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Guo S., Shen G.Q.P., Chen Z.M., Yu R. (2014). Embodied cultivated land use in China 1987–2007. Ecological Indicators 47, 198-209.

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 hectares/thousand Yuan in 1987 to 0.43 hectares/thousand Yuan in 2007, with an annual decrease rate of 13.09%. With respect

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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.

Key Words: Cultivated land use, input-output analysis, international trade, China

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; Wackernagel et al., 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,Wackernageland 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 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 et al. (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., 2007a; Lenzen et al., 2003; 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., 2007; Wiedmann et al., 2006), 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 1962～2001. 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; Chen et al., 2007; Chen et al., 2006b; 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 modelling 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.

Table 1

Basic structure of ecological input-output table (revised from Chen et al. (2010)).

Input / Output		Intermediate use				Final consumption					Export	Total output
		Sector 1	Sector 2	…	Sector n	Household consumption (Rural)	Household consumption (Urban)	Government consumption	Fixed capital formation	Inventory increase		
Intermediate inputs	Sector 1	z_{11}		…	z_{1n}			f_1			e_{x1}	x_1
	Sector 2											
	…	⋮		…	⋮			⋮			⋮	⋮
	Sector n	z_{n1}		…	z_{nn}			f_n			e_{xn}	x_n
Direct cultivated land use		l_1		…	l_n							

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 determining the distributing burden of each agent for cultivated land protection.

The production-based cultivated land, notated as ELP, is equal to the direct cultivated land use (Chen and Zhang, 2010), given as

$$ELP_j = L_j, \tag{4}$$

The consumption-based cultivated land, notated as ELC, is the cultivated land embodied in the whole supply chain of goods/services consumed by final consumption activities within the targeted system (Chen and Chen, 2011b). The final consumption activities are usually divided into five categories according on China's input-output statistics, namely, rural consumption, household consumption, government consumption, fixed capital formation and change of inventories.

$$ELC_j = \varepsilon_j F_j \, , \tag{5}$$

where F_j is the final consumption from Sector j.

International trade plays a significant role in redistributing the cultivated land resources through the trading products. Embodied cultivated land in imports (ELI) and embodied cultivated land in exports (ELE) are two important indicators to reflect the trading pattern in terms of cultivated land resources (Chen et al., 2013a). The difference of ELE and ELI is defined as embodied cultivated land trade balance, ELB. A positive ELB makes the country a net supplier of cultivated land resources in international trade (which means cultivated land deficit in footprint terminology) and a negative value implies it is a net receiver of cultivated land welfare from other countries (cultivated land overshoot in footprint terminology) (Chen and Chen, 2011c). The three indicators can be formulated as:

$$ELI_j = \varepsilon_j I_{mj}, \tag{6}$$

$$ELE_j = \varepsilon_j E_{xj}, \tag{7}$$

$$ELB_j = ELE_j - ELI_j, \tag{8}$$

where I_m denotes the imports from other regions.

To reflect the industrial-wide profiles of ELP, ELC, ELI and ELE along with the change of technological level, trading structures and policies, this paper makes horizontal comparison between sectors within the same time frame of 2007 to show the "common but differentiated" industrial responsibilities for cultivated land protection. At the same time, vertical comparison during 1987-2007 is presented to depict the changing trend to provide insight on the underlying incentive factors.

2.2 Data sources

In order to explore the time serial cultivated land data adequately, a detailed review on the development history of China's land statistical record system is helpful. Before 1999, land statistical record system of China was not established so that cultivated land data were integrated in and released by certain comprehensive statistics reports, such as Annual Report of the National Bureau of Statistics China, instead of by specific land use reports. Since 1999, land use data have been published regularly by the Ministry of Land Resources through several specific reports including China Land & Resources Almanac (1999-2012), China Communiqué of Land and Resources (1999-2012) and China Land and Resource Statistical Yearbooks (2005-2013). The latest updated report released by the end of 2013 provides land use information for the year of 2009 (Zhu, 2013). On the basis of the above data sources, Ministry of Agriculture synthesizes the cultivated land data between 1983 and 2008 in the Agricultural Development Report (2001-2013) and China Agriculture Yearbook (1980-2013). The cultivated land data of China used in this study, i.e., data over the period of 1983-2009, are obtained from the two statistics report and yearbook released by Ministry of Agriculture.

IOA was proposed by Leontief in the 1930s, which could be used to clarify the economic linkages among production and consumption activities based on the cross sector balance (Zhang et al., 2013). The national input-output tables published by National Statistical Bureau of China are used in this study. The first official input-output table for China is that for 1987, since which the benchmark tables are compiled every five years. Besides, extended tables are also compiled based on the latest benchmark tables every five years since 1990. Up to present, there are ten official national input-output tables for China, i.e., tables for 1987, 1990, 1992, 1995, 1997, 2000, 2002, 2005, 2007 and 2010 (Cao and Xie, 2007). With the available economic input-output table and cultivated land use data in China, this paper conducts a time-serial research during 1987-2007. To reflect the purchase power change during the research period, corresponding GDP deflators (see Appendix Table A1) are used to adjust price level to the base year of 1987.

3. Results and discussions

3.1 China's embodied cultivated land use in 2007

3.1.1 Intensity

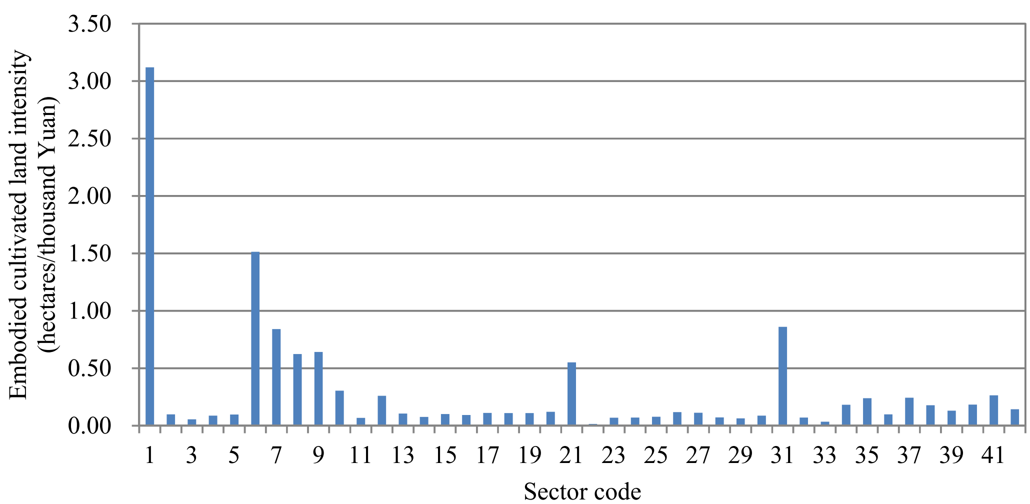

Fig. 1. Embodied cultivated land intensity by sector in 2007.

The embodied cultivated land intensities of the 42 sectors (sector information is provided in Appendix Table A2) for China 2007 are presented in Fig. 1. Sector 1 (*Agriculture*) has the highest intensity of 3.12 hectares/thousand Yuan, followed by Sectors 6 (*Food Processing*), 31 (*Hotels, Catering Service*) and 7 (*Textile Industry*) with intensities of 1.51, 0.86 and 0.84 hectares/thousand Yuan, respectively. All these four sectors are closely related to necessaries of daily life for residences, i.e., food and clothing, the production of which are highly associated with farm crops. In terms of more aggregated economic level, the average intensity of primary industries (3.12 hectares/thousand Yuan) is 9.93 times higher than that of secondary industries (0.29 hectares/thousand Yuan) and 16.94 times higher than that of tertiary industries (0.17 hectares/thousand Yuan). The huge industrial difference shows that industrial structure adjustment has great influence on cultivated land management in China.

