Article

Study on the Agricultural Land Transfer Embodied in Inter-Provincial Trade in China

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Abstract: The research on the land resources embodied in the inter-regional economic linkages is of great significance for the ecological compensation and sustainable use of the cultivated land. We constructed a model to estimate the agricultural land transfer embodied in inter-regional trade by using the agricultural land footprint model and the multi-regional input–output model. Taking China as an example, using a 2017 multi-regional input–output table and agricultural land and production data, we evaluated the agricultural land footprints embodied in the inter-provincial demand–supply chain in China and explored their characteristics, revealing the balance of income and expenditure that makes up the agricultural land footprint in each region. The results show that: (1) In 2017, China’s total agricultural land footprint was 557.63 million ha². Developed areas such as Shandong, Guangdong, and Jiangsu in the East generally had a greater footprint than the underdeveloped areas in the west. Provinces with more agricultural land do not necessarily have larger agricultural footprints. (2) The Agriculture, Hunting, Forestry, and Fishing industry and the Food, Beverages, and Tobacco industry were the main two sectors that contributed to the agricultural land footprint for each province, accounting for more than 60% of the total agricultural land footprint in China. (3) The embodied agricultural land transfer between regions showed two main directions on the whole: one was from north to south and the other from west to east, reflecting the transfer law of movement from the less developed regions to those that were more developed.

Keywords: agricultural land footprint; inter-regional trade; input–output analysis; embodied agricultural land; transfer pattern

1. Introduction

Since the reform and opening up, the economic and ecological ties between regions in China have become closer. Regional trade has become an important way for many areas to meet the local consumption demands. The growing inter-regional economic ties have brought about the allocation and embodied flow of resources and environmental elements over a larger area. Such transfer has further led to a new phenomenon of inequality between regions, that is, environmental inequality. Previous scholars have found evidence of global inequality stemming from the embodied land and water trade [1]. Therefore, studying the resources and environmental elements embodied in China’s inter-provincial economic ties is of great significance for correcting the imbalance between regional economic development and ecological responsibility, and further, promoting the high-quality development of China. Agricultural land is the ecological basis for human survival and the resource basis for socioeconomic development. Analyzing the occupancy and transfer of agricultural land embodied in inter-provincial economic ties helps to further clarify the mutual ecological responsibilities between regions, establish a horizontal agricultural ecological compensation system, conduct more targeted land use management, and promote the sustainable development of agricultural ecology.
In accounting for land transfers embodied in trade, many scholars have successively proposed concepts such as the ecological footprint, virtual land, virtual farmland, and embodied agricultural land to describe the impact of human consumption demands on land resources [2–5]. Early research mainly focused on virtual land research and ecological footprint studies. Virtual land is a quantitative measurement of the land resources embodied in trade production. This method is mainly based on the land occupancy coefficient of the unit of agricultural products and processed products, and the land resource occupancy of land resources is measured in combination with the output and trade transfer volume. This only measures the direct land resource used in the product, generally for agricultural products. As an example, from the perspectives of producers and consumers, Qiang et al. measured the trade in “virtual land” of crops and processed products in China from 1986 to 2009 [6]. The results showed that the crop trade between China and other countries had saved a lot of land globally. Yawson demonstrated a simple food balance approach to estimating virtual land use in the 2050s and found that the UK could face large virtual land use due to its imports, made necessary by the country’s small land area [7]. The use of the virtual land method can also be found in many other studies [8–12]. The concept of the ecological footprint was proposed by William E. Rees in the early 1990s [13]. This method is mainly used to measure the consumption of natural ecosystems by human activities and convert that into a unified comparable land or water area, including the impacts associated with trade. The National Footprint Accounts (NFA) by the Global Footprint Network (GFN) calculate the ecological footprints embodied in national trade by multiplying the footprint yield coefficient (t/ha) with the mass volumes of traded goods between countries from the United Nations Statistics Division (UNSD) global trade database, to create a “product land use matrix (PLUM)” [14]. Daniel et al. as an example, applied the PLUM approach to measuring the biophysical value of international trade flows [15].

However, virtual land methods and traditional ecological footprint methods have limitations in tracking the end-use of products, and they cannot measure land occupation caused by service provision. The ecological footprint model based on input–output analysis inherits the advantages of the traditional model and makes up for the shortcomings of the traditional model in revealing the true location and interconnection of the land footprint [16]. At the same time, it can effectively avoid making repeated calculations of the footprint components [17,18], meaning it is favored by researchers. Using the combination of input–output models and land footprints, many scholars have studied the flow of land resources embodied in global trade, including global demand–supply chains or the trade of certain agricultural products [19,20]. Due to China’s important position in world trade, many studies have explored the virtual land or arable land resources embodied in China’s trade [21–25], and some researchers have also estimated the forest land [26] or pasture land [27] embodied in the exports and imports of China. At the same time, further scholars have discussed the land resources embodied in international trade by other countries, such as Belgium, Spain, and Finland [28–30]. In addition to the study of land resources embodied in trade or the demand–supply chain, another research feature using input–output models is the study of the water–energy–food/land (WEF) nexus embodied in international trade or food products’ trade [31–35]. The WEF nexus can more comprehensively reflect the flow of natural resources embodied in the connections of human economic activities and thus has greater guiding significance for the realization of regional sustainable development [36].

