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# Growth, population and industrialization, and urban land expansion of China

Xiangzheng Deng [a,*], Jikun Huang [a], Scott Rozelle [b], Emi Uchida [c]

[a] *Center for Chinese Agricultural Policy, Institute of Geographical Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing 100101, China*
[b] *Freeman Spogli Institute for International Studies, Stanford University, Encina Hall East, E301 Stanford, CA 94305-6055, USA*
[c] *Department of Environmental and Natural Resource Economics, University of Rhode Island, Kingston, RI 02881, USA*

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**Abstract**

China is experiencing urbanization at an unprecedented rate over the last two decades. The overall goal of this paper is to understand the extent of and the factors driving urban expansion in China from the late 1980s to 2000. We use a unique three-period panel data set of high-resolution satellite imagery data and socioeconomic data for entire area of coterminous China. Consistent with a number of the key hypotheses generated by the monocentric model, our results demonstrate the powerful role that the growth of income has played in China's urban expansion. In some empirical models, the other key variables in the monocentric model—population, the value of agricultural land and transportation costs—also matter. Adapting the basic empirical model to account for the environment in developing countries, we also find that industrialization and the rise of the service sector appear to have affected the growth of the urban core, but their role was relatively small when compared to the direct effects of economic growth. We also make a methodological contribution, demonstrating the potential importance of accounting for unobserved fixed effects.


*Keywords:* Urbanization; Spatial scale; Monocentric urban model; Industrialization; Remote sensing; Econometric analyses; Decomposition analyses; China

* Corresponding author. Fax: +86 10 64856533.
*E-mail addresses:* dengxz.ccap@igsnrr.ac.cn (X. Deng), jkhuang.ccap@igsnrr.ac.cn (J. Huang), rozelle@stanford.edu (S. Rozelle), emi@uri.edu (E. Uchida).

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Economists in urban economics have long been interested in understanding the process of urbanization. In one of the earliest theoretical efforts, researchers defined and identified theoretically a number of the causes and consequences of the expansion of urban land [1,20,23]. Among other things, the monocentric urban model generates hypotheses linking the changes in urban land area to some of the fundamental building blocks of economies: income, population, agricultural land values and transportation costs. In subsequent years, empirical economists have tested these hypotheses with increasingly large data sets and increasingly precise measures. Many of them—from Brueckner and Fansler [2] to McGrath [18]—find support for the prediction of the monocentric city model.

Interestingly, although perhaps unsurprisingly, almost all large, systematic studies of the determinants of urban area have been done in developed countries. This is in spite of an argument that an understanding of urbanization is even more important in the developing world since cities are growing faster in developing countries, problems related to the conversion of land into built-up area are more severe and the scope for intervening (as well as the potential gains from good policies) may be greater. That is not to say that there have not been efforts to study the process of urbanization in developing countries and its causes [10,27,29,30]. But, most likely due to data limitations, large, nationwide econometric studies using high quality data are rare.

In response, the overall goal of this study is to provide empirical-based evidence that will help answer several key questions on the extent and causes of urban land expansions in the developing world—focusing in our case on China. Specifically, this study will begin with a conceptual framework from the urban economics literature and test a series of hypotheses from the monocentric city model using a China-wide dataset on the expansion of urban area in more than 2000 "metropolitan regions" over time. In the pursuit of this objective, we will seek to answer several fundamental questions about China: During the reform era, what has been the extent of urban land expansion of China? What are the main determinants that explain urban land expansion during the reform era? Which factors have been the *most important* in terms of their impact on the expansion of urban land? Taken together, we hope that we can provide information to policymakers about the extent and main causes of urbanization in China so that urban land use policy will have a more empirical basis. More generally, we also will show that when urban economists have access to data over time the choice of methodology that can control for many of the unobserved factors which affect the expansion of a region's urban area will affect the findings.

The rest of this paper is organized as the follows. The next section reviews the urban economic literature—both theoretical and empirical—and motivates the hypotheses to be tested. The third and fourth sections introduce the data used in this study and review the record of urban land expansion across China and how it correlates with some of the key variables that we are interested in. The fifth and sixth sections present the empirical model and describe the findings of the two main parts of our analysis: the determinants of urban expansion (in the econometric analysis) and measurement of the importance of the different determining factors (in the decomposition analysis). The final section concludes.

## 1. Spatial scale of cities: theoretical and empirical background

The fundamental theory in urban economics relevant to spatial expansion of urban areas is the monocentric urban model [1,20,23].[1] In the model $x$ denotes the distance from the central

[1] More recent studies have argued that the monocentric urban model is inadequate to explain the more complex, polycentric structure of the metropolitan regions in the US (e.g., Fujita and Ogawa [7], Garreau [8], McDonald [17]).

business district (CBD); it is equivalent to the radius of a circle. Urban residents commute to the CBD, where they earn income $y$ and incur a commuting cost $t$ per unit of distance. Land rental ($r$) and land consumption per capita ($q$) are functions of the distance from CBD ($x$), income ($y$), commuting cost ($t$) and a common utility level enjoyed by the residents ($u$). Hence, these variables can be expressed as $r(x, y, t, u)$ and $q(x, y, t, u)$.

The main idea of the monocentric model is that the distance to the edge of the city ($\tilde{x}$) and utility adjust until the two following conditions hold:

$$\int_0^{\tilde{x}} \frac{2\pi x}{q(x, y, t, u)}\, \mathrm{d}x = n, \tag{1}$$

$$r(\tilde{x}, y, t, u) = r_a. \tag{2}$$

Equation (1) requires that at equilibrium the total population fits inside the urban area. Equation (2) requires that the urban land rental and agricultural land rental are equal at the edge of the city. Based on these relationships, the implications of the model can be seen from the comparative statics. In short, the model implies that

$$\frac{\partial \tilde{x}}{\partial n} > 0, \quad \frac{\partial \tilde{x}}{\partial y} > 0, \quad \frac{\partial \tilde{x}}{\partial t} < 0, \quad \frac{\partial \tilde{x}}{\partial r_a} < 0,$$

or that urban area is increasing in population and income and is decreasing in transportation costs and agricultural rental rates [33].[2]

In adapting this model to testing in the developing world (including China), several factors need to be considered. In many developing countries, it is important to consider how well land markets operate. It is possible that without well-defined forces of supply and demand, there could be either excessive spatial growth of cities (perhaps the most plausible result of poor markets) or excessively limited growth. In the case of China, for example, prior to the reforms in urban land markets in the late 1980s, land markets in China were nearly nonexistent; and land allocation and development construction were controlled by the state [31]. Since 1988, land use rights have begun to be commercialized and the land leasing market has begun to develop. The depth of the reforms, however, varies across regions. While the reforms have moved forward aggressively in some coastal provinces (Liaoning, Beijing, Tianjin, Hebei, Shandong, Jiangsu, Shanghai, Zhejiang, Fujian, Guangdong and Hainan), allocation of land for development by the state still remains the primary method used to distribute rights to use urban land. It has been estimated that rights allocation accounts for nearly three quarters of the transactions and about 70 percent of land area distributed in the primary urban market during the 1990s [9]. These observations suggest that there are likely to be factors that determine spatial growth of cities that are not captured in the monocentric model.[3]

Some have argued that the appearance of multiple employment centers in the urban area has systematically contributed to expansion of urban areas throughout the post-war period. Others have identified fiscal and social disparities between cities and suburbs as another factor explaining urban expansion. While these factors have been found to be important in the US, in this study we first test the monocentric urban model.