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3.1.2 Trade

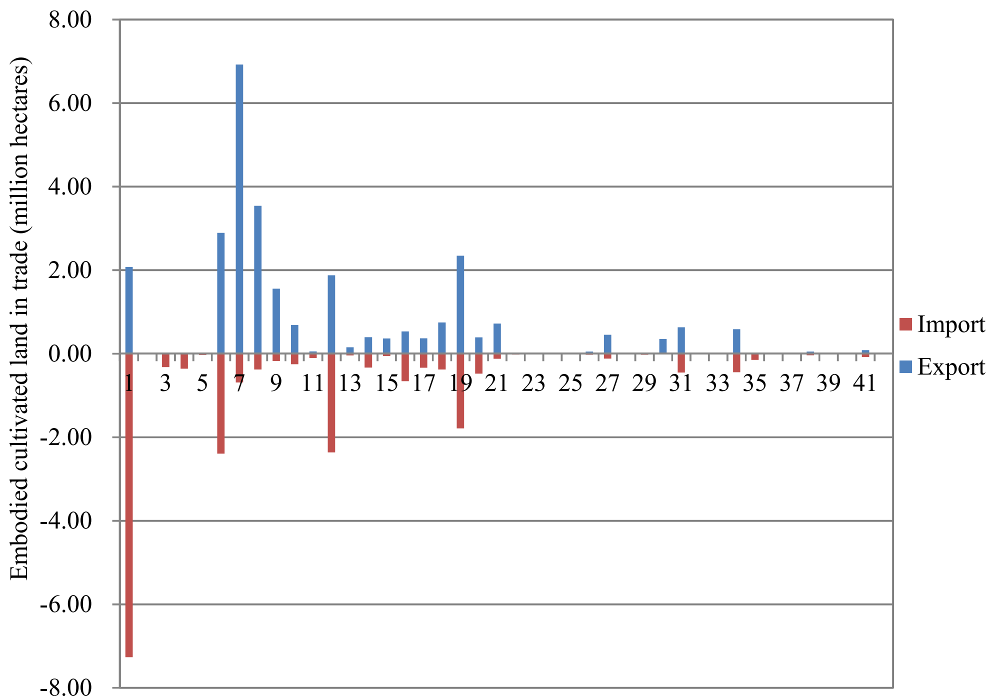

Fig. 2. Embodied cultivated land in trade by sector in 2007.

The distribution of embodied cultivated land in trade of the 42 sectors for China 2007 is presented in Fig. 2. For ELI, the largest importing sector in China is Sector 1 (*Agriculture*, 7.27 million hectares), followed by Sectors 12 (*Chemical Products*, 2.36millionhectares), 6 (*Food Processing*, 2.39million hectares) and 19 (*Telecommunications Equipment*, 1.79E million hectares). With respect to ELE, Sectors 7 (*Textile Industry*), 8 (*Garments*) and 6 (*Food Processing*) rank the top three with the values of 6.92, 3.54 and 2.89 million hectares. In terms of sectoral trade balance, Sector 1 (*Agriculture*) is the largest net importer of embodied cultivated land in China, while Sector 7 (*Textile Industry*) is the largest net exporter. Actually, China has entered an era of being net importer of agricultural products, especially for the three major staple grain crops of wheat, rice and corn, and the import dependency has a remarkable rising trend in the past 10 years (Xiaoyun, 2013). Therefore, China should take responsibility for occupying foreign agriculture land through the growing agricultural product trade. As a net exporter of cultivated land with total ELI and ELE of 19.92 and 27.97 million hectares, China transfers too much cultivated-land-intensive products, e.g., textile products, to other countries, especially under the circumstance that cultivated land resources are so scarce in this country. Therefore, it's important to establish strict export policies for these cultivated-land-intensive products.

3.1.3 Consumption

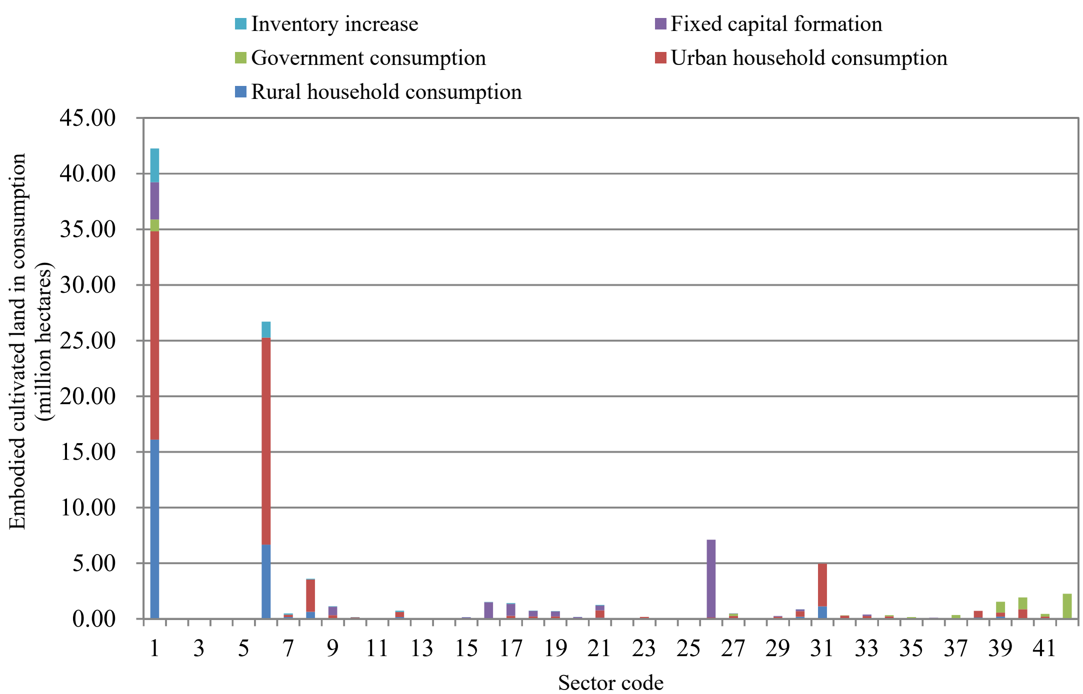

Fig. 3. Embodied cultivated land in consumption by sector in 2007.

Shown in Fig. 3 is ELC of the 42 sectors for China 2007. Sectors 1 (*Agriculture*) and 6 (*Food Processing*) embody the first and second largest volumes of cultivated land with 42.26 and 26.70 million hectares, mainly attributed to household consumption to meet the increasing food demand. Sector 26 (*Construction*) provides the third largest embodied cultivated land of 7.12 million hectares due to its significant fixed capital investment, even though the sector has a very lower embodied cultivated land intensity of 0.12 hectares/thousand Yuan. Sector 31 (*Hotels, Catering Service*) also accounts for considerable ELC, which is mainly contributed by urban household consumption of food in restaurants.

