Counting Errors: How Misunderstanding of China's Local Population and Employment Counts Affects Economic Analysis

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Abstract

A confusion over local population counts and employment counts in China persists throughout the economic literature. The existing studies within many branches of economics related to China commonly use the count of people with local *hukou* registration, the GDP *per capita* using the *hukou* count as the population denominator, and incomplete employment counts reported in various Chinese statistical yearbooks as if they were appropriate measures of local population, local employment and local *per capita* income. This misunderstanding of China's local population and employment counts may lead researchers astray and could contribute to wrong conclusions and mistaken policy implications. An analogous error would be to study the economic geography of, say, the United States using local population and employment counts that were only for citizens rather than for all residents; the resulting statistical pictures are likely to be biased since cities such as New York or Los Angeles have a much higher share of non-citizens than do other areas. Yet there is no similar criticism of the large and growing literature that relies on sub-national population counts for China, despite the equally egregious errors that are likely to have resulted from using the wrong population and employment counts.

Five economic issues that are pertinent to modern China are studied in this thesis using the most reliable estimates of local resident population and employment from China's 2010 population census. These issues are regional inequality, optimal city size, the city size distribution, the nature, location and size of urbanization economies, and the determinants of urban land area expansion. Each issue is studied in a single, self-contained, paper that in some cases has

already appeared in a peer-reviewed journal, and in other cases is under review at such journals. In general, the findings based on the most reliable local resident population counts and employment counts from the 2010 census extensively challenge the existing evidence in the literature. In some cases the policy implications from this new research are the opposite of what was previously suggested from research that was potentially distorted by the counting errors described here.

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Chapter 1

Introduction

The urbanization that China is experiencing is the largest and fastest in human history. China's urban population and its urbanization rate were only 308 million and 26% in 1990 but had climbed to 758 million and 54% by 2014 (UN World Urbanization Prospects, 2014). This doubling of the urbanization rate and the addition of 450 million urban residents is due largely to hundreds of millions of rural-to-urban migrants. These migrants have dramatically reshaped China's economic geography. However a complete understanding of this reshaping is currently lacking because China's statistical system has not fully coped with this massive internal migration. In particular, many of the published sub-national population counts, and data derived from these such as *per capita* GDP, are not based on where people are actually living. Some errors likely result from researchers misunderstanding what the available sub-national population counts actually do show and these errors may affect the way in which some socio-economic phenomena are interpreted. It is this potential for misinterpretation of contemporary China by the economics literature that is the subject of this thesis.

Practitioners who work with sub-national data for China face an important but largely ignored data problem.[1] The most widely available local population counts for provinces, prefectures, cities and counties are not counts of residents, as they would be in most other countries. Instead they are counts of the people whose address for their household registration (*hukou suozaidi*) is from within that locality. In some cases these data tell us who once may have lived in an area or who had parents living there, because their household registration is still from that place even though they now reside somewhere else that could be hundreds of miles away. More broadly, this could be thought of as a *de jure* count of where people are legally registered to live rather than a *de facto* count of where they actually live. Notably, while these counts are reported in annual yearbooks put out by China's statistics office, they are based on data provided by the Ministry of Public Security – China's police force.

The "counting errors" that result from treating the *de jure* count of the local *hukou* holders as if it shows the *de facto* local population have the potential to substantially distort economic analysis because population counts are fundamental to so many branches of applied economics. For example, in urban and regional economics the size of cities or of other spatial units is an important element in understanding the scope for higher productivity due to agglomeration effects from firms and workers locating in larger, denser environments. In development and welfare economics, and in studies of economic inequality, the interest of researchers is usually in income or output *per capita* since comparisons

[1] There is some coverage of this problem in the geography literature, particularly in papers by Kam-Wing Chan such as Chan (2009b) but in economics these data issues are largely ignored.

of totals for unequally populated areas are not very informative. In this regard, while there is some literature on the accuracy of China's economic statistics (e.g. Holz, 2004; Chow, 2006) much less attention is paid to the errors in the denominator of *per capita* indicators, where this denominator is based on reports of local population counts.

For most of the first three decades of the reform era in China since 1978, local GDP was divided by the count of people with local *hukou* registration for a particular sub-national area rather than by the count of the local resident population, whenever GDP *per capita* was reported. Yet it is not the *de jure* population (that includes people who don't live there and does not include some who do) whose activities contribute to the production and consumption that goes in to the measured local GDP. Instead it is the *de facto* population that matters to local economic activity. Thus, the GDP *per capita* data that were reported in statistical publications provided a potentially misleading measure of local productivity and of incomes, since GDP was being attributed to the wrong people. Similarly, various statistical yearbooks reported the size of sub-national units, such as cities or counties, based mostly on their *hukou* registered population rather than on their resident population. Likewise, local employment counts in those yearbooks excluded most private sector workers, with the private sector being where most people without local *hukou* registration tended to work. It is only since China's 2010 population census that reliable estimates of the local resident population and of local employment are available. This thesis relies heavily on these new population counts from the census to examine the errors that result from using the previously reported counts of local *hukou* holders as a measure of the local population. The long form of the census (given to 10 percent of respondents) also provides comprehensive employment counts that cover all workers in all sectors. These more accurate employment counts also are used in this thesis to evaluate the errors that result from relying on incomplete employment counts in statistical yearbooks.

The *hukou* system was created in 1958 and took away the freedom of internal migration and residence for Chinese residents, with all internal migration thereafter to be subject to approval from the authorities at the destination (Chan, 2009a). While a registration system for vital statistics already existed, a key feature of the *hukou* was the need for individual Chinese to maintain an up-to-date registration at local police stations and in this regard it operated like an internal passport system. The type of *hukou* one was classified as was either “agricultural” (*nongye*) or “non-agricultural” (*fei nongye*) *hukou*. In addition to type of *hukou*, each person was also categorized according to their place of *hukou* registration (*hukou suozaidi*). This was the individual’s official permanent residence in the eyes of the state and from then on, newborn Chinese were, and are largely still, given the same *hukou* as that of their mothers. In particular, switching out of the agricultural and into the non-agricultural *hukou* was (and still is) very hard; in each locality an annual quota for conversions set by the central government was usually no higher than 0.2 percent of the local non-agricultural population (Chan, 2009a). These administrative barriers to individual Chinese changing their *hukou* persisted into the reform era. For example, from the early 1980s through to 1997 China authorized about 18 million *hukou* changes per year (Au and Henderson, 2006). But these mainly involved urban-to-urban and rural-to-rural moves (so changes in *hukou* location) rather than the rural-to-urban moves (changes in both *hukou* location and *hukou* type) that were needed to underpin the urbanization of a country that central planning had made far too rural for its level of income and economic development.

Indeed, in the command economy era the *hukou* system was an important mechanism for the state to prevent a vast influx of peasants into cities. The holders of non-agricultural *hukou* were provided with goods and services from the state while the people with agricultural *hukou* were meant to be basically self-reliant. Since the command economy involved extracting resources from agriculture to fund industrialization, and to fund benefits to urban workers, the social welfare system was unlikely to cope with unrestricted population movement from rural to urban areas, and so the *hukou* was strictly enforced. The *hukou* was also used to limit internal population movement due to China's long-term aversion to large cities and these restrictions were maintained in the early reform era. For example, administration regulations issued in 1982 known as 'custody and repatriation' authorized police to detain Chinese living in cities who did not hold local non-agricultural *hukou* and to repatriate them to the places of their *hukou suozaidi*.

But despite the fact that the legal framework of the *hukou* system remains largely intact today, the enforcement of it in practice has partly broken down. The driving force for this breakdown is that the Chinese economic reforms have created pressures to encourage migration from the interior rural areas to the coastal urban areas in order to better facilitate the substantially increased economic production in coastal urban areas. This has provided incentives for

Chinese officials to not enforce regulations on inter-regional rural-to-urban migration. As a result, and given the difficulty of changing *hukou* status, the non-*hukou* urban residents have emerged to become a major group. These non-*hukou* urban residents are those people who are working and living permanently in cities while their *hukou* registration is from elsewhere. The stock of the non-*hukou* urban residents was already around 100 million in the mid-1990s (Chan, 2012).

More recently, from China's 2010 population census, the total count of non-*hukou* urban residents reached 226 million by 2010, which is one-third of China's overall urban resident population. Apparently, the *hukou* system can no longer properly identify where individual Chinese are working and living in contemporary China. Notwithstanding this fundamental change, the *hukou* population is still commonly provided by China's statisticians as a measure of the size of sub-national entities such as provinces or cities, despite it no longer being an appropriate count of the local population. Neither are the GDP *per capita* data that are based on the local *hukou* population and are reported in various statistical yearbooks appropriate for capturing local income levels in China since this ratio denominates local output by a population measure that does not correspond to the number of local residents who consumed or produced that output. Likewise, counts of the number of people in local employment reported in those yearbooks miss many private sector employees (the error is especially for the private sector since this is where most non-*hukou* residents work) and so are not appropriate for measuring the size of the local economy or the productivity of workers.

Yet confusion over local population counts and employment counts in China persists throughout the economic literature. The existing studies within many branches of economics related to China commonly use the *hukou* population count, the *hukou* population based GDP *per capita* and the incomplete employment count reported in various Chinese statistical yearbooks as if they were appropriate measures of local population, local employment and *per capita* income. This misunderstanding of China's local population and employment counts may lead researchers astray and could contribute to wrong conclusions and mistaken policy implications. An analogous error would be to study the economic geography of, say, the United States using local population and employment counts that were only for citizens rather than for all residents; the resulting statistical pictures would be biased since cities such as New York or Los Angeles have a much higher share of non-citizens, making such an analysis meaningless. Yet there is no similar criticism of the large and growing literature that relies on sub-national population counts for China, despite the equally egregious errors that are likely to have resulted from using the wrong population and employment counts.

Five economic issues that are pertinent to modern China are reprised in this thesis using the most reliable estimates of local resident population and employment from China's 2010 population census. These issues are regional inequality, optimal city size, the city size distribution, the nature, location and size of urbanization economies, and the determinants of urban land area expansion. Each issue is studied in a single, self-contained, paper that in some cases has already appeared in a peer-reviewed journal, and in other cases is under review at such journals. In general, the findings based on the most reliable local resident population counts and employment counts from the 2010 census extensively challenge the existing evidence in the literature. In some cases the policy implications from this new research are the opposite of what was previously suggested from research that was potentially distorted by the counting errors described here.

The remainder of the thesis is organized as follows. Chapter 2 focuses on regional inequality using provincial level data on GDP *per capita*. Three major counting errors in China's local population data are clearly described in this chapter. The first is the use of the local *hukou* registered population as a denominator for GDP, which leads to overstating GDP *per capita* in the provinces where non-*hukou* residents moved to and understating it in the provinces that they left. The second error is due to the sudden and uncoordinated switch to using a resident population denominator for GDP (that is, shifting from a *de jure* to a *de facto* population basis); in some provinces this switch was made as early as 1990 and in others it was as late as 2008. The third, and related, error is the double-count caused by the partial and inconsistent way that people were counted by each province in any given year; for example, in the case of someone who moved from a late switching province (e.g. Hubei) to an earlier switching province (e.g. Guangdong) there would be some years where they would show up in the population counts of both provinces. This double-counting problem amounted to almost 25 million people at its peak. The results in this chapter show that once these three counting errors are corrected by using retrospective resident population estimates that became available after the 2010 population census, much of the seemingly large rise in inter-provincial and inter-regional inequality in China that is much discussed in the literature (e.g. Fan et al, 2011) disappears.

Moreover, the apparent turning point in the mid-2000s where the rise in regional inequality seems to reverse, which happened to coincide with when China's national government made multi-billion dollar investments into so-called lagging regions, is shown to be largely an artifact of the change from a *de jure* population basis to a *de facto* population basis for denominating GDP *per capita*. This change in statistical procedures makes it difficult to assess any impacts on inequality of the government investment into lagging regions. This chapter is published in *World Development* (Li and Gibson, 2013).[2]

While the research reported in Chapter 2 contributes to the literature on China's regional inequality, it is by no means the end of the story. In particular, in order to cleanly identify the effect of counting errors on the trend in regional inequality without introducing auxiliary variations, there is no adjustment for spatial differences in prices in Chapter 2. Yet as a matter of fact, richer provinces in China are more expensive places to live, especially in urban areas (Brandt and Holz, 2006). This is a sub-national manifestation of the well-known Balassa-Samuelson effect that the price level is higher in richer countries. Moreover, under the command economy, urban housing markets were absent and so reform era spatial cost of living differences that are due to the urban housing market, (reflecting the fixity of land) have likely grown from a low base. Thus, some of the apparent rise in inequality in China that is found by many studies is probably just a growth in spatial price differences. Therefore in a companion study to the analysis in Chapter 2, a spatial price index was calculated based on prices for new dwellings (both with and without hedonic adjustments for dwelling attributes) to

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see what happens to the apparent inter-provincial (and also inter-city) inequality if the analysis is recast using spatially real prices. The results show that inter-provincial measures of inequality are overstated by at least 15 percent if spatially nominal prices are used in the analysis. This result on the effects of spatial price deflation, in conjunction with the results on the effects of adjusting for population denominator errors, provides grounds for caution when interpreting evidence on rising regional inequality in China. This companion paper is published in the *Asian Development Review* (Li and Gibson, 2014) and since it does not address the central issue of counting errors it is included in the appendices to the thesis rather than as one of the main chapters.[3]

While Chapter 2 describes the origin of the population counting errors and highlights the effects they have on one phenomena of interest – inter-provincial inequality – it may not do full justice in highlighting the magnitude of these errors. On the one hand, the issue of inter-regional inequality is ideal for demonstrating the problems caused by these counting errors since using the *de jure* population as a denominator for GDP *per capita* means that inequality will mechanically rise as rural to urban and inland to coastal migration increases (given that the urban, coastal areas are richer). But on the other hand, the severity of the counting error problems is not fully highlighted at the spatial scale of provinces. The reason is that any of the non-*hukou* urban residents who stay within the same province (e.g. moving from rural Sichuan into Chengdu) still get counted in the right province for denominating GDP *per capita* if the count of local *hukou* holders is used as a proxy for the count of local residents. But for

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smaller spatial units, such as cities, the scale of the error is much larger since the non-*hukou* urban residents have come from outside these city boundaries and so there are many more of them than there are of the non-*hukou* interprovincial migrants. Therefore the remaining chapters of the thesis consider sub-national spatial units that are smaller than provinces.

In Chapter 3 the focus of the thesis shifts to cities, or more specifically ‘urban cores’. In China, prefectural cities (*diji shi*) have an urban core of districts (*shiqu*) that is equivalent to a city proper (Roberts et al, 2012) or to the urbanized portion of a Metropolitan Statistical Area in the U.S. (Au and Henderson, 2006). In the analysis in Chapter 3, as in most studies of cities in China, contiguous districts within the same prefectural city are merged so there is one core per prefecture. This chapter considers the issue of optimal city size by estimating an inverted U-shaped relationship between output per worker and city scale. In contrast to existing evidence from Au and Henderson (2006), who provide the theoretical framework used in the chapter, the data come from local employment counts recorded in the long form version of China’s 2010 population census. The results show that four-fifths of Chinese cities are close to the estimated productivity-maximizing scale and that the predicted output losses due to sub-optimal scale are typically below 10%. Those findings challenge the often repeated claim in the literature (e.g. Au and Henderson, 2006) that China has too many small cities and foregoes agglomeration-based productivity gains as a result. The contribution of the chapter to the literature on whether the city size distribution in China is sub-optimal is significant since existing studies (e.g. Au and Henderson, 2006) use wrong measures of city scale based on incomplete local employment counts reported in China's statistical yearbooks. The counting error in employment data comes from a failure to fully cover the private sector workforce. In fact, in 2010 the incomplete local employment count reported in China's statistical yearbook averaged just 43% of the complete local employment count recorded for the same cities by China's population census. This is a useful reminder for future economic analysis on China of the need for caution when using local employment data for sub-national areas. Chapter 3 is published in *Economics Letters* (Li and Gibson, 2015).[4]

Chapter 4 uses a different framework to consider the city size distribution in China and switches from showing the impact of counting errors in employment data to showing the impact of errors in local population counts. One of the most robust empirical facts about the relative size of cities is that they follow either Pareto's or Zipf's Law (Gabaix, 1999) which give negative relationships between logarithms of city size and rank within a country (with a slope of minus one for Zipf's Law). Several recent studies in economics and in other disciplines estimate these relationships for China's cities. A common finding (e.g., Anderson and Ge, 2005) is that city sizes are becoming more evenly distributed over time (that is, the absolute value of the Pareto exponent is rising and moving further from what Zipf's Law implies). But the population counts that these studies use are counts of the local *hukou* registered population, which miss the flocking of millions of migrants into a small number of China's cities. In other words, non-*hukou* migrants voting with their feet seem to prefer a few, larger, cities and once their choices are considered by using more appropriate, residence-based, population

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counts, the evidence is that over time, city sizes in China are becoming less even. On top of answering a positive question, of whether the city size distribution is converging or diverging, this chapter also uses Pareto's Law to answer the normative question of which cities in China should accept more in-coming rural migrants (based on an objective function of moving the city size distribution closer to what Pareto's Law predicts). This analysis shows that only the very largest cities in China appear to have scope to absorb more non-*hukou* urban residents, which stands in sharp contrast to official policy prescriptions for encouraging migrants into small cities and limiting the growth of the biggest cities.

In Chapter 5 the effects of city size on productivity are reconsidered by examining the nature, location and size of urbanization economies. These economies are the the positive externalities arising from the scale of an area and the diversity of its economy and show up in higher output per worker. Using data on local GDP and on the urban resident population from the 2010 census, the analysis shows that these positive externalities occur only for already agglomerated areas (the urban districts) and do not occur at all for the county-level cities or counties. In terms of economic sectors, the positive urbanization externalities occur only for the tertiary (services) sector, and not for the secondary sector that includes manufacturing and construction. A comparison of industrial and spatial employment distributions in the 2000 and 2010 census shows that manufacturing and construction activity have been spreading towards counties. The results in this chapter suggest that there will be no positive externalities resulting from attempts to create a more dispersed form of urbanization from this spreading of secondary sector activity.

The final notable result in this chapter is that the estimated urbanization economies are of a similar size to those found in other countries. In contrast, Combes, Demurger and Li (2015) use China's Urban Household Survey (UHS) and claim that China's urbanization economies are up to three times larger than those observed elsewhere, and treat this as a symptom of China's maladjusted city size distribution. While the UHS data are not subject to the counting errors criticized here, they come from a sampling frame that ignores the non-*hukou* urban residents and so it is not clear what store can be placed on these results of much larger urbanization economies in China than elsewhere. If the UHS results are unreliable, and if the true situation is that urbanization economies in China do not look too unusual by international standards, then it partially corroborates the evidence from Chapter 3 that China is not suffering major productivity losses from having a malformed city size distribution.

In Chapter 6 the unit of analysis is still cities but the topical focus turns from purely economic indicators like GDP *per capita* or *per* worker to an economic and environmental indicator – urban land area; this attracts policy interest due to concern about 'urban sprawl'. The extant literature for China uses satellite remote sensing to measure urban land area and finds that area expands 3 percent for every 10 percent increase in economic output (county GDP) and that between 1995 and 2000, local GDP growth fully accounted for all urban area expansion with no independent effect of local population growth (Deng, Huang, Rozelle and Uchida, 2008; 2010). If rising city population does not translate into rising city land area, it implies that cities are becoming denser rather than more dispersed (that is, more sprawling). This densification is contrary to what is often asserted (e.g., World Bank, 2014), and also implies that the tradeoffs between urbanization and food security may be less severe than thought. But this prior evidence may be untenable because the population with local *hukou* registration is being used to explain urban area expansion and there is no reason to believe that this is a suitable proxy, since the uncounted non-*hukou* urban residents also need dwellings to live in, roads to drive on, and offices, shops and factories to work in, and all of these require land being converted from agricultural use to urban use.