[2] Although the comparative statics shown above are for the distance from CBD to urban fringe ($\tilde{x}$), the signs are identical for the total urban area ($A = \pi\tilde{x}^2$), which in this study we use as the dependent variable of the empirical model.

[3] In the monocentric model all factor markets are assumed to be competitive. If the assumption of competitive rental markets does not hold, the equilibrium defined in (2) may not hold. Hence, although we use this to motivate our empirical model, it certainly is not a sufficient model to describe all of the urban expansion in China.

In addition, the process of development and urbanization overlap in several other key areas. In the case of all economies that have developed during the 20th century, one empirical regularity is that as income growth has occurred, the structure of the economy has shifted from one that is based on agriculture to one that is increasingly dependent on manufacturing and the rise of service sector. Both of the expansion of industry and services logically will have an impact on changes to the size of the urban area. Hence, additional factors should be considered in studies (or at least controlled for) in study of the determinants of urbanization in China.

### *1.1. Empirical approaches*

Two of the most well-known previous studies that have tested the hypotheses of the monocentric model using data from metropolitan regions in the United States are by Brueckner and Fansler [2] and McGrath [18]. Brueckner and Fansler [2] utilized cross-sectional data from 40 small metropolitan regions. In each metropolitan region, the urban area that was contained within a single, relatively small county was measured. In their study they found that income, population and agricultural rental were statistically significant determinants of total urban land area. Each of these had the sign that was consistent with the prediction of the monocentric model. The coefficients of the variables measuring transportation costs were not significant.

More recently, McGrath [18] utilized a panel data set for 33 US metropolitan statistical areas from the decennial census data from 1950 to 1990. The study used total urbanized land area in square miles for the 33 cities in each sample area. These measures were then converted to a variable that proxied for city radius. This study also found that income, population and agricultural rent were statistically significant determinants of urban expansion in the US with signs that were also consistent with the hypotheses. Unlike Brueckner and Fansler [2], however, McGrath [18] found that the coefficient on the transportation costs variable was also statistically significant and had the expected (negative) sign.[4]

Importantly for our study, in addition to the four determinants of urban expansion that were included in Brueckner and Fansler [2], McGrath [18] also included a time trend variable to control for the fact that the data came from five decades in order to capture the time-variant unobservable factors that are common across all metropolitan areas. The study found that even when income, population, agricultural rents and transportations costs were held constant, the decade (or time) dummy variable was significant and the magnitudes and levels of significance of some of the coefficients changed (in particular, the coefficient on the transportation variable became negative and significant). However, methodologically the basic model still relied on the Ordinary Least-Squares estimator and did not attempt to fit a first-differences or a fixed effects model to capture time-invariant unobservable factors that may bias the coefficient estimates.

Using the size of the elasticities as measures of importance, among the four factors, Brueckner and Fansler [2] found that the most significant determinant of urban area was income (with an elasticity of 1.50), followed by population (1.10) and agricultural rent (−0.23). In contrast, McGrath [18] found that the most significant determinant was population (0.38), followed by income (0.33), transportation cost (−0.28) and agricultural land value (−0.10). The smaller coefficients found in McGrath's study may be partially due to the inclusion of time trend variable.

[4] The two studies used different proxies for transportation cost. Brueckner and Fansler [2] used two variables: percentage of commuters using public transit (high percentage implying high transportation cost) and percentage of households owning one or more automobiles (high percentage implying low transportation cost). McGrath [18] used average annual CPI for private transportation for each year, rescaled to each region using private transportation cost data for 1990.

## 2. Data

One of the strengths of our study is the quality of data that we use to estimate changes in urban land use. For our purposes, satellite remote sensing digital images are the most suitable data for detecting and monitoring land use change (LUC) at global and regional scales [13]. Remote sensing techniques also have been used widely to monitor the conversion of agricultural land to infrastructure [3,19,26,34]. In China land use change has been tracked by remote sensing data [14,28,29].

In our study we use a land use database developed by the Chinese Academy of Sciences (CAS). The data are from satellite remote sensing data provided by the US Landsat TM/ETM images which have a spatial resolution of 30 by 30 meters [32]. The database includes time-series data for three time periods:

(a) the late 1980s, including Landsat TM scenes from 1987 to 1989 (henceforth, referred to as 1988 data for brevity);
(b) the mid-1990s, including Landsat TM scenes from 1995 and 1996 (henceforth, 1995); and
(c) the late 1990s, including Landsat TM scenes from 1999 and 2000 (henceforth, 2000).

For each time period we used more than 500 TM scenes to cover the entire country. Specifically, we used 514 scenes in 1988, 520 scenes in 1995 and 512 scenes in 2000.[5] A hierarchical classification system of 25 land-cover classes was applied to the data. In this study the 25 classes of land cover were aggregated further into six classes of land cover-cultivated land, forestry area, grassland, water area, built-up area and unused land. The data team also spent considerable time and effort to validate the interpretation of TM images and land-cover classifications against extensive field surveys [16].[6]

### 2.1. Creating measures of urbanization

Before creating a measure of the change in the spatial scale of China's cities, we need to make several key decisions. First, in this study we use the *county* as the analytical unit. The county is the third level in the administrative hierarchy in China below the province and prefecture. Although we generically use the term *county* for all of our observations, our choice of analytical unit includes (autonomous) counties, county-level cities, banners (which are county-like administrative regions in northern China) and districts. There are over 2000 counties in China. We use the county as the analytical unit because in China we believe each county can be regarded as an administrative as well as an economic region. The average area of a county is between 3000 and 4000 square kilometers. Historically, counties grew up around an urban center, the county seat. Today, each county hosts an important administrative level of government (the county government) and in almost all cases one of the functions of the county government is to create its own land use plan and, as such, constitutes a region that can be used to study land use changes—especially of the urban core.

[5] A TM scene is the unit of area of coverage of digital images that are made by Landsat satellites. In the original Landsat material, which was configured by NASA before they provided the material to CAS, it took about 500 scenes to completely cover all of China's territory.

[6] Additional details about the methodology, which we used to generate the databases of land cover from Landsat TM, are documented in Liu et al. [15] and Deng et al. [5].

Studies that examine changes in urban land using Landsat images also need to make an important choice regarding the definition of urban land. Specifically, we need to decide what exact type of built-up area in each county constitutes urban land. Our data set includes three classifications of built-up area: the urban core, rural settlements and other built-up area. In constructing our data set, the *urban core* is defined as all built-up area that is contiguous to urban settlements. Each county in our sample, by definition, has at least one urban settlement. In other words, it is possible to have more than one urban settlement in a county. When there is more than one urban settlement, the sum of the areas of the urban settlements equals the area of the urban core. The expansion of the urban core from one time period to another is defined as all new built-up area that has appeared (e.g., between 1988 and 1995), which is contiguous to the urban settlements in 1988. The *rural settlements* category in our dataset includes all built-up area in small towns and villages. Urban settlements are differentiated from rural settlements during the interpretation phase of the data analysis according to standard Landsat imagery. Rural settlements can become urban settlements in two ways: by being surrounded by new built-up area and becoming part of the contiguous urban core; and by growing themselves to the point that the Landsat images change in color, texture and tone. The *other built-up area* category includes roads, mines and development zones that are not contiguous with the urban core.