3.2 China's embodied cultivated land use during 1987-2007

3.2.1 Temporal change of efficiency

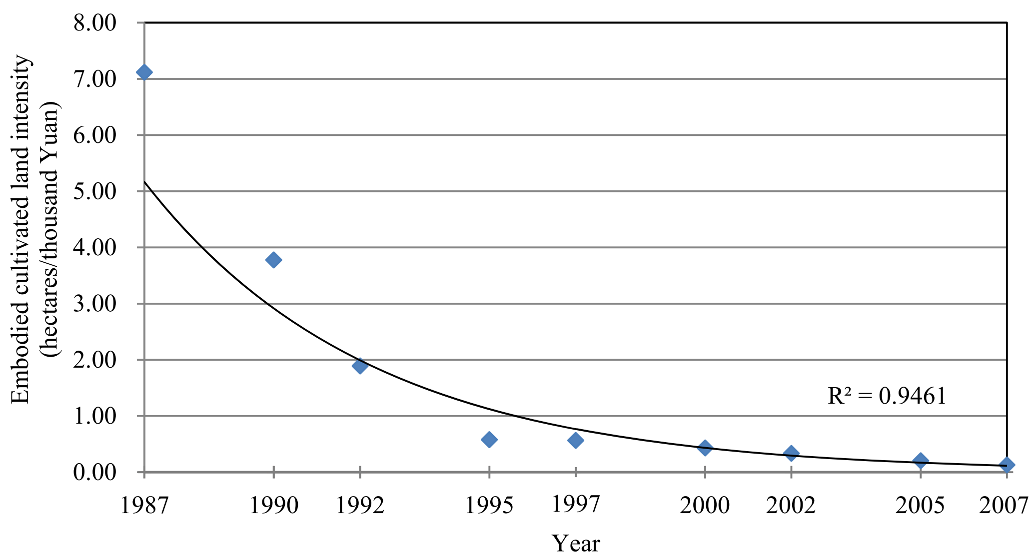

Fig. 4. Embodied cultivated land intensity, 1987-2007.

The cultivated land use efficiency is a measure of the overall (including direct and indirect) cultivated land costs per economic output, which can be expressed as the embodied cultivated land intensity. Fig.4 compares the embodied cultivated land intensities of the concerned years. The embodied intensities for these 20 years show a downward trend, declining from 7.12 to 0.13 hectares/thousand Yuan. The exponential trend line is simulated with a high goodness of fit as represented by a high R^2 value of 0.9461. The result shows China's effort and effectiveness to improve cultivated land use efficiency through technical development, land policies and industrial and trade structures adjustments. However, the average annual decrement rate has been declining from 1.11 to 0.04 hectares/thousand Yuan during this period, which shows the potential of increasing efficient to conserve cultivated land use is quite limited in the future. Therefore, China need to devote more effort to develop an integrated cultivated land use management mode combined with modern agricultural technology application and economic structure adjustment.

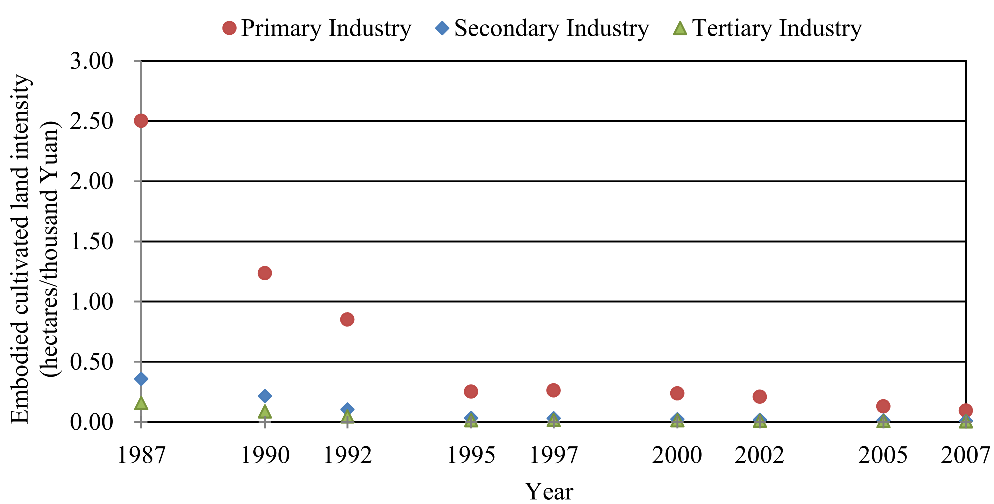

Fig. 5. Embodied cultivated land intensity by three major industries, 1987-2007.

Industrial structure analysis is identified as an important aspect in IOA, thus industrial embodied cultivated land intensity changes in China during 1987–2007 are showed as Fig. 5. In the intra-industry comparison, all the embodied cultivated land intensities of three major industries during the concerned years show downward trends: Embodied cultivated land intensity of primary industry declines greatly from 2.50 to 0.09 hectares/thousand Yuan, which can be attributed to the improvement of cultivated land use efficiency. By contrast, embodied intensities of secondary and tertiary industries drop slightly from 0.36 to 0.01 hectares/thousand Yuan and from 0.16 to 0.01 hectares/thousand Yuan, respectively. In the inter-industry comparison, a huge difference of three major industries is shown in 1987, that is, the intensity of primary industry is 5.98 and 14.83 times higher than the level of secondary and tertiary industries. But with the agricultural production technical development, the industrial difference of embodied cultivated land intensity has been narrowed over years. In 2007, the intensity of primary industry is reduced to the same level as the secondary and tertiary industries, demonstrating the limited improving potential of direct cultivated use efficiency in the future. Therefore, the industrial structure change will play an increasing important role in protecting cultivated land, and more emphasis should be given to the industrial structure adjustment in policy implications.

3.2.2 Temporal change of trade pattern

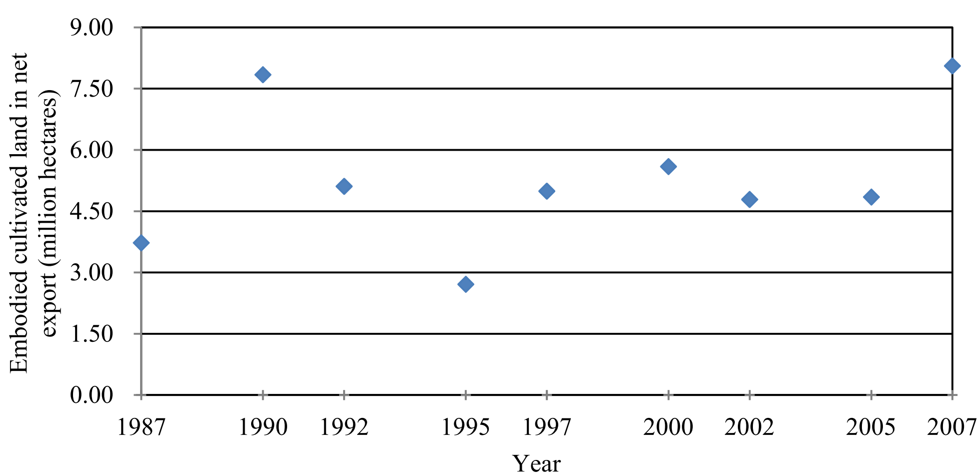

Fig. 6. Embodied cultivated land in trade balance, 1987-2007.

