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The impact of urban expansion on agricultural land use intensity in China

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ABSTRACT

China's urbanization has resulted in significant changes in both agricultural land and agricultural land use. However, there is limited understanding about the relationship between the two primary changes occurring to China's agricultural land – the urban expansion on agricultural land and agricultural land use intensity. The goal of this paper is to understand this relationship in China using panel econometric methods. Our results show that urban expansion is associated with a decline in agricultural land use intensity. The area of cultivated land per capita, a measurement about land scarcity, is negatively correlated with agricultural land use intensity. We also find that GDP in the industrial sector negatively affects agricultural land use intensity. GDP per capita and agricultural investments both positively contribute to the intensification of agricultural land use. Our results, together with the links between urbanization, agricultural land, and agricultural production imply that agricultural land expansion is highly likely with continued urban expansion and that pressures on the country's natural land resources will remain high in the future.

Introduction

During the past several decades, China has experienced rapid urban transformation, represented by significant changes in its demographic composition and large-scale expansion of the urban landscape (Pannell, 2002; Wang et al., 2012). Satellite imagery show that the urban areas of China increased by almost 25% during the 1990s (Liu et al., 2005) and that urban land cover is expanding at rates faster than the growth of urban population (Seto et al., 2011). This has resulted in both the massive loss of cultivated land in the coastal and central provinces and the expansion of cultivated lands into other regions, especially the northern and border provinces of the country (Deng et al., 2006; Lichtenberg and Ding, 2008; Yue et al., 2010). Although the exact figures on the loss in total cultivated land area in China remain controversial, there is some consensus that the newly reclaimed cultivated land is less productive than the converted land (Doos, 2002; Yan et al., 2009). Given the decline of cultivated land, the level of inputs and outputs or frequency of cultivation against constant land (Turner and Doolittle, 1978), or intensity of agricultural land use, is of great importance for maintaining the food production capacity. However, urban expansion and economic development can lead to a rise in the off-farm opportunities and the resulting labor shortage in the agricultural sector (Wu et al., 2011). Declines in the intensity of agricultural land use and farmland abandonment have been documented for many regions and for different crops (Chen et al., 2009; Li and Wang, 2003; Liu and Li, 2006). This has posed additional challenges for the security of food provision and the preservation of natural ecosystems.

Both the urban expansion on agricultural land and agricultural land use intensity affect agricultural production (Long and Zou, 2010; Jiang et al., 2012). The nature and magnitude of their relationship directly influence agricultural production and food provision and may have further outcomes on the patterns of a nation's agricultural land. An understanding of the relationship between urban expansion and agricultural land use intensity is critical in order to formulate appropriate policies that will balance the pressure between urban growth and agricultural land use and preservation. In addition, a decrease in agricultural land use intensity implies more future farmland expansion at the expense of other ecosystems. Therefore, understanding how urban land expansion affects agricultural land use intensity will facilitate a better examination of the environmental impacts of farmland expansion and the sustainability of the utilization of land resources.

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There is limited understanding about the linkages between the two primary changes that are occurring on China's agricultural lands: the urban expansion on agricultural land and agricultural land use intensity. Urban land expansion suggests both declining agricultural land and a higher level of urban development. It is expected that land scarcity will trigger a more intensive use of agricultural land (Ewert et al., 2006), while urban development increases off-farm employments, which will enhance the opportunity costs of more intensive farming (Phimister and Roberts, 2006; Uchida et al., 2009). Previous studies have investigated the effects of these factors related to urban expansion (Keys and McConnell, 2005; Shriar, 2005). However, to date, no study has systematically examined the influence of urban expansion on agricultural land use intensity. Moreover, the majority of empirical evidence about the changes in the intensity of agricultural land use in China are limited to regional case studies, with considerable variations for different regions and for different periods (Chen et al., 2009; Li and Wang, 2003; Liu and Li, 2006). Most of these studies have sought to explain changes in agricultural land use intensity with an analysis of the shift in the socioeconomic environments, but the analysis is basically descriptive in nature. Therefore, our study also contributes to the understanding about the mechanisms of the changes in China's agricultural land use intensity.

Our study examines the influence of the urban expansion and other socioeconomic factors on agricultural land use intensity at the national scale. The research questions that we ask include: What is the relationship between the urban expansion and agricultural land use intensity and what is the underlying mechanism? What is the impact of land scarcity on agricultural land use intensity? What is the impact of increasing income and other economic opportunities on agricultural land use intensity? What is the effect of agricultural investment on agricultural land use intensity? We aim to derive a better understanding about the links between urban expansion and agricultural land use intensity, and the insights derived are based on correlation coefficients estimated from panel econometric models. Identification of causality among the factors is not within the scope of this study.

Theories of agricultural land use intensity

The literature on agricultural land intensification provides explanations about the pathways through which these factors related to urban expansion affect the intensity of agricultural land use, and about other major factors contributing to intensification of land use. However, no study has empirically studied the links between urban expansion and agricultural land use intensity. Urban expansion on agricultural land is associated with changes in the level of land scarcity and off-farm opportunities.