In this study we choose to focus on the urban core part of built-up area. In simplest terms we choose to focus on the urban core for both practical and realistic reasons.[7] First, the data on the urban core is thought to be higher quality (mainly due to the fact that technically it is easier to identify the urban core compared to other types of built-up area), which will mean that the dependent variable in the analysis contains less inherent measurement error. Second, the urban core part of built-up area in China constitutes by far the type of built-up area that is growing the fastest.

One of the most onerous tasks in preparing the data was to create a set of county-level analytical units that were consistent over the study period. The problem of consistency of county-level analytical units over time arises because of changes in jurisdictional areas in administrative regions. The boundaries of some counties changed over time. In other cases towns in a single county were divided into two groups and made into two counties during the 1980s and 1990s. Occasionally the urban core of a county was removed from the jurisdiction of the original county government and became an independent county-level administrative unit.

Because of these changes the number of counties rose over the study period. For example, in 1988 China had 2156 administrative units at the county level, whereas in 2000 the number expanded to 2733. The organizational shifts of county-level administrative units are problematic for this study since data within each county observational unit need to be comparable over time.

In order to overcome this problem, we use the geocoding system of the National Fundamental Geographical Information System (NFGIS) [24] and a 1995 administrative map of China from Scientific Data Center of Chinese Academy of Sciences, which included a consistent geocoding system with that of NFGIS. Using these tools, if two counties had been subject to border shifts (e.g., one county ceded jurisdictional rights to another), we combined them into a single analytical unit for the entire sample period. In cases in which the city core of a county had been removed from the jurisdiction of the original county-level government, we re-aggregated the mu-

[7] Since we also are interested mainly in the process of urbanization, we do not include area built-up in rural settlements, although this is analyzed in Huang et al. [11]. Finally, unlike many studies in developed countries that are interested in urban sprawl (e.g., Burchfield et al. [3]), we focus on the urban core since the fragmented pattern of growth is not the major issue at this point of China's development process.

nicipal administrative zone back into the county-proper. In the case of large metropolitan areas (i.e., China's four provincial-level municipalities—Beijing, Tianjin, Shanghai and Chongqing; provincial capitals; and other large cities), the districts within city's administrative region were combined into a single, sample period-consistent analytical unit. This was also done in order to make sure the urban cores did not cross county borders. In this way, we ended up with a sample that includes 2348 analytical units at the county-level that are consistent in size and jurisdictional coverage over time. In this paper, even though the observations include municipality districts, cities and other administrative units that are larger (and more complex) than counties, we call all observations county *analytical units* (or simply counties).

### 2.2. *Other data sources*

Several data sets were used to generate variables that measure the socioeconomic attributes of each county and its location and geophysical attributes. These data sets include information that will be used to create measures of the variables for testing the hypotheses about the determinants of urban land area (e.g., measures of income, population, agricultural land values and transportation costs). Another set of variables will be used as statistical controls that will try to make the estimated parameters of the variables of interest more precise.

The data come from two general sources. The first type of data comes from a *GIS database* that is housed in the Chinese Academy of Sciences (from which the measure of the urban core—described above—was also taken). Since these data are highly disaggregated (mostly to the pixel level), they need to be aggregated to be consistent with the county-level analytical unit before being used in a study of county-level urban land change. In other words, all of the geophysical data, which are available in their most disaggregated form at the $1 \times 1$ square kilometer level, were spatially referenced to the county level using GIS geocoding methods.

One of the most important variables from the GIS database (because we use it to test a key hypothesis of the monocentric model) is a variable that measures the density of a county's highway network. This variable is based on a digital map of transportation networks that exist in each county. It was developed by Chinese Academy of Sciences (CAS) and the measure includes all highways, national expressways, provincial-level roads and other more minor roads in the mid-1990s. The variable (henceforth—*highway density*) is measured as the total length of all highways in a county divided by the land size of the county. This variable has been used in a number of other studies [12]. It does not vary over time.

The GIS database also provides a number of control variables that are frequently used in the LUC literature for understanding urban land use. Specifically, we have two measures of the location of each county (or more precisely its county seat, prefecture seat or provincial capital). One variable measures the distance in kilometers from the county seat to the provincial capital; the other variable measures the distance between the county seat and the nearest port city. The county seat location data used in the calculation of the distance variables are originally from the State Bureau of Surveying and Mapping of China. The data for locations of provincial capitals and port cities are from the CAS Data Center. The GIS database also includes several geophysical variables. A set of variables measures the nature of the terrain of each county that are generated from China's digital elevation model data set. Climatic variables are generated by the authors based on the site-based observation climatic data from the China Meteorological Administration from 1950 to 2000 [6].

The second source of data is that which provides information on socioeconomic phenomena. Socioeconomic variables, unlike those from the GIS database, do not require aggregation from