In order to determine if population counting errors may have caused the evidence on China's urban area expansion to be misinterpreted, this part of the thesis proceeds in two steps. The first step updates the remote sensing evidence on the expansion of China's urban areas; this is needed since reliable estimates of the local population are only available in the 2000 and 2010 census while existing remote sensing evidence on city area is from earlier years. An appendix to the thesis reports the results of using satellite-detected night time lights to measure city area in each year from 1993 to 2012 (for every city that meets the definitions used in Chapters 3 and 4). When the city-by-city expansion rates are related to annual changes in local GDP and in the population with local *hukou* registration, the results are very similar to what Deng et al (2008, 2010) found, which is that the elasticity of area with respect to city GDP is about 0.3 and that there is no effect of local population change on urban area. These results are published in *Sustainability* (Gibson, Li and Boe-Gibson, 2014) and are included as an appendix to the thesis.[5]

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Since the night lights provide similar evidence on urban expansion to what Deng et al (2008, 2010) report using Landsat data, they should provide a suitable testing ground for evaluating the effect of population counting errors on the prior conclusions in the literature about the causes of urban area expansion. This is the evaluation that is carried out in Chapter 6, where a statistical 'horse race' is carried out between two different models for explaining growth in urban area (as detected by night lights) for each city between 2000 and 2010. The first model uses the change in (log) GDP and the change in (log) *hukou* registered population for each city while the second model uses the change in (log) GDP and the change in (log) urban resident population for each city, as recorded by census. Consistent with the existing study by Deng et al (2008), changes in the number of people with local *hukou* registration has no effect on city area while the elasticity of city area with respect to local GDP is about 0.2. The results are very different when the urban resident population is used in the models; the elasticity of urban area with respect to resident population is about 0.4 and there is no significant effect of local GDP change. Non-nested model comparison tests conclusively favor the model that uses the resident population over the model that uses the local *hukou* registered population. In other words, the apparent non-effect of local population increase on urban area expansion that is reported by existing studies is probably an artifact of using the wrong population concept – there is no reason why city area would expand when a city has a larger *hukou* registered population since the *hukou* registered population do not necessarily live there. Thus, counting errors may distort understanding of the driving forces behind urban land area expansion in China. Moreover, it appears that population densities of the very largest

Chinese cities are lower and declining compared with those of other mega-cities elsewhere in the world, such as Hong Kong (Du et al, 2013). Thus, concerns in China about urban sprawl and threats to food security may have some justification after all and the revised understanding that comes from modelling urban expansion using changes in the appropriate resident population supports this.

Chapter 7 contains the conclusions of the thesis and highlights the overall contribution of the five main chapters. The theme that runs through all of these chapters is the need for researchers to be cautious when using China's sub-national data on employment and population, and when using any *per capita* or *per* worker variables derived from such data. Many of the patterns revealed by careful analysis of the data from the 2010 census of population suggest that some of the understanding in the economics literature about contemporary China may have been distorted by the counting errors described in this thesis.

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Chapter 2

Rising Regional Inequality in China: Fact or Artefact?

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Rising Regional Inequality in China: Fact or Artefact?

Abstract

China's local populations can be counted by how many people have *hukou* household registration from each place and by how many people actually reside in each place. For most of the first three decades of the reform era, the *hukou* count was used to denominate *per capita* GDP figures, creating a systematic and time-varying distortion in provincial GDP *per capita* figures. A discontinuity occurred when provinces switched from the *hukou* count to the resident count when reporting GDP *per capita*. Much of the apparent increase in inter-provincial inequality disappears once a consistent series of GDP per resident is used.

Keywords: Inequality, Growth, Regional development, Population, China, Asia

JEL: O15

2.1 INTRODUCTION

Nobel Prize winner Amartya Sen recounts how, as a nine-year-old boy, he saw unbelievably emaciated people dying in the streets during the 1943 Bengal famine (Sen, 1995). These were the rural destitute, who had trekked from the countryside into the cities in search of food; by one estimate they numbered at least 100,000 in Calcutta alone (Sen, 1981). Yet just 15 years later in the Great Leap famine in China, which killed at least 30 million people,[6] there was no similar trek by desperately hungry villagers seeking food in the cities. Instead, the strict controls on mobility in China under the *hukou* household registration system prevented the mass movement of people in search of food. So limited was movement that the excess mortality rate in one province – Anhui – was 17 times higher than that of a neighboring province, adding up to a difference of over six million excess deaths in Anhui between 1958 and 1961.[7]

Fast forward two decades to the beginning of China's economic reform and the *hukou* system was largely intact. Every person in China in 1958 had been given either "agricultural" (*nongye*) or "non-agricultural" (*fei nongye*) *hukou*, to determine entitlements to state-provided goods and services (regardless of

[6]Ashton et al (1984) estimate that there were about 30 million premature deaths between 1958 and 1962 and about 33 million fewer births than would be expected in the absence of the famine.

[7] Specifically, from 1958 to 1961 there were 6.3 million excess deaths in Anhui, equivalent to 18.4 percent of the population, but just 0.2 million excess deaths (one percent of the population) in neighboring Jiangxi (Yixin, 2010), even though these provinces share a 260 mile border. Brown (2010) reports evidence that urban residents even smuggled food *out* of cities to their nearby but immobilized (by inflexible *hukou*) rural friends and relatives.

location), which thereafter passed from mothers to children. In addition to *hukou* type, each person was categorized by their place of *hukou* registration (*hukou suozaidi*), which was their official and permanent residence in the eyes of the state (Chan, 2009). In the pre-reform era there was no freedom of movement, with all internal migration subject to approval from authorities at the destination, so the *hukou* operated much like an internal passport system (Chan and Zhang, 1999). But China's population was maladjusted for the needs of a market economy, with too many people in the interior, and too few in the soon-to-be-booming coastal cities. So the non-*hukou* migrants emerged, people who moved to live and work somewhere other than their place of *hukou* registration – often hundreds, or even thousands, of miles away.

China's statistical system had no way to deal with the non-*hukou* migrants, so for most of the first three decades of the reform era, local GDP was divided by *registered* population rather than by *resident* population whenever *per capita* figures were reported. In other words, official data on provincial GDP *per capita* (and also for prefectures, counties and cities) were not based on the average number of residents but instead, on the household registered population. In coastal provinces the household registered population is many millions less than the resident population, while the reverse is true for migrant-sending inland provinces, so a systematic and time-varying distortion in provincial GDP *per capita* data was created. For example, at the time of the 2000 census, Guangdong province had a registered population of 75 million but residents numbered 86 million, so using registered population to calculate GDP *per capita* gives a 15 percent overstatement. At finer spatial scales, such as for individual counties and cities, the error is much larger. The city of Shenzhen provides an outstanding example; its registered population was just over one million by the time of the 2000 census but its residents numbered seven million, so *per capita* GDP was overstated by almost 600 percent in the official data of the time (Chan, 2009a).

Every year an avalanche of data comes out of China's statistical system, with yearbooks for each province and for topics such as population, urbanization and the economy. The fact that these yearbooks regularly reported economic output of each province or sub-provincial area divided by a population concept that had no bearing to the actual number of people living in those areas has been routinely ignored by economists. As noted a decade ago by Rawski and Xiao (2001), few economists hesitated to utilize these standard yearbook data for their research. Instead, most debate by economists about economic statistics concerns the possible falsification of China's GDP growth figures (Rawski, 2001, Chow, 2006) and the threat to time series comparisons from varying rules for constructing consumption data (Holz, 2004). Much less attention is paid to the simpler issue of how to count China's local populations, despite the systematic distortion of *per capita* data created by using the wrong population figures.

In this paper we document these problems with China's population data and highlight some implications, especially for the literature on inter-provincial and inter-regional (coastal-inland) inequality. A general finding is that inequality rose in the reform era, although not necessarily with the same patterns at all spatial scales (e.g. Chen and Fleisher, 1996; Huang, Kuo and Kao, 2003; Fan and Sun, 2008; Li and Wei, 2010). Inequality seems to be low when policy encourages agriculture and the rural sector generally and high when the rural sector is neglected, as in the recent era of global integration dating from the 1990s (Fan, Kanbur and Zhang, 2011). But at least part of the apparent trend in regional inequality may be a statistical artefact caused by the unusual way that China has calculated local GDP *per capita*.

We also explore two other problems related to the wrong population being used for *per capita* statistics. First, a discontinuity occurred when provinces switched from reporting GDP per registered population to GDP per resident. This discontinuity causes a spurious trend change for measures of inter-provincial inequality, which coincides with initiatives to reduce inequality such as the West China Development Project (Fan and Sun, 2008), the Northeast China Revitalization Campaign (Zhang, 2008) and the Rise of Central China Plan (Lai, 2007). Second, there was a double-counting problem, since some provinces switched to reporting output per resident several years before others. Hence, the same person may have been in the denominator of GDP *per capita* for two different places at the same time; as a resident of one province and in the registered population of a province that was slow to switch to reporting output per resident. We estimate that up to 26 million people were included in this double-count.

These population errors have been discussed in the geography literature (Chan, 2007). But economists have largely ignored them, with just a single working paper devoted to this issue (Hoshino, 2011). In contrast to that previous study, we explore all of the problems with China’s local population data while

Hoshino just examines the problem of using GDP per registered population.[8] Furthermore, a common feature of much recent applied economic research on China has been to use data from sub-provincial levels, such as prefectures (Roberts et al, 2012) or counties (Banerjee, Duflo and Qian, 2012). Yet the problem of using the wrong population in *per capita* GDP statistics is much worse for smaller jurisdictions like counties, because many more people are defined as non-*hukou* migrants when working with smaller geographic units (Chan, 2012). Moreover, intercensal population figures for lower-level units only refer to the *hukou* registered population (Scharping, 2001). Consequently, there are no annual estimates of the *resident* population of small units like counties, so *per capita* GDP estimates for those small areas continue to be based on the wrong concept of local population.

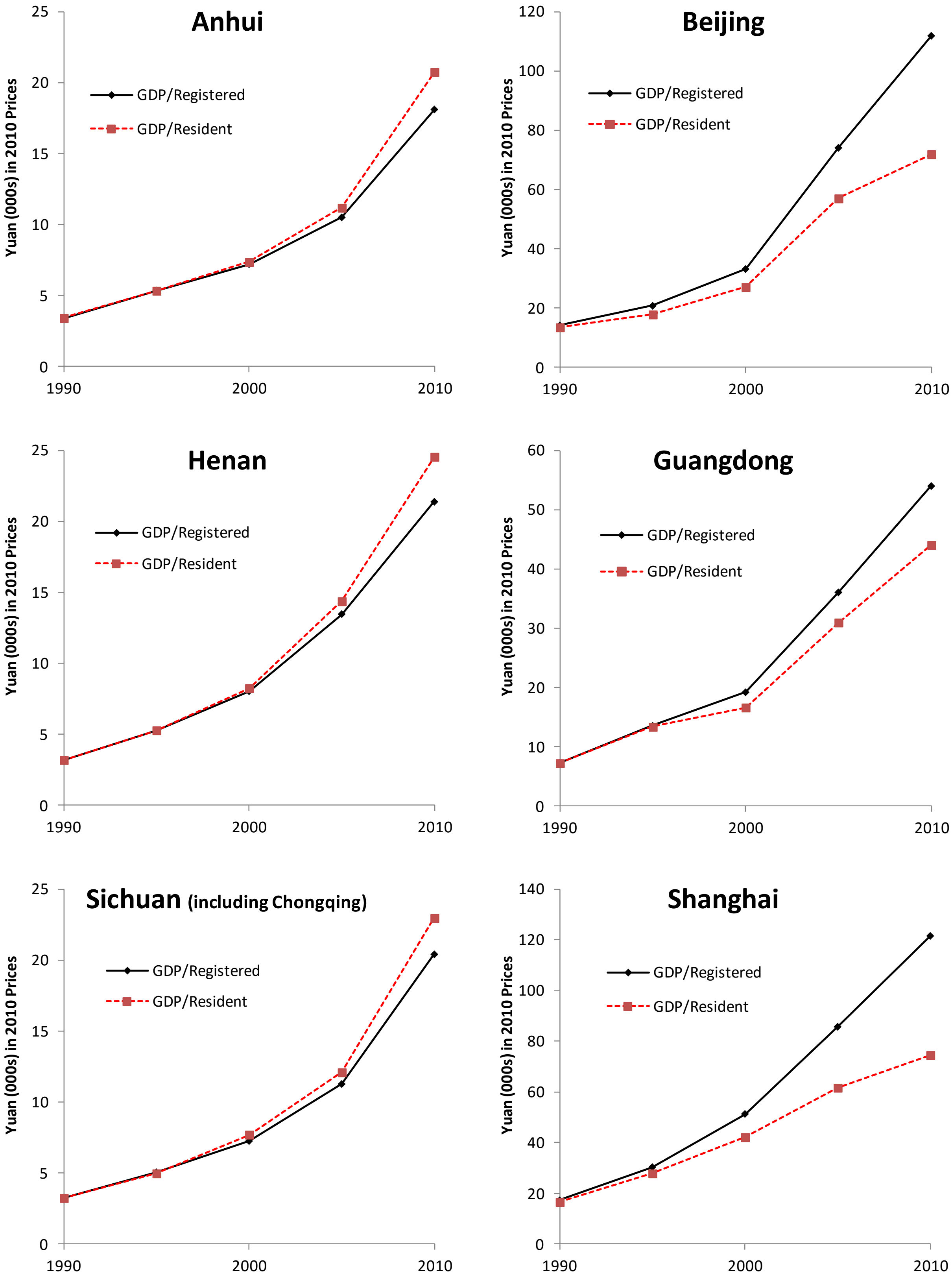
The analysis here uses provincial population and GDP data but we note that an alternative perspective on inequality in China comes from household survey data. Several studies with such data show inter-regional inequality to be of falling importance relative to interpersonal inequality over the reform period (Benjamin et al, 2005; Benjamin et al, 2008) while the effect of local inequality on growth also fades over time (Benjamin et al, 2011). For example, inequality decompositions by Benjamin et al (2005) show a falling contribution to total inequality from province of residence; down from 24 percent in 1987 to just 15 percent in 1999. To the extent that the household survey evidence challenges

[8] Moreover, the procedure used by Hoshino to develop an alternative to the officially reported GDP per registered population can be questioned because the way that the 1990 and 2000 census populations are spread over intercensal years suffers from the double-counting problem.

the view that inequality in China is primarily a geographic phenomena, it corroborates a finding from this paper that most of the reform era is not characterized by rising regional inequality once a consistent series of GDP per resident is used which accounts for the non-*hukou* migrants.

A feature of surveys is that they allow residency to be consistently determined by how long an individual has actually been living in a locality, rather than just relying on *hukou* status. But China's lack of a national sampling frame hinders surveys; the urban and rural household surveys by the National Bureau of Statistics are based on *hukou* registration rather than the census and so non-*hukou* migrants are missing from the sample frame (Ravallion and Chen, 2007). Hence, many surveys used to study inequality in China have only partial spatial coverage; the Research Centre on the Rural Economy (RCRE) surveys used by Benjamin et al (2005, 2011) are from nine provinces while the China Household Income Project (CHIP) used by Khan and Riskin (2005) surveys in 21 provinces for its rural sample and 12 provinces for its urban sample. Partly for this reason and also perhaps due to the accessibility of the statistical yearbooks, the areal data continue to be widely used; for example, only a minority of the studies of inequality trends covered by Gustafsson and Li (2002) use household survey data. Moreover, the areal data are also widely used to test models of sub-national economic growth and convergence, and so we do not further consider the household survey data in this paper.

Figure 1: Trends in GDP per Registered and per Resident Population: Selected Provinces



Notes: Chongqing included in Sichuan since they were one province until 1997. Values are in 2010 prices using the GDP deflator for China provided by the World Bank.

2.2 IMPACTS ON GDP *PER CAPITA* FROM USING THE WRONG POPULATION CONCEPT

The discrepancy between registered and resident population caused by the non-*hukou* migrants can only be clearly observed in years with either a microcensus or a full population census. The intercensal population data rely on the annual National Sample Survey on Population Changes, which appears to have understated non-*hukou* migrants, as we show below. In terms of the years with more reliable data, China has carried out a national census in 1982, 1990, 2000 and 2010, with a one percent microcensus in each of 1987, 1995 and 2005. But even the time-trend from census and microcensus data is not fully consistent since the duration required to be defined as a resident changed (Scharping, 2001). The 1982 and 1990 census counted non-*hukou* migrants as residents at their place of in-migration if they had lived there for more than one year, but each microcensus and the census in 2000 and 2010 used a six-month stay for someone to be defined as a *de facto* resident.[9]

This inconsistency causes the number of non-*hukou* migrants to be understated in earlier years and the gap between GDP per resident and GDP per registered population to be smaller than with a consistent definition. However our

[9] Tsui (2007) is an example of a study that (wrongly) ignores this change in the length of stay required to be defined as a resident. Tsui projects age-specific population cohorts forward from the 1982 and 1990 census and uses the gap between the actual figure in the next census and the projected figure for that year to estimate net in-migration and then spreads these evenly over the intercensal years. The six-month rule in the 2000 census gives more residents than the 12-month rule used in 1990, so this method will wrongly overstate the number of in-migrants in the 1990s.

main point is not much undermined by this inconsistency, since the non-*hukou* migrants were a much smaller group in the 1980s, increasing by just 15 million (from 6.6 million in 1982 to 21.6 million in 1990 – both figures on a one year residency definition). In contrast, Chan (2012) reports that the number of non-*hukou* migrants increased by almost 100 million between the 1995 microcensus and the 2000 census (both on a six month definition). So it is in the 1990s, and subsequently, that the trends in GDP *per capita* are most affected by the discrepancy between registered and resident population.

In Figure 1 we illustrate the trends in GDP *per capita* for six provinces, three migrant-senders in the left column and three migrant-receivers in the right.[10] The solid line is the ratio of provincial GDP (in 2010 prices) to the population with *hukou* for that province. The dashed line shows GDP divided by the local resident population, as counted in the census or microcensus (six-month residency criteria).[11] The GDP per resident of the migrant-sending provinces is about seven percent higher than GDP per registered population in 2005, and about 15 percent

[10] Beijing and Shanghai are province-level municipalities, along with Tianjin and (since 1997) Chongqing. Each is included as a separate entity in province-level statistics. Each of these municipalities also includes agricultural populations. For example, Chongqing municipality had a registered population of 30.9 million in the 2000 census but the non-agricultural population in its city districts was just 3.8 million (Chan, 2007).

[11] The resident population for 2000 and 2005 is based on revised figures for those years produced by the National Bureau of Statistics (NBS) after the 2010 census. The revisions raised the estimated resident population of Shanghai in 2005 by six percent and lowered the estimate for 2000 by four percent, while for the other provinces shown in the figure there were almost no changes from the initial counts made in 2000 and 2005.

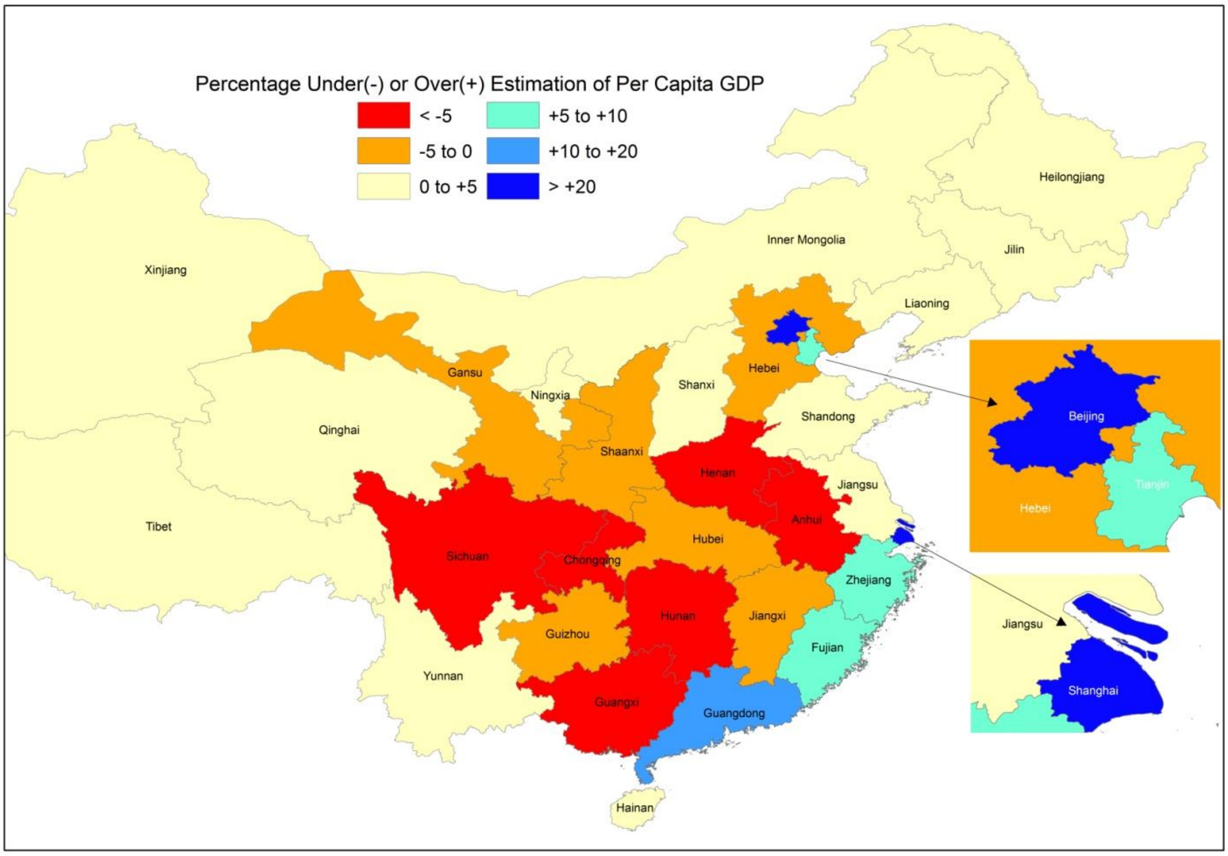
higher in 2010. The reason for the gap is that the permanent residents of the migrant-sending provinces are far fewer than the number of people with *hukou* registration for these provinces. In the case of Sichuan (including Chongqing) the difference in the two population counts is almost 15 million people by 2010, which is the number who left that province to live elsewhere – typically in the coastal cities. Yet for most of the economic reform period the officially reported GDP *per capita* figures for these inland provinces have included these missing people in their denominator.