Most of the above studies were based on the land or other resources embodied in global trade or the resources embodied in a country’s foreign trade. It is rare to pay attention to the land resources embodied in the economic ties among regions within a country. For a large country like China, however, that is important. Certain previous studies paid attention to this issue. For example, Shan et al. analyzed the cultivated land resources embodied in the inter-regional economic connections in the Beijing–Tianjin–Hebei region, to illustrate the issues of inequality and collaboration around a northern Chinese urban agglomeration [37]. Guo et al. [38] and Chuai et al. [39] both, meanwhile, studied virtual built-up land transfers embodied in China’s inter-regional trade.
In summary, the existing literature on China’s embodied land research focused on foreign trade, analyzing the flow of embodied land at the global spatial scale, industry characteristics, and driving factors [40]. Relatively few researchers studied the embodied land at the inter-provincial level in China, and the research was mainly on the virtual farmland of food trade, assessed through agricultural product measurement, while there was a lack of research on embodied land in the inter-regional economic relationship, as explored using the input–output method. To date, there are certain limitations to how the embodied land of inter-provincial trade is in terms of research scale, methods, and objects, while research on the virtual water flow has developed to become more mature [41,42]. Research on the embodied land behind China’s inter-provincial economic ties urgently needs to be further developed and the topic explored in depth. In that context, this paper presents a model of China’s inter-provincial agricultural land footprint, as determined via the agricultural land footprint method and the inter-regional input–output method. This article focuses on the relationship between regional land resource endowment, economic development, industries/sectors, and the agricultural land footprint. At the same time, it analyzes the size of China’s agricultural land footprint at different levels of inter-provincial economic ties, and further analyzes the spatial transfer pattern of embodied agricultural land, revealing the embodied agricultural land footprint behind the inter-provincial supply-demand chain and economic connection. The findings provide a scientific basis for clarifying the mutual ecological responsibilities of different regions, enriching the research on embodied land at the inter-regional level, and promoting the sustainable development of agriculture.

2. Materials and Methods
2.1. Concept Definition

The agricultural land footprint of one region refers to the sum of the whole industry chain’s agricultural land use, which depends on the end-use of resources from this region [43]. It should be noted that, unlike the traditional ecological footprint, the cultivated land footprint in this paper does not include the built-up area, and the water area only includes the freshwater area as a data limitation. In general, the ecological footprint of urban built-up areas is considered to represent the occupation of cultivated land. Yet, the urban built-up area accounts for a small proportion of the overall cultivated land, and the degree of land occupation of built-up areas by industry cannot be discerned. Moreover, most of the seawater area is not in the provincial administrative area, and it is impossible to distinguish the connections between regions. Therefore, the agricultural land footprint in this paper does not include construction land and seawater area.

This article also proposes several other related concepts, including direct agricultural land occupation, the direct agricultural land footprint, complete agricultural land footprint, embodied agricultural land footprint, etc., according to other studies [44]. Direct agricultural land occupation is calculated for each region as the sum of the area of various types of agricultural land. The direct agricultural land footprint is the conversion of the direct agricultural land occupation into a unified and comparable land area based on the yield factor and equilibrium factor. The complete agricultural land footprint is the sum of all direct agricultural land occupations caused by the end-use activities in an area, where, the direct agricultural land footprint is redistributed to different end-users according to the demand–supply chain. The direct agricultural land footprint of one area that is allocated to the part of the complete agricultural land footprint of another area is the embodied agricultural land footprint in the demand–supply chain.

2.2. Research Methods
2.2.1. Direct Agricultural Land Footprint Model

To make the agricultural land in each region comparable in quantity, it is necessary to convert the agricultural land into the land area with the national standard hectare (Nha)
as a unified unit. Regarding the ecological footprint accounting method [45], the direct agricultural land footprint of agricultural activities can be expressed as:

$$DALF_i = \sum_k \sum_h \frac{p_{hk}^{iagr}}{Y_{hk}^{N,agr}} \beta^k / \theta^k_i$$

(1)

where $DALF_i$ denotes the direct agricultural land footprint of agricultural activities in region $i$ (Nha), $p_{hk}^{iagr}$ denotes the average yield per unit area of $k$ types of land and $h$ types of crops/products in area $i$ (kg/a), $Y_{hk}^{N,agr}$ denotes the average yield per unit area of $h$ crops/products of $k$ types of land in the country (kg/a), $\beta^k$ denotes the equilibrium factor of $k$ land types, using the recommended value of the Global Footprint Network (GNP), and $\theta^k_i$ denotes the multiple crop index of $k$ types of land use types in area $i$. Table 1 shows the specific calculation methods and values. Land use types include five types: cultivated land, forest land, grassland, garden land, and freshwater areas. The crops/products corresponding to each land type are shown in Table 1. All crops/products except for meat and milk have data for the corresponding sown area or land area, while the weighted sum of meat and milk production needs to be calculated. This article uses the averages for pork and fresh milk in the current year.

Table 1. Relationships between land use types and crops/agricultural products.

| Land Type    | Crops/Products                  | Balance Factor | Remarks                                      |
|--------------|---------------------------------|----------------|----------------------------------------------|
| Arable land  | Grain, beans, potatoes, oil,    | 2.51           | The yield per sown area is used, and $\theta$ denotes the sown area divided by the arable land area |
|              | cotton, hemp, sugar, tobacco, vegetables, fruits |                |                                              |
| Woodland     | Wood                            | 1.26           | Unit forest land yield, $\theta = 1$         |
| Grassland    | Meat, milk                      | 0.46           | Unit grassland yield, $\theta = 1$          |
| Gardenland   | Tea, garden fruits              | 2.51           | Output per unit of gardenland, $\theta = 1$  |
| Freshwater area | Freshwater products             | 0.37           | Unit freshwater area production, $\theta = 1$ |

2.2.2. Complete Agricultural Land Footprint Model

The inter-regional input–output table is a mathematical model to measure the interdependence between the final use and intermediate inputs [46]. It can well identify the goods and services produced in one region but finally used in other regions. So, the complete agricultural land footprint (CALF) can be quantitatively calculated by using the inter-regional input–output table. Then, the embodied flow of agricultural land and the net agricultural footprint (NALF) by region can be further evaluated. The complete agricultural land footprint of a region includes two parts: the internal agricultural land footprint directly caused by the final use and the external agricultural land footprint indirectly caused by the final use. The former we call the direct consumption of agricultural land, the latter we call the indirect consumption of agricultural land. The specific derivation process is as follows:

Suppose there are $n$ regions in a country, and each region has $m$ sectors. According to the inter-regional input–output table [46]:

$$x = (I - A^d)^{-1} \left( \sum y^r + \sum e^r \right)$$

(2)

where $x$ denotes the total output, $A^d$ denotes the direct consumption coefficient between the domestic regions, $y^r$ denotes the final use in region $r$, and $e^r$ denotes the export of region $r$. For the convenience of calculation, we denote the Leontief inverse matrix as $b$, that is:

$$x = b \left( \sum y^r + \sum e^r \right)$$

(3)