The classical land intensification theory is based on a unidirectional process of intensification of land use in response to locally driven increased demands for land-based products and services (Boserup, 1965). The underlying assumption here is that land use intensity is based on a finite amount of land. Boserup's theory and others (Chayanov, 1966; Darity, 1980; Robinson and Schutjer, 1984) describe the long-term process of land use intensification as driven by population pressure and land scarcity, which endogenously induces technological and institutional innovations to raise agricultural output from the given land. The validity of the theory is confirmed by a large amount of evidence from the broad agrarian change history. Under the pressure of population growth, a shift from extensive to relative intensive systems of land use has been witnessed in almost every part of the world (Boserup, 1965). This explanation of land use transitions emphasizes the relationship between demand and land resources. Based on this explanation, it is anticipated that both increased demand caused by population growth and land scarcity caused by declining agricultural land are likely to trigger intensification of land use. Later scholars extended the theory, arguing that other demand factors such as consumer diets and affluence may also influence the intensity of agricultural land use (Ewert et al., 2006; Keys and McConnell, 2005).

Market-based explanations of agricultural land use intensification differ from Boserup's theory and account for market demands and off-farm employment (Lambin et al., 2000). Angelsen (1999) builds conceptual models that explore open economy situations, in which farmers make decisions about agricultural production by responding to market demands and exogenously given commodity prices. Angelsen finds that better off-farm employment opportunities which results in higher real wage will lead to longer fallow periods and less labor inputs. Despite an emphasis on the market influence, Angelsen recognizes that neglecting demand factors when analyzing agricultural land use intensity is less realistic for the macro studies of a region or country. In fact, a generally accepted view is that with a higher degree of the openness of economy, the intensity of agricultural land use will be less related to population and demand, but more dependent on production factors including costs of land, off-farm employment, and market access, and is closely related to environmental conditions (Keys and McConnell, 2005; Phimister and Roberts, 2006; Shriar, 2005).

In the case of China, the market of agricultural product is still heavily controlled by the government and state-owned companies and provincial governors are required to take responsibility for local grain self-sufficiency (Yang, 1999). Given the limited market openness of agricultural product, both demand and production factors determine agricultural land use intensity. Additionally, policy intervention seems to play an important role on the change of agricultural land use and production in China. Most notably, the Chinese government has consistently increased the amount of investment allocated to agriculture in order to improve agricultural productivity (Deng et al., 2008). The importance of subsidy intervention on agricultural land use intensification has been highlighted in a number of studies concerning the processes of regional and global land-use changes (Ewert et al., 2006; Keys and McConnell, 2005).

Data

Agricultural land use intensity is commonly measured in three ways: (1) cropping frequency for a constant unit of land and time period, (2) agricultural outputs per unit land per unit time, or (3) inputs of capital, labor and skills that contribute to agricultural production (Brookfield, 1972; Turner and Doolittle, 1978). We use cropping frequency as a measure of agricultural land use intensity, a direct measurement about how frequently land is cultivated. Cropping frequency has been used as a measurement of land use intensity in both theoretical literature (Boserup, 1965) and empirical studies (Li and Wang, 2003; Liu and Li, 2006). There are a couple of reasons why we use cropping frequency. First, this study focuses on understanding changes in the management of agricultural land rather than yield increase. Agricultural economists have extensively studied yield increase, the outcome of agricultural land use intensification, in relation to management practices and conditions using production functions (Huang and Rozelle, 1995; Yao and Liu, 2008). However, few studies have revealed the factors and mechanism that lead to changes in land use management (Lambin et al., 2000). Second, measures in value of production (e.g. total value of output and total production cost) at the county level are either not available or inconsistent (Fan and Zhang, 2002). Third, because of the geographic and cultural diversity in China, there are considerable variations in crop structure across regions. For example, with the same grain output, the composition of output among wheat, rice, and corn can be very different between counties in the south and north. Hardly does any single variable of output properly measure overall land use intensity. Whereas cropping frequency provides a relatively standard way of measurement. Specifically, We used multi-cropping index (MCI), defined as the ratio of total sown area of crops relative to cultivated land area in the current year, in this study.

We used two sources of data to construct the MCI: total sown area of crops and area of cultivated land. We collected data on total sown area of crops in 1995, 2000 and 2005 from the China Statistical Yearbooks. However, aggregated land use data published by the Chinese government have been questioned for underestimating the quantity of agricultural land and its rate of loss (Chow, 1994; Seto et al., 2000). Therefore, we used a land use data set that was derived from the NASA Landsat TM/ETM satellite, and analyzed by the Chinese Academy of Sciences (CAS) (Liu et al., 2003, 2002). This national data set, which has undergone extensive development and testing, contains high resolution and spatially explicit information about the extent of urban and cultivated land for the years 1989, 1995, 2000, and 2005. To facilitate the testing of our main hypothesis, using data from these years as baselines, we further calculated the amount of cultivated land loss resulting from urban conversion for the periods 1989–1995, 1995–2000, and 2000–2005.

In addition to variables of the cultivated land area and conversion land area, which were used for testing the main hypothesis, we used two sources of information to construct the other explanatory variables. We hypothesize that the intensity of agricultural land use is influenced by other important socioeconomic factors documented in the literature, including off-farm opportunities, income (affluence), and agricultural investments. To construct those socioeconomic attributes, we used data on total and sector gross domestic product (GDP) for individual counties, and data on total population for individual counties, which were collected by the CAS from Socioeconomic Statistical Yearbook for China's Counties and Population Statistical Yearbook for China's Counties (NBSC, 2001, 1996 and 1990). We synthesized the data of agricultural investment per capita in each county.

We included a group of biophysical variables to account for the geographical heterogeneities across space. Biophysical and environmental factors including geographical location, terrain conditions, temperature and precipitation constrain the use of farmland and act in concert with economic and institutional factors in shaping agricultural land use change (Keys and McConnell, 2005). The effects of those biophysical factors on agricultural land use intensity are tested in our analysis and the second data source was used to provide the relevant information. The distance from each county seat to the provincial capital was calculated by Deng et al. (2010, 2002) using data from the CAS data center. The measure about total length of all highways in a county was created by the CAS using a digital map of transportation networks. The data reflecting terrain attributes were generated from China's digital elevation model data set by the CAS. The climate data were generated by Deng et al. (2010, 2002) using the site-based observations from the China Meteorological Administration from 1950 to 2000.

