its cultivated land (Grassini et al., 2013; Wang et al., 2012). However, driven by the increasing food demand, expanding biofuel production as well as the rapid industrialization and urbanization in recent years, China is under unprecedented pressures on how to properly allocate its scarce cultivated land resources to meet future demands for goods and services (Qiang et al., 2013). Therefore, the research on China's cultivated land use becomes an urgent demand in the research field of land use. When the modern economic organization mode creates possibility to rematch resources supply and commodity demand by expanding the production chain or network, the indirect cultivated land use associated with consumption and trade flows has been a focus to achieve the cultivated land protection goal in China.

The interests for land use accounting in terms of consumption and trade can be dated back to the concept of "Ecological Footprint (EF)" proposed by Rees and Wackernagel in the 1990s (Rees, 1992, 1996; Wackernagel and Rees, 1996), defined as "the total area of productive land and water area required continuously to produce all the resources consumed and to assimilate all the wastes produced, by a defined population, wherever on earth that land is located" (Rees and Wackernagel, 1996). A standardized method, i.e., National Footprint Account (NFA), was later developed for EF accounting (Wackernagel et al., 1999, 1997) and then has been widely used in different spatial scales, including global (Wackernagel et al., 2013; Yu et al., 2013), national (Galli et al., 2012; Wiedmann, 2009) and urban scales (Chen, 2007). In 2003,Wackernagel and his colleagues established the Global Footprint Network (GFN), an international think tank working to advance sustainability through use of the EF based on NFA, which publishes the database of EFs for nearly 150 nations (Wackernagel et al., 2013).

Despite its great value in land resources accounting, the concept of EF is criticized for failing to depict the mutual interrelationships of economic activities and to assign the indirect environmental burden from inter-industrial dependencies (Costello et al., 2011). For

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example, though the concept aims to address consumer responsibility by summing up all the direct and indirect ecological impacts originated from a specific activity, it neglects the intrinsic linkages between consumption and resource depletion. Thus EF fails to reveal the causal relationship to trace back to the places where the ecological impacts really occur (Lenzen et al., 2007b).

In contrast, input–output analysis (IOA) is a well-established approach that allows resource flows and environmental impacts to be assigned to categories of final consumption through inter-industrial connection (Chen and Chen, 2013). The methodology provides a quantitative solution to represent the sectoral embodied ecological flows along with their economic counterparts based on the physical balance (Chen and Chen, 2011a). Resource uses and environmental emissions based on IOA have been quantified in different categories, such as energy consumption, water use, land use and greenhouse gas emissions (Guan et al., 2008; Guo and Chen, 2013; Guo et al., 2012a; Han et al., 2013; Ji et al., 2013; Peters, 2008; Weinzettel et al., 2013; Wiedmann, 2009). Especially, land use assessment based on IOA can be dated back to 1998, when Bicknell et al. (1998) proposed the method and applied it to New Zealand. Three years later, Ferng (2001) enhanced the applicability of the method by making several necessary corrections. Since then, a series of scholars have made great contributions to the development of IOA in the field of land use accounting (Galli et al., 2012; Lenzen et al., 2003, 2007a; Wood et al., 2006). Currently, this method has been widely adopted for land use accounting at global, national, urban and organizational scales (Hubacek et al., 2009; Lenzen and Murray, 2001; Wiedmann et al., 2006, 2007), showing its great significance for policy implications.