According to the direct agricultural land footprint of each region, the direct agricultural land footprint coefficient of area $r$ (direct agricultural land footprint per unit of total output)
can be obtained, which is recorded as $f$. There is a $1 \times m$ matrix in which only the agricultural sector has a non-zero value and the other sectors have zero values. Then, the footprint of complete agricultural land can be expressed as:

$$\text{CALF} = f \ast x = f \ast b \ast \left( \sum y^i + \sum e^i \right)$$  \hspace{1cm} (4)

$$f \ast x = \begin{bmatrix} b_{11} & b_{12} & \cdots & b_{1n} \\ b_{21} & b_{22} & \cdots & b_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ b_{n1} & b_{n2} & \cdots & b_{nn} \end{bmatrix} \ast \left( \sum y^r + \sum e^r \right)$$  \hspace{1cm} (5)

where $b^rs$ denotes the block matrix in the Leontief inverse matrix. Then, the complete agricultural land footprint in area $r$ can be expressed as:

$$\text{CALF}^r = f^r \ast \sum_i b^{ri} y^ij + f^{rs} \ast b^{rs} e^s$$  \hspace{1cm} (6)

The first item on the right side of the above formula represents the agricultural land footprint of region $r$ caused by the national final consumption (including investment, the same below). The second term represents the agricultural land footprint in area $r$ caused by exports ($i$ represents the sector, $j$ represents the region). Then, the agricultural land footprint in area $r$ caused by area $s$ can be expressed as:

$$\text{ALF}^rs = f^r \ast \sum_i b^{si} y^is + f^{rs} \ast b^{rs} e^s$$  \hspace{1cm} (7)

According to the principle of symmetry and the arbitrary nature of $r$ and $s$ [47], the agricultural land footprint in area $s$ caused by area $r$ can be obtained as follows:

$$\text{ALF}^sr = f^s \ast \sum_i b^{si} y^is + f^{sr} \ast b^{sr} e^r$$  \hspace{1cm} (8)

The net agricultural land footprint of $r$ area caused by area $s$ can thus be expressed as:

$$\text{NALF}^rs = \text{ALF}^rs - \text{ALF}^sr$$  \hspace{1cm} (9)

Since the above model contains information by sector, it can easily be obtained that the agricultural land transfer situation of each sector at the national level. Then the proportion of each sector could be obtained by dividing the data of each sector by the national gross agricultural land footprint.

2.3. Data Sources and Processing

2.3.1. Data Sources

The 2017 Chinese inter-regional input–output table was compiled by the author based on the 2012 table in China. Economic data were adopted, such as the final consumption, investments and exports, and populations in sub-regions, all from the "China Statistical Yearbook 2018". To facilitate calculation and analysis, the 42 sectors in the original input–output table were merged into 17 sectors according to the classification of sectors in the "China Statistical Yearbook" (Table 2). The agricultural land data by province and type in 2017 came from the "China Land and Resources Statistical Yearbook 2018". The crop sown area, output, and agricultural product output data in 2017 were from the "China Rural Statistical Yearbook 2018". The study area includes 30 provinces in China, of which Tibet, Taiwan, Hong Kong, and Macau are not included (Figure 1a). In some cases, for the convenience of analysis, we will divide China into eight large subnational regions, which are the northeast (NE, including Heilongjiang, Jilin, Liaoning), Beijing–Tianjin (JJ, Beijing, Tianjin), north coast (NC, Hebei, Shandong), east coast (EC, Shanghai, Zhejiang, Jiangsu), middle region (MR, Henan, Shanxi, Anhui, Hunan, Hubei, Jiangxi), South Coast (SC, Guangdong, Fujian, Hainan), northwest (NW, Inner Mongolia, Shaanxi, Gansu, Ningxia, ...
Qinghai, Xinjiang), and southwest (Sichuan, Chongqing, Yunnan, Guizhou, Guangxi), see Figure 1b.

Table 2. Division of sectors.

| No. | Sector                                                                 | Abb. | No.  | Sector                                                                 | Abb.          |
|-----|------------------------------------------------------------------------|------|------|------------------------------------------------------------------------|---------------|
| 1   | Agriculture, Hunting, Forestry, and Fishing                            | AGR  | 10   | Mechanical industry                                                   | MEC           |
| 2   | Mining and Quarrying                                                   | MIN  | 11   | Transportation equipment manufacturing industry                         | TRA           |
| 3   | Food, Beverages, and Tobacco                                           | FOO  | 12   | Electrical machinery and electronic communication equipment manufacturing industry | ELM           |
| 4   | Textiles and Textile Products, Leather, Leather and Footwear           | TEX  | 13   | Other manufacturing                                                   | OTM           |
| 5   | Wood Processing and Furniture Manufacturing                             | WOO  | 14   | Electricity, steam, hot water, gas tap water production, and supply industry | ENE           |
| 6   | Papermaking, Printing, Cultural and Educational Supplies Manufacturing | PAP  | 15   | Construction industry                                                 | CON           |
| 7   | Petrochemical Industry                                                 | PET  | 16   | Commerce, transportation                                              | COM           |
| 8   | Non-Metallic Mineral Products Industry                                 | NME  | 17   | Other service industries                                              | OTS           |
| 9   | Metal Mmelting and Products Industry                                   | MET  |      |                                                                        |               |

Figure 1. Cont.
2.3.2. Data Processing

To avoid imports influencing the calculation results, the intermediate input in the input–output table and the end-use import part were deducted proportionally. The original input–output table contained other items of data. To avoid them impacting our interpretation of the research results, such items were excluded from the final table used. The final output data were used to calculate the direct occupancy coefficient of agricultural land in various regions of the country and the complete agricultural land footprint.

3. Results

3.1. Analysis of Direct Agricultural Land Footprint

3.1.1. Overall Situation

(1) Direct agricultural land occupation analysis. The direct agricultural land occupation mainly came from the provinces with a large proportion of the primary industry, and the differences between provinces were obvious. For example, the direct agricultural land occupancy of the Inner Mongolia Autonomous Region was 82.88 million ha$^2$ and for Shanghai was 310,000 ha$^2$, which were the provinces with the largest and the smallest amounts, respectively. According to the regional division of China’s inter-regional input–output table, the sum of direct agricultural land in the northwest and southwest regions accounted for more than 60% of the countrywide total. On the contrary, the coastal areas with higher economic levels and the Beijing–Tianjin area had a relatively low direct occupation ratio, which was closely related to the local economic structure, development status, and the area’s agricultural land.