Empirical models and variable specifications

Our construction of the panel econometric model about the intensity of agricultural land use across space and time is based on theories of changes in agricultural land use intensity. Boserup's work has highlighted the importance of factors such as population, income, and land scarcity, while the market-based approach puts emphasis on production factors such as off-farm opportunities, market access and environmental conditions. We combine these two arguments and take account of policy interventions in the form of agricultural investments.

We use MCI, a measurement about the frequency of cultivation for a county in a given year (1995, 2000 or 2005), as our dependent variable. We intend to explain the change in MCI as a function of the urban expansion, agricultural land scarcity, income, other economic opportunities, agricultural subsidy, market access and a range of environmental conditions. *ConvertedLand* represents the amount of cultivated land that in a county has been converted to urban uses for each of the three time intervals: 1989–1995, 1995–2000 and 2000–2005. We use it to examine the relationship between urban expansion and agricultural land use intensity. The urban expansion on agricultural land is associated with both shrinking agricultural land area and a higher level of urban development. The former triggers greater land pressure and the latter indicates increasing off-farm employment opportunities. According to the theories of agricultural land use intensification, these two processes will result in contrary effects on the intensity of agricultural land use. Existing empirical studies on China's agricultural land use intensity contain limited and inconsistent information. Therefore, the nature of this relationship has to be determined through an empirical investigation.

AgriLand is the area of agricultural land per capita for a county in a given year (1995, 2000 or 2005) and it directly measures agricultural land scarcity. This variable, which captures the influence of land scarcity, is incorporated in the econometric model to facilitate the investigation of our main research question. To minimize the potential problem of endogeneity, which can jeopardize the consistent estimation of parameters, the values with a 5-year lag are used for the three socioeconomic explanatory variables: *GDP2*, *GDPpct* and *AgrInvest*. *GDP2* corresponds to gross industrial output for a county in a given year (1989, 1995 or 2000). High gross industrial output, which creates more off-farm employments, is expected to increase the opportunity costs of farming, and result in labor scarcity in the agricultural sector (Conelly, 1994). *GDPpct* is the gross domestic output per capita of a county for a given year (1989, 1995 or 2000) and is used as a proxy for population income. This variable is included for testing the influence of demand on agricultural land use intensity. A previous study on food consumption has found that not the sheer growth of population but the increase of income, which leads to a substantial change in dietary patterns, has significantly affected the country's grain demand (Pingali, 2007). *AgriInvest* means the agricultural investments per capita for a county in a given year (1989, 1995 or 2000). Agricultural investments from the national and provincial governments which are allocated at the county scale are aimed at enhancing agricultural production and promoting agricultural economic development. Since spatial heterogeneities and environmental conditions constrain the use of agricultural land, a group of biophysical variables, which do not vary over time, are specified and used to account for heterogeneities across space. Specifically, *Highway* is the total length of all highways in a county and *DistPCapit* is the distance from the county seat to the provincial capital. Together, they provide information about the relative location or market access of a county. *PlainRatio* is the ratio of land with an average slope in a county of less than eight degrees and *Elevation* is the average elevation of a county. These two variables measure the average terrain condition in a county. *Precipitation*, which is the average annual precipitation in a county, and *Temperature*, which is the average annual air temperature in a county, are controls for climate characteristics (Table 1).

Table 1
Description of key variables.

Variable	Description
Dependent variable	
MCI	Multi-cropping index (ratio)
Independent variables	
ConvertedLand	Area of land converted from agriculture to urban uses in a county within 1989–1995, 1995–2000, or 2000–2005 intervals (thousand hectares)
AgriLand	Area of cultivated land (thousand hectares)
GDP2	GDP in industrial sector (billion yuan)
GDPpct	GDP per capita (thousand yuan)
AgriInvest	Agricultural investment per capita (thousand yuan)
Highway	Total length of all highways (km)
DistPCapit	Distance from the county seat to the provincial capital (km)
PlainRatio	Ratio of land with a slope less than eight degrees (ratio)
Elevation	Average elevation (km)
Precipitation	Average annual precipitation (mm)
Temperature	Average annual air temperature (degree Celsius)

1 Chinese yuan ≈ 0.1574 US dollars.

The simplest linear panel econometric model for the relation between the MCI and its socioeconomic and biophysical determinants can be specified as

$$MCI_{it} = \mathbf{X}_{it}\boldsymbol{\beta} + u_{it} \tag{1}$$

where MCI_{it} is the multi-cropping index for county i in year t. $\mathbf{X}$ is a matrix of explanatory variables. $\boldsymbol{\beta}$ is a vector of regression coefficients to be estimated. u is a random disturbance term with mean 0. This standard linear pooling model assumes that $\boldsymbol{\beta}$ is the same for all counties and all time periods. We implement the Lagrange multiplier test of individual effect based on the result of the pooling model (Breusch and Pagan, 1980) and we reject the null hypothesis that variances across entities are zero (Chisq = 2978.9, $df = 1$, p-value < 0.0001). With evidence of significant differences across counties, models with a treatment of the individual effect have to be specified in order to capture county-specific heterogeneity that may bias the coefficient estimates.