From the perspective of trade balance, China is consistently a net exporter of cultivated land during 1987-2007 (see Fig. 6), which demonstrates that China has been a cultivated land supplier for the globalized economy. Despite receiving embodied cultivated land deficit during the whole research period, China's ELB varies greatly. The minimum ELB of 2.71 million hectares is obtained in 1995, while the largest two values are received in 2007 and 1990 with 8.06 and 7.84 million hectares. The fluctuation can be attributed to the evolutions of China's international trade system and trade structure. Since the reform and opening up in 1978, the volume of international trade of China continues to climb. In 2003, China overtook the United States and became the largest trading nation in the world. With the increasing net export volume but decreasing embodied cultivated land intensity, the EBL varies during 1987-2007. In the future, China will open itself wider to the outside world and the trade volume will keep in a high level. Therefore, how to balance the economic and environment benefits and avoid the cultivated land loss are highly important for the country. Downsizing the cultivated-land-intensive industries scale and adjusting the trade structure are two main factors for relieving the cultivated land use pressures. China's trade structure has changed significantly during the past decades: export structure changed from primary products dominated to manufactured goods dominated in the 1980s, from mainly light industrial and textile products to mainly mechanical and electronic products in the 1990s, and from traditional products to electronics and information technology commodities in the 2000s (IOSC, 2013). All these changes follow the cultivated land resource-conserving principle, that is, from cultivated-land-intensive industries dominated to lower-intensity industries dominated.

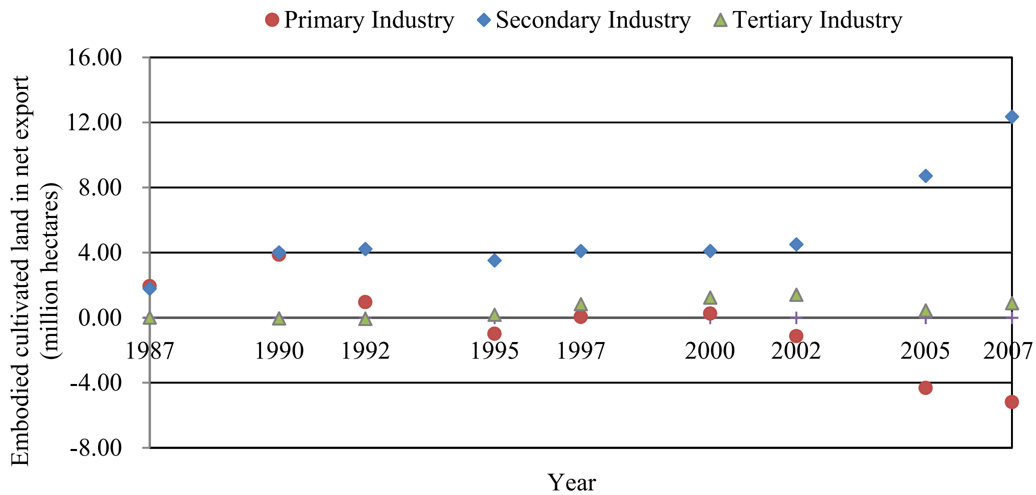

Fig. 7. Embodied cultivated land in trade balance by three major industries, 1987-2007.

The embodied cultivated land in trade balance of three major industries shows different trends as shown in Fig. 7. Primary industry changes from a net exporter to a net importer during 1987-2007 due to food demand growth, domestic and foreign price variance of agricultural product, which make China meet the challenge of agricultural production scarcity and food safety. The embodied cultivated land in net export of the secondary industry increases sharply since 2002, when China entered World Trade Organization (WTO) and became the "world factory" contributed by the fast growing manufacturing industry. The tertiary industry keeps a trade balance during the concerned years. To sum up, ELB's inflection points of the three industries arrives at 1990 and 2002, corresponding with some significant trade policies, such as China's market economy system reform and China's entering WTO.

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3.2.3 Production- versus consumption-based embodied cultivated land use

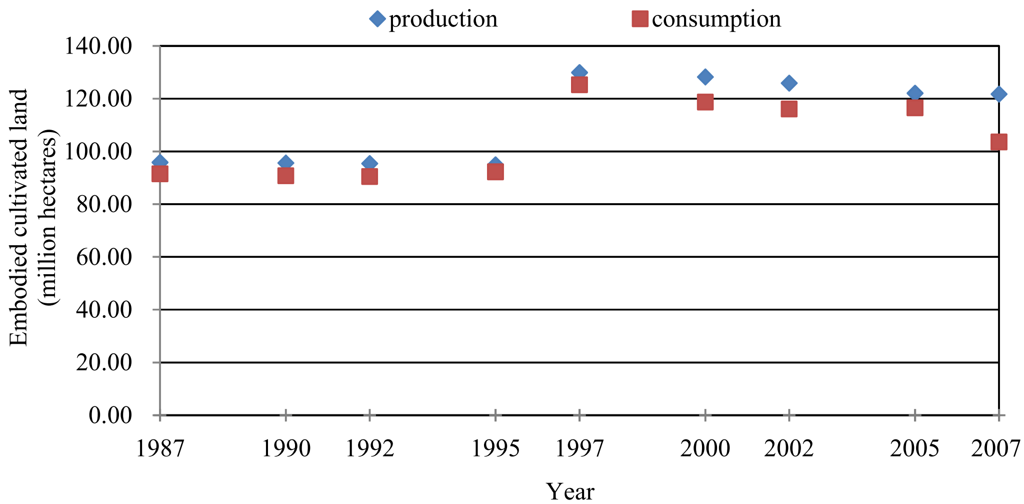

Fig. 8. Production- versus consumption-based embodied cultivated land use, 1987-2007.

Shown in Fig.8 is the comparison of production- and consumption-based embodied cultivated land during 1987-2007. The total cultivated land area in China from the perspective of production sees a modest decrease from 95.89 million hectares in 1987 to 94.97 million hectares in 1995, dropping by 0.12%. The cultivated land has a great increase of 18.39% in the next two years, which might be largely contributed by the change of land statistic system (Zhu, 2007). The next decade experiences a moderate downward trend from 129.90 million hectares to 121.74 million hectares. Under the stringent cultivated land protection policies made in the 11th Five-Year Plan to retain at least 120 million hectares of cultivated land, Cui and Kattumuri (2011) believe that most of the cultivated land loss during recent years can be attributed to ecological restoration and urban expansion. For example, 58.7% of the abandoned cultivated land lost used for ecological restoration between 1997 and 2008 (Comin, 2010). On the other hand, China has entered a period of accelerating urbanization, leading to the changes of industrial structure and corresponding land use pattern, which means the built-up land is also taking up a lot of cultivated land (Chen, 2007).

The consumption-based embodied cultivated land shows a similar changing trend: it decreases from 91.51 million hectares in 1987 to 90.53 million hectares in 1992, then slightly increases to 92.26 million hectares in 1995 and sharply increases to 125.28 million hectares in 1997. After that, it gradually decreases to 103.60 million hectares in 2007 with the descent rate of 1.73% per year. However, the cultivated land embodied in consumption is always smaller than the direct cultivated land use within China's territory in 1987-2007, and the difference is expanding. This result shows that China has paid a high cultivated land resource cost to satisfy consumption outside its territory. Therefore, corresponding trade policies avoiding the virtual cultivated land resources leakage are required in China based on the consumer responsibility principle. Meanwhile, from the perspective of production principle, China should make great efforts to develop high-tech agriculture and adjust the industrial structure to improve cultivated land use efficiency. Only by the criterion of responsibilities shared both as the producer and the consumer, the cultivated land in China can be protected and exploited to the greatest extent.