As to China's land use, GFN publishes EF report for the country annually using the NFA method (WWF et al., 2012). Moreover, many Chinese researchers have involved in applying or modifying the EF methodology for China: Liu and Peng (2004) calculated the time series of EF in China between 1962 and 2001. Chen and his colleagues assessed the natural resource use of China using modified EF method in a series of studies (Chen and Chen, 2006, 2007; Chen et al., 2006a, 2006b, 2007; Shao et al., 2013). However, only a limited numbers of studies focus on China's specific land use based on IOA. Hubacek and Sun (2001) calculated China's virtual land requirements by an input–output modeling to assess how the changes in the economy and society affect land use and land cover. Zhou and Imura (2011) calculated EFs for China 2000 based on a multi-region input–output model to trace the origin of regional consumption and to systematically account for the ecological impacts embodied in interregional trade. In spite of the scarcity situation of cultivated land in China, no research is specially targeted at cultivated land use based on embodied concepts, although there are already some studies concerning China's ecological footprints. However, the ecological footprint studies only take cultivated land as part of the research objectives, so that the cultivated land use pattern are not fully explained. To fill in this gap, this paper presents an embodiment analysis on China's cultivated land use with high sectoral resolution and time series input–output data, aiming at demonstrating how cultivated land in China is utilized to meet the requirements of domestic consumption and international trade during 1987–2007.

2. Methodology and data

2.1. Algorithm

In an attempt to calculate and compare quantitatively the embodiment of cultivated land in different economic activities, i.e., production, consumption, export and import, the ecological input–output model is used in this paper, whose origin dates back to Odum's ecological and general systems theory (Odum, 1983, 2000). The model integrates ecological endowments into economic network to reveal the resources profile associated with all the economic flows in and out the concerned system (Chen et al., 2013b; Guo et al., 2012b).

Up to now, the IOA methodology has been well developed, and some crucial assumptions and data aggregation have both been discussed in a series of studies (Su and Ang, 2010, 2011, 2013, 2014; Su et al., 2013). The empirical results vary with different model assumptions. Due to the data availability, it is assumed in current research that:

1) The approach used in this study is based on the emissions avoided by import assumption, i.e., imported commodities have the same embodied cultivated land intensities as domestic ones due to the limitation of import intensities, though the imported commodities show a substantial difference from domestic ones (Su and Ang, 2013).
2) Constrained by the availability of economic and environmental data in export trade, the study uses the uniform export assumption and thus does not distinguish the processing and normal exports (Su et al., 2013).

Embodied cultivated land intensity of a specified sector is defined as the sum of direct and indirect cultivated land use in the whole supply chain to produce per unit monetary value of the targeted good/service (Yang et al., 2013), which is different from EF aggregating different kinds of land resources into one common denominator (Qiang et al., 2013). The calculation of embodied cultivated land flows relies on a database including the embodied intensities of every commodity within the economy. To obtain the intensity database, the ecological input–output table integrating direct cultivated land uses and economic flows is compiled as shown in Table 1, in which l_j stands for the direct cultivated land use by Sector j, z_{ij} the economic value of intermediate inputs from Sector i to Sector j, f_j the economic value of output from Sector j used as final consumption, e_{xj} the economic value of export from Sector j and x_j the economic value of total output from Sector j.

Based on the ecological input–output table, the sectoral biophysical balance for the embodied land flows can be formulated as:

$$\varepsilon_j x_j = \sum_{i=1}^{n} \varepsilon_j z_{ij} + l_j, \tag{1}$$

where ε_j is the embodied cultivated land intensity of good/service from Sector j.

Then for all the interactive sectors, the aggregate matrix form of Eq. (1) can be deduced as:

$$EX = EZ + L, \tag{2}$$

where the direct cultivated land use matrix $L = [l_j]_{1\times n}$, embodied cultivated land intensity matrix $E = [\varepsilon_j]_{1\times n}$, intermediate input matrix $Z = [z_{ij}]_{n\times n}$, and total outputs matrix $X = [x_{ij}]_{n\times n}$, in which $i, j \in (1, 2, ..., n)$, $x_{ij} = x_j (i = j)$ and $x_{ij} = 0 (i \neq j)$.

Then the embodied cultivated land intensity matrix E is calculated as:

$$E = L\ (X - Z)^{-1}. \tag{3}$$

This paper calculates and compares production-based cultivated land use (direct cultivated land use related to production activities for a targeted sector/system) and consumption-based cultivated land use (embodied, i.e. direct and indirect, cultivated land related to consumption activities for a targeted sector/system) (Cadarso et al., 2012) flows of China, which are instrumental in