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Spatial shifts in grain production increases in China and implications for food security

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ABSTRACT

China's food security remains a worldwide concern due to its huge population and rapid urbanization. As demonstrated by statistics, China's total grain output has been continuously increasing since 2003. Meanwhile, the grain production growth has shown various spatial disparities across the country. This paper explores the spatial shifts in grain production increase and their potential impacts at county-level in China. The results show that the barycenter of grain production has moved northward obviously and crossed the Yellow River, which served as the main irrigation water source for agriculture in North China. Both absolute grain output growth and relative growth patterns demonstrate that North China, especially the region of north bank of the Yellow River, has been the significant area contributing to grain production. China has shifted grain production to the marginal regions with lower land productivity and higher natural risk. Although China's grain output has increased continuously, the grain output system is now more vulnerable and unstable than before. In the final part, the paper discusses the three main factors influencing the spatial shifts in grain output, which are farmland protection system, farmer-protecting grain subsidy policies and the dramatic improvement in agricultural infrastructure, and gives some suggestions on the improvement of farmland protection system and agricultural support policy.

1. Introduction

Food security always remains a worldwide concern since it is the fundamental requirement for human survival and development (Rosegrant and Cline, 2003). To ensure food supply, most countries and regions make great efforts to increase grain production (UNICEF, 2014). However, global food security is still facing significant challenges due to farmland loss, water shortage, soil pollution and climate change and so on (Godfray et al., 2010; Rosegrant and Cline, 2003; Schmidhuber and Tubiello, 2007). In addition, it has adverse ecological impact on local development by pursing single object of grain yield growth (Bommarco et al., 2013; Godfray et al., 2010; Morton et al., 2006; Zhang et al., 2006).

China is a large country of agriculture with a huge population that will peak at 1.5 billion around 2030. Its food supply capability has received close attention worldwide for its rapid population growth and unprecedented urbanization (Chen, 2007; Veeck, 2013). In spite of rapid urban expansion and high-quality farmland loss, China has been making efforts to feed 21% of the world's population with merely 7% of the world's arable land. It has made outstanding contribution to the United Nations Millennium Development Goals in its efforts for poverty reduction and increased food production (UNICEF, 2014). In 2015, China's grain production reached a record of 621.4 million tons, marking 12 years of consecutive increases.

China's grain output has maintained continuous and stable increase through various means. These means are not only made to improve farming conditions, such as the enlargement of irrigation area (Cao et al., 2015), the provision of enough water resources (Shahbaz et al., 2009), and the development of widespread land reclamation (Zhang et al., 2003), but also to adopt positive agriculture support policy and strict farmland protection systems, for instance, the Chinese government has issued policies to rescinded agricultural tax and added 4 types of agricultural subsidy (*yi mian si bu*) (Huang et al., 2010; Yu et al., 2015), proposed requisition-compensation balance of arable land (*gengdi zhan bu ping heng*)(Chien, 2015; Ding, 2003; Lichtenberg and Ding, 2008), and issued 'increasing vs. decreasing balance' land-use policy (Long et al., 2012). However, the grain output growth performed uneven trends through different regions in China. Some research described that the barycenter of grain production had moved towards north and west (Liu et al., 2009; Wang and Liu, 2009). The spatial mismatch of grain production and farmland resource caused the inefficient use of and decreasing amounts of available farmland (Li et al.,

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2017). Climate warming provided good conditions for arable land expansion, which is the fundamental support to grain growth in Heilongjiang Province, Northeast China (Gao and Liu, 2011).

Previous research mostly focused on the grain production growth at the temporal dimension and analyzing its influence factors (Chen et al., 2011; Veeck, 2013). However, the regional disequilibrium of grain growth has disorganized the traditional spatial patterns of grain production. In fact, the barycenter of grain production moving northward and westward, to some extent, worsen the shortage of water resources in the northwest region and changed the grain circulation pattern from "grain in the south being transported to the north" to "grain in the north being transported to the south"(Liu and Zhai, 2009; Shahbaz et al., 2009; Simelton, 2011; Wang and Liu, 2009; Xu et al., 2013).

The purposes of this paper are not only to analyze the spatial shift of Chinese increasing grain output at the scale of county-level, but also to discuss the potential influences of the spatial shift trend, which would make contribution to comprehensively understanding China's continuous grain growth and rethinking the current support policies and farmland protection systems on food security.

2. Materials and methods

2.1. Data source and processing

We collected the grain output data from the Statistical Yearbook published by National Bureau of Statistics of China. County-level grain output data was collected from the *China County Statistical Yearbook* of 2004, 2006, 2011 and 2015. According to Chinese statistical data, grain outputs include corn, rice, soybean, wheat, potato and sweet potato. It is different from statistics from Food and Agriculture Organization of the United Nations (FAO) and World Bank who exclude sweet potato. Chinese sweet potato output accounted for approximately 5 percent of total grain output. Besides, the land use data was collected from the Chinese Land Resource Bulletin.