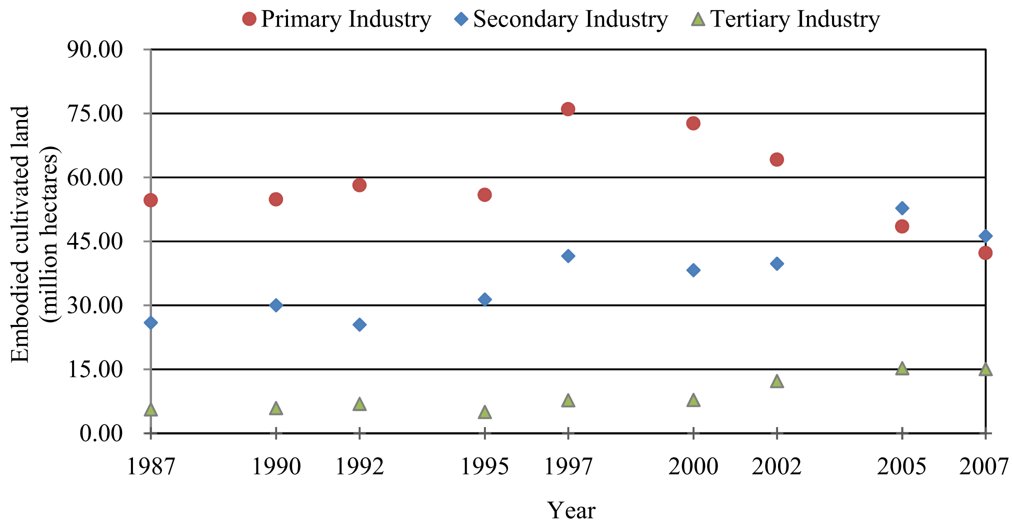

Fig. 9. Consumption-based embodied cultivated land use by three major industries, 1987-2007.

From the perspective of production, cultivated land resources are all occupied by the agricultural sector. While from the perspective of consumption, cultivated land resources are assigned to all the economic sectors. For the three major industries, primary industry utilizes the largest proportion of ELC during 1987-2002, but ELC by the secondary industry surpasses the primary industry since 2005 with China's fast process of industrialization and urbanization. The tertiary industry's ELC increases in fluctuation but still only occupies the smallest resources among these three major industries. The above results imply the consumption of secondary and tertiary industries will have greater influence on the cultivated land use in China due to the upgrading of domestic industrial structure.

4. Discussions

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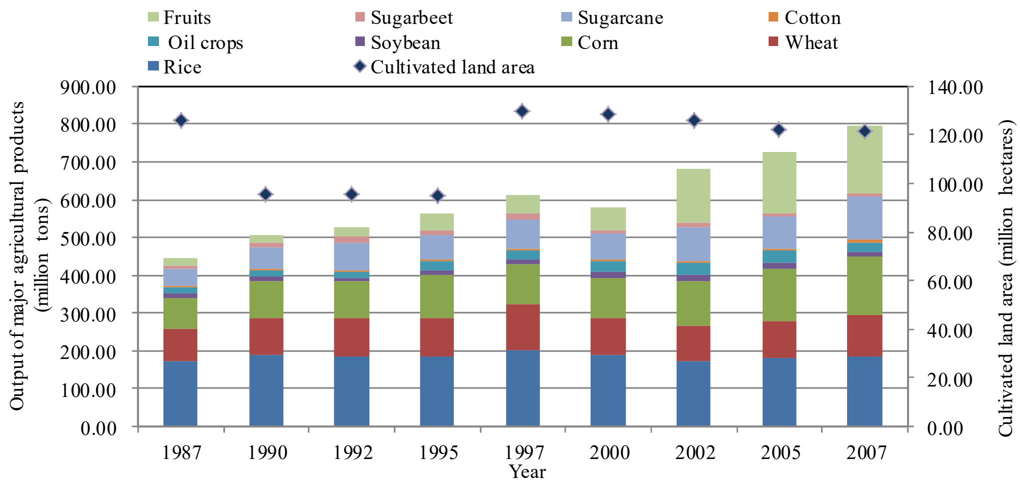

Fig. 10. Output of major agricultural products and cultivated land area change, 1987-2007

Demographic pressure and increasing competition for land in China are likely to increase vulnerability to food security. This study illustrates the embodied cultivated land use in China to meet the requirements of domestic consumption and international trade during 1987-2007. Cultivated land area coupled with agricultural products should be of concern when facing a severe food security situation. Fig. 10 compares the output of major agricultural products and the responding cultivated land area to illustrate the linkage of agricultural products and cultivated land resources. China's cultivated land area has a general trend of fluctuations during 1987-1997, then it levels off in the next ten years. However, the output of major agricultural products increases steadily during 1987-2007, mainly driven by the significant increasing trend of fruits products. China has been the largest fruits production country with the yield rising from 16.68 million tons in 1987 to 181.36 million tons in 2007. As the most important agricultural crops, cereal crops, including rice, wheat and maize, have a relatively steady yield. Grassini et al. (2013) estimated that about 30% of the global cereal crops have reached their maximum possible crop yield potential. The production proportion of cereal crops drops from 39.29% to 23.34% during 1987-2007 followed by the growth of other agricultural production.

5. Conclusions and policy implications

The evolution of China's cultivated land use policies is closely related to the economic and social changes and has shown different features in different periods. Before the reform and opening up in China, the cultivated land use policy subordinated to the planned economy policy. The land tenure system was established to separate ownership and use right in the 1980s (Wang et al., 2012). Associated with the land tenure system, a series of laws and regulations were promulgated, including Agriculture Law, Land Management Law, Water and Soil Conservation Law, Equilibrium of Requisition-Compensation of Cultivated Land, etc. (Yang and Li, 2000). Afterward, the 11th Five-Year Plan set a goal that "the total area of cultivated land in China stays above the 'red line' of 120 million hectares", which is the bottom-line area of cultivated land in China (Cui and Kattumuri, 2011). In addition, the marketization of land resources has been initiated based on the "double maintenance policy-making strategy" of maintaining economic development and land resources conservation (Wang et al., 2012). To fully realize land marketization and balance better demand and supply of cultivated land, it's necessary to know the economic driving forces of cultivated land use.

During recent years, the issue of cultivated land conservation in China is becoming more and more important owing to the increasing food demand, the expansion of biofuel production, and especially, the rapid urbanization (Fan et al., 2013; Qiang et al., 2013). For example, the urban areas of China increased by almost 25% during the 1990s, resulted in massive cultivated land loss (Jiang et al., 2013). Acknowledging the scarcity of cultivated land in China, studies on how cultivated land in China is distributed to meet the requirements of consumption and trade based on IOA are relatively few. Under these circumstances, an ecological input-output modelling is carried out in China to analyze the cultivated land embodied in domestic consumption and international trade in 2007 with sectoral details. Further, to identify the factors influencing China's embodied cultivated land resources utilization, a temporal simulation of ELP, ELC, ELI and ELE during 1987-2007 is conducted. Specific results are as follows:

(1) Sectoral analysis on China's embodied cultivated land use.

With regards to China's cultivated land in 2007, Sector 1 (*Agriculture*) has the highest embodied intensity of 3.12 hectares/thousand Yuan, followed by Sectors 6 (*Food Processing*), 31 (*Hotels, Catering Service*) and 7 (*Textile Industry*), which are all closely related to residents' daily lives. Based on the intensity database, the sectoral distributions of cultivated land embodied in trade and consumption are presented. Sector 1 (*Agriculture*) is the largest net embodied cultivated land importing sector of China due to its high dependency of foreign agricultural products, while Sector 7 (*Textile Industry*) is the largest net exporter since China is the largest producer and exporter of textile. Sectors 1 (*Agriculture*) and 6 (*Food Processing*) have the largest ELCs with 42.26 and 26.70 million hectares to meet the household food demand.

(2) Temporal analysis on China's embodied cultivated land use.