(2) Direct agricultural land footprint analysis. There were obvious differences in the direct agricultural land footprint of each province, and the corresponding direct agricultural land occupation also had different degrees of difference. This specifically manifested in the following two regards: on the one hand, the direct agricultural land footprint was related to the land production efficiency and regional direct agricultural land occupation. The direct footprints of areas with low land production efficiency or direct occupation were thus
relatively small. On the whole, the direct footprints of northwestern regions such as Gansu and Qinghai, as well as areas with less direct agricultural land such as Beijing, Tianjin, Shanghai, and Ningxia, were smaller than those of other regions (Table 3). On the other hand, the difference between the direct agricultural land footprint and direct agricultural land occupation was related to the regional economic level. Generally, the direct footprint of economically developed regions was greater than that of direct occupation, and the opposite was true for underdeveloped regions. For example, Shanghai’s direct footprint was much larger than its direct occupation, while the direct footprint of Gansu, Qinghai, Xinjiang, and other regions was much smaller than the direct occupation.

| Province      | Direct Occupation | Direct Footprint | Province      | Direct Occupation | Direct Footprint | Province      | Direct Occupation | Direct Footprint |
|---------------|-------------------|------------------|---------------|-------------------|------------------|---------------|-------------------|------------------|
| Beijing       | 115               | 179              | Zhejiang      | 859               | 1679             | Hainan        | 297               | 695              |
| Tianjin       | 69                | 207              | Anhui         | 1112              | 2449             | Chongqing     | 706               | 952              |
| Hebei         | 1306              | 3334             | Fujian        | 1086              | 2154             | Sichuan       | 4213              | 3142             |
| Shanxi        | 1003              | 735              | Jiangxi       | 1441              | 1566             | Guizhou       | 1473              | 1040             |
| Inner Mongolia| 8288              | 1626             | Shandong      | 1149              | 4390             | Yunnan        | 3293              | 1945             |
| Liaoning      | 1153              | 2233             | Henan         | 1266              | 4442             | Shaanxi       | 1856              | 1421             |
| Jilin         | 1659              | 1413             | Hubei         | 1573              | 2983             | Gansu         | 1855              | 819              |
| Heilongjiang  | 3991              | 2564             | Hunan         | 1817              | 3242             | Qinghai       | 4509              | 208              |
| Shanghai      | 31                | 146              | Guangdong     | 1492              | 2689             | Ningxia       | 381               | 331              |
| Jiangsu       | 647               | 3556             | Guangxi       | 1953              | 2131             | Xingjiang     | 5172              | 1495             |

3.1.2. Coefficient Analysis

The direct agricultural land occupancy coefficient represents the direct agricultural land occupancy of the total output of a regional unit. Since only agricultural activities are directly related to agricultural land in regional economic activities, all other industries are zero. Therefore, the direct occupation coefficient of industries other than agriculture is correspondingly zero. Qinghai, Xinjiang, and Inner Mongolia had high direct agricultural land occupancy coefficients, indicating that the above-mentioned provinces had a relatively large amount of agricultural land occupation per unit of agricultural output, and the land utilization rate was relatively low, which is inevitably related to the local climate, land quality, production technology, productivity level, and economic development level. On the whole, the direct occupancy coefficients of areas with lower economic levels were generally higher, and the direct occupancy coefficients varied greatly among provinces.

There is a significant difference between the direct agricultural land footprint coefficient and the occupation coefficient (Table 4). The direct footprint coefficient in 2017 was 0.704 ha/CNY 10,000 at the national level. Compared with the direct occupancy coefficients of various provinces, the direct occupancy coefficients of northwestern regions such as Qinghai and Xinjiang were much larger than the direct footprint coefficients. However, the direct occupancy coefficient of the Beijing–Tianjin area and the eastern coastal area was lower than the direct footprint coefficient, that is, the agricultural land occupied by the unit output in relatively developed regions was smaller. For example, in Shanghai, the direct occupancy coefficient was 0.15 ha/CNY 10,000, which was only about one-fifth of the direct footprint coefficient.

In summary, the agricultural land footprint of regional agricultural economic activities in relatively developed and populated areas was greater than the direct occupation of agricultural land, while the opposite was true in economically underdeveloped areas, i.e., the former was significantly smaller than the latter. For example, the direct agricultural land footprint caused by agricultural economic activities in Shanghai and Jiangsu was much larger than the direct agricultural land occupation, while the direct agricultural land footprint of Qinghai and Xinjiang was much smaller than their corresponding direct occupation. Hence, greater direct agricultural land occupation does not mean that there will be a larger direct agricultural land footprint.
Table 4. Direct agricultural land occupation coefficients (ha/CNY $10^4$).

| Province | Coefficient | Province | Coefficient | Province | Coefficient |
|----------|-------------|----------|-------------|----------|-------------|
| Beijing  | 0.45        | Zhejiang | 0.36        | Hainan   | 0.30        |
| Tianjin  | 0.24        | Anhui    | 0.32        | Chongqing| 0.52        |
| Hebei    | 0.28        | Fujian   | 0.36        | Sichuan  | 0.94        |
| Shanxi   | 0.96        | Jiangxi  | 0.65        | Guizhou  | 1.00        |
| Inner Mongolia | 3.59   | Shandong | 0.18        | Yunnan   | 1.19        |
| Liaoning | 0.36        | Henan    | 0.20        | Shaanxi  | 0.92        |
| Jilin    | 0.83        | Hubei    | 0.37        | Gansu    | 1.60        |
| Heilongjiang | 1.10   | Hunan    | 0.39        | Qinghai  | 15.27       |
| Shanghai | 0.15        | Guangdong| 0.39        | Ningxia  | 0.81        |
| Jiangsu  | 0.13        | Guangxi  | 0.65        | Xinjiang | 2.44        |

3.2. Fully Agricultural Land Footprint Analysis

3.2.1. Total Footprint of Complete Agricultural Land

The complete agricultural land footprint of a region includes two parts: the internal agricultural land footprint and the external agricultural land footprint. The internal and external footprints of different regions presented different characteristics. Table 5 shows the complete agricultural land footprint of 30 provinces in China in 2017. Through analysis, we can see:

Table 5. Complete agricultural land footprint ($10^4$ ha).

| Province | Internal Footprint | External Footprint | Province | Internal Footprint | External Footprint | Province | Internal Footprint | External Footprint |
|----------|--------------------|--------------------|----------|--------------------|--------------------|----------|--------------------|--------------------|
| Beijing  | 58                 | 1220               | Zhejiang | 1283               | 1782               | Hainan   | 135                | 219                |
| Tianjin  | 105                | 676                | Anhui    | 733                | 1021               | Chongqing| 538                | 568                |
| Hebei    | 1255               | 1887               | Fujian   | 1788               | 332                | Sichuan  | 2450               | 533                |
| Shanxi   | 671                | 436                | Jiangxi  | 812                | 474                | Guizhou  | 664                | 470                |
| Inner Mongolia | 612       | 846                | Shandong | 3423               | 2324               | Yunnan   | 1296               | 692                |
| Liaoning | 1106               | 795                | Henan    | 1940               | 1222               | Shaanxi  | 426                | 712                |
| Jilin    | 503                | 208                | Hubei    | 2301               | 224                | Gansu    | 360                | 315                |
| Heilongjiang | 637       | 838                | Hunan    | 1540               | 559                | Qinghai  | 163                | 130                |
| Shanghai | 132                | 1422               | Guangdong| 2427               | 1934               | Ningxia  | 282                | 193                |
| Jiangsu  | 2130               | 1719               | Guangxi  | 908                | 358                | Xinjiang | 623                | 353                |

First, the total agricultural land footprint of the eastern region was larger than that of the western region. In 2017, the country’s total agricultural land footprint was 557.63 million ha, of which the areas with a large agricultural land footprint were Shandong, Guangdong, Jiangsu, Henan, and other provinces. The total footprint of the above four provinces accounted for more than 30% of the country’s total agricultural land footprint that year, which was related to factors such as resource endowments, large population, and economic levels (Table 5). Besides those, Beijing, Shanghai, and other places with higher economic levels also had larger footprints, with most products coming from outside the region, meaning indirect consumption and occupation of agricultural land in other regions.

Second, the footprint of external agricultural land in economically developed regions was larger than that of local agricultural land, while the opposite was true in underdeveloped regions. Due to the widespread inter-provincial trade activities inherent in the process of economic development, in the demand–supply chain, the end-use of a region will not only directly consume local agricultural land resources in production activities but also indirectly consume and occupy agricultural land in other regions. As shown in Table 5, the external footprint of Beijing, Tianjin, Shanghai, and other places was much larger than the local footprint, while provinces such as Xinjiang, Ningxia, and Gansu showed the opposite. This indicates that areas with lower economic levels consume and occupy less agricultural land than other provinces and cities. However, areas with higher economic levels, such as Beijing and Shanghai, have a low proportion of primary industry and relatively limited land area. To meet the needs of local development, products, resources, and services outside
the region are often obtained through trade and other means, thereby indirectly occupying and consuming agricultural land in other regions, and causing a larger external footprint.

3.2.2. Agricultural Land Footprint by Sector

The economic development model has a certain relationship with the industrial structure. From the perspective of the sector, agriculture, food manufacturing, and tobacco processing were the main industries that caused the agricultural land footprint of each province, and the sum of those accounted for more than 60% of the overall footprint (Figure 2). In 2017, the footprint caused by agriculture accounted for 40.45% of the total national footprint, and the footprint caused by food manufacturing and tobacco processing accounted for 23.75% of the total national footprint. Secondly, the footprints caused by the construction industry, textile and clothing industry, other service industries, and commerce and transportation accounted for 8.56%, 5.94%, 5.44%, and 4.64% of the country’s total footprint, respectively. However, there was a big gap between the two main industries: agriculture versus food and tobacco processing. At the same time, there were also large differences in the industrial agricultural land footprint structure between provinces. For example, for Beijing, the footprint caused by the food manufacturing and tobacco processing industries accounted for more than half of its total footprint, and the proportions of other service industries and construction industries were second and third, respectively, followed by agriculture. The footprint caused by agriculture in Qinghai, meanwhile, made up 63.91% of its total footprint. The agricultural land footprints of other sectors were relatively small. This industry footprint feature is thus also a direct manifestation of the industrial structure of each region.

![Complete agricultural land footprints by sectors.](image)

3.3. Embodied Agricultural Land Transfer Pattern

In regional economic relations, a region is not only a transfer-in area of embodied agricultural land but also a transfer-out area. The transfer-in amount is the footprint of agricultural land transferred-in from other regions, which is the footprint of external agricultural land, and the transfer-out amount is the footprint of agricultural land transferred to other regions. The sum of the two is the total amount of embodied agricultural land transferred in the region, and the difference between the two is the net amount of embodied agricultural land transferred in the region. The results are shown in Table 6. The embodied agricultural land transfer structures of China’s provinces were quite different. The four provinces of Hebei, Henan, Shandong, and Jiangsu had the highest total transfer volume, with specific transfer volumes of 39.65, 37.25, 32.97, and 31.45 million ha². The net transfer volume of Hebei and Jiangsu was relatively low, indicating that the transfer-in and transfer-out scales of embodied agricultural land in these two provinces were relatively balanced.
The two provinces of Shandong and Henan had higher net transfer volumes. Shandong was the net transfer-in area and Henan was the net transfer-out area. Both of them had a larger scale of transfer of embodied agricultural land, but each had its own focus. Areas such as Qinghai and Ningxia were limited largely to their own resource. Their economic ties with other provinces were relatively weak, so their total transfer volumes and net transfer volumes were relatively low. The embodied agricultural land transfer structure of a region is a comprehensive manifestation of its economic level, industrial structure, and resource endowment conditions.