Either fixed effects model or random effects model can be estimated to account for the spatial heterogeneity and stable unobservable characteristics associated with individual counties (Baltagi et al., 2003; Croissant and Millo, 2008; Hausman, 1978). Assuming that the random disturbance term has two separate components, the resulting model can be described in a common form as:

$$MCI_{it} = \mathbf{X}_{it}\boldsymbol{\beta} + \mu_i + \varepsilon_{it} \tag{2}$$

where μ is the individual error component specific to each county and ε is the idiosyncratic error that is assumed independent of both the regressors and the individual error component. The choice between the fixed and random effects specifications for this equation depends on the properties of the individual error component. If μ is correlated with the regressors, the OLS estimator becomes inconsistent. In this case, the fixed effects model in which μ is treated as a set of fixed but unknown constants, is used to derive consistent estimates. A disadvantage for the fixed effects model is that it does not allow for estimating the coefficients of the time-invariant regressors. Alternatively, a situation in which μ is uncorrelated with the regressors, the random effects model is used. This specification assumes μ is drawn from a normal distribution with a zero mean and a variance of σ^2_μ. In our study, both the fixed and random effects models are estimated and their estimation results are compared using the Hausman test. For the fixed effects model, we estimate a two-ways effect model which also incorporates the time effect to control for time trends that are uniform across counties.

Table 2
Results from Panel Econometric Models for the Intensity of Agricultural Land Use.

	Dependent variable: MCI	
	Fixed effects model	Random effects model
Intercept		0.720*** (14.94)
ConvertedLand	−0.010** (−2.19)	−0.016*** (−3.75)
AgriLand	−0.652*** (−6.60)	−0.883*** (−17.81)
GDP2	−0.010*** (−3.99)	−0.011*** (−5.61)
GDPpct	0.004* (1.89)	0.006*** (4.02)
AgrInvest	0.706** (2.55)	0.671*** (3.30)
Highway		0.0007*** (6.91)
DistPCapit		−0.0005*** (−4.46)
PlainRatio		0.369*** (12.06)
Elevation		−0.077*** (−4.80)
Precipitation		0.0002*** (7.45)
Temperature		0.027*** (8.62)
Observations	5010	5010
R-squared	0.21	0.31

Note: *t* statistics in parentheses.
* $p < 0.1$.
** $p < 0.05$.
*** $p < 0.01$.

Results

We estimate models for the intensity of agricultural land use for 1670 counties across three time periods using both the fixed and random effects models as specified in Eq. (2). The estimation results in Table 2 show that each of the explanatory variables is significantly correlated with the multi-cropping index. Moreover, the coefficient estimates of all the socioeconomic determinants of agricultural land use intensity have consistent signs with minor differences in magnitudes between the fixed and random effects specifications, indicating the robustness of these estimates. However, based on the Hausman test ($p < 0.0001$), we reject the null hypothesis of no significant differences between the random and fixed effects estimates. This demonstrates that the fixed effects model, which generates consistent estimates even when the unobserved factors are correlated with regressors, is a more appropriate specification. Therefore, we use the fixed effects model to illustrate the effect of each socioeconomic variable.

Both *ConvertedLand*, which is the urban conversion of cultivated land, and *AgriLand*, which is the area of cultivated land per capita, are negatively correlated with multi-cropping index. *AgriLand* is a direct measure about land scarcity. Its estimated effect conforms to our expectation declining cultivated area per capita may lead to land pressures and more intensive uses of agricultural land. With the control of the effect of land scarcity by *AgriLand*, the urban conversion of cultivated land mainly serves as a proxy for the level of urban development, which correlates with the ampleness of off-farm employment opportunities (Burchfield et al., 2006). The estimated effect of *ConvertedLand* indicates that increasing off-farm opportunities associated with a higher level of urban development is the dominant impact of urban land expansion. As urban development continuous to attract agricultural labors from farming, a smaller percentage of population will engage in agricultural production. Given the rising labor scarcity in the agricultural sector, there are two likely situations: changes is made in methods of agricultural production to increase the profits of farming. If the profits earned from changes in agricultural methods are still lower than the opportunity costs of farming, farmland abandonment may take place. Both situations can lead to a decline of cropping intensity.

Two categories of changes in methods of agricultural production can explain the decline of cropping intensity – productivity increase or changes in crop type. A substantial improvement in productivity has been documented since the introduction of the Household Responsibility System (HRS) to China's agriculture in the early 1980s (Yang, 1999), evidenced by a large increase in agricultural output and a modest decrease in total sown area (NBSC, 2006). It appears that the gain in efficiency of agricultural production has reduced the need for intensive cropping. Technological innovations including the application of new varieties and the adoption of modern inputs have played an imperative role in promoting the improvement (Huang et al., 2006). Since the 1990s, the development of land rental markets and the resultant increase in farm size, which facilitate mechanization and the implementation of new technologies, have also accelerated the progress (Chen et al., 2011; Deininger and Jin, 2005). The farmland rental activities are most prominent in the more developed provinces, where urbanization and the thriving of non-agricultural economy have induced a greater tension of labor availability in the agricultural sector. For example, in Zhejiang, a province on the east coast, approximately one-third of cultivated land is being rented (Kung, 2002; Rozelle et al., 2002).

To raise the profits of farming, there are also incentives for farmers to transform traditional farming systems that are dominated by paddy production to more diversified agricultural systems (Van den Berg et al., 2007). With the rise in market demand for higher-value food products, an increasing area of agricultural land is used for growing vegetables (Long et al., 2009; Wolf et al., 2003). Labor constraints, together with the relative low rice prices and the low marginal return from double cropping have led to a sweeping shift from double-rice to single-rice production (Yang, 1999). Considering that the prevailing vegetable systems embrace one to three consecutive crops (Van den Berg et al., 2007), with similar average rotations as traditional rice systems, their direct impact on multi-cropping index is small. Yet, the substantial drop in cropping frequency associated with grain crops can ultimately result in the decline of cropping intensity.