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China's embodied cultivated land intensities during 1987-2007 show a downward trend, declining from 7.12 to 0.43 hectares/thousand Yuan, showing China's effort and effectiveness to improve the cultivated land use efficiency. Despite receiving embodied cultivated land deficit during the whole research period, China's cultivated land embodied in trade balance varies greatly from the minimum of 2.71 million hectares in 1995 to the maximum of 8.06 million hectares in 2007, which are closely related to the evolutions of China's international trade system and trade structure. The production- and consumption-based cultivated land use patterns show similar shape trends: changes moderately during 1987-1995 and 1997-2007 but has a sudden rise from 1995 to 1997.

According to the industrial analysis of embodied cultivated land in this paper, it's necessary and important to establish the shared responsibility criterion in all the industries for cultivated land conservation. The obligation of cultivated-land-intensive industries is to improve land utilization efficiency by means of technical development and resources reallocation. For example, agricultural mechanization and automation are highly instrumental in effective use of cultivated land in Sector 1 (*Agriculture*). Yet industries with lower cultivated land intensity are to make greater contribution to consumption and trade activities. More export products from high-tech and service industries occupying less cultivated land resources are very helpful to restrict the outflow of cultivated land resources from China.

In order to provide a consistent data supporting basis for policy making, it's important to establish the historical cultivated land database regularly by an effective accounting mechanism. According to the results of this study, China has paid a high cultivated land resource cost to satisfy consumption outside its territory, though a downward trend of embodied intensities for the 20 years confirms the country's effort and effectiveness to improve cultivated land use efficiency. Encouragingly, China places high priority on trade structural change, i.e., increasing export of manufactured, high-tech products such as electronic devices (with lower cultivated land intensity) to replace the traditional, low-end products such as textile (with higher cultivated land intensity), which is beneficial to balance the economic and environment benefits and avoid cultivated land loss.

Our attempt to evaluate China's cultivated land use during 1987-2007 has several limitations. First, this study tries to analyze China's overall cultivated land resources, which are aggregated into only one sector (Agriculture Sector) but not separated into different sectors based on the cultivated land use types due to the data availability. Therefore, the embodied cultivated land intensities of different agricultural products are equal since they derive from the same industrial sector. However, to facilitate a better examination of China's cultivated land protection policies, a much more detailed understanding about various cultivated land use types for different agricultural products in China requires further research. Second, as in conventional input-output studies, it is assumed that imported commodities have the same embodied cultivated land intensities as domestic ones due to the limitation of import intensity data, though the imported commodities show a substantial difference from domestic ones (Weber et al., 2008). Third, different sector classifications from different original input-output data sources are used in this study, which impedes detailed sectoral comparison. Sector consistency is required if a comparative study is conducted (Su et al., 2010). But corresponding error will be generated due to different sector classifications in China's original IO tables. However, this research focuses on the comparison of China's overall cultivated land change, which is not sensitive to the level of sector classification. Therefore, this paper doesn't consider sector classifications difference and sector aggregation or disaggregation. If the sector aggregation or disaggregation is considered in this study, additional sector aggregation or disaggregation error also needs to be analyzed. Fourth, China's land statistic system was set up in 1987, since then, the statistic procedures have experienced three stages: before 1996, information was collected from year-round survey from Jan 1st to Dec 31st; then during 1996-2006, the survey was adjusted to cover from only Mar 1st to Oct 31st of a year; since 2007, the survey was reverted to the initial year-round standard (Jiang, 2013; Wang et al., 2012). The change in the land data collection procedures has a negative impact on data quality and consistency, which increases difficulties for time-serial study. However, as land use pattern is comparatively stable during a year at the national scale, the data discrepancy introduced from collection procedure changes is considered to be acceptable for this study. Last but not least, this study applies national GDP deflators to adjust price change instead of using other price indicators. It should be noticed that price change during the research period varies from sectors to sectors and thus a more detailed sectoral price level indicators can portray such variation more precisely. However, due to data limitation the sectoral level price indicator is not available in this study.

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References

Bicknell, K.B., Ball, R.J., Cullen, R., Bigsby, H.R., 1998. New methodology for the ecological footprint with an application to the New Zealand economy. Ecological Economics 27, 149-160.

Cadarso, M.Á., López, L.A., Gómez, N., Tobarra, M.Á., 2012. International trade and shared environmental responsibility by sector. An application to the Spanish economy. Ecological Economics 83, 221-235.

Cao, S., Xie, G., 2007. Applying input-output analysis for calculation of ecological footprint of China. Acta Ecologica Sinica 27, 1499-1507 (in Chinese).

Chen, B., Chen, G.Q., 2006. Ecological footprint accounting based on emergy - A case study of the Chinese society. Ecological Modelling 198, 101-114.

Chen, B., Chen, G.Q., 2007. Modified ecological footprint accounting and analysis based on embodied exergy—a case study of the Chinese society 1981–2001. Ecological Economics 61, 355-376.

Chen, B., Chen, G.Q., Yang, Z.F., 2006a. Exergy-based resource accounting for China. Ecological Modelling 196, 313-328.

Chen, B., Chen, G.Q., Yang, Z.F., Jiang, M.M., 2007. Ecological footprint accounting for energy and resource in China. Energy Policy 35, 1599-1609.

Chen, G.Q., Chen, Z.M., 2011a. Greenhouse gas emissions and natural resources use by the world economy: Ecological input-output modeling. Ecological Modelling 222, 2362-2376.

Guo S., Shen G.Q.P., Chen Z.M., Yu R. (2014). Embodied cultivated land use in China 1987–2007. Ecological Indicators 47, 198-209.

Chen, G.Q., Guo, S., Shao, L., Li, J.S., Chen, Z.M., 2013a. Three-scale input-output modeling for urban economy: Carbon emission by Beijing 2007. Communications in Nonlinear Science and Numerical Simulation 18, 2493-2506.

Chen, G.Q., Jiang, M.M., Chen, B., Yang, Z.F., Lin, C., 2006b. Emergy analysis of Chinese agriculture. Agric. Ecosyst. Environ. 115, 161-173.

Chen, G.Q., Zhang, B., 2010. Greenhouse gas emissions in China 2007: Inventory and input-output analysis. Energy Policy 38, 6180-6193.

Chen, J., 2007. Rapid urbanization in China: A real challenge to soil protection and food security. CATENA 69, 1-15.

Chen, Z.M., Chen, G.Q., 2011b. Embodied carbon dioxide emission at supra-national scale: A coalition analysis for G7, BRIC, and the rest of the world. Energy Policy 39, 2899-2909.

Chen, Z.M., Chen, G.Q., 2011c. An overview of energy consumption of the globalized world economy. Energy Policy 39, 5920-5928.

Chen, Z.M., Chen, G.Q., 2013. Virtual water accounting for the globalized world economy: National water footprint and international virtual water trade. Ecological Indicators 28, 142-149.

Chen, Z.M., Chen, G.Q., Chen, B., 2013b. Embodied carbon dioxide emission by the globalized economy: A systems ecological input-output simulation. Journal of Environmental Informatics 21, 35-44.

Chen, Z.M., Chen, G.Q., Zhou, J.B., Jiang, M.M., Chen, B., 2010. Ecological input-output modeling for embodied resources and emissions in Chinese economy 2005. Communications in Nonlinear Science and Numerical Simulation 15, 1942-1965.

Comin, F.A., 2010. Ecological restoration: A global challenge. New York:

Guo S., Shen G.Q.P., Chen Z.M., Yu R. (2014). Embodied cultivated land use in China 1987–2007. Ecological Indicators 47, 198-209.

Cambridge University Press.