**Table 6. Amount of embodied agricultural land transfer (10⁴ hectares).**

| Province      | Total Transfer | Net Transfer | Province      | Total Transfer | Net Transfer | Province      | Total Transfer | Net Transfer |
|---------------|----------------|--------------|---------------|----------------|--------------|---------------|----------------|--------------|
| Beijing       | 1341           | 1100         | Zhejiang      | 2177           | 1386         | Hainan        | 779            | −340         |
| Tianjin       | 778            | 574          | Anhui         | 2736           | −695         | Chongqing     | 983            | 153          |
| Hebei         | 3965           | −192         | Fujian        | 698            | −34          | Sichuan       | 1225           | −159         |
| Shanxi        | 500            | 372          | Jiangxi       | 1228           | −280         | Guizhou       | 846            | 95           |
| Inner Mongolia| 1860           | −168         | Shandong      | 3291           | 1358         | Yunnan        | 1341           | 43           |
| Liaoning      | 1922           | −332         | Henan         | 3725           | −1280        | Shaanxi       | 1707           | −282         |
| Jilin         | 1118           | −703         | Hubei         | 907            | −458         | Gansu         | 774            | −144         |
| Heilongjiang  | 2765           | −1089        | Hunan         | 2262           | −1144        | Qinghai       | 175            | 86           |
| Shanghai      | 1435           | 1409         | Guangdong     | 2196           | 1672         | Ningxia       | 243            | 144          |
| Jiangsu       | 3145           | 293          | Guangxi       | 1581           | −864         | Xinjiang      | 1225           | −519         |

Note: In the net transfer amount, a positive value indicates a net transfer-in, and a negative value indicates a net transfer-out.

To explore the embodied agricultural land transfer relationship between regions more intuitively, according to the above regional division standard, a diagram of the transfer of embodied agricultural land between regions was drawn (Figure 3). The different colors in the figure represent the eight regions, and the relationship zone corresponds to the embodied agricultural land transfer area and transfer volume. From the perspective of the transfer of agricultural land footprints in each region, the central, northeast, and northwest regions had the highest transfer-out volumes of agricultural land (62.53, 34.23, and 30.74 million ha², respectively), making them, collectively, the main source of embodied agricultural land. The eastern and northern coastal regions, meanwhile, were the regions with the highest transfer-in volumes of agricultural land (44.78 and 37.36 million ha², respectively). They mainly played the role of embodied agricultural land “consumers” in inter-regional trade. The central region was not only the main source but also the main “consumer”, but the scale of transfer-out was much larger than the scale of transfer-in, so it was still one of the most important embodied agricultural land “suppliers”. Since primary industry accounts for a relatively low proportion of the economic structure in areas with higher economic levels such as coastal areas and Beijing–Tianjin, the scale of agricultural land transfer-out was small, and the agricultural land footprint was mainly derived from external sources, representing the main embodied agricultural land “consumption”. From the point of view of the net transfer of agricultural land in each region, the Beijing–Tianjin area and northern, eastern, and southern coastal areas were net transfer-in areas, and the northeast, central, northwest, and southwestern areas were net transfer-out areas. The overall direction of the net transfer of land showed a trend from north to south and west to east, which specifically manifested in a shift from the underdeveloped areas in the central, western, and northeastern regions to the Beijing–Tianjin area and the developed coastal areas. For example, central and western regions such as Henan, Hunan, and Xinjiang were transferring agricultural land to Beijing, Tianjin, Shanghai, Jiangsu, Zhejiang, Guangdong, Shandong, and other regions. At the same time, northeast regions such as Jilin and Heilongjiang were also important agricultural land transfer-out areas. In general, areas with higher economic levels were mostly agricultural land transfer-in areas, and areas with relatively low economic levels were mostly net-out areas.
Due to the particularity of its geographical location, the central region is very closely connected with other regions in inter-regional economics and trade. In addition to the industrial structure with a high proportion of primary industry, the central region has a large transfer of embodied agricultural land to other regions. In particular, in this research, the eastern and northern coastal regions accounted for 51.3% of the total transfer-out volume in the central region, much higher for other regions. In contrast, the embodied agricultural land interaction relationship among other regions is weak, which may be due to different industrial structures and insufficient trade links. Therefore, it is necessary to further improve the level of agricultural production, strengthen inter-regional trade exchanges, promote the coordinated development of inter-regional economies, and realize the optimal allocation of agricultural land resources to ease the pressure on land use.

4. Conclusions and Discussion

This article took the embodied agricultural land footprints between provinces in China as a starting point to calculate the complete agricultural land footprint and the net agricultural land footprint, to understand the distribution and transfer of agricultural land footprints. The main conclusions are as follows: (1) There were obvious differences between the direct agricultural land occupation and direct agricultural land footprint in each province. Higher direct agricultural land occupation does not necessarily lead to a higher direct agricultural land footprint. The direct agricultural land footprint of regional agricultural economic activities in relatively developed and populated areas was greater than the direct occupation of agricultural land, while the opposite was true in economically underdeveloped areas, i.e., the former was significantly smaller than the latter. The direct agricultural land occupancy coefficient was generally higher in areas with lower levels of economic development. (2) The agricultural land footprint of areas with a higher level of economic development was generally higher than that of areas with a lower level of economic development. The external footprint of developed regions such as Beijing, Tianjin, and Shanghai was much larger than the local footprint, while the underdeveloped regions such as Xinjiang, Ningxia, and Gansu showed the opposite.
Agriculture, food manufacturing, and tobacco processing were the main industries that caused the agricultural land footprint of each province. The sum of those accounted for more than 60% of the total agricultural land footprint that year, and there were large differences in the agricultural land footprint structure of industries between provinces. (3) The embodied agricultural land transfer structures of various provinces were quite different. For example, among the four provinces of Hebei, Henan, Shandong, and Jiangsu, where the total transfer amount was relatively high, Hebei and Jiangsu were balanced, while Shandong was the net transfer-in type, and Henan was the net transfer-out type. The embodied agricultural land transfer between regions showed two main directions, on the whole, the one is from north to south, the other one is from west to east, which reflects the transfer law from the less developed regions to the developed regions.