Reforms in methods of agricultural production have been carried out actively in order to generate incomes comparable to urban wages from the non-agricultural sectors. However, these reforms can end up with a failure. In regions where industry and service activities concentrate, opportunity costs of farming are especially high. Profits earned from changes in agricultural methods hardly compete with the opportunity costs of farming. In this situation, farmers will still leave their land to pursue non-agricultural employment, resulting in a decline of cropping intensity or even farmland abandonment (Baumann et al., 2011; Liu and Li, 2006).

As anticipated, *GDP2*, GDP in the industry sector, as an indicator of off-farm economic opportunities, is negatively correlated with the multi-cropping index. That explains why farmers in the economically advanced regions are more likely to leave land and become migrant workers. Labor absorption from the industry sector can result in a decline in the intensity of agricultural land use. *GDPpct* has a positive effect on the multi-cropping index. The increase of income can stimulate agricultural production and a more intensive use of agricultural land through the change in dietary patterns – a decrease in the consumption of food grains and a rise in the consumption of egg, milk and livestock products. This dietary change can significantly increase the country's grain demand, which requires a corresponding increase in agricultural production. *AgrInvest* has a positive effect. As an important policy intervention, agricultural investments essentially subsidize agricultural production. This result shows that agricultural investments have had success in boosting the intensity of agricultural land use and production.

The results of the random effects model provide coefficient estimates for a group of time-invariant biophysical variables. The coefficient estimate associated with *Highway* is positive and that associated with *DistPCapit* is negative, indicating that counties with locational advantages or better market access tend to have their agricultural land more intensively cropped. This conforms to the prediction of the market-based explanation that market proximity facilitates agricultural production and therefore will promote a more intensive use of agricultural land (Keys and McConnell, 2005; Shriar, 2005). *PlainRatio*, *Precipitation*, and *Temperature* are positively related to the multi-cropping index, while *Elevation* is negatively related. This result is not surprising since areas with good terrain and climate conditions are generally more favorable to agricultural production. We expect that counties with flatter terrain, more precipitation, and warmer climates will experience more intensive agricultural land use, *ceretis paribus*. This is consistent with the fact that most of China's agricultural land is concentrated in the South, which is both relatively warmer and flatter than the rest of the country.

Discussion

Both the urban conversion of agricultural land and GDP in the industrial sector are negatively correlated with agricultural land use intensity. Why would urban expansion on agricultural land result in a decline in agricultural land use intensity? First, it is useful to note that it is in the southern provinces where urban conversion of agricultural land is primarily taking place. Because of the warmer climate and abundant rainfall, the southern provinces have higher rates of farmland multiple cropping (Lichtenberg and Ding, 2008). Since the 1990s, the rate of urbanization and the resulting transfer of farm labors have led to a decline of the agricultural land use intensity in these provinces (Chen et al., 2009). During the same period, farming investments, multiple cropping, and mechanization consistently increased in the central and northern provinces (Long and Zou, 2010). We expect that as the southern provinces become increasingly urbanized and developed, the growth of the more "cropping intensive crops" will shift to the inland regions of the country.

Our findings illustrate the linkages between urban expansion, agricultural land, and agricultural production. We identified a negative relationship between urban expansion and agricultural land use intensity. A declining level of agricultural land use due to urban labor absorption suggests that other factors of production have to compensate for the decrease in agricultural production capacity in order to meet the country's increasing demand for food. There are several possible outcomes: improvement of agricultural productivity, agricultural imports, and agricultural land expansion. Land consolidation and extended mechanization might lead to further improvement in the efficiency of production. However, the contributions of technology improvements will be limited (Kastner et al., 2012; Long and Zou, 2010). Between 1995 and 2005, imports and exports of grain fluctuated and approached a net balance, while imports of oil-crop and soybeans increased multi-fold (Yue et al., 2010). In 2003, China imported 56% of the soybeans it consumed (Lichtenberg and Ding, 2008). Extrapolated from this trend, it is likely that China will partially alleviate its scarcity of land by increasing the import volume of non-strategic commodities such as oil-crop and livestock feeds. However, given the sheer amount of land required for grain and other food and the government's stringent control for self-sufficiency in strategic commodities, agricultural land expansion is inevitable.

Using satellite images, Deng et al. (2006) estimated that between late 1980s and 2000, 5.7 million hectares of new cultivated land were created. We analyzed the same data set and calculated the area of the remaining and new cultivated land for individual provinces across our study period, using 1989 as the reference year (Fig. 1). The results demonstrate that land reclamation took place in all provinces, including both the developed southern provinces such as Guangdong and Zhejiang and the less developed northern provinces such as Xinjiang and Inner Mongolia. The net gain