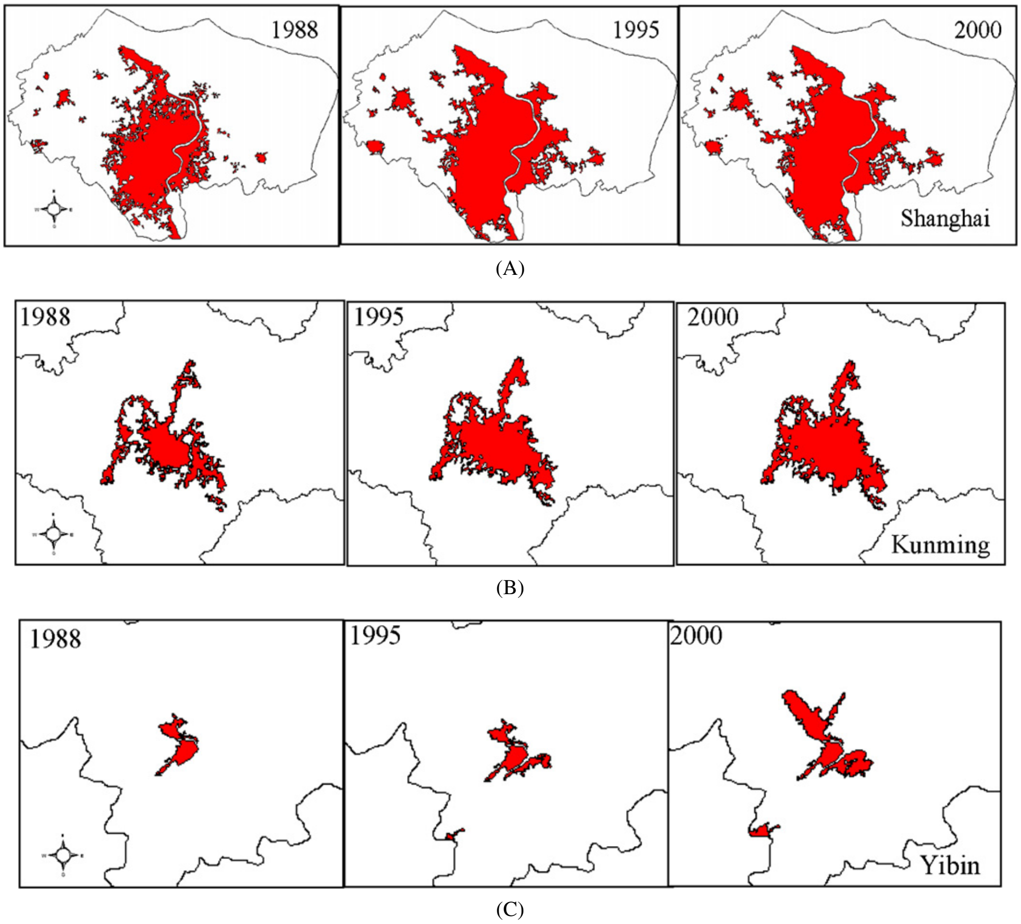


Fig. 1. Maps showing expansion of urban core in Shanghai (A), Kunming (B) and Yibin (C) from 1988 to 2000.

sub-county levels. Information on gross domestic product (GDP) for each county for 1995 and 2000 are from *Socioeconomic Statistical Yearbook for China's Counties* [25], supplemented by each province's annual statistical yearbook for 1995 and 2000. Investment in the agricultural sector for each county is from each province's annual statistical yearbook for 1995 and 2000. The demographic data for 1995 and 2000 are from *Population Statistical Yearbook for China's Counties* [21,22], which is published by the Ministry of Public Security of China.

## 3. Changes in China's urban land

To illustrate the nature of our data and the scope of the urban expansion that we are interested in, we show maps created from Landsat images for the three years (1988, 1995 and 2000) from three selected cities (Fig. 1). Shanghai is included as an example of a large metropolitan region in the rapidly developing coastal area (panel A). Kunming is an example of a large city in China's inland region (panel B). Yibin, which is located 270 kilometers to south-

Table 1
Changes of income, population and other explanatory factors associated with the monocentric model (plus the factors needed for the analysis of developing countries) and the rate of growth of the urban core in China between 1995 and 2000

| Items | Relatively slow urban core growth[a] | Relatively high urban core growth[a] |
|---|---|---|
| Growth in GDP | 70.1 | 78.4 |
| Population growth | 2.3 | 3.5 |
| Agricultural investment | 31.1 | 22.3 |
| Highway density | 20.8 | 42.2 |
| Industrial GDP growth | 77.8 | 81.8 |
| Growth of GDP from service sector | 94.0 | 95.5 |

[a] Relatively slow growth of the urban core is associated with the counties that are in the lowest quartile (experiencing growth of less than 0.02% per year between 1995 and 2000). Relatively high growth of the urban core is associated with the counties that are in the highest quartile (experiencing growth of more than 13.55% per year between 1995 and 2000).

east of Chengdu in Sichuan province, is included to illustrate changes in a small, prefectural level city (panel C). Although the scales of the maps are obviously different, examining their changes over time allows us to see that there are differences among the county analytical units in the levels and rates of expansion of their spatial scale. When looking at the images, it is clear that there are differences in the rates of growth of the urban core—both across cities (or county analytical units) and over sub-periods. Our entire data set for the 2348 county analytical units also show that the expansion of the urban core is variable across space and time. Distributions of growth rates of urban core for the two periods show that the growth rates range from zero percent to over 90 percent, indicating a wide variability across space and time.

### *3.1. Size of the urban core and correlates of change*

The descriptive evidence also shows that economic forces—some of which were predicted by the monocentric model of urban expansion—may be associated with the changing urban landscape. When we use disaggregated data, we find that changes in the urban core are associated with other changing economic and demographic factors (Table 1). When dividing our counties into two parts based on expansion of the urban core growth (relatively slow urban core growth—column 1; relatively high urban core growth—column 2), the percent changes in GDP shifts systematically. The rate of GDP growth (70.1 percent) is lower for those counties that were growing relatively slow compared to those that were growing fast (78.4 percent—row 2). However, it should also be noted that other dimensions of the economy also are changing with the rate of growth of urban core—e.g., population (row 2); Agricultural investment (row 3); and highway density (row 4). Interestingly, these the changes in these variables are all moving in the direction that is predicted by the monocentric model. In addition, the rate of growth of industry (row 5) and the rate of growth of the service sector (row 6) also rise in cities that are growing fast in spatial scale (compared with cities that are growing relatively slow). Clearly, given these descriptive statistics (and the experience of the rest of the literature in isolating the factors that affect urban core expansion), there is descriptive evidence that China's cities are expanding in a way that is consistent with the monocentric model.

## 4. Empirical model and variable specification

Following the monocentric urban model's approach and the two key empirical studies conducted in the US, we seek to explain differences in urban expansion across space and time as a function of economic (broadly defined) and geophysical factors. Conceptually, our model is

$$\begin{aligned}\text{urban land area} = f(&\text{income growth, demographic shifts, agricultural land value,}\\ &\text{transportation costs; changes in structure of the economy;}\\ &\text{other location and geophysical variables}),\end{aligned} \tag{3}$$

where, as discussed above, urban land area is defined as the total contiguous land area that makes up the urban core. Using the first four elements on the right-hand side of Eq. (3), this conceptual model allows us to test the hypotheses of the monocentric urban model. We also account for the factors that may be expected to affect urban expansion in developing countries, such as changes in the structure of the economy.[8] Finally, following Burchfield et al. [3], we include a set of variables to control for other location and geophysical factors.

To empirically implement the conceptual model in Eq. (3), we specify an econometric model that accounts for differences in the spatial scale of cities across space and over time

$$\begin{aligned}UrbanCore_{it} = f(&GDP_{it}, Population_{it}, AgriInvest_{it}, DensityHwy_i, GDP2\_share_{it},\\ &GDP3\_share_{it}, DistPort_i, DistProvCapital_i, SharePlain_i, Rainfall_i,\\ &Slope_i, Temperature_i, Elevation_i, UrbanCore_{1988}),\end{aligned} \tag{4}$$

where $UrbanCore_{it}$ is the total area (in hectares) that makes up the urban core in the $i$th county sampling unit in year $t$ (1995 or 2000). In order to test the hypotheses of the effects of the factors motivated by the monocentric model, the explanatory variables in our empirical model includes gross domestic product, $GDP_{it}$, as a proxy for income. In fact, GDP measures the value of all goods and services produced in the county during the year; after the early 1990s the GDP measures generated by NBSC at all levels of statistical data collection (county, province and national) are consistent across administrative districts.[9] We also include population, $Population_{it}$, for each county. These data include non-rural and rural residents who have their official residence permit (*hukou*) in the county sampling unit (regardless of whether they reside in the urban core or not). People from other counties that have not officially moved their *hukou* or who have not registered with the local bureau of public security are not included.[10] Unfortunately, no direct measure of agricultural rent or commuting cost per mile exists for entire China over time. As a proxy