Overall, most of the regions with higher economic development levels are net imports of agricultural land. This indicates that agricultural land in developed regions cannot support its own end-use and needs to maintain its economic development by importing agricultural products. On the contrary, the economically underdeveloped areas are mostly net exporters of agricultural land, especially some provinces with a large proportion of agricultural activities, such as Henan and Sichuan provinces, which have sufficient agricultural land and can provide agricultural products for the final use of other provinces. Assuming that there is no difference in value increase between agriculture and other industries, the above situation will not lead to further widening of the regional economic gap. However, if the price of agricultural products has been maintained at a lower level than that of other industries, the spatial shift pattern of the above agricultural land footprint will lead to the expansion of regional differences. Research has shown that the price of agricultural products in China has always been in a disadvantageous position relative to the price of industrial products and services [48]. Therefore, the agricultural land transfers among regions within China are actually the transfer of wealth, which is not conducive to the reduction of regional economic differences. On the other hand, due to the decrease in the income of agricultural land, farmers may exacerbate the unsustainable use of agricultural land in order to increase their income. Some scholars have found that global agricultural trade has had a negative impact on the global land ecosystem since around 2000 [49]. Therefore, in order to improve the level of sustainable land use, policy-makers should also pay attention to the transfer of agricultural land.

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References
1. Chen, W.; Kang, J.; Han, M. Global environmental inequality: Evidence from embodied land and virtual water trade. Sci. Total Environ. 2021, 783, 146992. [CrossRef] [PubMed]
2. Laura, W.; Thomas, K.; Claudia, R.B. Virtual land use and agricultural trade: Estimating environmental and socio-economic impacts. Ecol. Econ. 2006, 57, 679–697.
3. Guo, S.; Shen, G.; Chen, Z.; Yu, R. Embodied cultivated land use in China 1987–2007. Ecol. Indic. 2014, 47, 198–209. [CrossRef]
4. Tian, X.; Bruckner, M.; Geng, Y.; Bleischwitz, R. Trends and driving forces of China’s virtual land consumption and trade. Land Use Policy 2019, 89, 104194. [CrossRef]
5. Feng, Z.; Yang, Y.; Zhang, Y.; Li, Y. Grain-for-green policy and its impacts on grain supply in West China. *Land Use Policy* 2005, 22, 301–312. [CrossRef]

6. Qiang, W.; Liu, A.; Cheng, S.; Kastner, T.; Xie, G. Agricultural trade and virtual land use: The case of China’s crop trade. *Land Use Policy* 2013, 33, 141–150. [CrossRef]

7. Yawson, D.O. Estimating virtual land use under future conditions: Application of a food balance approach using the UK. *Land Use Policy* 2021, 101, 105132. [CrossRef]

8. Yawson, D.O. Estimating virtual water and land use transfers associated with future food supply: A scalable food balance approach. *MethodsX* 2020, 7, 100811. [CrossRef] [PubMed]

9. Yawson, D.O.; Mulholland, B.J.; Ball, T.; Adu, M.O.; Mohan, S.; White, P.J. Effect of Climate and Agricultural Land Use Changes on UK Feed barley Production and Food Security to the 2050s. *Land* 2017, 6, 74. [CrossRef]

10. Kearney, J. Food Consumption Trends and Drivers. *Philos. Trans. R. Soc. B Biol. Sci.* 2010, 365, 2793–2807. [CrossRef] [PubMed]

11. Liu, X.; Yu, L.; Cai, W.; Ding, Q.; Hu, W.; Peng, D.; Li, W.; Zhou, Z.; Huang, X.; Yu, C.; et al. The land footprint of the global food trade: Perspectives from a case study of soybeans. *Land Use Policy* 2021, 111, 105764. [CrossRef]

12. Meier, T.; Christen, O.; Semler, E.; Jahreis, G.; Voget-Kleschin, L.; Schrode, A.; Artmann, M. Balancing virtual land imports by a shift in the diet. Using a land balance approach to assess the sustainability of food consumption. Germany as an example. *Appetite* 2014, 74, 20–34. [CrossRef] [PubMed]

13. Rees, W.E. The Ecology of Sustainable Development. *Ecologist* 1990, 20, 18–23.

14. Kitzes, J.; Peller, A.; Goldfinger, S.; Wackernagel, M. Current method for calculating National Ecological Footprint Accounts. *Sci. Environ. Sustain. Soc.* 2007, 4, 1–9.

15. Moran, D.D.; Wackernagel, M.C.; Kitzes, J.A.; Heumann, B.W.; Phan, D.; Goldfinger, S.H. Trading spaces: Calculating embodied Ecological Footprints in international trade using a Product Land Use Matrix (PLUM). *Ecol. Econ.* 2009, 68, 1938–1951. [CrossRef]

16. Wiedmann, T. A first empirical comparison of energy Footprints embodied in trade—MRIO versus PLUM. *Ecol. Econ.* 2009, 68, 1975–1990. [CrossRef]

17. Xi, J.; Han, M.; Ugliati, S. Optimal allocation of direct and embodied arable land associated to urban economy: Understanding the options deriving from economic globalization. *Land Use Policy* 2020, 91, 104392.

18. Weinzettel, J.; Hertwich, E.G.; Peters, G.P.; Steen-Olsen, K.; Galli, A. Affluence drives the global displacement of land use. *Glob. Environ. Chang.-Hum. Policy Dimens.* 2013, 23, 433–438. [CrossRef]

19. Chen, G.; Han, M. Global supply chain of arable land use: Production-based and consumption-based trade imbalance. *Land Use Policy* 2015, 49, 118–130. [CrossRef]

20. Qiang, W.; Niu, S.; Liu, A.; Kastner, T.; Bie, Q.; Wang, X.; Cheng, S. Trends in global virtual land trade in relation to agricultural products. *Land Use Policy* 2020, 92, 104439. [CrossRef]

21. Chen, G.; Han, M. Virtual land use change in China 2002–2010: Internal transition and trade imbalance. *Land Use Policy* 2015, 47, 55–65. [CrossRef]

22. Han, M.; Chen, G. Global arable land transfers embodied in Mainland China’s foreign trade. *Land Use Policy* 2018, 70, 521–534. [CrossRef]

23. Wang, J.; Wang, S.; Zhou, C.; Sun, D. Uncovering the patterns and driving forces of virtual forestland flows in China. *J. Clean. Prod.* 2022, 339, 130598. [CrossRef]

24. Ren, D.; Yang, H.; Zhou, L.; Yang, Y.; Liu, W.; Hao, X.; Pan, P. The Land-Water-Food-Environment nexus in the context of China’s soybean import. *Adv. Water Resour.* 2021, 151, 103892. [CrossRef]