The discrepancy between GDP per resident and GDP per registered population is much larger for the three migrant-receiving provinces shown in the right column of Figure 1. This reflects the funneling of migrants from many source provinces into just a few destinations, along the coast between Shanghai and Guangdong, and into the Beijing-Tianjin conurbation. For example, the registered and resident populations for Shanghai were 13.2 million and 16.7 million in the 2000 census, so dividing GDP just by the registered population results in a 27 percent upward bias in the *per capita* estimates. The gaps are even larger in 2010, at 55 percent for Beijing, 23 percent for Guangdong and 63 percent for Shanghai. In terms of annual trend growth rates in GDP *per capita*, wrongly using the GDP per registered population would overstate growth rates for Beijing and Shanghai by about two percentage points per year. Since there is an understated growth rate for all the migrant sending provinces, the scope for distorted findings from studies that use uncorrected provincial GDP *per capita* figures should be apparent.

To illustrate the situation more generally across all provinces, the percentage understatement or overstatement of *per capita* GDP at the time of the 2005 microcensus is mapped in Figure 2. For the six provinces in the central interior of China with the largest understatement, on average GDP *per capita* was seven percent lower using registered rather than resident population. A group of six adjacent (but still interior) provinces had lower rates of understatement, averaging two percent. The next group of 13 provinces forms a band around the western, northern and northeastern periphery where a very slight upward bias, averaging just two percent, results from dividing GDP by the registered population. These provinces are neither important sources nor destinations for non-*hukou* migrants. The final six provinces are all main destinations for non-*hukou* migrants, with *per capita* GDP overstated by at least five percent (and averaging 15 percent). This final group of provinces includes those on the southeast coast (Shanghai, Zhejiang, Fujian and Guangdong) and the Beijing-Tianjin conurbation.

If the map in Figure 2 was redrawn for 2010 the patterns would be the same but the rates of over- and under-statement would be larger. Such a map could be considered misleading, however, because by 2009 all provinces in China had, finally, switched to reporting *per capita* GDP on a resident basis rather than using the misleading *hukou*-registered population as the denominator. But the way in which this switch was implemented introduced a further set of problems with China's local population data, which we describe in the next section.

Figure 2: Percentage Difference in GDP per Registered and per Resident Population: 2005



2.3 DISCONTINUITIES AND DOUBLE-COUNTS

The population denominator used for *per capita* economic statistics of many provinces switched abruptly from a registered to a resident population basis. This change occurred around 2005 for the largest migrant-senders and receivers, but varied for other provinces. Switching denominator for GDP *per capita* raises the apparent living standards in inland provinces while lowering it for coastal provinces, since it (correctly) accounts for the inter-provincial non-*hukou* migrants. But the abrupt change by provinces with the largest migrant in-flows and out-flows creates a discontinuity in estimates of inter-provincial inequality, when many government-led initiatives to reduce regional inequality were at their peak. It is likely that at least part of the claimed success of these initiatives in reducing the coastal-inland gap (Fan et al, 2011) was simply due to the timing of the change in the way that China's economic statistics counted local populations.

We illustrate the sudden switch in the denominator of official GDP *per capita* estimates by charting time series of populations for the six provinces used in Figure 1. Two other features of China's provincial population data are also highlighted by this exercise; first, the reports of the resident population in the *Statistical Yearbooks* appear unreliable for most years, and second, the most plausible time series of resident population for each province have only been available since 2011. Hence research using provincial population estimates published before 2011 and relying on a concept of *resident* population – as most *per capita* economic statistics should – is likely to be distorted.

To explain each of these points fully, four time series are needed for each province:

- GDP implied population - the population values underlying reported GDP *per capita* figures. We derived these annual average population estimates by dividing current reported provincial GDP by current reported provincial GDP *per capita*.[12]
- Registered population - the year-end registered population (*hukou suozaidi*) for each province, as reported in *China Population Statistical Yearbook*

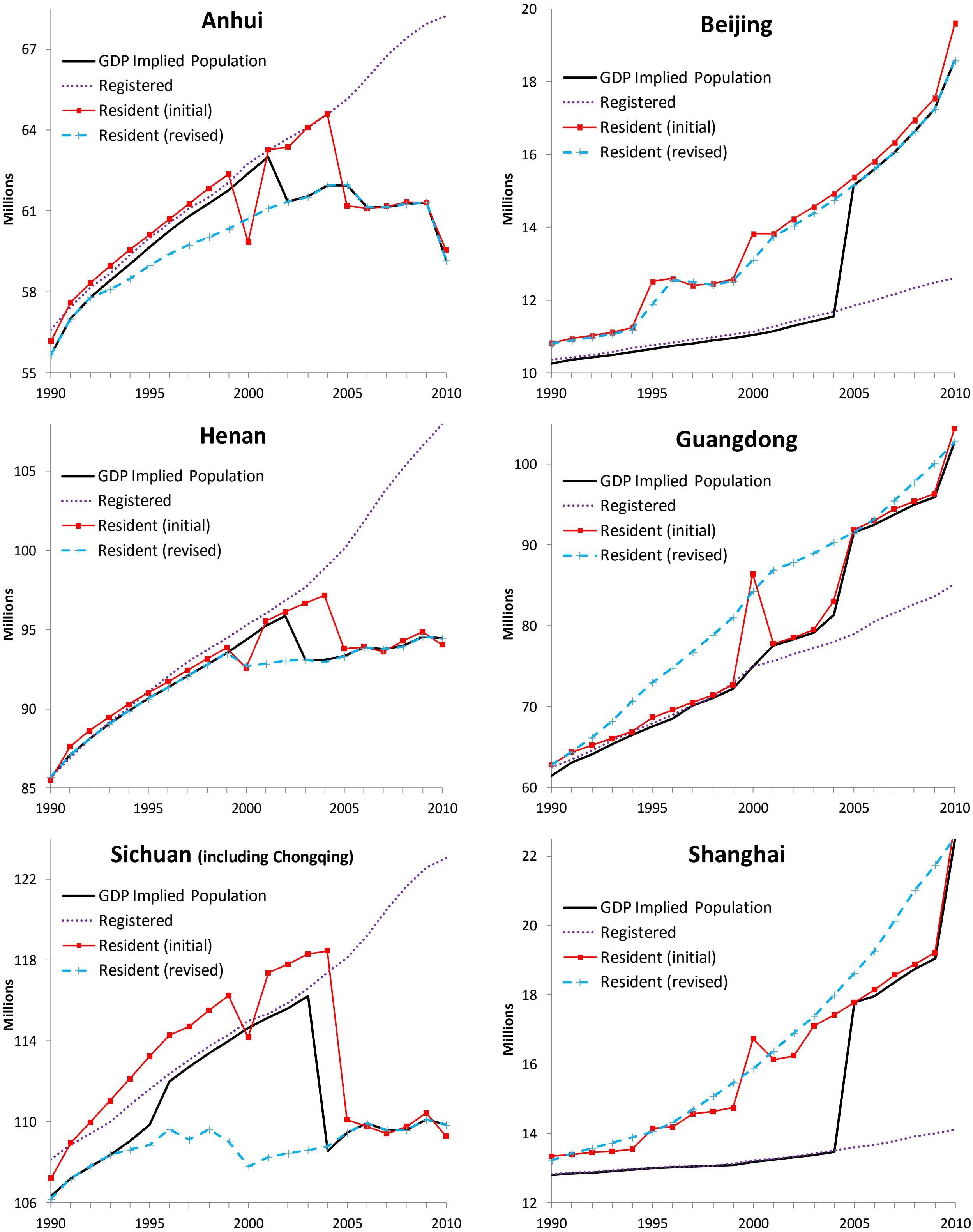
[12] Holz (2004) uses the same approach to derive the urban and rural populations that are implied by household consumption statistics. Our particular sources are the *Comprehensive Statistical Data and Materials on 50 Years of New China*, the *China Statistical Yearbook for Regional Economy 2001-2011*, and the historical sections of the 2011 edition of the *Statistical Yearbook* for each province.

1991-2006, *China Population and Employment Statistical Yearbook* 2007-2011.

- Resident (initial) population - the estimated year-end resident population, reported each year in *China Population Statistical Yearbook* 1991-2006, *China Population and Employment Statistical Yearbook* 2007-2011. In years without a census or microcensus, this resident count comes from the annual National Sample Survey on Population Changes and from the census data otherwise.
- Resident (revised) population - the annual average of the resident population in previous years back to 1990 that was released by NBS in 2011 in the statistical yearbooks for each province, derived by dividing reported provincial GDP by reported provincial GDP *per capita*. This revision uses the results from the 2010 census and attempts to smooth out discrepancies in the time series of resident population.

For each of the six provinces shown in Figure 3, the GDP implied population tracks the registered population from 1990 to 2004 (Beijing and Shanghai) or to slightly earlier (Guangdong and Sichuan – 2003; Henan – 2002; Anhui – 2001). The implied population in Beijing and Shanghai then jumps, while dropping for the three migrant-sending provinces. For Beijing and Shanghai the population jump is equivalent to over 30 percent of the previous year population, while for the three provinces shedding population the decline is equivalent to four percent of the previous year population. After this abrupt change the implied population then tracks either or both of the two resident population time series. The only province where the switch from registered to resident population time

Figure 3: Trends in Implied, Registered and Resident Population: Selected Provinces



Source: Author's calculations from the sources described in text. For other notes see Figure 1.

series takes more than one year is Guangdong, where it is spread over the years from 2001 to 2005.

The next feature of the provincial population data shown in Figure 3 is the volatility of the time series of initial estimates of the resident population. The three migrant-sending provinces all show sharp dips in the time series in 2000 and then sharp declines in 2005 that are not reversed. For the migrant-receivers, the estimated number of residents spikes in 2000 and rises rapidly again in 2010, and also in 2005 for Guangdong. For each province the year(s) that do not fit with the trend for the surrounding years, or that mark a shift to a different time trend all have either a census or microcensus. For the intercensal years the resident population count comes from the National Sample Survey on Population Changes, which is just a 0.1 percent sample. It appears that this sample is not able to adequately cover non-*hukou* migrants, compared with the more extensive efforts of the census and microcensus and that an adjustment was made in census years to align the results with the more comprehensive census count.[13] Thus even if economists were concerned that official GDP *per capita* figures relied on the wrong denominator – the registered population – and had tried to adjust by

[13] In unreported regressions we compare 2000 census resident counts for each province with the resident population predicted from the trend in the yearbooks for the two surrounding years. The method used to form the estimates of resident population that were initially reported in the *Statistical Yearbooks* for non-census years appears to overstate the population of migrant-sending provinces by more than two percent and understates it for receiving provinces by five percent, which could only result from underestimating the number of non-*hukou* migrants.

dividing by the reported resident population, the data available would not have allowed correct adjustment, except in census years.

The third feature of the provincial population data in Figure 3 is that the most plausible time series of resident population have only been available since 2011. These data, shown by the dashed line labeled “Resident (revised)”, represent the work by the National Bureau of Statistics (NBS) to use the latest census counts to correct the initial estimates of the resident population in each province. [14] The initial estimates, reported year-by-year in each province’s *Statistical Yearbook*, are quite volatile between census and non-census years but the revised estimates smooth the time series. Nevertheless, we must stress that it will never be known for certain what the annual resident population of China’s provinces was for most of the first three decades of economic reform.

The final idiosyncratic feature of China’s provincial population data is not apparent from Figure 3. Some provinces have been reporting output per resident rather than output per registered population since 1990. The year in which each province switched to reporting GDP per resident is shown in Table 1. We determine this date using charts like those in Figure 1, but for all provinces, since there is no explicit discussion of the (changing) population basis for GDP *per capita* calculations in contemporary statistical documents. The registered and

[14] The 2010 population census (and the Second Economic Census, conducted in 2008) provides corrected endpoints for recalculating trends in GDP and GDP *per capita*. This “new trend” can then be used to revise previous annual estimates. Specifically, annual deviations from a “historical trend” (based on the previous *Yearbook* data that did not benefit from the latest census results) are applied to the new trend. Wu (2007) provides details for GDP revisions.

Table 1: Year of First Using Resident Population in Official GDP *per capita* Estimates

Province	Registered Population (2010 mil)	Resident Population (2010 mil)	Non-*hukou* migrants (2010 mil)	Migrants as % of residents	Year of GDP switch to residents
Shanghai	14.1	23.0	8.9	39%	2005
Beijing	12.6	19.6	7.0	36%	2005
Tianjin	9.9	13.0	3.1	24%	2005
Guangdong	85.2	104.4	19.2	18%	2001
Zhejiang	47.5	54.5	7.0	13%	2001
Jiangsu	74.7	78.7	4.0	5%	1990
Fujian	35.3	36.9	1.6	4%	2000
Shanxi	34.7	35.7	1.0	3%	1991
Liaoning	42.5	43.7	1.2	3%	1990
Qinghai	5.5	5.6	0.1	2%	1990
Tibet	2.9	3.0	0.1	2%	2000
Yunnan	45.3	46.0	0.7	2%	1991
Xinjiang	21.6	21.9	0.2	1%	1990
Jilin	27.2	27.5	0.2	1%	1997
Inner Mongolia	24.5	24.7	0.2	1%	1991
Shandong	95.4	95.9	0.5	1%	1997
Heilongjiang	38.4	38.3	-0.1	0%	1990
Hebei	73.0	71.9	-1.0	-1%	1991
Ningxia	6.4	6.3	-0.1	-2%	2001
Hainan	9.0	8.7	-0.3	-3%	2003
Shaanxi	38.7	37.4	-1.4	-4%	1992
Jiangxi	46.9	44.6	-2.3	-5%	1990
Gansu	27.1	25.6	-1.5	-6%	1995
Hubei	61.5	57.3	-4.2	-7%	2005
Hunan	70.7	65.7	-5.0	-8%	2001
Sichuan	90.0	80.4	-9.6	-12%	2004
Chongqing	33.0	28.8	-4.2	-15%	2004
Anhui	68.3	59.6	-8.7	-15%	2002
Henan	108.0	94.1	-13.9	-15%	2003
Guangxi	53.3	46.1	-7.2	-16%	2003
Guizhou	41.9	34.8	-7.1	-20%	2008

Notes: Year of GDP switch to residents is the year in which official average population became resident population (before which it was registered population). Provinces are sorted according to the migrant percentage.

resident population for each province, as counted in the 2010 census is also reported in Table 1, along with the number of non-*hukou* migrants (positive for in-migrants and negative for out-migrants) and their percentage of the resident population.[15]

Figure 4 sums the population of each province for the 1990-2010 years. The national sum of residents should be less than the national sum of the *hukou* registered population, since the People's Liberation Army and Chinese with foreign permanent residency are not counted as residents but do have household registration status. Yet between 1990 and 2005 the sum of the resident population (shown by the solid line) exceeded the registered population (shown by the dotted line). The excess number of people counted as residents was especially apparent between 2000 and 2004, when it averaged 24 million people (with a maximum of 26 million). This excess occurs because what was called 'resident' in many provinces was, in fact, registered population, which exceeded residents. Hence, someone may have been in the denominator of GDP per capita for two different places at the same time; as a resident of one province and in the registered population of a province that was slow to switch to reporting output per resident – reducing the overall average *per capita* GDP.

The final population time series shown in Figure 4 is for the sum of each province's revised resident population, shown by the dashed line. These revised counts use the results from the 2010 census to correct the initial estimates of resident population in each province using the trend-deviation interpolation

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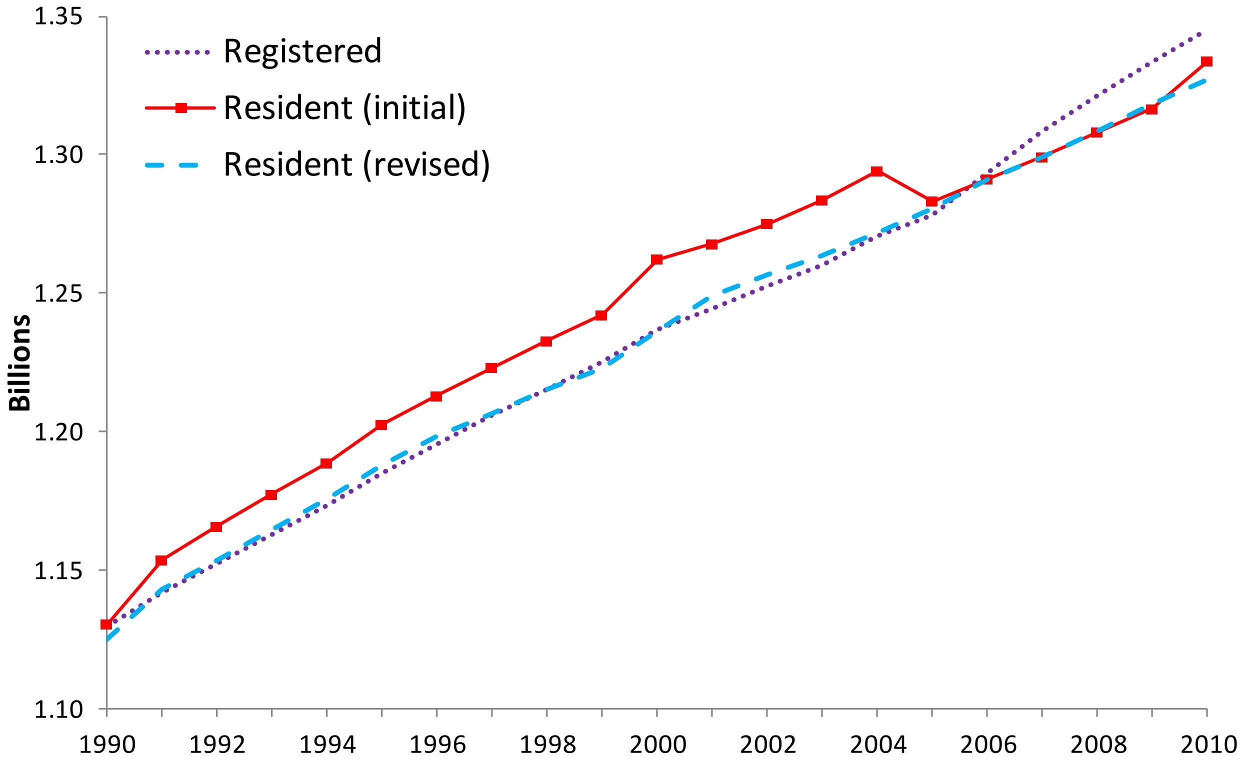
[15] In unreported regressions we test if the switch date relates to whether provinces are migrant-senders or receivers, to the number of their non-*hukou* migrants and to the size of their total population. No clear relationships emerge to explain why the statistical authorities in some provinces switched to reporting GDP per resident earlier than others.

approach (described in endnote 8). For all but nine provinces this revision by the NBS went back to 1990,[16] and for these nine the authors use the same approach to backdate the revised resident counts to 1990. The sum of these revised counts is shown in Figure 4 and they almost completely eliminate the double-count problem. Nevertheless, it is only for the most recent years that there can be any great confidence in the estimates of the resident population of China's provinces.