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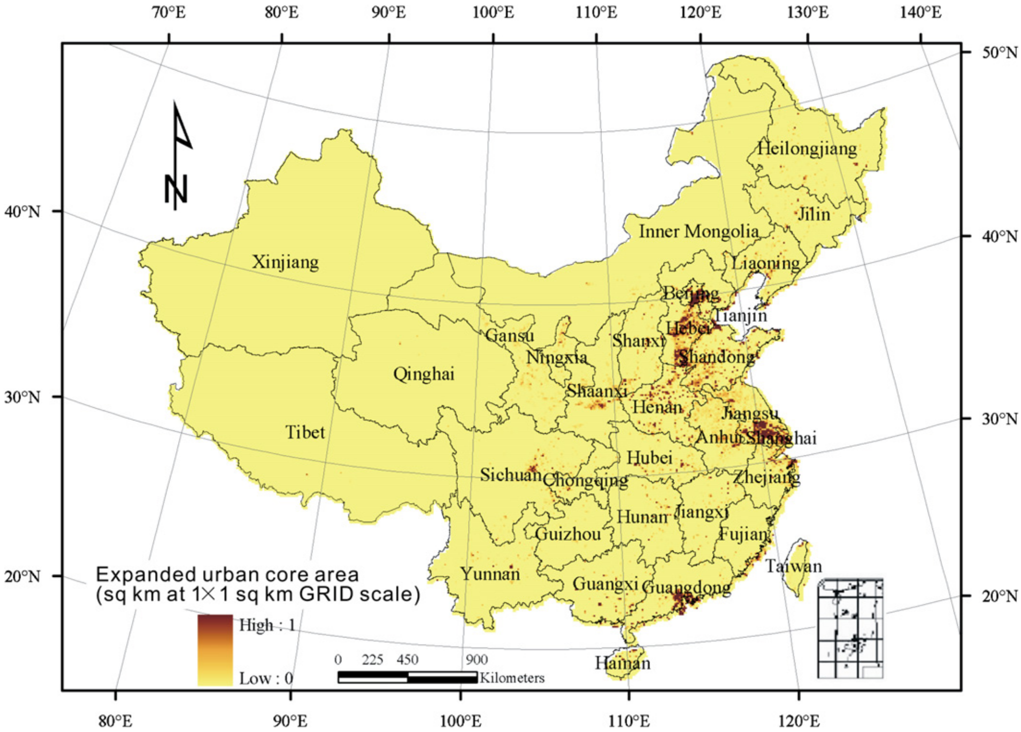
[8] The relationship between urbanization and changes in the structure of the economy have been looked at by others studies on urban land expansion at the regional scale. For example, Seto and Kaufman [30] study urban expansion in the Pearl River Delta and estimate an econometric model that examines the socioeconomic drivers of urban land expansion. In this study, the ratio of agricultural land productivity and industrial land productivity is one of the essential variables was identified as one the essential variables that cause the conversion of agricultural land to urban land.

[9] The correlation coefficient between GDP per capita and income per capita in the years and areas which have both measures is 0.853.

[10] Because of the nature of China's population statistics, this is the only measure that is available. As such, it differs from the measures used in other empirical studies (which typical are based on census district data—and so the measure of the size of population of the urban area is relatively more accurate. However, since by far the largest share of the non-rural population in a county is in the urban settlements (our guess: around 90%), the measurement of the urban population in the urban core will not be that bad. To the extent that there is measurement error, it could be that the estimated coefficients could be underestimated [4].

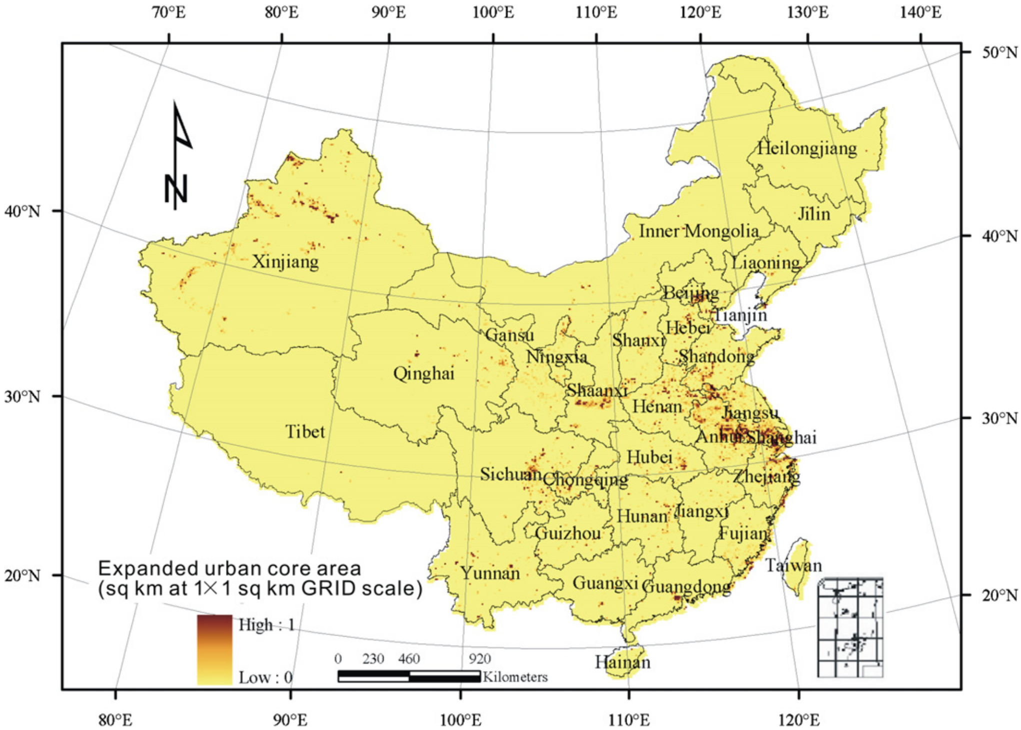



(A) Changes from 1988 to 1995

Fig. 2. Percentage changes in areas of urban core in each pixel in China, 1988 to 2000.

for agricultural rent, we include a measure of the amount of investment allocated to agriculture ($AgriInvest_{it}$). The idea of including this variable is that such investment could lead to higher productivity in agriculture, hence increasing the opportunity cost of converting to urban area. If a land market exists, the higher productivity should be capitalized into land rental. In addition, as a proxy for commuting costs, we include highway density ($HwyDensity_i$). The underlying assumption is that investments in highways make traveling faster and more convenient, which reduces the cost of commuting and enables residents to enjoy cheaper housing in the suburbs while paying lower commuting costs. As a result, we would expect that the demand for suburban locations increases as commuting costs fall and hence leads to spatial growth of the urban area. With the exception of highway density, all of these variables—urban core, income, population and agricultural land value—vary over time (that is, we have information for both 1995 and 2000).