25. Jiang, L.; Guo, S.; Wang, G.; Kan, S.; Jiang, H. Changes in agricultural land requirements for food provision in China 2003–2011: A com-parison between urban and rural residents. *Sci. Total Environ.* 2020, 725, 138293. [CrossRef] [PubMed]

26. Kan, S.; Chen, B.; Han, M.; Hayat, T.; Alsulami, H.; Chen, G. China’s forest land use change in the globalized world economy: Foreign trade and unequal household globalization. *Land Use Policy* 2021, 103, 105324. [CrossRef]

27. Guo, S.; Jiang, L.; Shen, G.Q. Embodied pasture land use change in China 2000–2015: From the perspective of globalization. *Land Use Policy* 2019, 82, 476–485. [CrossRef]

28. Infante-Amate, J.; Aguilera, E.; Palmeri, F.; Guzmán, G.; Soto, D.; García-Ruiz, R.; de Molina, M.G. Land embodied in Spain’s biomass trade and consumption (1900–2008): Historical changes, drivers and impacts. *Land Use Policy* 2018, 78, 493–502. [CrossRef]

29. Anna, V.; Valerie, D.; Eva, K.; Elke, R.; Hubert, G. Virtual farmland: Grasping the occupation of agricultural land by non-agricultural land uses. *Land Use Policy* 2015, 42, 547–556.

30. Chen, B.; Han, M.; Peng, K.; Zhou, S.; Shao, L.; Wu, X.; Wei, W.; Liu, S.; Li, Z.; Li, J.; et al. Global land-water nexus: Agricultural land and freshwater use embodied in worldwide supply chains. *Sci. Total Environ.* 2018, 613-614, 931–943. [CrossRef] [PubMed]

31. Saikku, L.; Mattila, T.J. Drivers of land use efficiency and trade embodied biomass use of Finland 2000–2010. *Ecol. Indic.* 2017, 77, 348–356. [CrossRef]

32. Terrapon-Pfaff, J.; Ortiz, W.; Dienst, C.; Gröne, M.C. Energising the WEF nexus to enhance sustainable development at local level. *J. Environ. Manag.* 2018, 223, 409–416. [CrossRef] [PubMed]

33. Oliver, T.; Dario, C. Drivers of water and land use embodied in international soybean trade. *J. Clean. Prod.* 2019, 223, 83–93.

34. Liu, Y.; Wang, S.; Chen, B. Water–land nexus in food trade based on ecological network analysis. *Ecol. Indic.* 2019, 97, 466–475. [CrossRef]
35. Niu, B.; Peng, S.; Li, C.; Liang, Q.; Li, X.; Wang, Z. Nexus of embodied land use and greenhouse gas emissions in global agricultural trade: A quasi-input–output analysis. *J. Clean. Prod.* **2020**, *267*, 122067. [CrossRef]

36. Zheng, Y.; Hong, J.; Xiao, C.; Li, Z. Unfolding the Synergy and Interaction of Water-Land-Food Nexus for Sustainable Resource Management: A Supernetwork Analysis. *Sci. Total Environ.* **2021**, *784*, 147085.

37. Guo, S.; Wang, Y.; Wang, Y.; Wang, M.; He, P.; Feng, L. Inequality and collaboration in north China urban agglomeration: Evidence from embodied cultivated land in Jing-Jin-Ji’s interregional trade. *J. Environ. Manag.* **2020**, *275*, 111050. [CrossRef]

38. Guo, S.; Wang, Y.; Shen, G.Q.; Zhang, B.; Wang, H. Virtual built-up land transfers embodied in China’s interregional trade. *Land Use Policy* **2020**, *94*, 104536. [CrossRef]

39. Chuai, X.; Gao, R.; Huang, X.; Lu, Q.; Zhao, R. The embodied flow of built-up land in China’s interregional trade and its implications for regional carbon balance. *Ecol. Econ.* **2021**, *184*, 106993. [CrossRef]

40. Wang, J.; Wang, S.; Zhou, C. Quantifying embodied cultivated land-use change and its socioeconomic driving forces in China. *Appl. Geogr.* **2021**, *137*, 102601. [CrossRef]

41. Wu, S.; Ben, P.; Chen, D.; Chen, J.; Tong, G.; Yuan, Y.; Xu, B. Virtual land, water, and carbon flow in the inter-province trade of staple crops in China. *Resour. Conserv. Recycl.* **2018**, *136*, 179–186. [CrossRef]

42. Fang, D.; Cai, Q.; Wu, F.; Chen, B.; Zhang, L. Modified linkage analysis for water-land nexus driven by interregional trade. *J. Clean. Prod.* **2022**, *353*, 131547. [CrossRef]

43. Han, M.; Li, S. Transfer patterns and drivers of embodied agricultural land within China: Based on multi-regional decom-position analysis. *Land Use Policy* **2021**, *10*, 213. [CrossRef]

44. Han, M.; Chen, G.; Dunford, M. Land use balance for urban economy: A multi-scale and multi-type perspective. *Land Use Policy* **2019**, *83*, 323–333. [CrossRef]

45. Borucke, M.; Moore, D.; Cranston, G.; Gracey, K.; Iha, K.; Larson, J.; Lazarus, E.; Morales, J.C.; Wackernagel, M.; Galli, A. Accounting for demand and supply of the biosphere’s regenerative capacity: The National Footprint Accounts’ underlying methodology and framework. *Ecol. Indic.* **2013**, *24*, 518–533. [CrossRef]

46. Liu, H.; Fan, X. Value-Added-Based Accounting of CO2 Emissions: A Multi-Regional Input-Output Approach. *Sustainability* **2017**, *9*, 2220. [CrossRef]

47. Liu, H.; Liu, W.; Fan, X.; Zou, W. Carbon emissions embodied in demand–supply chains in China. *Energy Econ.* **2015**, *50*, 294–305. [CrossRef]

48. Zhou, C.; Wu, F.; Zhang, J. The Occult Metastases and its Measurement of Urban and Rural Factor Income in China. *Stat. Res.* **2017**, *34*, 63–74.

49. Nicolas, R.; Thomas, K.; Karl-Heinz, E.; Helmut, H. Does agricultural trade reduce pressure on land ecosystems? Decomposing drivers of the embodied human appropriation of net primary production. *Ecol. Econ.* **2021**, *181*, 106915.