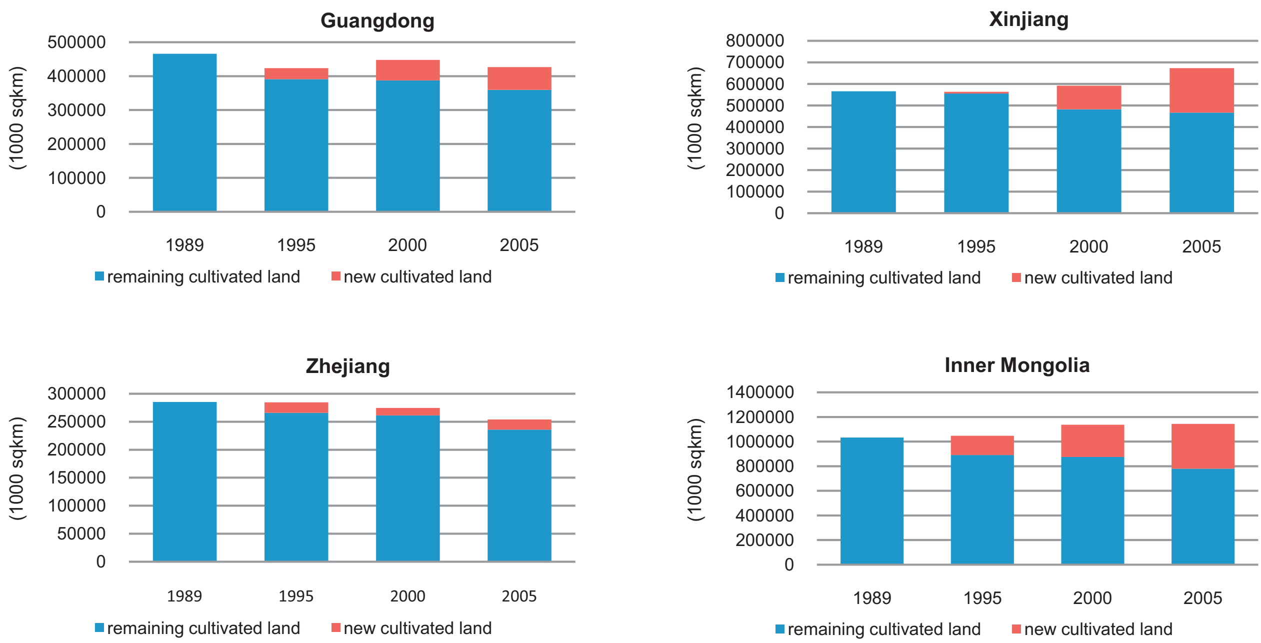

Fig. 1. Remaining and new cultivated land area for Guangdong, Zhejiang, Xinjiang, and Inner Mongolia provinces, with 1989 as the reference year.

of cultivated land in the northern provinces coexisted with the net loss of cultivated land in the developed provinces. Given the inferior soil and climate conditions in the northern provinces (Ash and Edmonds, 1998), more land reclamation is required to offset the lost production capacity in the southern provinces. This is likely to put additional pressures on the country's natural land resources.

Our results draw attention to the tension between China's urban growth and agricultural land use and the sustainability of its use of land resources. Examples from other parts of the world show that land conversion is necessary for urbanization and economic development (Ramankutty et al., 2002). However, urban expansion also leads to a decline of agricultural land use intensity, which will generate continuing pressure on the country's agricultural land and natural land resources. Although China has remained largely self-sufficient in food supply for several decades, this does not mean that its agricultural production and the use of land resources are sustainable in the long run.

In order to achieve the twin goals of urban growth and preservation of farmland, effective land use management and planning are critical. Rigid designation of basic farmland and a one-fits-all farmland preservation policy may result in leapfrog urban development, chaotic land use patterns, and inefficient use of land resources (Lichtenberg and Ding, 2008). Integrated land use management which incorporates urban planning into the formulation of farmland preservation policy could improve the land use inefficiency and alleviate the tensions between urban growth and farmland preservation. In addition, investments in agricultural infrastructure and institutions such as tenure security which can enhance the economic returns from intensive farming are important for maintaining the intensity of agricultural land use. This will reduce the need of land conversion from natural ecosystems into agricultural land, hence preventing excessive exploitation of natural land resources.

Our attempt to evaluate the influence of the urban expansion and other socioeconomic factors on agricultural land use intensity has several limitations. First, using counties as the analytical unit, our study is capable of capturing the overall process by which urban expansion affects agricultural land use intensity. However, a more profound understanding about how decisions made by farmers (to work on or off farm) influence land use dynamics may require further research at the micro level. Second, it is possible that lower quality associated with new cultivated land causes a decline in land use intensity. Given the data constraints, we are not able to treat land use intensity for existing and new cultivated land separately. Third, the design of this study only examines how urban expansion in one place affects agricultural land use intensity in the same location. The influence of cross-regional migration and how urban expansion in one place affects agricultural land use intensity in other places are issues that require more research.

Our study evaluates the impact of urban expansion on agricultural land use intensity at the national scale. There may be variations in terms of the impacts of urban expansion across regions. Our analysis indicates that the coefficient estimates of all socioeconomic variables of agricultural land use intensity have consistent signs across regions, but there are variations in magnitudes for some of those estimates. These provide some evidence about the existence of regional differences in terms of the impact of urban expansion and other socioeconomic forces.

Conclusion

In this paper, we used panel econometric models to investigate the influence of urban expansion and other socioeconomic factors on agricultural land use intensity. Our results show that urban land expansion is associated with a decline in agricultural land use intensity. The area of cultivated land per capita, a measurement of land scarcity, is negatively correlated with agricultural land use intensity. We also find that GDP in the industrial sector has a negative impact on agricultural land use intensity. Finally, consistent with expectations, GDP per capita and agricultural investments both positively contribute to the intensification of agricultural land use. Our results suggest that with the ongoing urbanization-driven labor transfer, the spatial patterns of agricultural land use are likely to change, with a shift of the "cropping intensive crops" to the inland provinces. Our results suggest that agricultural land expansion is likely to continue. Without expansion of agricultural production in other regions, total agricultural production in the country is likely to decline due to reductions in agricultural land intensity.