Given the rapid structural change taking place in developing countries and the impact of these shifts on urbanization, as in Seto and Kaufman [30] and Burchfield et al. [3], we also include measures to control for industrialization. Our measure of industrialization is constructed as the value of GDP created in the industrial sector divided by total GDP ($GDP2\_share_{it}$). In China's statistical data the sectors considered as part of industry include manufacturing, construction, transportation and communication and commerce. A similar measure was created for the service sector ($GDP3\_share_{it}$). The sectors considered as part of the service category include transport, postal and telecommunication services, wholesale, retail trades and catering services. Data are available for 1995 and 2000 for both of these variables.




(B) Changes from 1995 to 2000

Fig. 2. (*continued*)

Finally, following Burchfield et al. [3], we also control for climatic and geophysical variables. In our data set none of these variables vary over time. First, we include two climatic variables. Measures of average annual rainfall in a county over a 50-year period, 1950 to 2000 ($Rainfall_i$) and average annual air temperature ($Temperature_i$) are calculated as the sum of daily average temperature in a county over a 50-year period, 1950 to 2000. Readings are available for over 400 national meteorological stations. We use these readings and China-specific climate interpolation models to interpolate the data from specific meteorological stations, changing them into spatial data (at the $1 \times 1$ kilometer level) and then aggregating them to county sampling units. Second, we also include three terrain variables. The first, $Elevation_i$, is measured as the average elevation of the county's entire land area (both urban core and non-urban core area). $Slope_i$ is the average slope of a county and is intended to measure the steepness of a county's hills and mountains. $SharePlain_i$ is a variable that is created by dividing the land area in a county that has a slope that is less than eight degrees by the total land area of the county. Taken together, these three variables provide a control for the ruggedness of a county's terrain, which should be correlated with the difficulties of constructing urban infrastructure and buildings. Finally, two variables, both in kilometers, control for the distance from county sampling units to specific types of locations. $DistPort_i$ measures the distance to the nearest port city; and $DistProvCapital_i$ measures the distance to the capital of the province to which the county belongs. In addition to the economic and geophysical variables of interest, the model includes a measure of urban core area in 1988 ($Urban_{1988}$) in order to control for the overall size of the county sampling unit.

### 4.1. Accounting for unobservables: first-differences model

While the specifications in Eqs. (3) and (4) contain the elements that will allow us to examine the determinants of changes to the urban core in China's counties, it is possible that the presence of certain unobserved or unmeasured factors which are correlated with city size and one or more of the explanatory factors may be affecting the sign, significance and/or magnitude of the coefficients of interest. For example, one city may have an inherent attractiveness as a place to live and work due to its history and culture, or due to general expectations about its future growth prospects. We have two options to account for these factors. The first is to specify the model as a fixed effects model by including county-level dummy variables ($\mathrm{D}_i^{\mathrm{county}}$), which involves creating and including over 2000 indicator variables (one for each county analytical unit minus one). By doing so, unlike previous empirical attempts to model urban area, we capture the time-invariant unobservable factors for each county.[11] We also (like McGrath [18]) include a time dummy (*Year2000* = 1, for all observations from 2000 and zero for observations from 1995) to account for time trends that are common across all counties. When doing this, the new model for explaining urban core expansion is

$$UrbanCore_{it} = f\big(GDP_{it}, Population_{it}, AgriInvest_{it}, GDP2\_share_{it}, GDP3\_share_{it}, \mathrm{D}_i^{\mathrm{county}}\big). \tag{5}$$

Equation (5) differs from Eq. (4) in two fundamental ways. First, $\mathrm{D}_i^{\mathrm{county}}$ are added to the specification. Second, all variables that do not vary over time (or all variables that do not have a $t$ subscript in Eq. (4) are subsumed in the county dummies. Note, that in adopting this framework, since our measure of transportation cost does not vary over time, we are unable to test for this hypothesis, although all time invariant transportation characteristics are controlled for.

Alternatively, it is possible to respecify Eq. (5) as a first-differences model. This is done by redefining the five time variant variables in Eq. (5), subtracting the observation from 1995 from the observation from 2000. The redefinition creates a set of five new differenced variables that are noted by a delta sign preceding the variable name. After doing so, the model to be estimated becomes

$$\Delta UrbanCore_{\mathrm{i}} = f(\Delta GDP_{\mathrm{i}}, \Delta Population_{\mathrm{i}}, \Delta AgriInvest_{\mathrm{i}}, \Delta GDP2\_share_{\mathrm{i}}, \Delta GDP3\_share_{\mathrm{i}}). \tag{6}$$

Although the results from Eq. (5) and Eq. (6) will be exactly the same, the number of observations is exactly half, the county dummy variables are no longer needed and the degrees of freedom are exactly the same. In the next section, we only report the results from the first-differences model.

## 5. Results of the multivariate analysis

The role of the factors identified by the monocentric model in the expansion of the urban core is clear when we estimate Eq. (2). Holding constant the area of the urban core in 1988,

[11] To the extent that there are omitted variables that are correlated with our variables of interest, the estimated coefficients will be biased and the analysis based on the results may be misleading. Although to our knowledge there are no national-level analyses that are testing the monocentric model that include fixed effects, such a problem is noted in the work of Seto and Kauffman [30].

Table 2
Ordinary least-squares estimator of the expansion of the spatial size of China's cities

| | Dependent variable: Ln(urban core area), in hectares | | | | | | |
|---|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) |
| Ln(*GDP*) | 0.397 | 0.369 | 0.373 | 0.364 | 0.344 | 0.308 | |
| | (47.81)** | (30.61)** | (29.33)** | (27.80)** | (21.12)** | (18.28)** | |
| Ln(*Population*) | | 0.057 | 0.091 | 0.094 | 0.115 | 0.186 | |
| | | (3.47)** | (5.23)** | (5.34)** | (5.95)** | (9.61)** | |
| Ln(*AgriInvest*) | | | −0.017 | −0.016 | −0.016 | −0.012 | |
| | | | (3.60)** | (3.52)** | (3.53)** | (2.73)** | |
| Ln(*HwyDensity*) | | | | 0.005 | 0.004 | 0.001 | 0.016 |
| | | | | (3.07)** | (2.92)** | (3.07)** | (10.64)** |
| *GDP2_share* | | | | | 0.103 | 0.178 | |
| | | | | | (1.32) | (2.35)* | |
| *GDP3_share* | | | | | 0.315 | 0.543 | |
| | | | | | (3.16)** | (5.60)** | |
| Ln(urban core in 1988) | 0.504 | 0.501 | 0.484 | 0.483 | 0.481 | 0.438 | 0.589 |
| | (69.78)** | (69.24)** | (64.07)** | (63.88)** | (63.61)** | (58.35)** | (79.74)** |
| Ln(*DistPort*) | | | | | | −0.015 | −0.050 |
| | | | | | | (2.81)** | (8.41)** |
| Ln(*DistProvCapital*) | | | | | | 0.002 | 0.006 |
| | | | | | | (0.74) | (2.16)* |
| *SharePlain* | | | | | | 0.243 | 0.489 |
| | | | | | | (6.18)** | (11.55)** |
| Ln(*Rainfall*) | | | | | | −0.150 | −0.073 |
| | | | | | | (7.60)** | (3.55)** |
| Ln(*Slope*) | | | | | | −0.037 | −0.026 |
| | | | | | | (4.62)** | (2.96)** |
| Ln(*Temperature*) | | | | | | −0.048 | −0.280 |
| | | | | | | (1.55) | (9.06)** |
| Ln(*Elevation*) | | | | | | 0.021 | 0.001 |
| | | | | | | (3.05) ** | (0.10) |
| Constant | −1.295 | −1.669 | −2.229 | −1.923 | −2.086 | −1.092 | 1.295 |
| | (15.97)** | (12.52)** | (14.83)** | (12.70)** | (13.21)** | (4.63)** | (5.46)** |
| Observations | 4482 | 4482 | 4482 | 4482 | 4482 | 4482 | 4482 |
| Adj. $R$-squared | 0.79 | 0.79 | 0.79 | 0.79 | 0.79 | 0.81 | 0.74 |