Figure 4: The Double-Count in Resident Population (Summation over all Provinces)



Source: Author's calculations from the sources described in text.

[16] The provinces and their earliest year with revised data are: Zhejiang (2000), Jiangxi (2000), Henan (2003), Hubei (2000), Hunan (2002), Guangxi (1998), Sichuan, including Chongqing (2000), Guizhou (2006) and Gansu (2006).

2.4 IMPACTS OF POPULATION ERRORS ON TRENDS IN INTER-PROVINCIAL AND INTER-REGIONAL INEQUALITY

Despite the shaky foundations created by China's official data using a population concept that had no bearing to the actual number of people living in each province, a large literature that relies on reports of provincial GDP *per capita* has already emerged. In this section we show how the problems described above may have distorted some of the conclusions reached by one strand of this literature – that related to inter-provincial and inter-regional (coastal-inland) inequality. In Table 2 we survey studies published in the last 15 years that use provincial GDP *per capita* as their economic indicator for analyzing trends in regional inequality. Only four of the 14 studies make any adjustment to the data from the *Statistical Yearbooks* to account for the distortions from using registered population as the denominator.[17] Findings from the studies that rely on unadjusted data are potentially misleading, at least for the period since 1990 when the number of non-*hukou* migrants greatly increased. Even when the potential bias from using GDP per registered population is recognized, the adjustment procedures can be questioned, not least because they all lacked the results from the latest 2010 census that support the most plausible revisions of resident population estimates.[18]

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[17] China occasionally releases compilations of data from the *Statistical Yearbooks* covering two or more decades, typically with titles of "20 years …" etc but these do not show any consistent adjustment to the population data initially published year-by-year so studies using these compilations are counted in the group using unadjusted data.

[18] Specific concerns with the adjustments of Hoshino (2011) and Tsui (2007) are listed in footnotes 3 and 4. The Fan and Sun (2008) adjustment is to replace census estimates of resident population

To illustrate the potential bias in previous studies we calculate three of the most commonly used statistics of inter-provincial inequality – the Theil index, the coefficient of variation (CoV), and the Gini coefficient.[19] We compare the time series for each statistic using three different population denominators to calculate GDP *per capita* for each province:

- GDP implied population
- Registered population
- Resident (revised) population

which have been previously described in the discussion of Figures 3 and 4.[20] The revisions to the resident population estimates only go back as far as 1990 (by the NBS for 21 provinces and by us for the remaining nine) so this comparison is limited to the 21 years from 1990 to 2010. To put this starting date into context, from the beginning of economic reform in 1978 until 1990, inter-provincial

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with the surrounding year estimates from the *Yearbooks*. Figures 3 and 4 suggest that the opposite procedure should be used. The Chan and Wang (2008) paper does not adjust for the double-count issue shown in Figure 4.

[19]The Theil index is: $T_w = \sum_{j=1}^{m} (p_j/P)(y_{wj}/\mu)\ln(y_{wj}/\mu)$ where m=30 provinces (Sichuan and Chongqing merged), p_j is the population of the j^{th} province, P is overall population, y_{wj} is the GDP *per capita* of the j^{th} province, and μ is the overall population-weighted mean of GDP *per capita* for all provinces. The (weighted) coefficient of variation is: $CoV = \sqrt{\sum_{j=1}^{m} (p_j/P)(y_{wj} - \mu)^2} \Big/ \mu$. The Gini coefficient is: $G = \left(\sum_{i=1}^{m} \sum_{j=1}^{m} p_i p_j \left| y_{wi} - y_{wj} \right| \right) \Big/ 2\sum p_i^{\,2} \mu$.

[20] We do not need to use the "Resident (initial) population" as an alternative denominator for GDP *per capita* in this illustration because we have already shown that these initial estimates of the resident population were unreliable (Figure 4).

inequality in China fell rapidly, with trend annual rates of decline of 4.6 percent (Theil), 3.9 percent (CoV) and 0.5 percent (Gini).[21] This falling inequality resulted from the early decollectivization of agriculture, which saw incomes in rural provinces close some of the gap with the three richest urban provinces (Shanghai, Beijing and Tianjin). Also, at the start of the reform period, the soon-to-be-booming southeast coastal provinces of Guangdong, Fujian and Zhejiang were not even in the top one-third of provinces (ranking 10th, 23rd and 16th according to GDP *per capita* in 1978), so the tremendous growth that they soon experienced had an equalizing impact.[22] Therefore in our illustration of the impact of population errors on regional inequality trends, the starting point happens to be the most equal year in the reform era.

For all three of the inequality statistics shown in Figure 5, the 1990 to 2000 trend using the GDP implied population (shown by the solid line) is almost identical to that using registered population (shown by the dotted line). This is unsurprising since most large provinces were still reporting GDP *per capita* on a registered population basis during these years (Table 1). Yet, while inequality in the officially reported GDP *per capita* was rapidly rising in the decade from 1990 (at a three percent annual rate in the case of the Theil index) it was largely

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[21] Trend rates are estimated from a semi-logarithmic regression on time, and are statistically significant at the one percent level (Theil and CoV) and the eight percent level (Gini) using Newey-West heteroscedasticity and autocorrelation consistent (HAC) standard errors with a single lag. The provincial GDP *per capita* data underlying the inequality statistics are all based on registered population from 1978 to 1990.

[22] China had only 29 provinces until 1988.

Table 2. Selected Recent Studies of Inter-Provincial and Inter-Regional Inequality in China that Use Provincial GDP *per capita* as an Indicator

Authors	Period	Statistic(s)	Scale	Key patterns in inequality (in reform era)	Population data sources used in GDP *per capita* denominator
Duncan and Tian (1999)*	1952–95	CV	InterP, IntraP	Rose in the first half of the 1990s	China Statistical Yearbook, Provincial Statistical Yearbook
Ying (1999)	1978–94	Theil	InterP	Declined until 1990; then increased	40 Years (a); China Statistical Yearbook, 1985-94
Fujita and Hu (2001)	1985–94	CV, Theil	InterP	Declined in the 1980s; increased in 1990s	China Statistical Yearbook
Cai et al. (2001)	1978–99	CV, Theil	InterP	Declined between 1978 and 1990 but increased since around 1990	50 Years
Lu and Wang (2002)*	1978–98	CV, GINI, Theil	InterP, 3 regions, R/U	Declined from 1978 to 1990 and then increased steadily	China Statistical Yearbook, 40 Years (a) and 20 Years
Huang et al. (2003)	1991–01	GINI	7 regions	Increased	China Statistical Yearbook
Kanbur and Zhang (2005)	1952–00	GINI	InterP, R/U coastal-inland	Increased sharply and steadily since 1984	1952-1978: 40 Years (b); 1978-2000: 50 Years, Agricultural 50 Years, China Statistical Yearbook, China Rural Statistical Yearbook
Xu and Li (2006)	1978-04	GINI	InterP	A slight decline beginning around 2003	Provincial Statistical Yearbooks
Tsui (2007)	1952–99	Theil	InterP	Upward trend in first half of 1990s, results based on official data show sharp increase since 1995 while author's adjusted data show no change	1952-1981: 50 Years and Provincial Statistical Yearbooks; 1982-1999: extrapolation from 1982, 1990 and 2000 population censuses
Liu and Zhang (2007)	1952-06	CV, GINI	InterP	Declined in 2000-2001 and 2003-2006	1952-1998: 50 Years; 1999-2006: China Statistical Yearbook
Fan and Sun (2008)	1978–06	CV, Theil, GINI	InterP, 3 regions, InterR	Declined in 1980s; increased in1990s, then stabilized	1978-2004: 55 Years; 2005-2006 China Statistical Yearbook; extrapolation: replacing 1990, 1995, 2000, 2005 census and sample survey population by averaging prior and subsequent year annual yearbook population
Chan and Wang (2008)	1990-06	CV	InterP	Rose in the first half of the 1990s; levelled off and stable since 1995 due to impact of long-distance migration	1990-2000: Benchmark of population censuses and sample survey in 1990, 2000 and 1995; 2000-2006: China Statistical Abstract
Li and Wei (2010)	1978-07	CV, Theil, GINI	InterP, 3 regions, InterR	Declined in 1980s; increased since 1990; declined since 2004	China Data Online
Hoshino (2011)	1979-09	CV, Theil, GINI, MLD, A(e)	InterP, 3 regions, IntraR	Declined in 1980s; increased in 1990s, especially if using registered population as denominator; stable or declining since 2004, depending on choice of population denominator	1978-1981: China Population Statistical Yearbook 1990; 1982-2005: extrapolation from 1982, 1990, 2000 population censuses and 2005 population sample survey; 2006-2009: China Statistical Abstract 2010

Notes: *=also uses indicators other than *per capita* GDP. CV = coefficient of variation, MLD = mean logrithimic deviation, A(e)=Atkinson inequality index. InterP = interprovincial; IntraP = intraprovincial; InterR = interregional, IntraR = intraregional; R/U = rural/urban.

Details for Population Source Data:

20 Years = National Bureau of Statistics (NBS). 1998. The twenty years of spectacular achievements. Beijing: Statistics Press of China.

40 Years (a) = Hsueh T-T., Li, Q. and Liu, S. (Eds). 1993. China's provincial statistics 1949-1989. Boulder CO: Westview Press.

40 Years (b) = National Bureau of Statistics (NBS), Historical Statistical Materials for Provinces, Autonomous Regions and Municipalities 1949-1989 (*Quanguo Gesheng Zizhiqu Zhixiashi Lishi Tongji Ziliao Huibian*). Beijing: China Statistical Publishing House (1990).

50 Years = National Bureau of Statistics (NBS), Comprehensive Statistical Data and Materials on 50 Years of New China (*Xin Zhongguo Wushinian Tongji Ziliao Huibian*). Beijing: China Statistical Publishing (1999).

Agricultural 50 Years = National Bureau of Statistics (NBS), Comprehensive Agricultural Statistical Data and Materials on 50 Years of New China (*Xin Zhongguo Wushinian Nongye Tongji Ziliao Huibian*). Beijing: China Statistical Publishing House (2000).

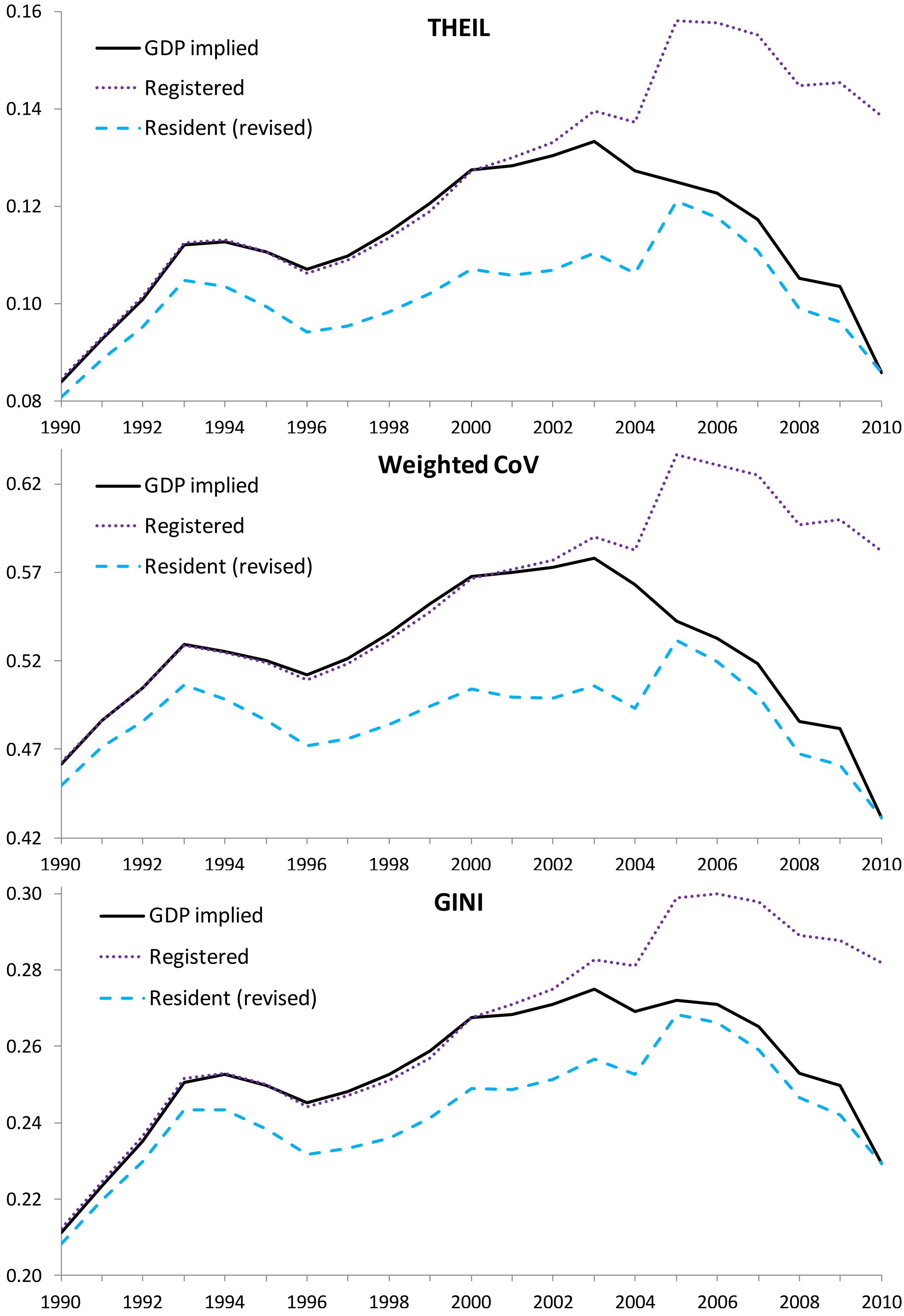
55 Years = National Bureau of Statistics (NBS), China Compendium of Statistics 1949-2004 (*Xin Zhongguo Wushiwunian Tongji Ziliao Huibian*). Beijing: Statistics Press of China, 2005.

divorced from the (correct) trend shown when GDP *per capita* is calculated using the revised resident population estimates (the dashed line in Figure 5). In fact, the apparent rise in inter-provincial inequality between 1990 and 2000, when using the Theil index calculated from the official data of the time, is 66 percent greater than the actual rise, based on the revised resident series. For the CoV and the Gini, the overstatement created by using uncorrected *Yearbook* data for GDP *per capita* is 94 percent and 38 percent, as of the year 2000.

Absent any change in the denominator for GDP *per capita*, the apparent trend in inter-provincial inequality would have carried on rising strongly (for example, there is a 1.4 percent per annum trend rise in the Theil index when using registered population over 2001-10). But, in fact, inter-provincial inequality returns almost exactly to its starting point by 2010 (for the Theil index; the CoV is slightly lower and the Gini slightly higher than their 1990 values) in the time series using the corrected data. Thus if GDP per registered population had continued to be used as the official data, *all* of the apparent rise in inequality would have been what we call "proxy measurement error" where a potentially accurately measured variable (the *hukou* count, in this case) does not match with the concept that it is meant to be measuring, which in this case is the resident count, since it is residents who contribute to (and thus, should denominate) local GDP.

The other feature illustrated by Figure 5 is the apparent change in the trend in inter-provincial inequality, when using the GDP implied population series. From 1990 to 2003 the trend annual rate of increase was 2.9 percent (for the Theil index; 1.5 percent for the CoV and 1.6 percent for the Gini), which sharply

Figure 5: Inter-Provincial Inequality in GDP *per capita* With Various Denominators



reversed, to decline by 5.6 percent per year (3.8 percent using CoV and 2.3 percent for the Gini) over 2003-2010. But rather than reflecting any major change in the true situation in 2003, this is an artefact resulting from the switch to reporting *per capita* GDP on a resident basis. Inequality in GDP per resident is lower than inequality in GDP per registered population, so this switch in statistical procedure mechanically reduces measured inequality in the officially reported GDP *per capita* without any underlying change necessarily occurring in the economy in that year. In fact, in both the registered-based and resident-based series in Figure 5, the turning point in the inequality trend does not occur until 2005, which happens to be the year that the coastal provinces reached their maximum share of GDP.

There are several possible causes of declining inter-provincial inequality after 2005. This may reflect lagged effects of the investments into western and inland China made as part of state-led initiatives to reduce regional inequality (Fan et al, 2011). Contraction in the export-oriented coastal provinces after the Global Financial Crisis also may have been equalizing, especially as many non-*hukou* migrants left the coastal cities and began raising output in the interior provinces (Huang et al, 2011). But it may also be that after 2005 various convergent forces of market integration and catch-up growth simply begun to surpass opposing pressures for divergence. Despite well-known claims that reform-era China suffered from various inter-provincial barriers due to imperfect factor mobility, local protectionism and dual-track and gradual price reform (Young, 2000) the contemporary evidence finds China to be a relatively well integrated market economy. Evidence in favor of the law-of-one-price and rapid price convergence is reported by Fan and Wei (2006) and Ma, et al (2009), while Lan and Sylwester (2010) find half-live divergences from the law-of-one-price of just a few months, which is faster even than the speed of adjustment found in the United States.[23] This rising market integration is also apparent in the labor market; since 1997, urban wages in China's interior provinces have risen at a faster rate than in coastal regions – although the absolute wage gap continues to grow (Li et al, 2012).

A reasonable summary of the patterns in the inter-provincial inequality time series, based on the most plausible revised population estimates, is that there was a largely stable pattern of inter-provincial inequality between 1993 and 2004. Over those years, the average annual deviation was just four percent of the 1993-04 mean (for the Theil index). The only two occasions of notable change in inter-provincial inequality were from 1990-93, when there was a sharp increase in inequality; and from 2005-2010, when that initial increase was more than fully reversed. Recalling that the 12 years prior to 1990 had witnessed an almost continuous decline in inter-provincial inequality (reducing the Theil index from 0.16 to 0.08), the solitary three year episode of rising inequality from 1990-93 – which lifted the Theil index back to just over 0.10 – hardly qualifies as strong support for the claim from the literature that regional inequality has risen in the reform era.

Our final illustration of how apparent trends may be affected by the switch from reporting GDP per registered population to GDP per resident is for a

[23] For example, Parsley and Wei (1996) find convergence rates to purchasing power parity in the United States of five quarters for tradable goods and fifteen quarters for services.

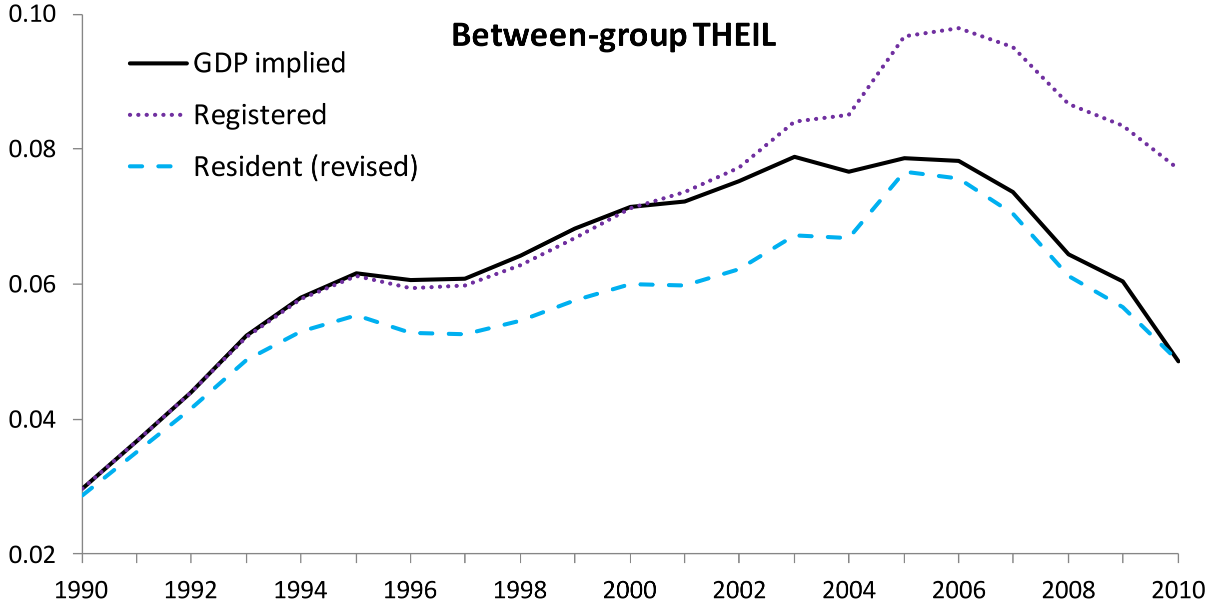
regional decomposition of inequality. Several papers in the literature group China's provinces into regions and examine the between-region inequality trends. We carry out a similar exercise for the coastal-inland comparison, using the Theil index (which decomposes exactly, unlike the Gini coefficient). In Figure 6 we show the time series for the between-group Theil index and it is apparent that inequality between the coast and inland provinces rises, by about 0.04 points, from 1990 to around 2005.[24] But from 2000 to 2005, while the time series of inequality using the GDP implied denominator is detaching from the registered population series and moving toward the resident-based series, this movement makes it seem that there is a largely unchanged between-group component. Specifically, the increase from 2000 to 2005 in the GDP implied time series in Figure 6 is just ten percent, versus a 36 (27) percent increase when inequality is measured using the registered (resident) population.