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References

Angelsen, A., 1999. Agricultural expansion and deforestation: modelling the impact of population, market forces and property rights. Journal of Development Economics 58 (1), 185–218.

Ash, R.F., Edmonds, R.L., 1998. China's land resources, environment and agricultural production. The China Quarterly 156, 836–879.

Baltagi, B.H., Bresson, G., Pirotte, A., 2003. Fixed effects, random effects or Hausman–Taylor? A pretest estimator. Economics Letters 79 (3), 361–369.

Baumann, M., Kuemmerle, T., Elbakidze, M., Ozdogan, M., Radeloff, V.C., Keuler, N.S., Prishchepov, A.V., Kruhlov, I., Hostert, P., 2011. Patterns and drivers of post-socialist farmland abandonment in Western Ukraine. Land Use Policy 28 (3), 552–562.

Boserup, E., 1965. The Conditions of Agricultural Growth. Allen & Unwin, London.

Breusch, T.S., Pagan, A.R., 1980. The Lagrange multiplier test and its applications to model specification in econometrics. The Review of Economic Studies 47 (1), 239–253.

Brookfield, H.C., 1972. Intensification and disintensification in Pacific agriculture: a theoretical approach. Pacific Viewpoint 13 (1), 30–48.

Burchfield, M., Overman, H.G., Puga, D., Turner, M.A., 2006. Causes of sprawl: a portrait from space. The Quarterly Journal of Economics 121 (2), 587–633.

Chayanov, A.V., 1966. Peasant farm organization. In: Thorner, D., Kerblay, B., Smith, R.E.F. (Eds.), The Theory of Peasant Economy. Irwin, Homewood, pp. 21–57.

Chen, Y., Li, X., Tian, Y., Tan, M., 2009. Structural change of agricultural land use intensity and its regional disparity in China. Journal of Geographical Sciences 19 (5), 545–556.

Chen, Z., Huffman, W.E., Rozelle, S., 2011. Inverse relationship between productivity and farm size: the case of China. Contemporary Economic Policy 29 (4), 580–592.

Chow, G.C., 1994. Understanding China's Economy. World Scientific Pub Co Inc., Singapore.

Conelly, W.T., 1994. Population pressure, labor availability, and agricultural disintensification: the decline of farming on Rusinga Island, Kenya. Human Ecology 22 (2), 145–170.

Croissant, Y., Millo, G., 2008. Panel data econometrics in R: The plm package. Journal of Statistical Software 27 (2), 1–43.

Darity, W.A., 1980. The Boserup theory of agricultural growth: a model for anthropological economics. Journal of Development Economics 7 (2), 137–157.

Deininger, K., Jin, S., 2005. The potential of land rental markets in the process of economic development: evidence from China. Journal of Development Economics 78 (1), 241–270.

Deng, X., Huang, J., Rozelle, S., Uchida, E., 2010. Economic growth and the expansion of urban land in China. Urban Studies 47 (4), 813–843.

Deng, X., Huang, J., Rozelle, S., Uchida, E., 2008. Growth, population and industrialization, and urban land expansion of China. Journal of Urban Economics 63 (1), 96–115.

Deng, X., Huang, J., Rozelle, S., Uchida, E., 2006. Cultivated land conversion and potential agricultural productivity in China. Land Use Policy 23 (4), 372–384.

Deng, X., Liu, J., Zhan, J., Zhao, T., 2002. Modeling the relationship of land use change and some geophysical indicators: a case study in the ecotone between agriculture and pasturing in Northern China. Journal of Geographical Sciences 12 (4), 397–404.

Doos, B.R., 2002. Population growth and loss of arable land. Global Environmental Change – Human and Policy Dimensions 12 (4), 303–311.

Ewert, F., Rounsevell, M., Reginster, I., Metzger, M., Leemans, R., 2006. Technology development and climate change as drivers of future agricultural land use. In: Brouwer, F., McCarl, B.A. (Eds.), Agriculture and Climate Beyond 2015. Environment and Policy 46, pp. 33–51.

Fan, S., Zhang, X., 2002. Production and productivity growth in Chinese agriculture: new national and regional measures. Economic Development and Cultural Change 50 (4), 819–838.

Hausman, J.A., 1978. Specification tests in econometrics. Econometrica: Journal of the Econometric Society 46 (6), 1251–1271.

Huang, J., Rozelle, S., 1995. Environmental stress and grain yields in China. American Journal of Agricultural Economics 77 (4), 853–864.

Huang, Q., Rozelle, S., Lohmar, B., Huang, J., Wang, J., 2006. Irrigation, agricultural performance and poverty reduction in China. Food Policy 31 (1), 30–52.

Jiang, L., Deng, X., Seto, K.C., 2012. Multilevel modeling of urban expansion and cultivated land conversion for urban hotspot counties in China. Landscape and Urban Planning 108 (2–4), 131–139.

Kastner, T., Rivas, M.J.I., Koch, W., Nonhebel, S., 2012. Global changes in diets and the consequences for land requirements for food. Proceedings of the National Academy of Sciences 109 (18), 6868–6872.

Keys, E., McConnell, W.J., 2005. Global change and the intensification of agriculture in the tropics. Global Environmental Change 15 (4), 320–337.

Kung, J.K., 2002. Off-farm labor markets and the emergence of land rental markets in rural China. Journal of Comparative Economics 30 (2), 395–414.

