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Assessing the effectiveness of land consolidation for improving agricultural productivity in China

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ABSTRACT

Agricultural production in China is crucial for socioeconomic development and food security. Land consolidation has been regarded as an important way to maintain food security and is highly valued by the Chinese government. However, whether productivity improvements can be achieved through land consolidation is not yet clear. To address this, we propose a straightforward method to assess agricultural productivity changes using remote-sensing data. The normalized difference vegetation index (NDVI) is used to represent yield, as its changes correlate significantly with yield changes. The analysis uses a Moderate Resolution Imaging Spectroradiometer NDVI time series covering a period of 13 years (2001–2013) at a spatial resolution of 250 m and data on projects completed in 2006 and 2007. Control sites near the projects are used to eliminate the influence of other factors. The results show that 62.90% and 58.34% of projects in 2006 and 2007, respectfully, were effective at improving productivity, whereas 56.51% and 52.56%, respectfully, effectively stabilized productivity. Generally speaking, 78.67% of projects in 2006 and 78.32% of those in 2007 proved effective at either improving or stabilizing productivity; however, only 40.56% and 34.34%, respectfully, were effective at doing both. Furthermore, it should be noted that areas with effective productivity improvements mainly benefitted from growth in the cropping area and that the annual yield per unit area on project areas decreased within a few years after consolidation. The lack of effectiveness may be caused by problems of engineering, construction, and subsequent management. Governments must thus consider new consolidation projects comprehensively and cautiously before launching them.

1. Introduction

Land as a resource has been under increasing pressure amid the rapid socioeconomic development marking recent decades in China (Liu et al., 2005; Liu et al., 2008). Cropland in particular is threatened by urban sprawl and infrastructure development (Du et al., 2014), which could negatively affect grain production. China has only 0.08 ha of cropland per capita, far below the global average with 0.20 ha per capita, even though it accounts for over 20% of the world's population (Qiang et al., 2013). Furthermore, population increases and structural changes to diets are likely to exacerbate existing pressures on grain demand. As such, China's grain security has received great attention from scholars (Deng et al., 2006; Du et al., 2015; Verburg et al., 2000; Yan et al., 2009; Zhou et al., 2012), especially after Brown (1995) put forward the question "Who Will Feed China?".

Improving agricultural technologies and policies are effective measures to meet food demand (Laurance et al., 2014). However, cropland quality and quantity are the primary factors determining grain production. To address the rapid decline in cropland and the continuous fall in grain production capacity due to cropland loss, the Chinese central government is implementing a series of policies and measures to protect cropland. Among these, the most important is land consolidation, which aims to protect cropland and increase agricultural productivity (Song and Pijanowski, 2014). Although it has been widely accepted that land consolidation could improve agricultural infrastructure and land quality, thereby increasing agricultural productivity and resilience, the history of land consolidation in China is not long. China has been implemented large-scale land consolidation since the mid-1990s. According to aims of land consolidation, its history can be divided to two periods: (1)1998-2007, the initial aims were to increase cropland, reduce fragmentation, and promote agricultural productivity; (2) 2008-, the aims of the LC is shifting toward becoming the integrated goals of increasing cropland, reducing fragmentation, improving agriculture infrastructure, promoting agricultural productivity, and improving environmental quality. From 2006–2012 in China, 8.29 million ha of cropland were renovated and 2.7 million ha of new cropland was

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gained through land consolidation (Guan et al., 2013). According to the national land consolidation plan for 2011–2015, an additional 26.7 million ha of prime cropland will be established. Meanwhile, the plan has set 1,500 kg/ha as a minimum cropland productivity improvement target after land consolidation.

While the quantity of new cropland added through land consolidation is easy to measure, it is difficult to assess and monitor the resulting productivity change because grain production is affected by many factors, such as climate and agricultural management. There are extensive literature has been dedicated to agricultural productivity change after land consolidation project, however, most of the studies consider only soil quality, land quality or potential productivity (Deng et al., 2006; Gao et al., 2016; Luo and Zhao, 2013; Song et al., 2015; Song and Liu, 2017). In reality, actual grain yield data for project sites is unavailable, and grain yields are generally reported by local governments for administrative units. To date, few studies have evaluated the productivity change resulting from land consolidation projects at the national scale. As China has high hopes for land consolidation, such a national-level assessment is crucial for policymakers. In this study, we thus attempt to assess the effects of land consolidation on productivity by using remote sensing.