In terms of policy evaluation, the most active period of state intervention to close the regional gaps had already run its course by 2005, by which time more than 1 trillion Yuan (US$180 billion) of state-led infrastructural investment had been placed in western China (Yao, 2009). Some authors have suggested that a leveling off of the coastal-inland gap in this period reflects the good effects of these interventions (Fan et al, 2011). But an alternative explanation is that the

[24] The identical time series, but rescaled, would be shown if we examined the ratio of mean GDP *per capita* in the coastal provinces to mean GDP *per capita* in the inland provinces. This ratio starts at just over 1.6 in 1990, peaks at 2.2 in 2005 and was back below 1.9 by 2010.We group Hainan, Guangdong, Fujian, Zhejiang, Shanghai, Jiangsu, Shandong, Hebei, Tainjin and Beijing together as the coastal provinces.

apparent leveling off over those years is just an artefact created as the population series used to denominate GDP *per capita* progressively switched from one based on registered population to one based on resident population which involved switching from a higher trending inequality time series to a lower trending one, creating an apparently static period.

Figure 6: Coastal-Inland Inequality With Various Denominators for GDP *per capita*



Source: Decomposition of Theil index into within-group and between-group components.

2.5 OTHER ADJUSTMENTS

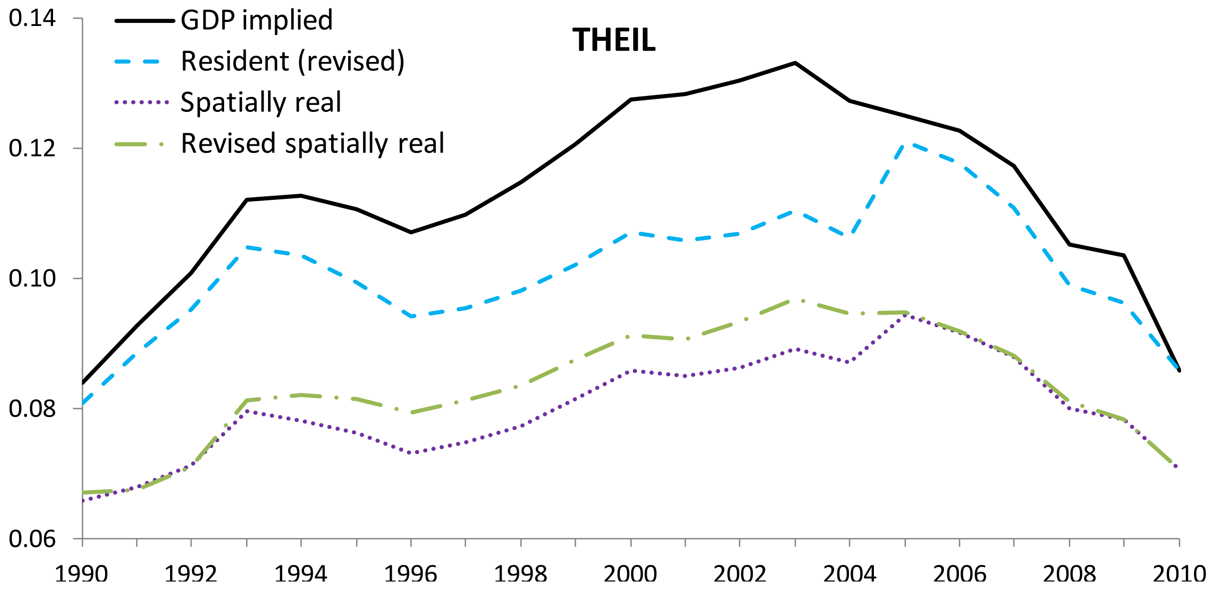
The analyses reported thus far only consider problems in the population denominator for GDP *per capita*, leaving possible issues with the numerator unchallenged. At least two adjustments to the numerator might also affect the level and trend in regional inequality. First, richer provinces in China appear to have higher costs of living (Brandt and Holz, 2006) so analysis using spatially real prices should find less inter-provincial inequality than when based on nominal data. Second, the nominal GDP data also have problems capturing the output of the non-*hukou* migrants, many of whom are involved in the service sector (often self-employed) and in small-scale industry. For provinces that are major migrant destinations, understating the contribution to local GDP of the migrants might have a large enough effect that it offsets some of the overstatement caused by denominating output by the registered population.

In terms of the issue of spatial price differences, Brandt and Holz (2006) use provincial price data from 1990 to form a spatial price index by pricing national rural and urban expenditure baskets (40-60 items) and a population-weighted combined basket. Then using the annual rate of change in the CPI for each province they extend from the base year, back and forth in time, providing annual spatial deflators for each province from 1984 to 2004. This time series has been used by other researchers studying inequality (e.g., by Sicular et al, 2007) and has the advantage of allowing easy updating since it just relies on the annual rate of change in each province's CPI. Data issues that potentially undermine the accuracy of these spatial deflators are amply discussed by Brandt and Holz (2006) but a conceptual problem is largely overlooked. Hill (2004) shows that both theoretically and empirically it may be impossible to construct such panel price indexes that are unbiased across space and time if the required multilateral index methods are not used.[25] Also, in the particular case of China, there is concern that

[25] An example of such bias is given by Gluschenko (2006) using spatial price data for Russia in two different years to compare a direct spatial price index calculated for period *t* using spatial prices for the same period with an indirect spatial price index for period *t* that is extrapolated from a direct spatial price index for period t_0 using local CPIs to update prices from t_0 to *t*. The direct

the temporal CPI is a biased measure of price changes, especially in rural areas (Almås and Johnsen, 2012).

Figure 7: Inter-Provincial Inequality After Both Numerator and Denominator Adjustments



Despite reservations about the Brandt and Holz deflators, we update these to 2010 using movements in each province's CPI and calculate spatially real GDP *per capita* for each province for 1990-2010. The impact of this deflation on estimates of inter-provincial inequality is shown in Figure 7 using the Theil index,

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method gives a spatial price index for each province whose range is 44 percent of the national mean price level, but the indirect method gives a range of 72 percent. Gluschenko concludes that CPI-updated (indirect) price levels cannot adequately proxy for cross-spatial price levels and that the large bias that is induced distorts cross-spatial comparisons.

for the series labeled “spatially real” (dotted line).[26] To allow comparison, two series from Figure 5 are also included; nominal GDP denominated either by GDP implied population (solid line) or by the revised resident population (dashed line). The Thiel index is 20-40 percent higher using nominal GDP per capita compared with the spatially real series, with the biggest gap in the early 1990s. Since the Brandt and Holz deflator is based on 1990 data, the effect of spatial deflation should be most reliably estimated for that period. Whether the subsequent slight closing of the gap between the nominal and real series of inequality measures reflects problems of extrapolating the spatial price index forward from 1990 is difficult to ascertain because of the lack of other spatial deflators for China.

In terms of the other issue, of nominal GDP missing some of the output produced by the migrants, in 2006 and 2009 the National Bureau of Statistics retrospectively adjusted provincial GDP for 1993-2003 and 2005-2008 following results from China’s First and Second Economic Census in 2004 and 2009. These adjustments were not incorporated into the estimates shown in Figures 5 and 6, so as to focus just on the effects of the population errors by basing calculations on the originally published GDP data rather than on the recently revised series. However, at least one effect of these GDP adjustments is to raise the size of the urban service sector, where many of the non-*hukou* migrants are working (Park and Cai, 2011). We therefore incorporate the revised GDP data into the final series in Figure 7, labeled “revised and spatially real” (dash-dot lines), which is

[26] Specifically, this is unadjusted provincial GDP for each year converted into Beijing prices (Theil index results are the same if converting into national average prices) which is then denominated by the revised resident population.

denominated by the revised resident population and is also spatially deflated. The adjustments to GDP data have the largest effect between 1993 and 2004, when they raise inequality slightly compared with the pattern in the unrevised GDP data. Nevertheless, when compared with the "revised and spatially real" series, the time series of inequality based on data that had been published year-by-year in the *Statistical Yearbooks* ("GDP implied") overstated inequality by an average of 35%.

2.6 CONCLUSIONS AND IMPLICATIONS

We have shown how changes over time in the population denominator used for China's provincial GDP *per capita* statistics may distort understanding of recent trends in regional inequality. Much of the apparent trend increase, and change in trend in 2003, disappear once proper account is taken of non-*hukou* migrants, so that GDP per resident is calculated correctly for each province of China over 1990-2010. Putting the corrected data for the last two decades into the context of the entire reform era, the changing pattern of inter-provincial inequality can be thought of as composing four episodes, only one of which involves rising inequality. From 1978 until 1990 inter-provincial inequality declined almost continuously; about one-third of this decline was reversed over the next three years; then a decade of little change in inequality was ended by a one-year rise in 2005 but even with that rise, inequality had returned to only two-thirds of its starting value in 1978; finally, inter-provincial inequality fell sharply after 2005, so that by 2010 it was right back at the low levels previously seen in 1990. Thus the only sustained episode of rising inequality in the reform era was from 1990 to 1993, representing just three out of 33 years since liberalization began.

The three errors in China's local population data described here – using registered population as a denominator, the sudden, uncoordinated switch to using a resident denominator, and the double-count caused by the partial and inconsistent way that residents were counted by each province in any given year – can also be expected to bias econometric research using extant data on provincial GDP *per capita*. The proxy measurement errors from using the wrong concept (denominating by the *hukou* count rather than the resident count) are correlated with the levels and growth rates of GDP per capita, since the non-*hukou* migrants were moving into richer, faster growing provinces, and the errors are increasing over time (at least until each province switches to reporting GDP per resident). In contrast to random (classical) measurement errors, which cause no bias when just in the dependent variable and which always attenuate the coefficient on a single error-ridden explanatory variable, the effects of these proxy measurement errors will be more complex and pernicious. Moreover, the main correction used by economists for ameliorating error bias – instrumental variables (IV) – is inconsistent when errors are correlated with true values (Black, Berger and Scott, 2000). The trend in applied research on China to use data from smaller spatial units is especially vulnerable to the threat posed by these errors since there are more non-*hukou* migrants when working with smaller units and also because the sort of correction exercise documented here of retrospectively adjusting estimates of the resident population is yet to be done for sub-provincial units.

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Chapter 3

City Scale and Productivity in China

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City Scale and Productivity in China

Abstract

We examine effects of city scale on output per worker in China. Existing studies use wrong measures of scale. Four-fifths of cities are close to the estimated productivity-maximizing scale. Output losses from sub-optimal scale are typically below 10%.

Keywords: Agglomeration, Cities, Population, Productivity, Scale, China

JEL: R12, O15

3.1 INTRODUCTION

A claimed legacy of China's command economy era, and the *hukou* restrictions on migration, is that China's cities are too small to fully exploit gains from agglomeration (Au and Henderson, 2006; Xu 2009). But extant studies wrongly measure city scale.[27] For example, Xu (2009) uses data from 1990-97 that only counts people with local *hukou* registration for each city, ignoring more than 100 million city residents with *hukou* registration from elsewhere (Chan, 2012). Au and Henderson (2006) measure city scale by 1997 employment but their data exclude most private sector workers.[28] It is only since China's 2010 population census that reliable city-level estimates of the urban population and of total employment are available.

In this paper we use these new, more reliable data, to estimate the relationship between net output per worker and city scale. The flexible functional forms of Au and Henderson (2006) [henceforth, AH] are used, but with more controls for city industrial structure and more complete data on city scale (employment) that counts all private sector workers. Most cities are close to their productivity-maximizing scale, with losses from sub-optimal scale typically below 10%. Evidently, millions of non-*hukou* migrants are reshaping China's

[27] Even simple descriptive claims are wrong. Au and Henderson (2006, p.557) say China had nine metro areas with populations over 3 million and 125 in the 1-3 million range in 2000; this ratio of large to small cities (0.07) was well below the global average of 0.27. But measuring cities by their residents in the 2000 census, China had 20 cities over 3 million and 89 cities of 1-3 million, giving a ratio of 0.23 – just below the global average. The 2010 census shows 38 cities with resident population over 3 million versus 97 cities of 1-3 million, giving a large-to-small ratio of 0.39. But using the local *hukou* registered population rather than the resident population makes the ratio just 0.18.

[28] Au and Henderson use *City Statistical Yearbook* (*CSY*) data, where 'private sector' employment was titled as self-employed (with a very low share of the total); private sector employees are apparently excluded. Long-form census data on employment by sector show that *CSY* substantially undercounts private sector employment.

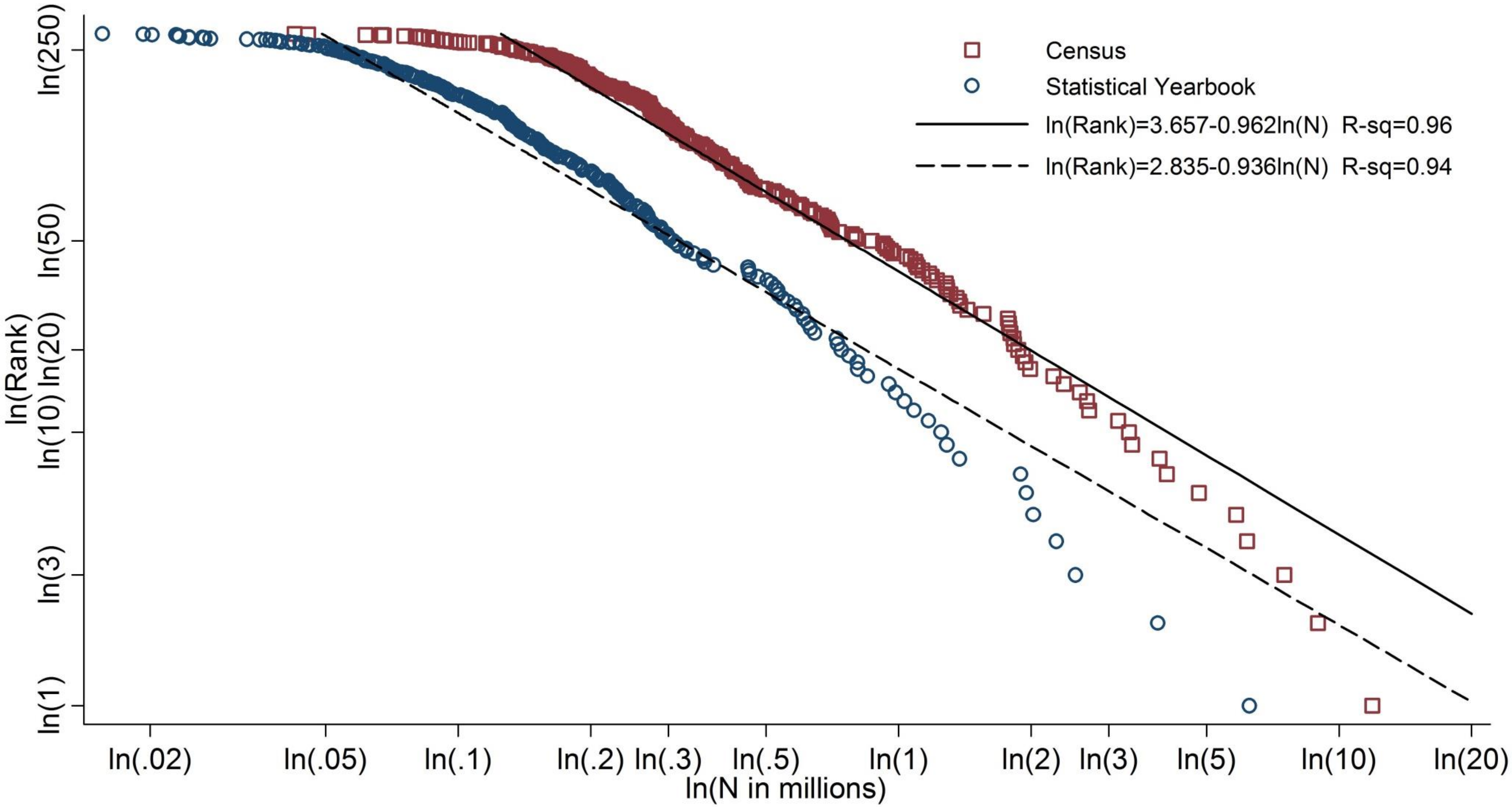
economic geography, forming an urban system with smaller productivity losses than previously thought. Other studies note relaxed *hukou* restrictions are changing China's city size distribution (Luckstead and Devadoss, 2014) but this is the first to report results that challenge the often repeated claim that China foregoes agglomeration-based productivity gains from having too many small cities.

3.2 DATA AND MODEL SPECIFICATION

The sample is 286 urban cores ('cities') in 2010. Specifically, prefectural cities (*diji shi*) have an urban core of districts (*shiqu*) equivalent to a city proper (Roberts et al, 2012) or to the urbanized portion of a Metropolitan Statistical Area (MSA) in the U.S. (AH, 2006). Contiguous districts within the same prefectural city are merged so there is one core per prefecture. These data are at the same spatial level as AH (2006) and Xu (2009) but cover more of China; the prefectures these cores come from are the location of 97% of China's GDP. We use two main sources: the *City Statistical Yearbook* (*CSY*) (NBS, 2011), and the 2010 Population Census (NBS, 2012).[29] City-level GDP data are from *CSY* but not city scale estimates; *CSY* only counts local *hukou* holders so omits over 100 million urban residents with *hukou* registration from elsewhere, and also omits most private sector workers. Instead of using *CSY*, more complete population and employment data from the 2010 Population Census long form are used to measure city scale.

[29] To form an instrumental variable we also use the 2001 Yearbook of the Ministry of Public Security (MPS, 2001) which provides counts for each city of the number of people with non-agricultural *hukou* registration for that city.

Figure 1. Rank-Size Plots using Census of Population and Statistical Yearbook Estimates of Non-Agricultural Employment in 2010



Notes: N is non-agricultural employment (secondary and tertiary sectors). Number of observations is 286 cities.

While we mainly follow the approach of AH (2006) to estimate how big a city should be to maximize predicted output per worker, other benchmarks for an efficient city size distribution can be used, such as the fit to Zipf's Law (Gabaix, 1999). We therefore start with a log-log plot of city employment against city rank, which shows several features of the data (Figure 1). First, the city size distribution is significantly (p<0.001) closer to Zipf's Law if Census employment is used, with a coefficient of -0.962 compared with -0.936 for *CSY* employment (standard errors of 0.012 and 0.014), though both reject the coefficient of -1 needed for an exact fit to Zipf's Law. Second, the rank-size curve shifts left if using *CSY* employment, which averages just 43% of employment recorded for the same cities by the Census, due to the *CSY* data missing many private sector workers. Third, the tails of very small and very large cities are where there is most divergence from the linear fit of log rank on log size. To confirm that results are not due just to cities in the tails, results weighted by city employment are reported in addition to using equal weights for cities (so unequal weights for workers).