Lambin, E., Rounsevell, M., Geist, H.J., 2000. Are agricultural land-use models able to predict changes in land-use intensity? Agriculture, Ecosystems & Environment 82 (1–3), 321–331.

Li, X., Wang, X., 2003. Changes in agricultural land use in China: 1981–2000. Asian Geographer 22 (1–2), 27–42.

Lichtenberg, E., Ding, C., 2008. Assessing farmland protection policy in China. Land Use Policy 25 (1), 59–68.

Liu, J., Zhan, J., Deng, X., 2005. Spatio-temporal patterns and driving forces of urban land expansion in China during the economic reform era. Ambio 34 (6), 450–455.

Liu, J., Liu, M., Deng, X., Zhang, Z., Zhuang, D., 2003. Study on spatial pattern of land-use change in China during 1995–2000. Science in China Series D: Earth Sciences 46 (4), 373–384.

Liu, J., Liu, M., Deng, X., Zhuang, D., 2002. The land use and land cover change database and its relative studies in China. Journal of Geographical Sciences 12, 275–282.

Liu, C., Li, X., 2006. Regional disparity in the changes of agricultural land use intensity in China during 1980–2002. Journal of Geographical Sciences 16 (3), 286–292.

Long, H., Zou, J., 2010. Grain production driven by variations in farmland use in China: an analysis of security patterns. Journal of Resources and Ecology 1 (1), 60–67.

Long, H., Liu, Y., Wu, X., Dong, G., 2009. Spatio-temporal dynamic patterns of farmland and rural settlements in Su-Xi-Chang region: implications for building a new countryside in coastal China. Land Use Policy 26 (2), 322–333.

Ministry of Public Security of China (MPS) China Counties and Cities Population Yearbook, 1990, 1996, and 2001. Chinese Public Security Univ. Press, Beijing.

NBSC, 2001/2006. China Social-Economic Statistical Yearbooks for China's Counties and Cities. China Statistics Press, Beijing.

Pannell, C.W., 2002. China's continuing urban transition. Environment and Planning A 34 (9), 1571–1590.

Phimister, E., Roberts, D., 2006. The effect of off-farm work on the intensity of agricultural production. Environmental and Resource Economics 34 (4), 493–515.

Pingali, P., 2007. Westernization of Asian diets and the transformation of food systems: implications for research and policy. Food Policy 32 (3), 281–298.

Ramankutty, N., Foley, J.A., Olejniczak, N.J., 2002. People on the land: changes in global population and croplands during the 20th century. Ambio 31 (3), 251–257.

Robinson, W., Schutjer, W., 1984. Agricultural development and demographic change: a generalization of the Boserup model. Economic Development and Cultural Change 32 (2), 355–366.

Rozelle, S., Huang, J., Zhang, L., 2002. Emerging markets, evolving institutions, and the new opportunities for growth in China's rural economy. China Economic Review 13 (4), 345–353.

Seto, K.C., Kaufmann, R.K., Woodcock, C.E., 2000. Landsat reveals China's farmland reserves, but they're vanishing fast. Nature 406 (13), 121.

Seto, K.C., Fragkias, M., Güneralp, B., Reilly, M.K., 2011. A meta-analysis of global urban land expansion. Plos ONE 6 (8), e23777, http://dx.doi.org/10.1371/journal.pone.0023777.

Shriar, A.J., 2005. Determinants of agricultural intensity index "scores" in a frontier region: an analysis of data from northern Guatemala. Agriculture and Human Values 22 (4), 395–410.

Turner, B.L., Doolittle, W.E., 1978. The concept and measure of agricultural intensity. The Professional Geographer 30 (3), 297–301.

Uchida, E., Rozelle, S., Xu, J., 2009. Conservation payments, liquidity constraints, and off-farm labor: impact of the Grain-for-Green program on rural households in China. American Journal of Agricultural Economics 91 (1), 70–86.

Van den Berg, M.M., Hengsdijk, H., Wolf, J., Van Ittersum, M.K., Wang, G., Roetter, R.P., 2007. The impact of increasing farm size and mechanization on rural income and rice production in Zhejiang province, China. Agricultural Systems 94 (3), 841–850.

Wang, L., Li, C., Ying, Q., Cheng, X., Wang, X., Li, X., Hu, Liang, L., Yu, L., Huang, L., Gong, H.P., 2012. China's urban expansion from 1990 to 2010 determined with satellite remote sensing. Chinese Science Bulletin 57 (22), 2802–2812.

Wolf, J., van Wijk, M.S., Cheng, X., Hu, Y., van Diepen, C.A., Jongbloed, A.W., van Keulen, H., Lu, C.H., Roetter, R., 2003. Urban and peri-urban agricultural production in Beijing municipality and its impact on water quality. Environment and Urbanization 15 (2), 141.

Wu, J.J., Fisher, M., Pascual, U., 2011. Urbanization and the viability of local agricultural economies. Land Economics 87 (1), 109–125.

Yan, H., Liu, J., Huang, H.Q., Tao, B., Cao, M., 2009. Assessing the consequence of land use change on agricultural productivity in China. Global and Planetary Change 67 (1–2), 13–19.

Yang, H., 1999. gGrowth in China's grain production 1978–1997: a disaggregate analysis. World Development 27 (12), 2137–2154.

Yao, S., Liu, Z., 2008. Determinants of grain production and technical efficiency in China. Journal of Agricultural Economics 49 (2), 171–184.

Yue, T., Wang, Q., Lu, Y., Xin, X., Zhang, H., Wu, S., 2010. Change trends of food provisions in China. Global and Planetary Change 72 (3), 118–130.