Costello, C., Griffin, W.M., Matthews, H.S., Weber, C.L., 2011. Inventory development and input-output model of US land use: Relating land in production to consumption. Environmental Science & Technology 45, 4937-4943.

CSY, 2012. China Statistical Yearbook 2012. China Statistical Publishing House, Beijing [in Chinese].

Cui, S., Kattumuri, R., 2011. Cultivated land conversion in China and the potential for food security and sustainability Asia research center working paper 35, http://www.lse.ac.uk/asiaResearchCentre/_files/ARCWP35-CuiKattumuri.pdf.

Fan, Z.M., Li, J., Yue, T.-X., 2013. Land-cover changes of biome transition zones in Loess Plateau of China. Ecological Modelling 252, 129-140.

Ferng, J.J., 2001. Using composition of land multiplier to estimate ecological footprints associated with production activity. Ecological Economics 37, 159-172.

Galli, A., Wiedmann, T., Ercin, E., Knoblauch, D., Ewing, B., Giljum, S., 2012. Integrating ecological, carbon and water footprint into a “footprint family” of indicators: Definition and role in tracking human pressure on the planet. Ecological Indicators 16, 100-112.

Grassini, P., Eskridge, K.M., Cassman, K.G., 2013. Distinguishing between yield advances and yield plateaus in historical crop production trends. Nat Commun 4.

Guan, D., Hubacek, K., Weber, C.L., Peters, G.P., Reiner, D.M., 2008. The drivers of Chinese CO2 emissions from 1980 to 2030. Global Environmental Change 18, 626-634.

Guo, S., Chen, G.Q., 2013. Multi-scale input-output analysis for multiple responsibility entities: Carbon emission by urban economy in Beijing 2007. Journal of Environmental Accounting and Management 1, 43-54.

Guo S., Shen G.Q.P., Chen Z.M., Yu R. (2014). Embodied cultivated land use in China 1987–2007. Ecological Indicators 47, 198-209.

Guo, S., Liu, J.B., Shao, L., Li, J.S., An, Y.R., 2012a. Energy-Dominated Local Carbon Emissions in Beijing 2007: Inventory and Input-Output Analysis. Scientific World Journal. doi: 10.1100/2012/923183.

Guo, S., Shao, L., Chen, H., Li, Z., Liu, J.B., Xu, F.X., Li, J.S., Han, M.Y., Meng, J., Chen, Z.M., Li, S.C., 2012b. Inventory and input-output analysis of CO_2 emissions by fossil fuel consumption in Beijing 2007. Ecological Informatics 12, 93-100.

Han, M.Y., Guo, S., Chen, H., Ji, X., Li, J.S., 2013. Local-scale systems input-output analysis of embodied water for Beijing economy 2007. Front. Earth Sci. In Press.

Hubacek, K., Guan, D., Barrett, J., Wiedmann, T., 2009. Environmental implications of urbanization and lifestyle change in China: Ecological and Water Footprints. Journal of Cleaner Production 17, 1241-1248.

Hubacek, K., Sun, L., 2001. A scenario analysis of China's land use and land cover change: incorporating biophysical information into input–output modeling. Structural Change and Economic Dynamics 12, 367-397.

IOSC, 2013. China's foreign trade. http://www.china-embassy.org/eng/zt/bps/t943740.htm.

Ji, X., Chen, Z., Li, J., 2013. Embodied energy consumption and carbon emissions evaluation for urban industrial structure optimization. Front. Earth Sci., 1-12.

Jiang, L., 2013. Three periods of land statistics http://news.dc2000.cn/redianjujiao/20121024_21027.html.

Jiang, L., Deng, X., Seto, K.C., 2013. The impact of urban expansion on agricultural land use intensity in China. Land Use Policy 35, 33-39.

Lenzen, M., Borgstrom Hansson, C., Bond, S., 2007a. On the bioproductivity and land-disturbance metrics of the Ecological Footprint. Ecological Economics 61, 6-10.

Lenzen, M., Murray, J., Sack, F., Wiedmann, T., 2007b. Shared producer and consumer responsibility — Theory and practice. Ecological Economics 61, 27-42.

Lenzen, M., Murray, S.A., 2001. A modified ecological footprint method and its application to Australia. Ecological Economics 37, 229-255.

Lenzen, M., Murray, S.A., Korte, B., Dey, C.J., 2003. Environmental impact assessment including indirect effects—a case study using input–output analysis. Environmental Impact Assessment Review 23, 263-282.

Liu, Y., Peng, X., 2004. Time series of ecological footprint in China between 1962～2001: Calculation and assessment of development sustainability. Acta Ecologica Sinica 24, 2257-2262.

Odum, H.T., 1983. Systems ecology. New York: Wiley.

Odum, H.T., 2000. Handbook of emergy evaluation: a compendium of data for emergy computation issued in a series of folios; Folio#2: Emergy of global processes. Gainesville: Center for Environmental Policy. University of Florida.

Peters, G.P., 2008. From production-based to consumption-based national emission inventories. Ecological Economics 65, 13-23.

Qiang, W., Liu, A., Cheng, S., Kastner, T., Xie, G., 2013. Agricultural trade and virtual land use: The case of China's crop trade. Land Use Policy 33, 141-150.

Rees, W., 1992. Ecological footprints and appropriated carrying capacity: what urban economics leave out. Environment and urbanization 4, 120-130.

Rees, W., 1996. Revisiting carrying capacity: Area-based indicators of sustainability. Popul Environ 17, 195-215.

Rees, W., Wackernagel, M., 1996. Urban ecological footprints: Why cities cannot be sustainable—And why they are a key to sustainability. Environmental Impact Assessment Review 16, 223-248.

Shao, L., Wu, Z., Chen, G.Q., 2013. Exergy based ecological footprint accounting for

Guo S., Shen G.Q.P., Chen Z.M., Yu R. (2014). Embodied cultivated land use in China 1987–2007. Ecological Indicators 47, 198-209.

China. Ecological Modelling 252, 83-96.

Su, B., Ang, B.W., 2010. Input-output analysis of CO2 emissions embodied in trade The effects of spatial aggregation. Ecological Economics 70, 10-18.

Su, B., Ang, B.W., 2011. Multi-region input-output analysis of CO2 emissions embodied in trade: The feedback effects. Ecological Economics 71, 42-53.

Su, B., Ang, B.W., 2013. Input-output analysis of CO2 emissions embodied in trade: Competitive versus non-competitive imports. Energy Policy 56, 83-87.

Su, B., Ang, B.W., 2014. Input-output analysis of CO2 emissions embodied in trade: A multi-region model for China. Appl. Energy 114, 377-384.

Su, B., Ang, B.W., Low, M., 2013. Input-output analysis of CO2 emissions embodied in trade and the driving forces: Processing and normal exports. Ecological Economics 88, 119-125.

Su, B., Huang, H.C., Ang, B.W., Zhou, P., 2010. Input-output analysis of CO2 emissions embodied in trade: The effects of sector aggregation. Energy Economics 32, 166-175.

Wackernagel, M., Burns, S., Lisac, D., 2013. The homepage of global footprint network. http://www.footprintnetwork.org/en/index.php/GFN/.

Wackernagel, M., Onisto, L., Bello, P., Callejas Linares, A., Susana López Falfán, I., Méndez García, J., Isabel Suárez Guerrero, A., Guadalupe Suárez Guerrero, M., 1999. National natural capital accounting with the ecological footprint concept. Ecological Economics 29, 375-390.