We use two flexible functional forms to relate output per worker, *GDP/N* to city scale, *N*, industrial structure, capital per worker, and other covariates, largely following AH (2006). First,

$$\ln(\frac{GDP}{N}) = \alpha_1 N^2 + \alpha_2 N + \alpha_3 N \times msgdp + \alpha_4 N \times gdp1 + \beta \ln(\frac{Capital}{N}) + \gamma X \qquad (1)$$

allows the scale that maximizes output per worker of the k^{th} city to be calculated as:

$$N_k^* = -\frac{\widehat{\alpha_2} + \widehat{\alpha_3} \times msgdp_k + \widehat{\alpha_4} \times gdp1_k}{2 \times \widehat{\alpha_1}}. \qquad (2)$$

The industrial structure variables *msgdp* (ratio of secondary sector to tertiary sector GDP) and *gdp1* (share of primary sector GDP) are needed since productivity maximizing scale is higher in service-intensive cities. The vector of control variables, X includes population-weighted distance to all other cities (to proxy for domestic market potential), distance to the ten largest ports (to proxy for foreign market access), average years of schooling (to proxy for labor quality), and the output of foreign-affiliated firms relative to domestic firms (to proxy for technology).

With equation (1), estimated peak points for some cities are negative. This is less of a problem with a Generalized Leontief specification, which also was preferred by AH (2006):

$$\ln(\frac{GDP}{N}) = \alpha_1 N + \alpha_2 N^{0.5} + \alpha_3 N^{0.5} \times msgdp^{0.5} + \alpha_4 N^{0.5} \times gdp1^{0.5} + \beta \ln(\frac{Capital}{N}) + \gamma X \quad (3)$$

with the scale that maximizes output per worker of the k^{th} city given by:

$$\sqrt{N_k^*} = -\frac{\widehat{\alpha_2} + \widehat{\alpha_3} \times msgdp_k^{0.5} + \widehat{\alpha_4} \times gdp1_k^{0.5}}{2 \times \widehat{\alpha_1}}. \quad (4)$$

When actual scale (as measured by total employment) for city k, N_k is less than N_k^* the city is deemed under-sized, otherwise it is considered over-sized. If N_k is outside the 95% confidence interval surrounding N_k^* we consider the city significantly under- or over-sized.

Equations (1) and (3) assume workers are more productive in a bigger city. But being more productive may cause a city to grow, making scale endogenous. The planned size of cities from the command economy era is a valid instrumental variable (Li and Gibson, 2014), and is used here to test for endogeneity bias.

These tests are on a linear model, using either N or $\sqrt{N}$ because coefficients on higher order terms become insignificant when instrumented.

3.3 RESULTS

The results in the first three columns of Table 1 consider the endogenous quantity of labor issue. Instrumenting for city scale makes no difference, so OLS is used for the remaining models.[30] The results for equation (1) are in columns (4) and (5), and for the Generalized Leontief model in columns (6) to (8). In columns (1) to (7) each city is weighted equally while results in column (8) use employment weights. These models explain two-thirds of cross-city variation in GDP per worker, which is much higher than for the flexible functional form results of AH (2006).

Including *gdp*1 (which AH do not use) adds explanatory power. Without this there is no inverted U; the $\hat{\alpha}_2$ coefficients of equations (1) and (3) are insignificant in columns (4) and (6). The need for both *msgdp* and *gdp1* is shown by the example of the city of Huzhou, in Zhejiang Province; *msgdp* is 1.42 and yet its inverted U-shaped curve for output per worker at varying city scale matches Hohhot in Inner Mongolia, where *msgdp* is just 0.25. The *gdp1* for Huzhou is four times that of Hohhot (0.066 versus 0.017) and the joint effect of these two industrial structure variables shifts the output-scale curve. Similarly, Jingzhou city in Hubei Province has almost the same *msgdp* ratio as Huzhou but its output-scale curve is shifted well to the left (so the productivity-maximizing total employment level is lower) because its *gdp1* ratio is twice as high.

[30] The Hausman test results for the model in column (1) versus (2), and column (1) versus (3) are 2.05 and 1.29, with p=1.00 for both. The same lack of bias due to endogeneity is seen if models are re-estimated using N instead of $\sqrt{N}$.

Table 1. Determinants of Urban Productivity, Allowing for Endogenous Quantity of Labor and Flexible Functional Forms (n=286)

	Endogenous Quantity of Labor			Flexible Functional Form Specifications				
				Equation (1) – variables in [ ]		--------------Generalized Leontief--------------		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Scale and industrial structure variables								
$\sqrt{N}$	0.151 (0.048)***	0.196 (0.054)***	0.186 (0.053)***					
$[N^2]$ or N				-0.018 (0.009)**	-0.039 (0.010)***	-0.068 (0.068)	-0.192 (0.070)***	-0.162 (0.060)***
[N] or $\sqrt{N}$				0.046 (0.074)	0.231 (0.079)***	-0.067 (0.217)	0.464 (0.236)*	0.426 (0.221)*
$[N \times msgdp]$ or $\sqrt{N} \times \sqrt{msgdp}$				0.106 (0.043)**	0.094 (0.041)**	0.401 (0.114)***	0.340 (0.110)***	0.216 (0.101)**
$[N \times gdp1]$ or $\sqrt{N} \times \sqrt{gdp1}$					-5.618 (1.122)***		-1.902 (0.400)***	-1.168 (0.378)***
Control variables								
Capital/N	0.328 (0.023)***	0.330 (0.022)***	0.330 (0.022)***	0.307 (0.025)***	0.274 (0.025)***	0.274 (0.027)***	0.241 (0.027)***	0.279 (0.028)***
Market Potential (Pop-Weighted Distance)	0.385 (0.319)	0.410 (0.299)	0.404 (0.299)	0.263 (0.316)	0.165 (0.302)	0.195 (0.316)	0.165 (0.303)	0.166 (0.311)
Average Distance to 10 Largest Ports	-0.341 (0.281)	-0.334 (0.263)	-0.335 (0.263)	-0.250 (0.280)	-0.042 (0.270)	-0.178 (0.278)	0.015 (0.270)	-0.083 (0.273)
Average Years of Schooling	1.078 (0.243)***	0.972 (0.238)***	0.997 (0.237)***	1.221 (0.248)***	0.583 (0.269)**	1.290 (0.249)***	0.508 (0.290)*	0.976 (0.301)***
Foreign-Domestic Industrial Output Ratio	-0.022 (0.037)	-0.030 (0.035)	-0.028 (0.035)	-0.016 (0.037)	-0.043 (0.036)	-0.014 (0.037)	-0.033 (0.035)	-0.035 (0.031)
Constant	0.587 (1.639)	0.567 (1.536)	0.572 (1.534)	1.416 (1.670)	2.800 (1.618)*	0.764 (1.613)	1.791 (1.562)	1.029 (1.690)
Adjusted R-squared	0.612			0.620	0.653	0.629	0.659	0.651
Cragg-Donald Wald test[a]		597	318					
Sargan test p-value[b]			0.161					

Notes: The dependent variable is (log) non-agricultural GDP per worker. Variables in *italics* are in logarithms. Each regression also includes 29 province-level fixed effects. Standard errors are in parentheses; * significant at 10%; ** at 5%; *** at 1%. Models in columns (2) and (3) use instrumental variables (the square root of (log) number of non-agricultural *hukou* in 2000 for each city, plus in (3) a dummy for cities with higher registered non-agricultural population than resident urban population in 2010). All other models are estimated with OLS, with observations weighted by city employment in column (8).

[a] First-stage F statistic for the instruments. [b] Over-identification test.

The results of comparing actual city scale with the productivity-maximizing scale that is calculated from equation (4) are shown in Figure 2 (based on the employment-weighted results in column (8) of Table 1). Nine cities are significantly over-sized and these are home to 29% of workers; almost as many as the 32% of workers in the 162 statistically significantly under-sized cities. While almost five-sixths of cities are below productivity-maximizing scale these hold just over one-half (57%) of the workers and in most cases the losses from sub-optimal scale are very small. The patterns are similar if using un-weighted results from column (7) of Table 1 instead; 31% of workers are in ten significantly over-sized cities and 25% are in 131 significantly under-sized cities, with 52% of overall employment in cities below peak size.

The percentage output loss from not being peak scale can be calculated as:[31]

$$\ln\left(\frac{\widehat{net\ output_k}}{N_k}\right)^* - \left(\ln\left(\frac{\widehat{net\ output_k}}{N_k}\right)\right)_{N=N_K} =$$

$$\left(\frac{1}{1-\hat{\beta}}\right) \times \left(\left(\widehat{\alpha_2} + \widehat{\alpha_3} \times msgdp_k^{0.5} + \widehat{\alpha_4} \times gdp1_k^{0.5}\right) \times \left(N_k^{0.5*} - N_k^{0.5}\right) + \widehat{\alpha_1} \times \left(\left(N_k^{0.5*}\right)^2 - N_k\right)\right) \quad (5)$$

For most cities, the slope to the left of the peak is steeper than to the right, implying a bigger loss for under-sized cities than for over-sized cities. For example, employment in Dongguan is three million over its peak point (N_k^*=3.1 million) with a predicted output loss from being too big of just over 10% but at three million below the peak the predicted output loss would be almost 50%.

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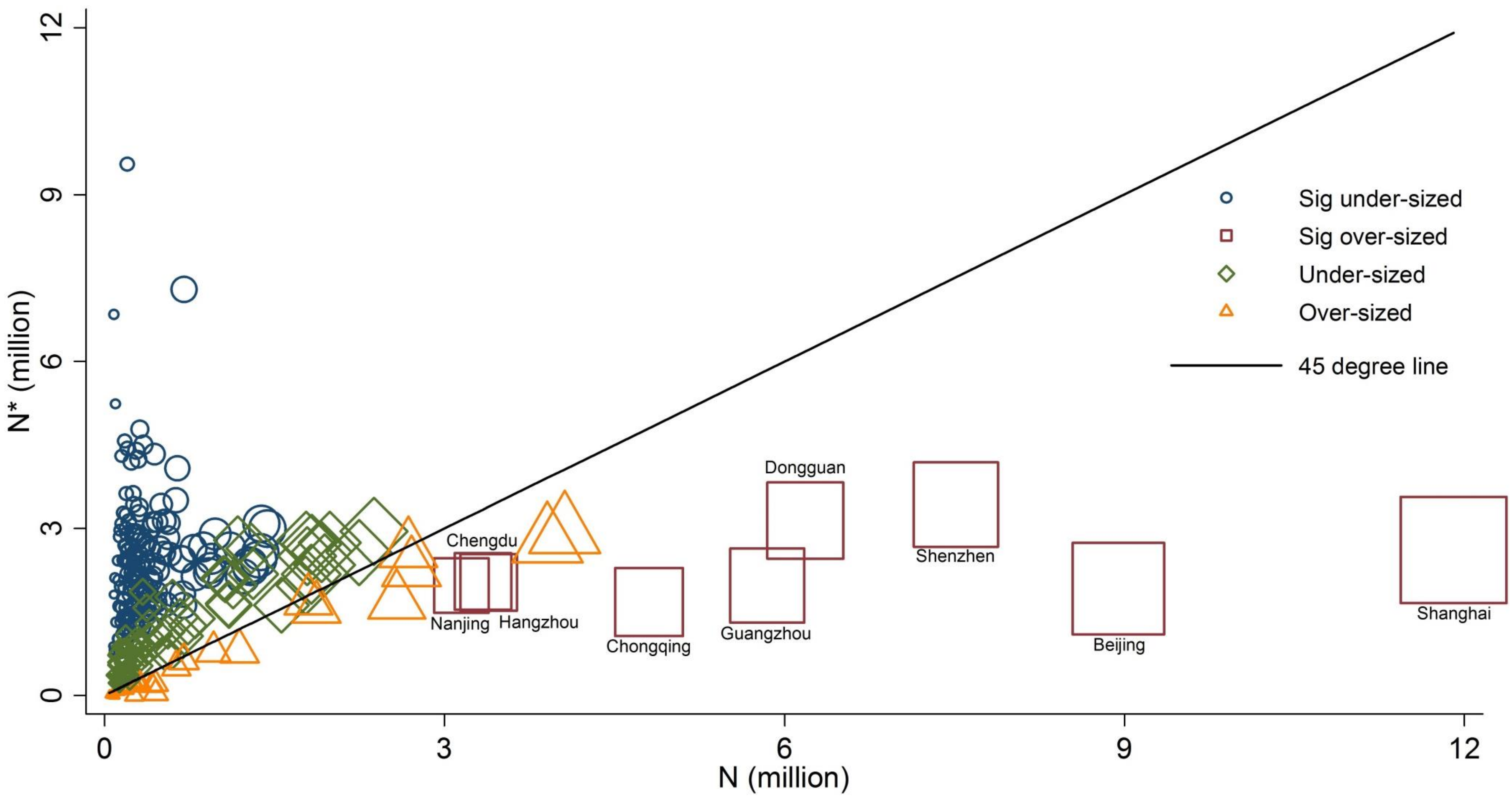
[31] This uses net output per worker, which AH (2006, p.553) note is city GDP less the rental cost of capital, and can be derived from GDP per worker using the transformation: $\ln(net\ \widehat{output}/N_k) = (1/(1-\widehat{\beta})) \times \ln(\widehat{GDP_k}/N_k)$. We compare predicted output at actual and peak scale, so model errors cancel (unlike comparing actual output to predicted output). These calculations exclude 3 cities where the Generalized Leontief gives negative peak points.

Figure 2. Comparison of Actual City Scale and Peak Points



Notes: Markers are proportional to city scale (employment reported by the 2010 Census). Significantly over-sized cities are labeled. *N*=283 cities (3 cities with negative peak points are omitted).

In order to provide a complete evaluation, Table 2 reports details of using equation (5), with cities divided along two dimensions: scale relative to peak point and the size of the output loss from not being at the peak point. The modal category is for a 0-5% loss; this covers 37% of cities (with 45% of workers). The median loss from a city not being at peak point is 8%, and the mean loss is 15%. Being significantly under-sized causes bigger losses than being significantly over-sized but over-sized cities have more workers. For example, 8% of workers are in 55 cities with output losses above one-quarter, due to being significantly under-sized, but 11% are in the two significantly over-sized cities with similar output losses. In contrast to the current results, AH (2006) report a median (mean) loss from cities not being at their peak point of 17% (30%); twice what is estimated here. These differences persist throughout the distribution; cities at the 75th, 90th, 95th and 100th percentiles of the loss distribution have losses of 20%, 33%, 48% and 157%, while equivalent values from AH are 38%, 69%, 103% and 229%.

If equation (5) is calculated using the un-weighted results from column (7) of Table 1, the patterns of output losses from sub-optimal scale are similar to what is shown in Table 2. The modal loss category is still 0-5%, and has 44% of cities and 42% of workers. But the tails are a little larger, with four cities (home to 17% of workers) with output losses exceeding one-quarter due to being significantly over-sized. In both weighted and un-weighted results a similar number of cities have output losses of more than one-quarter from being significantly under-sized but the losses are bigger (up to 242%) in the un-weighted results.

Table 2. Number of Cities and Workers in Terms of the Size of the Net Output Loss per Worker From Scale Not Being at the Peak Point

% Loss in Net Output per Worker from being away from peak point	Number of Cities (% of total)					Millions of Workers (% of total)				
	Sig under-sized	Under-sized	Over-sized	Sig over-sized	Total	Sig under-sized	Under-sized	Over-sized	Sig over-sized	Total
100%-160%	2				2	0.3				0.3
	0.7%				0.7%	0.2%				0.2%
50%-100%	10			2	12	2.8			20.9	23.6
	3.5%			0.7%	4.2%	1.5%			11.0%	12.5%
25%-50%	43				43	11.2				11.2
	15.2%				15.2%	5.9%				5.9%
10%-25%	69	1		4	74	23.3	0.3		24.3	48.0
	24.4%	0.4%		1.4%	26.1%	12.3%	0.2%		12.9%	25.4%
5%-10%	32	14	2		48	15.1	5.1	0.7		20.9
	11.3%	4.9%	0.7%		17.0%	8.0%	2.7%	0.4%		11.0%
0%-5%	6	67	28	3	104	7.2	41.6	26.4	9.9	85.1
	2.1%	23.7%	9.9%	1.1%	36.7%	3.8%	22.0%	14.0%	5.2%	45.0%
Total	162	82	30	9	283	59.9	46.9	27.1	55.1	189.0
	57.2%	29.0%	10.6%	3.2%	100%	31.7%	24.8%	14.3%	29.1%	100%

Notes: Calculation of the net loss is based on equation (5) in the text, using results from column (8) of Table 1. Significantly under-sized and over-sized cities are those outside the 95% confidence interval for their peak point, while under-sized and over-sized cities are above or below their peak point but within the 95% confidence interval. The sample size is 283 because 3 cities with negative peak points are omitted.

3.4 CONCLUSIONS

This paper reappraises the claim that China foregoes agglomeration-based productivity gains from having too many small cities. In contrast to prior studies we use more complete data on city employment and also include the primary sector share of GDP in the regression models. We find much smaller losses in net output per worker from being away from the productivity-maximizing peak scale than is suggested by Au and Henderson (2006). Four-fifths of cities are close to peak scale, with net output losses of less than 25%, and these cities are home to over 80% of urban China's workers. The millions of non-*hukou* urban residents seem to be reshaping China's economic geography in ways that are reasonably consistent with productivity maximization.

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Chapter 4

Pareto's Law and City Size in China: Only Very Large Cities Are Too Small!

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Pareto's Law and City Size in China: Only Very Large Cities Are Too Small!

Abstract

Using Pareto's Law as a benchmark, only the very largest cities in China have scope to absorb more migrants, contrary to the pro-small bias in urban policy. We use population census data from 2000 and 2010 to study the evolution of the size distribution of Chinese cities. Previous studies may mislead because they measure cities by how many people have *hukou* household registration for each place, and not by who actually lives there. Migrants without local *hukou* registration increasingly congregate in a few larger cities, so the count of *hukou* holders wrongly makes the city size distribution seem more even.

Keywords: Agglomeration, City Size, *Hukou*, Migration, Pareto's Law, China

JEL: R12, O15

4.1 INTRODUCTION

China's urban population is forecast to be one billion by 2030; an increase of 350 million from 2010 (MGI, 2009). This urban expansion may occur by existing big cities joining Shanghai as a mega-city but also by China's central and local governments growing new cities in currently less urbanized areas. There may be quite different effects on house prices, wages and productivity, land and water use, food security, and environmental stress of taking one path versus the other. The scale of the required urban expansion, and China's need for resources, may see these effects spilling into global markets. Consequently, there is much debate about whether small and medium-sized cities in China should be favored over expansion of big cities.

Efforts to limit China's big cities have a long history. The 1990 'City Planning Law' (*Zhonghua Renmin Gongheguo Chengshi Guihua Fa*) mandated 'strictly controlling the size of large cities and developing medium-sized and small cities' (Xu, 2009). New cities in this era were often just counties with new labels. This experiment of creating cities was ended in the late 1990s (Fan et al, 2012). More even-handed policy followed, with the Tenth Five-Year Plan (2001-2005) seeking balanced development of large, medium-sized, and small cities and the Eleventh Five-Year Plan (2006-2010) emphasizing development of metropolitan regions. In line with this balanced approach, the 1990 'City Planning Law' was replaced in 2008 by a new 'Urban and Rural Planning Law' (*Zhonghua Renmin Gongheguo Chengxiang Guihua Fa*) and the key phrase "strictly controlling the size of large cities" was dropped from the law (Fan et al, 2012).

The policy pendulum is now moving against the biggest cities. In 2014 President Xi Jinping announced reforms to assist rural migrants into small towns but restrict access to bigger cities: "…the overall principle is to fully remove *hukou* restrictions in towns and small cities, gradually ease restrictions in medium-sized cities, set reasonable conditions for settling in big cities, and strictly control the population of megacities".[32] Big city growth also may be limited by land use controls. Citing food security concerns, land on the outskirts of the biggest cities like Beijing and Shanghai is being classified as "permanent basic farmland" to be used only for cultivation. In announcing these controls the Minister for Land and Resources claimed that good farmland has been 'eaten by steel and cement'.[33] Conversely, land use controls for small urban areas are less strictly enforced and fiscal decentralization creates incentives for local officials to convert more farmland to industrial or residential use than is actually needed (Lichtenberg and Ding, 2009).