Remote sensing provides an excellent source of data for monitoring vegetation growth (Patel et al., 1985). The relationship between the vegetation index obtained from remote sensing and the productivity of the associated vegetation has been widely studied; as a result, remote sensing has been recognized as an effective and powerful tool for evaluating grain yield (Bastiaanssen and Ali, 2003; Padilla et al., 2012; Patel et al., 1985; Peng et al., 2014; Reeves et al., 2005). In particular, Lobell (2013) found that variations in the normalized difference vegetation index (NDVI) can explain more than 80% of the observed variation in crop yields. This suggests that we can assess whether productivity is improved after land consolidation by comparing the NDVI change. As mentioned above, grain yields are affected by many factors. We thus try to distinguish the influence of land consolidation from other factors by using control sites in the area immediately surrounding the project sites. By assuming that the agricultural management of project and control sites is same, we can compare the NDVI changes between project and control sites before and after consolidation to evaluate whether productivity has improved.

2. Data sources and methods

2.1. Data sources

Two types of data were used in this paper: the NDVI data and data on land consolidation projects. The NDVI data was obtained from the Moderate Resolution Imaging Spectroradiometer (MODIS) satellite. MODIS NDVI data is characterized by high resolution (250-1000 m) and is publically available (Peng et al., 2014). We thus downloaded a 250 m 16-day NDVI dataset covering 2001–2013 from NASA Reverb (http://reverb.echo.nasa.gov/).

The land consolidation project data included detailed information on each project, such as location, boundary, area, construction completion date, newly added cropland area, and so on. The data were obtained from the National Rural Land Consolidation Monitoring and Regulation System maintained by the Ministry of Land and Resources of China. According to data availability and objectives of land consolidation, projects implemented in 2006 and 2007 were selected for use in the study. In practice, there are three forms of land consolidation: cropland consolidation, land exploitation, and land reclamation. Cropland consolidation aims to enhance the agricultural productivity and resilience of the existing cropland. Land exploitation focuses on conversion of non-cropland (unused land or natural land) to cropland. Land reclamation seeks to convert cropland that has been damaged by construction, disasters, and other incidents.

It is clear that land exploitation and reclamation can increase agricultural productivity, especially when involving the conversion of unused or destroyed land to cropland. Land exploitation, which can increase productivity by increasing the amount of new cropland, is of particular importance, as the Chinese government has dictated that new cropland added by land exploitation should account for more than 60% of the projects' construction area. In contrast, the proportion of new cropland obtained through cropland consolidation projects is far smaller. In reality, however, a project may include two or three consolidation types. In this study, we focus on projects that consist mainly of cropland consolidation.

In addition, a project usually consists of several independent parcels. As some parcels were too small to be represented adequately by 250 m spatial resolution MODIS NDVI data, we selected parcels larger than 100 ha in size to represent the projects conducted in 2006 and 2007. Climate conditions are highly similar in adjacent area, so buffer around the parcel can be used to eliminate effects of climate change (Song and Deng, 2015). Meanwhile, the new cropland mainly converted from redundant roads, irrigation and drainage systems, small ponds, and so on. In other words, the new cropland was not concentrated contiguous and the mode of agricultural production wouldn't change before and after land consolidation, which was undertaken by individual households. For natural condition, social condition and cropping pattern were similar in adjacent area, we assumed the management practices in buffer area and project area were same. In a word, we try to distinguish the effects of land consolidation by buffer comparison. According to NDVI pixels size and distance to town, a 3-km buffer areas around the selected parcels were selected as control sites.

The spatial boundaries of the selected parcels and corresponding control sites were used to extract NDVI values and associated pixel reliability indices from the NDVI time series data. Only high-quality (reliability index ≤ 1) pixels were used for the study, with 939 parcels considered as qualified for inclusion in the study. Mean NDVI values were calculated for each parcel and control site. As the original NDVI data were noisy and may have missed values at some times, we smoothed the data using SG in TIMESAT software to remove noise and fill data gaps (Jönsson and Eklundh, 2004). Finally, NDVI time series data covering a period of 13 years (2001–2013) at a spatial resolution of 250 m was obtained and NDVI values from the same years were summed into an annual NDVI (AN).

2.2. Analysis methods

Agricultural productivity improvements arising from land consolidation can be measured in two different ways: increased production and stable production. As such, two indexes were used to evaluate the effects of land consolidation. The first was the rate of change in the mean annual NDVI (MAN) values before and after consolidation, and the second was the coefficient of variation (CV) of the MAN before and after consolidation. According to our data, most of the projects' construction periods were less than one year; we thus assume that all parcels were constructed and completed in the same year. For example, for a project completed in 2006, years 2001–2005 were considered before consolidation, and 2007–2013 were considered after consolidation. The rate of change in the MAN and CV can be calculated with the following formulas.

$$MAN_{change} = \frac{MAN_{after} - MAN_{before}}{MAN_{before}} \times 100\% \quad (1)$$

Where MAN_{before} and MAN_{after} are mean AN before and after construction, respectively.

$$CV_{change} = \frac{CV_{after} - CV_{before}}{CV_{before}} \times 100\% \quad (2)$$

Where CV_{before} and CV_{after} are CV before and after construction, respectively, and CV can be calculated as in Eq. (3).