Wackernagel, M., Onisto, L., Linares, A.C., Falfán, I.S.L., García, J.M., Guerrero, A.I.S., Guerrero, M.G.S., 1997. Ecological footprints of nations: how much nature do they use? How much nature do they have? Commissioned by the Earth Council for the Rio+5 Forum. Distributed by the International Council for Local Environmental

Guo S., Shen G.Q.P., Chen Z.M., Yu R. (2014). Embodied cultivated land use in China 1987–2007. Ecological Indicators 47, 198-209.

Initiatives, Toronto.

Wackernagel, M., Rees, W., 1996. Our Ecological Footprint: Reducing Human Impact on the Earth. New Society, Gabriola Island, BC, 190.

Wang, J., Chen, Y., Shao, X., Zhang, Y., Cao, Y., 2012. Land-use changes and policy dimension driving forces in China: Present, trend and future. Land Use Policy 29, 737-749.

Weber, C.L., Peters, G.P., Guan, D., Hubacek, K., 2008. The contribution of Chinese exports to climate change. Energy Policy 36, 3572-3577.

Weinzettel, J., Hertwich, E.G., Peters, G.P., Steen-Olsen, K., Galli, A., 2013. Affluence drives the global displacement of land use. Global Environmental Change 23, 433-438.

Wiedmann, T., 2009. A review of recent multi-region input–output models used for consumption-based emission and resource accounting. Ecological Economics 69, 211-222.

Wiedmann, T., Lenzen, M., Turner, K., Barrett, J., 2007. Examining the global environmental impact of regional consumption activities — Part 2: Review of input–output models for the assessment of environmental impacts embodied in trade. Ecological Economics 61, 15-26.

Wiedmann, T., Minx, J., Barrett, J., Wackernagel, M., 2006. Allocating ecological footprints to final consumption categories with input–output analysis. Ecological Economics 56, 28-48.

Wood, R., Lenzen, M., Dey, C., Lundie, S., 2006. A comparative study of some environmental impacts of conventional and organic farming in Australia. Agricultural Systems 89, 324-348.

WWF, IGSNRR, GFN, IOZ, ZSL, 2012. China's ecological footprint report 2012.

Guo S., Shen G.Q.P., Chen Z.M., Yu R. (2014). Embodied cultivated land use in China 1987–2007. Ecological Indicators 47, 198-209.

http://www.footprintnetwork.org/images/article_uploads/China_Ecological_Footprint_2012.pdf.

Xiaoyun, L., 2013. China staple agricultural products stepping into 'net import age'. http://en.xinhua08.com/a/20130702/1204576.shtml.

Yang, H., Li, X., 2000. Cultivated land and food supply in China. Land Use Policy 17, 73-88.

Yang, Q., Guo, S., Yuan, W.H., Shen, Q., Chen, Y.Q., Wang, X.H., Wu, T.H., Chen, Z.M., Alsaedi, A., Hayat, T., 2013. Energy-dominated carbon metabolism: A case study of Hubei province, China. Ecological Informatics.

Yu, Y., Feng, K., Hubacek, K., 2013. Tele-connecting local consumption to global land use. Global Environmental Change 23, 1178-1186.

Zhang, B., Chen, Z.M., Xia, X.H., Xu, X.Y., Chen, Y.B., 2013. The impact of domestic trade on China's regional energy uses: A multi-regional input–output modeling. Energy Policy 63, 1169-1181.

Zhou, X., Imura, H., 2011. How does consumer behavior influence regional ecological footprints? An empirical analysis for Chinese regions based on the multi-region input–output model. Ecological Economics 71, 171-179.

Zhu, J., 2013. Survey shows 135.4m hectares of cultivated land. http://www.chinadaily.com.cn/china/2013-12/30/content_17204961.htm.

Zhu, Q., 2007. Discussion about statistical method of cultivated land area Tibet's Science and Technology 9, 10-12 (in Chinese).

Appendix A

See Appendix Table A1 and A2.

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Table A1

GDP deflators during 1987-2007 (calculated from CSY (CSY, 2012CSY, 2012)).

Year	1987	1990	1992	1995	1997	2000	2002	2005	2007
GDP deflator	100.00	128.76	148.87	235.16	254.09	253.68	260.42	296.87	331.71

Table A2

Sectors for China's economic input-output table 2007.

Code	Sector	Short Name	Industrial Classification
1	*Farming, Forestry, Animal Husbandry, Fishery and Water Conservancy*	*Agriculture*	Primary Industry
2	*Coal Mining and Dressing*	*Coal Mining*	Secondary Industry
3	*Petroleum and Natural Gas Extraction*	*Petroleum Extraction*	
4	*Ferrous and Nonferrous Metals Mining and Dressing*	*Metals Mining and Dressing*	
5	*Nonmetal and Other Minerals Mining and Dressing*	*Minerals Mining and Dressing*	
6	*Food Processing, Food Production, Beverage Production, Tobacco Processing*	*Food Processing*	
7	*Textile Industry*	*Textile Industry*	
8	*Garments and Other Fiber Products, Leather, Furs, Down and Related Products*	*Garments*	
9	*Timber Processing, Bamboo, Cane, Palm and Straw Products, Furniture Manufacturing*	*Timber Processing*	
10	*Papermaking and Paper Products, Printing and Record Medium Reproduction, Cultural, Educational and Sports Articles*	*Paper Products*	
11	*Petroleum Processing and Coking, Gas Production and Supply*	*Petroleum Processing*	
12	*Raw Chemical Materials and Chemical Products, Medical and Pharmaceutical Products, Chemical Fiber, Rubber Products, Plastic Products*	*Chemical Products*	
13	*Nonmetal Mineral Products*	*Nonmetal Mineral Products*	

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Code	Sector	Short Name	Industrial Classification
14	*Smelting and Pressing of Ferrous and Nonferrous Metals*	*Smelting and Pressing of metal*	
15	*Metal Products*	*Metal Products*	
16	*Ordinary Machinery, Equipment for Special Purpose*	*Ordinary Machinery*	
17	*Transportation Equipment*	*Transportation Equipment*	
18	*Electric Equipment and Machinery*	*Electric Equipment*	
19	*Electronic and Telecommunications Equipment*	*Telecommunications Equipment*	
20	*Instruments, Meters Cultural and Office Machinery*	*Instruments, Meters*	
21	*Manufacture of Artwork and Other Manufactures*	*Manufacture of Artwork*	
22	*Waste*	*Waste*	
23	*Electric Power/Steam and Hot Water Production and Supply*	*Electric Power*	
24	*Gas Production and Supply Industry*	*Gas Production and Supply*	
25	*Water Production and Supply Industry*	*Water Production and Supply*	
26	*Construction Industry*	*Construction*	
27	*Transport and Storage*	*Transport and Storage*	Tertiary Industry
28	*Post*	*Post*	
29	*Information Transmission, Computer services and Software*	*Information*	
30	*Wholesale, Retail Trade*	*Wholesale, Retail Trade*	
31	*Hotels, Catering Service*	*Hotels, Catering Service*	
32	*Financial Industry*	*Financial Industry*	
33	*Real Estate*	*Real Estate*	
34	*Leasing and Commercial Services*	*Leasing*	
35	*Research and Experimental Development*	*Research*	
36	*Polytechnic Services*	*Polytechnic Services*	
37	*Water conservancy, Environment and Public Facilities Management*	*Environment*	
38	*Service to Households and Other Service*	*Service to Households*	
39	*Education*	*Education*	

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Code	Sector	Short Name	Industrial Classification
40	*Health, Social Security and Social Welfare*	*Health*	
41	*Culture, Sports and Entertainment*	*Culture*	
42	*Public Management and Social Organization*	*Public Management*	