What is missing in this swing back to a pro-small bias is consideration of the evidence on China's evolving urban system. In this paper we use Pareto's Law as a benchmark, and find only the very largest cities in China have scope to absorb more migrants, contrary to the pro-small bias in urban policy. One of the most robust empirical facts about the relative size of cities in market economies is that they follow either Pareto's or Zipf's Law (Gabaix, 1999).[34] This negative relationship between logarithms of city size and rank is used here to identify the

[32] A report on the speech is here:
http://english.peopledaily.com.cn/n/2014/0607/c90785-8738238.html.
[33] Details are in *Xinhua* 2014-11-04:
http://news.xinhuanet.com/english/china/2014-11/03/c_133763130.htm
[34] Zipf's Law is a special case of the Pareto distribution, with a Pareto exponent equal to one.

cities hosting too many migrants and those with the potential to take more, in terms of having a city-size distribution that exactly follows Pareto's Law. We use population census data from 2000 and 2010, while previous studies are misleading because they use annual data that measure cities by how many people have *hukou* household registration for each place, and not by who actually lives there.[35]

The census counts show that migrants increasingly congregate in a few larger cities, so if cities are measured by the count of local *hukou* holders the size distribution wrongly seems more even. This error is like studying the size distribution of, say, cities in the United States with city size calculated only for citizens rather than for all residents; this would be biased since cities such as New York have a higher share of non-citizens than do other cities. This issue of *de facto* versus *de jure* measures of city size matters more for China than elsewhere, due to the scale of non-*hukou* migration, at over 200 million by 2010.[36] Thus, prior studies that ignore non-*hukou* migrants (e.g. Song and Zhang, 2002; Xu and Zhu, 2009) and claim city sizes are becoming more evenly distributed over time misunderstand China's evolving urban system. A key feature of this evolving system is that millions of non-*hukou* migrants, voting with their feet, seem to prefer large cities. For example, there are urban districts in each of China's 287 prefectures but just 27 districts are the destination for 71 million of the 117 million non-*hukou* migrants residing in urban districts in the 2010 census. There is a potential mis-match between migrants funneling into a few large cities

[35] Examples include Anderson and Ge, 2005; Liang, 2010; Peng, 2010; Chen et al, 2013; Li and Sui, 2013.

[36] Non-*hukou* migrants are people who move somewhere other than where their *hukou* registration is from without converting either their type of *hukou* (agricultural or non-agricultural) or their place of registration (*hukou suozaidi*). The problems for the interpretation of China's statistics due to these migrants are discussed in Li and Gibson (2013).

and governments trying to steer them into smaller cities. One result of this mis-match is 'ghost towns' where empty new housing units sit on recently converted farmland in small cities.[37]

Another problem with prior studies is that county-level cities (*xianji shi*) are often included in samples along with urban districts (*shiqu*). But some county-level cities are just relabeled counties and do not differ from rural counties in economic performance (Li, 2011; Fan et al, 2012) or in lacking urbanization externalities (Li and Gibson, 2015). The rural nature of county-level cities is seen by a majority (54%) of their residents not having urban status in the 2010 census, while for urban districts just 28% of the population lack urban status. Thus a focus of some studies on the apparent growth of small cities (e.g. Anderson and Ge, 2005) may be misplaced since many of these county-level cities are not big enough to be cities at all. Thus, it is important to exclude county-level cities when using Pareto's Law in China, as is done in this study.

In the next section we describe our data and methods. We pay particular attention to the threshold for a city to be in the sample, since the fit of Pareto's Law is sensitive to the sample truncation approach used (Li and Sui, 2013). In Section 3 we report several results: (i) measuring cities by how many *hukou* registrations they have makes cities seem more evenly sized; (ii) the city size distribution is becoming less even over time; (iii) it is moves away from the middle of the size distribution causing the divergence in city size; and, (iv) very

[37] For an example, see "Ghost Town" *China Daily* June 10, 2010 http://www.chinadaily.com.cn/china/2010-06/10/content_9958431.htm

large cities appear to have the most scope for absorbing more migrants. Our conclusions are in Section 4.

4.2 DATA AND MODEL SPECIFICATION

A review of data quality issues showed that the most reliable information on city size is from China's Population Census in 2010 and 2000. The census counts residents of an area as those living there at least six months, giving a more realistic measure of a city's size than the count of people whose *hukou* registration is from that place since many of them may live elsewhere. In contrast, existing studies rely on the *China City Statistical Yearbook* (NBS, 2011), whose English name varies but in Chinese is consistently *Zhongguo Chengshi Tongji Nianjian*. We do not rely on *Yearbook* data, which ignore non-*hukou* residents. When we need *hukou* counts, to contrast with results using counts of residents, we take them from the Ministry of Public Security (MPS, 2001, 2011). A further problem with *Yearbook* data is that they do not report on urban cores. In contrast, the census and MPS report on each individual district within a prefectural city, and contiguous districts are the best proxy for an urban core in China (Roberts et al, 2012).[38]

Our full sample is the urban cores of all 287 prefectural cities in the 2010 census. These include 24 that were Leagues, Regions or Autonomous Prefectures in 2000, prior to an upgrade to prefectural city status. To maintain geographical coverage, these 24 are treated as if they were prefectural cities in 2000. This was easily done because each is a single district that had been either a county-level

[38] The urban core of a prefectural city is made up of adjacent districts (*shiqu*). The exceptions in our data are ten districts of Chongqing (Puling, Wansheng, Shuangqiao, Changshou, Jiangjin, Hechuan, Yongchuan, Nanchuan, Wanzhou and Qianjiang) that are excluded due to being largely non-urbanized and only recently upgraded from county-level city or county status, plus four districts of Wuhan (Caidian, Jianxia, Huangpi and Xinzhou) and one from Kunming (Dongchuan) that are similar to county-level cities or counties.

city or county in 2000. Moreover, the lower thresholds set on the estimation samples (see below) exclude 20 of these 24, so our inclusive approach to treating them as if they were cores of prefectural cities in 2000 should not cause bias.

We use Ordinary Least Squares (OLS) to estimate:

$$\ln(Rank) = \alpha - \beta \ln(Size) + \varepsilon \tag{1}$$

with $\hat{\beta}$ the Pareto exponent and ε a random error. The special case of $\hat{\beta} = 1$ is Zipf's law.[39] Prior studies for China mainly use this specification (e.g., Anderson and Ge, 2005; Liang, 2010; Li and Sui, 2013) or else a specification of Gabaix and Ibragimov (2006) that shifts city ranks by 0.5 but gives similar results (Xu and Zhu, 2009; Chen et al, 2013). We estimate equation (1) with four measures of city size and city rank: the non-agricultural *hukou* population (NA) and the urban resident population (U) for 2000, and for 2010. Comparing results for NA and U helps to assess possible bias in prior studies that only use NA to measure city size. Comparing 2000 and 2010 shows if the city size distribution is converging.

A typical pattern if equation (1) is compared with a scatter plot is for the lower tail to be flatter, due to 'cities' too small to distinguish from rural areas (Brakman et al, 1999). Studies set various lower thresholds to exclude small cities (Giesen et al, 2010). For example, thresholds for China range from 80,000 (Xu and Zhu, 2009) or 100,000 (Anderson and Ge, 2005; Liang, 2010) to 200,000 and 500,000 (Chen et al, 2013), and also use relative values such as the smallest city in the top 70% of cities (Li and Sui, 2013) and rolling sample approaches that constantly change the threshold (Peng, 2010). Thresholds such as 80,000 once

[39] Gabaix and Ioannides (2004) suggest Pareto exponents between 0.8 and 1.2 are consistent with Zipf's law.

coincided with official city size definitions but are less relevant now due to growth in average city size. Our approach is to set a threshold for the indicator that most reliably measures city size (the urban resident count) and hold constant the proportion of cities below that threshold in the other samples. A threshold of 0.3 million for U in 2010 excludes *n*=36 (one-eighth) of the total sample (only 2% of the urban population are in these small cities). In order to also drop the smallest one-eighth of cities for each of the other three samples, thresholds of 0.204 million for urban residents in 2000, and 0.147 and 0.197 million for the non-agricultural *hukou* counts in 2000 and 2010 are used. These four estimation samples, each of *n*=251, are used in the rest of this study.

Comparing estimated Pareto exponents gives a general idea of dynamics in the city size distribution and if it is converging but does not show where change is occurring. Kernel density plots of relative city size can show this, and these are presented below for all four samples. The Markov transition matrix is another nonparametric approach that we use, dividing cities in each of our four samples into six groups defined by cut-points at 0.4, 0.6, 1.2, 2, and 4 times the population of the average city in a particular sample.[40] The higher the Markov transition probability for moving into a new group between 2000 and 2010, the less stable are cities in the original size range.

We also consider deviations of actual city size from the size predicted by Pareto's Law, given a particular city rank:

[40] For the urban resident population (U) in the 2010 census, these relative cut-points correspond to 0.56 million (m), 0.84m, 1.69m, 2.80m, and 5.63m. These ranges are quite similar to those announced by the *State Council* in 2014 for adjusting standards for categorizing city sizes; 0.5 million, 1m, 3m, 5m, and 10 million except that the very small cities are divided into two groups with another threshold at 0.2 million in the *State Council* guidelines.

$$\widehat{Size} = \exp\left(\frac{\ln(Rank)-\hat{\alpha}}{\hat{\beta}}\right) \quad (2)$$

where equation (2) is applied to each of our four samples. These deviations show where, from the standpoint of Pareto's Law, cities are made 'too large' or 'too small' by either policy (showing up when using the NA *hukou* count to measure cities) or by the choices of migrants (showing up when using the urban resident count). We then see where these 'oversized' or 'undersized' cities move in the distribution over time and consider what may cause these moves.

For example, if the lowest ranked cities are made too large by pro-small policy biases, it should show up as deviations from Pareto's law when using the NA *hukou* count, and the Kernel density and Markov transition matrix would show movement of small cities into the middle-sized groups. This would be a case of urban planning and other policy biases causing a more even city size distribution. Existing studies for China show this, with Pareto exponents rising over time, and authors attribute this either to the growth of small cities (e.g. Anderson and Ge, 2005; Xu and Zhu, 2009) or to restrictions on large cities (e.g. Chen et al, 2013; Li and Sui, 2013). But if this pattern is not apparent when using data on the urban resident population, it suggests a statistical artefact in previous studies, resulting from city size in China being measured in terms of *hukou* registration rather than by the count of how many people actually live in each city.

The comparison between city sizes under planning and city sizes based on decisions of migrants can also be examined more directly. The number of non-*hukou* migrants (M) in each city in 2010 can be calculated as:

$$M\,2010 = U\,2010 - NA\,2010 \quad (3)$$

and we can compare the actual stock of incoming and outgoing migrants in 2010 with the movement of people needed in order for the city size distribution to exactly follow Pareto's Law. That is, we can use equation (2) to calculate the predicted size for each city in terms of both urban residents and non-agricultural *hukou* holders and then examine hypothetical flows based on the deviation of the two actual population series from these two predictions:[41]

$$\widehat{M\ 2010} = \widehat{Size} - Size \tag{4}$$

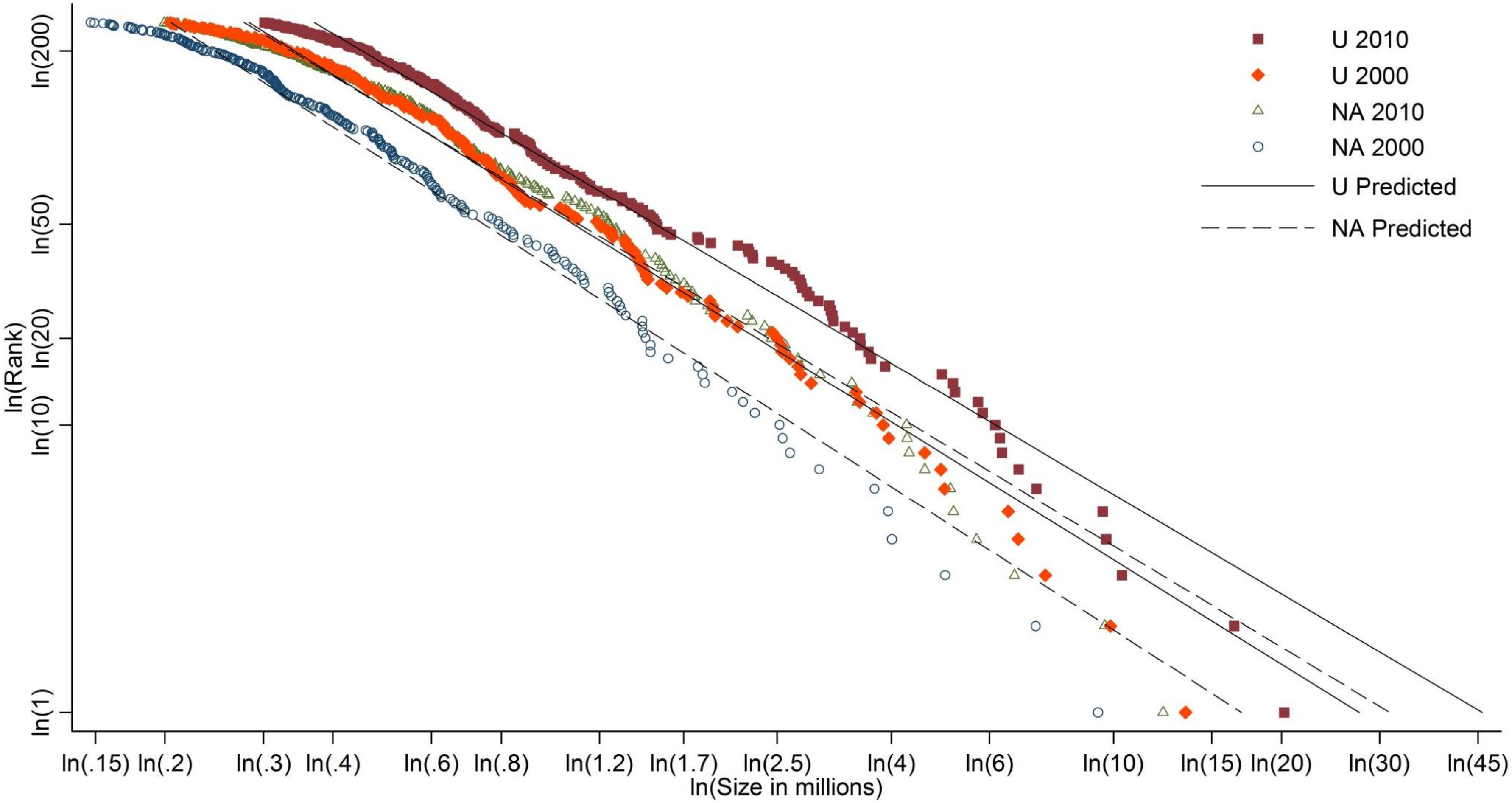
The comparison of the actual stock of migrants with the hypothetical number that would hold under Pareto's Law can identify whether it is large or small cities that have already taken in enough migrants and what type of cities can take in more.

4.3 RESULTS

The results of estimating equation (1) on the four samples are reported in Table 1 and the raw data and fitted trends are shown in Figure 1. The first notable finding is that measuring city size by the number of *hukou* registrations (NA) makes Pareto exponents significantly larger than if cities are measured by their number of residents.[42] Larger Pareto exponents imply a more even distribution of city sizes (and a more steeply sloped trend line in Figure 1 since small changes in city size are associated with larger changes in rank). Intuitively, ignoring non-*hukou* residents, as existing studies have done, leads one to miss the fact that most migrants congregate into a few large cities, and being blind to this pattern wrongly implies a more even city size distribution.

[41] This comparison is restricted to the n=244 cities that are common to the NA 2010 and U 2010 samples.
[42] Equality of the Pareto exponents using NA versus U is rejected at p=0.000 for both 2000 and 2010.

Figure 1. Rank-size Plot



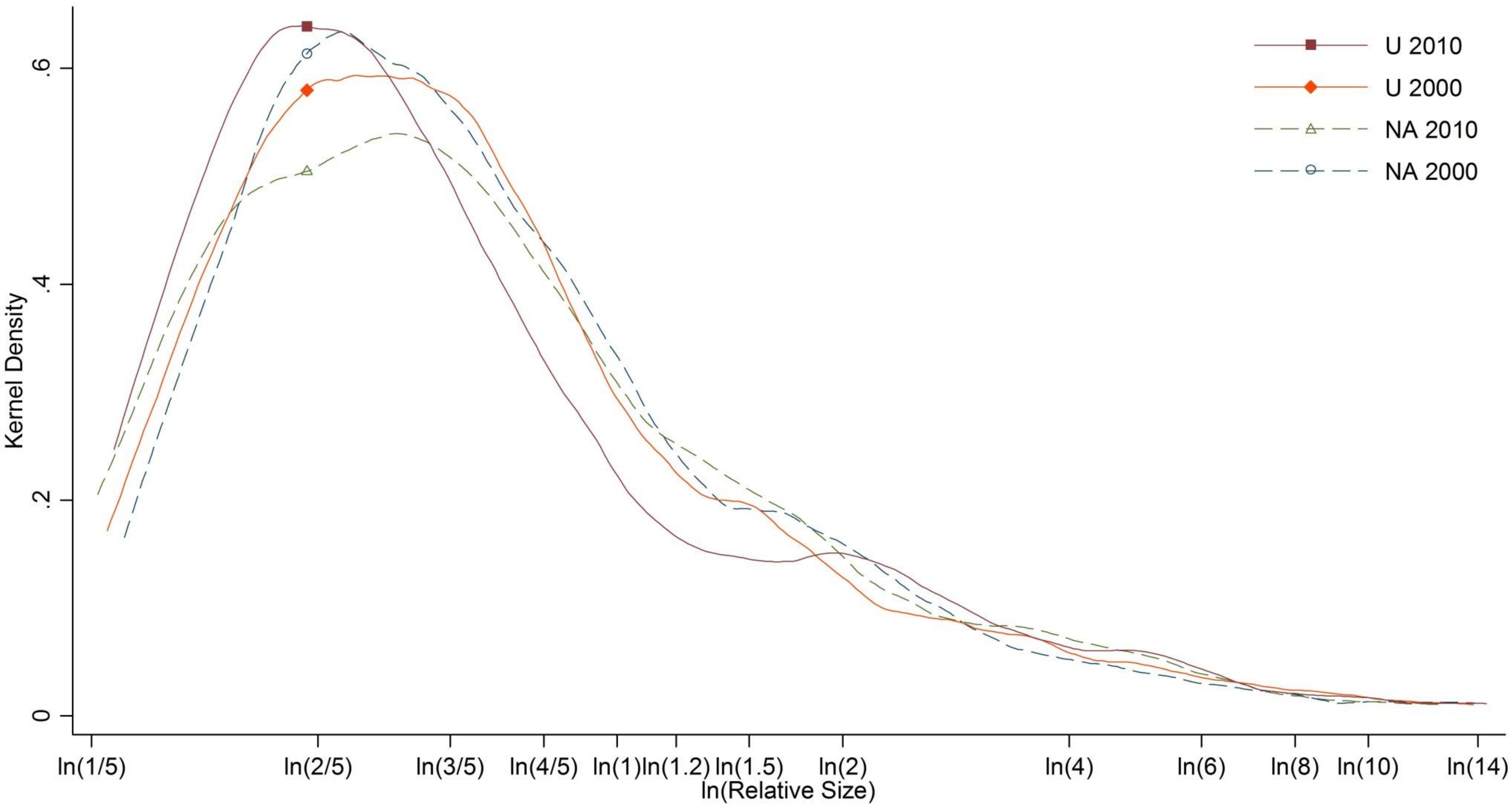
Notes: The number of observations is 251 for all four samples (NA 2000, U 2000, NA 2010 and U 2010) whose details are in Appendix Table 1.

Table 1. Rank-size Regression

	(1)	(2)	(3)	(4)
	OLS	OLS	OLS	OLS
	Ln(Rank NA 2000)	Ln(Rank U 2000)	Ln(Rank NA 2010)	Ln(Rank U 2010)
Ln(NA 2000)	1.251			
	(0.011)***			
Ln(U 2000)		1.207		
		(0.011)***		
Ln(NA 2010)			1.169	
			(0.013)***	
Ln(U 2010)				1.147
				(0.009)***
Constant	3.542	4.002	4.026	4.386
	(0.012)***	(0.010)***	(0.012)***	(0.008)***
Observations	251	251	251	251
Adjusted R-squared	0.98	0.98	0.97	0.98

Notes: Standard errors are in parentheses. *** Significantly different from 0 (constant) or 1 (for the Pareto exponent) at p=0.01 confidence level. NA is the non-agricultural *hukou* population and U is the urban resident population. See Appendix Table 1 for details.