*Note*: $t$ statistics in parentheses.
* Significant at 5%.
** Significant at 1%.

the importance of *GDP* (or income) in explaining the expansion of the urban core in the late 1990s is seen by its positive and highly significant coefficient when it is added by itself (Table 2, column (1)). The magnitude of the coefficient, 0.397, intuitively means that as GDP grows by 10 percent (for example), the urban core expands by 3.97 percent. Moreover, even as we incrementally add other key variables in the modified monocentric model—*Population* in column (2), *AgriInvest* in column (3), *HwyDensity* in column (4)—as well as measures of industrialization (*GDP2_share*) and the rise of the service sector (*GDP3_share*) in column (4), the importance of GDP growth remains. When adding these variables, the magnitude of the coefficient changes little, only falling from 0.397 in column (1) to 0.344 while remaining significant statistically (column (5)). The high adjusted $R$-squares in columns (1) to (5) also illustrates that income, by itself (holding constant the urban core in 1988), and in concert with the rest of the variables raised in the monocentric model, can explain a large amount of the variability of the expansion of the urban core. If these results were to hold up throughout our analysis, clearly income is an important force that is expanding the urban core.

Our results also show that, holding GDP constant, demographic, agricultural land values and transportation costs—the other variables in the traditional monocentric model—are significant statistically with the expected signs. When only considering economic factors (and not considering any geophysical factors), *Population* is significant and positive when added by itself (column (2)) and together with the other economic variables (columns (3)–(5)). The elasticity, however, is lower ranging between 0.057 and 0.115. In contrast, the sign on the coefficient of the *AgriInvest* variable, our proxy for agricultural land values, is negative and is in accordance with the monocentric model. Ceteris paribus, the higher the land values, the slower the expansion of the urban core. The coefficient on the transportation cost variable, proxied by the density of the highway network (*HwyDensity*), is positive which is also as expected. When transportation networks are well developed (or dense), the cost of transportation is low and the urban core should be expected to expand relatively more. Hence, when using an OLS estimator, like McGrath [5], the coefficients on the key variables of interest have the expected sign and are significant.

Interestingly, in this relatively parsimonious model (that is, without controls for geographic variables) the coefficients on the variables that we have added (in addition to the variables in the traditional monocentric model) to make the model more appropriate for understanding the spatial scale of cities in developing countries also are consistent with our expectations. Specifically, the coefficient on the industrialization variable (*GDP2_share*) is positive and significantly different than zero (column (5)). Likewise, the rise of the service sector (*GDP3_share*) is positive and significant. In the OLS version of the model, while it may be somewhat surprising that the coefficient on the industrialization variable is smaller than that on the service sector variable, it could be that, in fact, growth in the service sector actually requires more land (it increased its share of GDP by 4 percentage points in our sample to only 1 percentage point for industrialization). Together, the signs and significance of all of these variables in our analysis suggest that, although complex, variables of the monocentric model—both those related to the economy and demography—are useful in explaining the spatial scale of cities in developing countries (including China).

Even when geophysical factors are added to the model in columns (6) and (7), all of the coefficients of the variables from the modified monocentric model retain their same signs. The magnitudes of the coefficients and levels of statistical significance also are almost the same. Most conspicuously, when all of the geophysical variables (distance, terrain and climate variables) are added, the coefficient of the GDP variable, while still positive and significant, falls by 4 percentage points (from 0.351 to 0.308—about 12 percent). At the same time, the coefficient on the *Population* and *GDP3_share* become larger and *GDP2_share* becomes significant. The lesson from this part of the analysis is that when attempting to measure the effect of economic/demographic variables on urban core expansion, it is important to consider the effect of geophysical factors. Without accounting for them the coefficients of the variables of interest are subject to modest omitted variable bias.

An even more important lesson about the process of building a model of urban core expansion is seen by comparing column (6), the model with economic and geophysical factors, and column (7), the model with only geophysical factors. In the same way that the magnitudes of the signs of the economic variables changed between models with and without geophysical factors, the signs on the coefficients of the geophysical factors change when economic factors are added or deleted. In fact, the magnitude of the changes (in percentage terms) for many of the variables

Table 3
Results from a first-differences model of the expansion of the spatial size of China's cities with no intercept term

| | Dependent variable: Ln(urban core area), hectares | | | |
|---|---|---|---|---|
| | (1) | (2) | (3) | (4) |
| Ln(*GDP*) | 0.082 | 0.083 | 0.082 | 0.070 |
| | (19.97)* | (19.60)* | (18.42)* | (13.09)* |
| Ln(*Population*) | | 0.006 | 0.011 | 0.012 |
| | | (0.37) | (0.66) | (0.72) |
| Ln(*AgriInvest*) | | | −0.006 | −0.007 |
| | | | (1.03) | (1.29) |
| *GDP2_share* | | | | 0.035 |
| | | | | (1.14) |
| *GDP3_share* | | | | 0.153 |
| | | | | (5.10)* |
| Observations | 4482 | 4482 | 4482 | 4482 |
| Number of code | 2241 | 2241 | 2241 | 2241 |
| $R$-squared | 0.15 | 0.15 | 0.15 | 0.15 |

*Note*: $t$ statistics in parentheses.
* Significant at 1%.

is much higher (in absolute value terms). Most coefficients change significantly. Geographical variables play an important role in explaining differences across space in urban core expansion, but to more precisely measure their impacts, the effects of economic variables are needed to be controlled for likely because of their powerful role in pushing the boundaries of the urban core.

### 5.1. First-differencing: accounting for fixed effects

When moving from Table 2 to Table 3, the hazard of estimating the determinants of urban area in an estimation framework that does not control for *all* fixed effects is seen. Most prominently the coefficients of all time-varying variables in the first-differences model—which are all of the economic/demographic variables in the monocentric model except the transportation cost variable—are significantly different. Specifically, in the case of *population*, *agricultural investment* and *GDP2_share*, the coefficients become insignificant from zero. While the coefficients of the other variables—income and *GDP3_share*—are significant in all of models (columns (1)–(4)), their magnitudes are much lower.

The largest absolute drop in magnitude occurs in the case of GDP. The coefficient on GDP remains significant throughout all of the specifications in Table 3. Its magnitude, however, is much smaller. The magnitude of the elasticity of urban core expansion with respect to GDP falls to less than $1/4$ of what it was in Table 2 (from 0.308 to 0.070). According to Table 3, if GDP (or income) increased by 10 percent, the urban core area would only increase by less than 1 percent (0.7 percent).