Spatial data include the digital grid map of average annual precipitation (AP), > 10 °C accumulated temperature (AT) and the administrative boundary map of counties, which were applied from Data Center for Resources and Environmental Sciences, Chinese Academy of Sciences (RESDC) (http://www.resdc.cn). Till now, there are 2861 county-level administrative units in China in total, including 845 municipal districts, pasture or forestry counties. In this study, 2040 counties were involved with complete information. The municipal districts, pasture or forestry counties with almost no marked grain production and other counties with no complete data due to reasons like administrative division adjustment were excluded from the study. Due to the lack of relevant data, Hong Kong, Macao and Taiwan are not included in this study also.

2.2. Calculating the barycenter of grain production

The concept of barycenter stems from physics and it refers to a certain spatial point, in all directions of which the powers are relatively balanced. As an important analysis tool for studying changes of spatial patterns, the barycenter models, such as population barycenter, economic barycenter and energy barycenter model, are also frequently used for the spatial analysis (Bigot and Klein, 2012; Dicken, 2003; Zhang et al., 2012). The grain output barycenter is formed according to above theory. The barycentric coordinates can be calculated by the following formula:

$$x_j = \sum_{i=1}^{n} (T_{ij}\cdot x_i)/\sum_{i=1}^{n} T_{ij} \quad y_j = \sum_{i=1}^{n} (T_{ij}\cdot y_i)/\sum_{i=1}^{n} T_{ij}$$

Where, T_{ij} (i = 1, 2, 3, … n) means the grain output of the i^{th} county; $P_i(x_i, y_i)$ is the barycentric coordinate of each county; $P_j(x_j, y_j)$ is the national barycentric coordinate of grain output in the j^{th} year. Assuming barycentric coordinate at the k and $k+m$ year are $P_k(x_k, y_k)$ and $P_{k+m}(x_{k+m}, y_{k+m})$, the deviation angle of the barycenter movement from P_k to P_{k+m} should be calculated as follow:

$$\theta_m = \arctan((y_{k+m} - y_k)/(x_{k+m} - x_k))$$

And the displacement of barycenter is:

$$d_m = \sqrt{(x_{k+m} - x_k)^2 + (y_{k+m}\text{-}y_k)^2}$$

2.3. Exploratory spatial data analysis (ESDA)

Exploratory spatial data analysis (ESDA) is an extension of exploratory data analysis as it explicitly focuses on the particular characteristics of geographical data (Dall'erba, 2009). It can be used as a common index to detect when certain phenomenon is significantly correlated to the observation value of adjacent units. ESDA can be used for describing the distribution pattern of matter or phenomenon, and having visualized research of relative difference between distribution mode and space of regional attribute values. ESDA includes global spatial autocorrelation (Global Moran's I) and local spatial autocorrelation (Local Moran's I). In this study, the grain output increase in all phases of county unit is calculated firstly. Software GeoDA was used for calculating the Global Moran's I Index of grain output growth in all phases, checking when there's spatial agglomeration trend in China's grain yield growth of all stages and having quantitative expression of the spatial agglomeration trend strength (Anselin et al., 2006). The calculation formula is as follow:

$$\text{Moran}'\text{sI}= \frac{n}{\sum_{i=1}^{n}\sum_{j\neq 1}^{n} W_{ij}} \times \frac{\sum_{i=1}^{n}\sum_{j\neq 1}^{n} W_{ij}(x_i - \bar{x})(x_j - \bar{x})}{\sum_{i=1}^{n} (x_i - \bar{x})^2}$$

Where, x_i and x_j represent the attribute value of Unit i and j respectively; W_{ij} means the adjacent weight of space unit; $\bar{x}$ refers to the arithmetic average of the value. Global Moran's I value is between −1 and 1. If it is closer to 1, it means agglomeration of similar attributes; inversely, if it is closer to −1, it indicates agglomeration of different attributes. If value is closer to 0, it means the spatial distribution is random.

Based on the Global Moran's I of grain output growth, the local spatial autocorrelation is existed in general to calculate the Local Moran's I index:

$$\text{Local Moran}' I_i = \frac{(x_i - \bar{x})}{S^2} \sum_{j=1, j\neq i}^{n} W_{ij}(x_j - \bar{x})$$

$$S^2 \frac{1}{n} \sum (x_i - \bar{x})^2$$

Finally, the LISA (Local Indicators of Spatial Association) for Local Moran's I index of all county units was drawn using Geodata software. The univariate LISA analysis examines the spatial association between a county and its neighbors in terms of a variable of interest and puts counties with same spatial association into a group (Anselin, 1995). The result means, under the significant level of 0.05, the grain yield increase of the i^{th} county and grain yield increase of adjacent counties are of high increase area, i.e. H-H cluster; or low increase area, i.e. L-L cluster; if a high-increase county is surrounded by low-increase areas, or a low-increase area is surrounded by high-increase areas, it means there exists spatial abnormity, i.e. H-L cluster and L-H cluster.

3. Results

3.1. The overall increasing trend of chinese grain production

China has been under internal and external pressures for grain supplies since its founding in 1949. Chinese government takes grain