Interestingly, in the first-differences model, the effects of population and the expansion of the industrial sector (*GDP2_share*) also fall sharply. The insignificant signs, among other things, may mean that the expansion of the urban core is not being driven by rising population or industrialization per se, but rather is the result of the rapid income growth process. Hence, besides the contribution of the service sector, the differences in the expansion of urban core only are being explained by differences across counties in income growth rates. In China (at this point in its development) income growth may be the driver of the rise of the spatial scale of the urban core.[12]

## 5.2. Decomposition analysis

When using the approaches of previous work, we find that our ranking of the importance of determinants of the spatial size of cities has similarities to previous work. In earlier work, Brueckner and Fansler [2] concluded that the rankings were: income, population, agricultural rents and transportation costs (although the last variable was insignificant from zero). McGrath [18] found a different ranking: population, income, transportation costs and agricultural rents. It should be noted that in the case of these earlier empirical works ranked the importance of variables by the size of their elasticities. If we had ranked our variables by the size of the elasticities using the OLS results (from column (4)) our rankings are: income, population, agricultural land values (or investment in agriculture) and transportation cost (highway density), which is the same as Breuckner and Fansler [2].

However, using the sizes of elasticities as criteria for determining the importance of factors that cause shifts in the size of the urban core over time can be deceiving. Elasticities are marginal measures. The total effect of a factor on the change of another variable over time depends on both the size of the elasticity and size of the change in the variable. In other words, even if an elasticity $\varepsilon = \mathrm{d}Y/\mathrm{d}X * X/Y$ is large, if $X$ does not change much over the time that we are measuring the change in $Y$, $X$ will contribute only marginally to the total change in $Y$. Decomposition analysis is a better way to rank the importance of elements in a set of explanatory variables in the change of a variable of interest (some $Y$) since they account for both the size of the marginal effects and the size of the change of the explanatory variables.

The decomposition results (Table 4), which use the results from the fixed effects models in Table 3, confirm the findings of the descriptive and regression analyses.[13] Growth (or income) is by far the most important factor affecting growth. It explains 121 percent of the spatial growth of the urban core (Table 4). What this means is that urban core "should" have increased by 4.905 with 70.08 percent increase of GDP. In fact, the urban core actually only expanded by 4.05 percent. In other words, other (unmeasured) factors that must have slowed urban core expansion.

While all of the other time-varying economic factors (except agricultural investment), including changes in population growth, expansion of industrialization and the rise of the service sector, positively influence urban core expansion, their joint impact is small (Table 4). The effects of population and the expansion of industrialization and the service sector are all positive, but jointly they only explain 1.5 percent of the growth in the urban core. The overall process of

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[12] The reader should be cautioned, however, that in this case the first differences model is trying to estimate the change in the size of the urban core which has occurred only after five years. Since this period is a relatively short interval, these findings could differ if the exercise was conducted using data the spanned a greater length of time. However, the sharp differences in the results at the very least should raise the question about how accounting for unobserved effects actually does affect the findings of work examining the determinants of the spatial size of cities.

[13] We could have used GDP per capita in our specification instead of GDP. If we would have, the population variable's coefficient, instead of being statistically zero, would have been positive and statistically different from zero (0.082). In fact, if we had specified the equation this way, the elasticity on population would have been larger than the elasticity on GDP (which would have been *exactly* the same; as would all of the other elasticities). However, in an alternative decomposition because the change in population is so small (at least relative to the change in GDP/capita), the final decomposition would have differed little. It could also be that the magnitude of the population variable is underestimated due to measurement error (as discussed in footnote 10).

Table 4
Decomposition analysis of the sources urban core expansion in China, 1995 to 2000[a]

| Variables | (1) Estimated parameter | (2) Percentage changes in variables | (3) Impact on urban core (%) | (4) Contribution (%) |
|---|---|---|---|---|
| Based on Table 3, column (4) | | | | |
| *GDP* | 0.07 | 70.08 | 4.905 | 121 |
| *Population* | 0.012 | 2.76 | 0.033 | 1 |
| *AgriInvest* | −0.007 | 2.89 | −0.020 | −0.5 |
| *GDP2_share* | 0.035 | 0.01 | 0.000 | 0.0 |
| *GDP3_share* | 0.153 | 0.04 | 0.006 | 0.2 |
| *Residual* | | | −0.87 | −22 |
| Urban core | | 4.05 | | 100 |

*Note*: For ratios of industrial or service GDP, they are measured as changes in the ratios.

[a] The decomposition analysis is conducted as follows. We first calculate the percentage change of each variable during 1995 through 2000 (column 2). We then multiply column (2) by the parameters estimated from the fixed effects model (column 1) to obtain the impact of each variable on urban core (column 3). Finally, we divide impact of each variable (column 3) by the percentage change in urban core during this period (4.05) to obtain the contribution of each variable on change in urban core (column 4).

income growth completely dominates. The importance of using the first-differences model also becomes clear in this case. Even with this smaller coefficient (from Table 3 instead of Table 2), growth in GDP (income) explains *all* of urban expansion. If we would have used the coefficient of the growth variable from the OLS equation in Table 2 (any of the columns), it would have implied that, due to growth, the cities should have grown by more than they actually did. Such a finding is not believable and it reinforces the need to carefully model the impact of economic factors on urban core expansion.

## 6. Conclusion

In this paper we have shown that the monocentric model when applied to developing countries—in this case China—has fairly high explanatory power and produce results strikingly similar to analyses in the past. When we use specifications that were used in the literature on the US, we find evidence that all of the hypotheses of the standard monocentric model are valid. Income, population and transportation costs positively affect the spatial size of the urban cores of China's cities. Agricultural rents detract from the expansion of the urban core.

Although we have not accounted explicitly for policy (mainly due to the lack of a good set of measures), the decomposition results suggest that something apart from the economic factors included in the first-differences model slowed the growth of the urban core. Had it not been for these factors embodied in the residual, the urban core would have been 22 percent larger. While it is impossible to interpret precisely the meaning of the residual, it is possible to speculate that policy may have played a role in slowing growth.

Methodologically, our paper suggests that in the future economists must utilize urban spatial and economic/demographic data over time in the analysis of the determinants of urban land size and more precisely decompose the changes in the spatial size of cities. Although the time interval between the observations (5 years) is short, our results suggest that when time series are available and a first-differences model is used, the nature of the results might change. The magnitudes of many variables fall and some of the coefficients become insignificant. One of the lessons of this paper is that accounting for unobserved effects by using a fixed effects or first-differences model may matter. The expansion of the urban core is a complex process and it is difficult to include measures of all of the factors that affect the spatial size of cities.

Be that as it may, whether using results from the OLS or first-differences model, the paper demonstrates the powerful role that income growth has played in shaping China's current economy, including the spatial size of its cities. Moreover, regardless of the empirical approach we also found that the role of the other factors in China is relatively small—even when considered jointly. If our results are correct, this suggests that if China wants to continue to grow at high rates of GDP growth, the urban core may have to continue to expand. Since China's modernization hopes are tied to income growth, there will almost certainly be a lot more urbanization before China becomes a modern nation.

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