Figure 2. Relative City Size Distribution



Notes: City size is relative to the mean of each distribution, as described in Appendix Table 1.

But even with the smaller Pareto coefficients for city size measured in terms of residents, the null hypothesis of $\beta = 1$ is rejected and so Zipf's Law does not hold. This confirms prior studies for China that find evidence against the parallel growth of cities (Chen et al, 2013). It is thus unlikely that city size growth processes in China follow Gibrat's Law of a common expected growth rate and standard deviation (giving the Zipf's Law pattern in the steady state). This may reflect the powerful force of central and local government in shaping the city size distribution.

The second notable finding in Table 1 is that Pareto exponents fell significantly from 2000 to 2010, regardless of whether city size is from counting residents or from counting the number of non-agricultural *hukou* registrations. Thus, the city size distribution in China became less even over the decade; this divergence is not something noted in the prior literature. Indeed, some studies claim the reverse, of a convergence in the city size distribution (e.g. Anderson and Ge, 2005; Xu and Zhu, 2009). Regressions cannot show where the divergence in city size occurs but the kernel densities in Figure 2 give some clues, especially if using the urban resident population (we contend this is the most correct measure of city size). In particular, it seems that between 2000 and 2010 there has been a movement away from the middle of the distribution, with a fall in the proportion of cities that are from 0.4 to two times the mean size, and rises in the proportions that are either smaller than 0.4 of the mean or larger than twice the mean.[43]

[43] This contrasts with Anderson and Ge (2005) whose Kernel density plot shows a rise in the number of cities in the center of the distribution. But their sample mixes together county-level cities, which often are not very urbanized, with genuine urban cores (districts).

Table 2. Markov Transition Matrices for City Size Groups

Using the Urban Resident Population

U 2010	U 2000					
	S	SM	M	LM	L	VL
S	**79.2%**	41.9%				
(89)	(57)[a]	(26)				
SM	12.5%	**46.8%**	31.8%			
(59)	(9)	(29)	(21)			
M		9.7%	**65.2%**	32.1%		
(58)		(6)	(43)	(9)		
LM		1.6%	1.5%	**50%**		
(16)		(1)	(1)	(14)		
L				17.9%	**85.7%**	
(17)				(5)	(12)	
VL			1.5%		14.3%	**100%**
(12)			(1)		(2)	(9)
Total	91.7%	100%	100%	100%	100%	100%
(251)	(72)	(62)	(66)	(28)	(14)	(9)

Using the Non-agricultural *hukou* Population

NA 2010	NA 2000					
	S	SM	M	LM	L	VL
S	**78.5%**	37.3%				
(80)	(51)[a]	(25)[a]				
SM	12.3%	**43.3%**	17.1%			
(49)	(8)	(29)	(12)			
M	3.1%	13.4%	**71.4%**	24%		
(67)	(2)	(9)	(50)	(6)		
LM	1.5%	4.5%	10%	**60%**	29.4%	
(31)	(1)	(3)	(7)	(15)	(5)	
L			1.4%	12%	**58.8%**	
(14)			(1)	(3)	(10)	
VL				4%	11.8%	**100%**
(10)				(1)	(2)	(7)
Total	95.4%	98.5%	100%	100%	100%	100%
(251)	(65)	(67)	(70)	(25)	(17)	(7)

Notes: Transition probability (in %) is calculated by dividing the number of cities that move to a size range in 2010 by the total of cities in the range they left in 2000. The number of cities in each cell is in ( ), with 251 cities in total. The abbreviations S, SM, M, LM, L, and VL stand for small, small medium, medium, large medium, large and very large, and are based on cut-points of 0.4, 0.6, 1.2, 2, and 4 times the mean city size (as measured by either U or NA, in either 2000 or 2010).

[a] A city that was below the threshold size in 2000 occurs in this size range in 2010 or vice versa. These cities are counted in the column total, but not in the particular cell, to restrict attention to cities that were in the size categories considered here (above the threshold for sample inclusion) in both years.

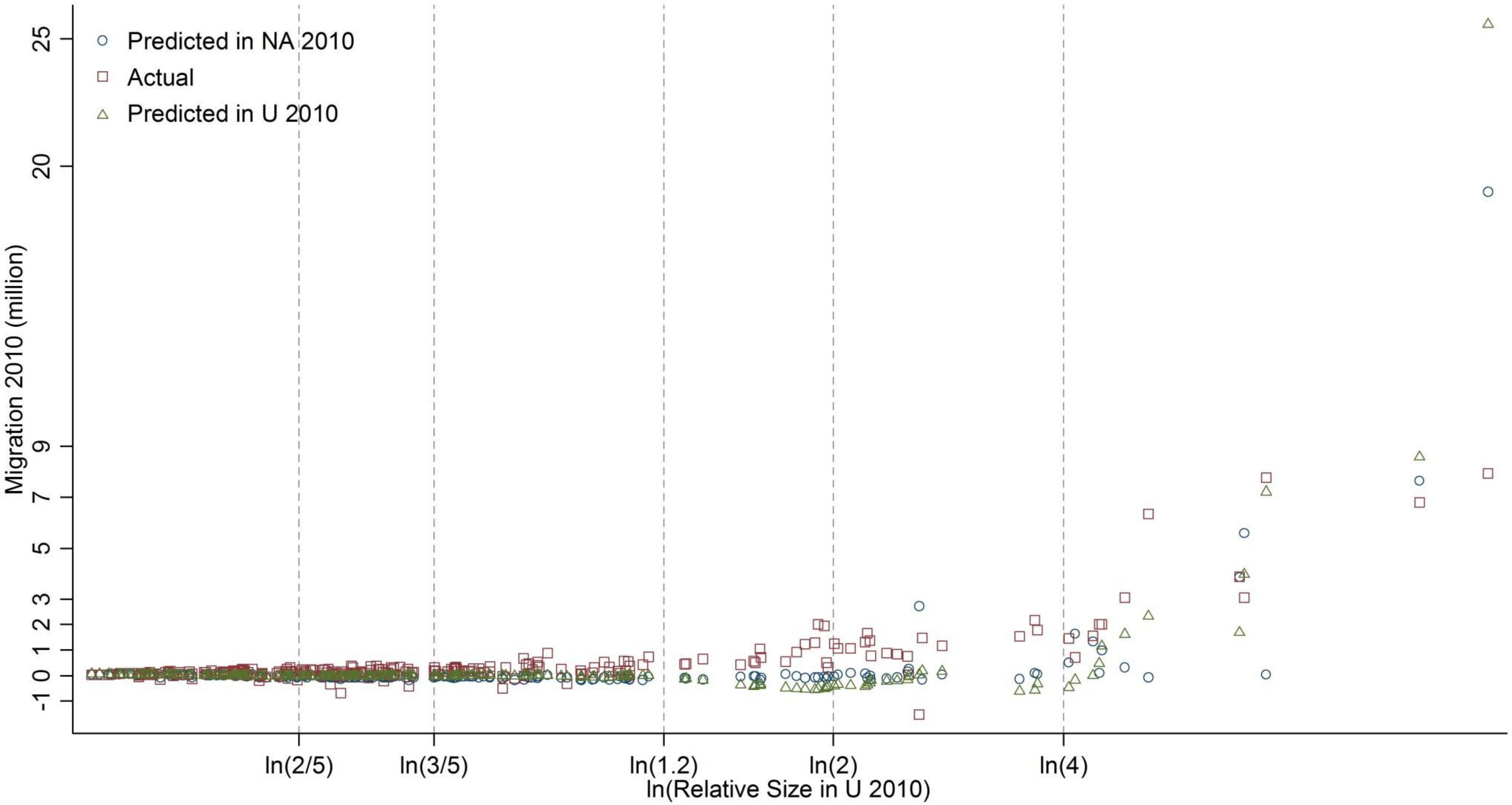
Further evidence on dispersion away from the medium size range comes from the Markov transition matrices for city size groups reported in Table 2 according to residents (left panel) or non-agricultural *hukou* holders (right panel). Cut-points of 0.4, 0.6, 1.2, 2, and 4 times mean city size define groups we label as 'small', 'small-medium', 'medium', 'large-medium', 'large', and 'very large' in the table. The small-medium, medium, and large-medium cities have the lowest odds of staying in the same resident size range from 2000 to 2010, with probabilities from 47% to 65%. In contrast, 79% of small cities, and (100%) 86% of (very) large cities stay in the same size range between the two censuses. For cities starting in the middle size ranges and moving into a different group, usually it is a move downwards, indicating a fall in size relative to the mean. While upward moves are less common they do include the only instances of moves to non-adjacent groups, which are both from Guangdong province; Foshan went from medium size in 2000 to very large in 2010 and Huizhou went from small-medium size to large-medium. The example of Foshan shows the error in using the count of non-agricultural *hukou* holders as a measure of city size; there were 3.7 million people whose non-agricultural *hukou* registration in 2010 was from Foshan but the census reveals that the resident population of this city was almost twice as large, at 6.8 million.

The risk of misunderstanding city size dynamics from using the count of local *hukou* holders as a measure of city size can be seen by comparing the two panels in Table 2. When the *hukou* count is used, instability in the middle of the size range is obscured; there is no clear pattern of lower transition probabilities along the main diagonal once one goes below the very large size group. In contrast, when cities are classified according to their residents it is clear that for sizes from small-medium to large-medium there is a substantial chance of dispersion; cities in the middle of the main diagonal had much lower odds of staying in the same size groups between 2000 and 2010 than did cities who started in the tails of the distribution. The different patterns for the two matrices are due to the fact that the number of non-agricultural *hukou* holders for a city evolves only slowly over time, given that *hukou* status is inherited and hard to convert, and so misses the rapid changes in size that can come from migrants voting with their feet.

The driving forces behind stability of relatively small to medium cities, and dispersion of medium to large cities, are likely to include both pro-small policy biases and choices made by migrants. Consider first restrictions that may make small cities bigger than one would expect from their rank in the city-size distribution (with expected size from the benchmark provided by Pareto's Law, taken here as a proxy for what the city size distribution may have looked like if China had a market economy history). If those enlarged cities attract few migrants (they may be unattractive locations whose size reflects planning decisions rather than market outcomes) they eventually become relatively smaller if measured by the number of residents (which includes the non-*hukou* migrants). In other words, migrants who vote with their feet by not going to these destinations help return them back to a smaller relative size more in keeping with what is predicted by their rank under the Pareto distribution. This pattern describes the Markov transition matrix in the left panel of Table 2 that uses residents to classify cities; an average of 35% of the cities that were large-medium, medium, or small-medium in 2000 had fallen into the next lower size category by 2010. In contrast, when the size groupings are according to the *hukou* count, just 26% of cities in these size ranges, on average, had fallen into a lower size range by 2010 due to the slower evolution of the spatial pattern of *hukou* registrations.

There are too few migrants to overcome the fact that the largest cities remain undersized, in terms of Pareto's Law. Consider the top seven cities by urban resident population in 2010; all are well below the Figure 1 trend line showing the size needed to fit an exact Pareto distribution. The shift to the right needed to move data points for those seven cities on to the trend line is a crude indicator of how many more migrants are needed to produce cities of the right size for their rank. Why do these cities have too few migrants? One possibility is that potential migrants are deterred by extremely high housing costs that result from restrictions on urban land expansion for the largest cities. For example, Li and Gibson (2014) use a hedonic model to compare apartment prices across Chinese cities; for a city like Beijing (ranked 2nd by size) the prices are 230% higher than for a city like Changsha (ranked 27th by size). It may be that those wanting to move into very large Chinese cities are deterred by the high housing costs and instead go into large and large-medium cities like Changsha. In fact, most of the cities in Figure 1 for sizes between two million and five million residents (including Changsha) seem much larger than what the Pareto distribution would predict (so are above the trend line). The deviation above the trend line for this group of cities was much less apparent in 2000, when house prices were more equal.

Figure 3. Stock of non-*hukou* Migrants 2010 and Hypothetical Stock Needed for Exact Pareto Distributions Versus City Size



Notes: Relative size is according to the mean city size by urban residents in 2010. The stocks of actual and hypothetical migrants are based on equations (3) and (4). The number of observations is 244, which are the cities that are common to both the NA 2010 and U 2010 samples.

The destination choices of non-*hukou* migrants, and the scope for cities to absorb more, are shown by applying equations (3) and (4) and comparing the results to the size of each city. In Figure 3 this is done for all 244 cities that are common to the NA and U samples for 2010 (so the city is in the largest 87.5% of cities according to both counts). The stock of non-*hukou* migrants (from equation (3)) ranges from over seven million for Shanghai and Shenzhen (ranked 1st and 3rd by residents) to -1.5 million for Shantou (ranked 18th by residents, but 5th in terms of non-agricultural *hukou* registrations), and these stocks are shown by the red squares in the figure. The hypothetical number of extra non-*hukou* migrants to give an exact Pareto distribution in terms of the number of residents is shown by the green triangle markers, and to give an exact Pareto distribution in terms of non-agricultural *hukou* registrations is shown by the blue circles. These hypothetical values come from equation (4) and they can be negative, which corresponds to cities that were larger in 2010 than what would be predicted from the rank of that city.

This exercise suggests that the scope to absorb more non-*hukou* migrants is mainly limited to the very large cities, defined as those with four or more times the mean number of residents. The cut-points that give the six size groups (from "very large" to "small") are shown by the vertical lines on Figure 3, and the tabulation of the results based on these size classes is in Table 3. Consider the 12 cities in the "very large" size class; in 2010 these were the home to 47 million non-*hukou* migrants. For each of those cities their number of urban residents exceeded their non-agricultural *hukou* (so there are no net out-migrants). In the next class of cities, the migrants total 19 million and are funneled into 16 cities.

One city in this size range (Shantou) has 1.5 million out-migrants (that is, the number of urban residents is fewer than the number of people registered with non-agricultural *hukou* from here). The large-medium and medium size classes each hold 14-15 million migrants while the small-medium and small size classes each hold 8-9 million migrants, and these are spread over many cities. The three smallest size classes also include 22 cities that are the source of 3.5 million out-migrants (that is, the number of people with non-agricultural *hukou* from these cities exceeded their number of urban residents in the 2010 census).

When attention shifts from the actual pattern of migration to the hypothetical pattern needed to produce exact Pareto distributions for city size and rank, the relevant values are shown in the last four columns of Table 3. Consider the results for urban residents in 2010; an extra 52.6 million migrants could go into ten of the very large cities while 0.6 million could leave the other two very large cities and the resulting size distribution would sit exactly on the trend line shown in Figure 1. The other main change to get an exact Pareto distribution is for the large and large-medium cities to have about ten million fewer migrants (by moving them into the very large size class). This result is just another way of noting the pattern from Figure 1; cities between 1.2 and 4 times the mean city size (in terms of residents these are cities of from two million to five million people in 2010) seem larger than what would be predicted from their rank under an exact Pareto distribution while the very largest cities are smaller than what is predicted. For the three smallest size groups in Table 3, the extra inward or outward migration needed to get to an exact Pareto distribution never amounts to more than one million people per group.

Table 3. Stocks of non-*hukou* Migrants and Hypothetical Number Needed for Exact Pareto Distributions in 2010

City Size Groups (based on 2010 resident count)	Actual		Hypothetical Extra Migration to Give an Exact Pareto Distribution			
			Urban Residents 2010		Non-agricultural *hukou* 2010	
	In	Out	In	Out	In	Out
Very Large	46.58		52.63	-0.64	41.02	-0.07
	(12)		(10)	(2)	(11)	(1)
Large	19.21	-1.52	0.42	-4.41	3.59	-0.71
	(16)	(1)	(3)	(14)	(9)	(8)
Large-Medium	13.63			-6.26	0.05	-1.12
	(16)			(16)	(1)	(15)
Medium	15.12	-0.94	0.38	-0.98	0.02	-4.51
	(53)	(5)	(25)	(33)	(1)	(57)
Small-Medium	8.77	-1.74	0.03	-1.13	0.09	-2.75
	(52)	(7)	(8)	(51)	(10)	(49)
Small	8.28	-0.83	1.31	-0.38	1.92	-0.89
	(72)	(10)	(44)	(38)	(53)	(29)
Total	111.59	-5.04	54.77	-13.80	46.69	-10.05
	(221)	(23)	(90)	(154)	(85)	(159)

Notes: The number of actual and hypothetical migrants is in millions, with the number of cities in ( ). *N*= 244 based on cities common to the samples for NA 2010 and U 2010.

The hypothetical migration needed for an exact Pareto distribution for the non-agricultural *hukou* population of each city is quite different. First the scale of required migration is much smaller, with a net influx of just 37 million (from 46.7 million coming in and ten million going out). The measures of city size using the *hukou* registered population ignore existing non-*hukou* migrants so this 37 million should be compared with the sum of the actual number of non-*hukou* migrants (112 million) plus the 41 million net extra migrants needed to get to an exact Pareto distribution. In other words, if *de jure* city size is used rather than the correct *de facto* measure, it appears that only about one-quarter as many people have to move around to have cities that are the right size for their rank as is truly the case. There are two reasons for this; first, measuring cities by how many *hukou* registrations they have already starts out with a seemingly more even distribution since the funneling of most non-*hukou* migrants into just a few destination cities is ignored, and second, the Pareto distribution for the non-*hukou* count is more evenly spread than is the one for the resident count (Table 1 and Figure 1) so it takes less movement to get to this target.

The second difference between using the *hukou* count and the resident count, in terms of the hypothetical migration to have cities that are the right size for their rank, is a lack of apparent 'queuing' for the very large cities. When cities are measured in terms of residents, the large and large-medium size groups seem to have 'too many' migrants; removing ten million of them and transferring them into the very large cities would give sizes more consistent with the Pareto distribution. One plausible explanation for this pattern is that potential migrants are deterred from moving to very large cities by extremely high housing costs that result from restrictions on urban land expansion and so they instead move to large and large-medium cities where housing costs may be less than half of those in the largest cities. But this pattern is not apparent when city size is measured by the *hukou* count, and it is the small-medium and medium sized cities that appear to be the most over-sized (for their rank). The number of people with non-agricultural *hukou* registration for a particular place does not reflect individual behavioral choices and instead reflects (past) planning decisions, so there is no obvious reason for why the *hukou* count for these types of cities appears too large for their rank.

Despite these differences between the two sets of results for hypothetical migration, a key point from Table 3 is their similarity in showing that it is only the very large cities with scope to accept many more non-*hukou* migrants, from the standpoint of having city sizes that more closely follow a Pareto distribution. This finding is interesting because it contrasts with the views of leaders such as Xi Jinping and also because it potentially informs us about the nature of China's evolving urban system. The limited capacity of small and medium sized cities to absorb migrants, either in terms of the actual stock in 2010 or the hypothetical number of extra migrants to get to an exact Pareto distribution, shows that an urbanization process of nearby rural-urban migrants going to live in small, local cities is unlikely to succeed in transforming China into a fully urbanized country. Instead, it is the agglomeration processes that not only absorb nearby rural-urban migrants but also take in inter-regional rural-urban and urban-urban migrants that are a key to China's urban transition. Moreover, it is the very large cities, and not the small towns, that provide agglomeration-related productivity advantages.

These advantages appear to operate only in the tertiary sector and not in the secondary sector activities like construction and manufacturing that increasingly spread out of urban districts and into smaller towns between 2000 and 2010 (Li and Gibson, 2015). Thus, a focus on directing migrants into small cities will not put them into the places that they are likely to be the most productive, and this misallocation will be especially costly as China rebalances the economy by developing the under-sized services sector and reducing reliance on the over-sized manufacturing sector (Ghani, 2012).

4.4 CONCLUSIONS

Starting from a *positive* standard, of how China's urban system is evolving, we uncover two facts obscured by prior studies. First, measuring cities by their number of non-agricultural *hukou* registrations – as previous studies have done – causes Pareto exponents to seem larger than they actually are. These prior studies miss the funneling of non-*hukou* migrants into just a few large cities and once this fact is missed, statistical inquiries into Pareto and other distributions tend to find a more even city size distribution than truly exists. This bias is exacerbated by studies that include county-level cities in their samples, despite such 'cities' lacking an urban core (Roberts et al, 2012). The second fact that is not apparent from prior studies is that the city size distribution in China is becoming less even over time with movement out of the middle of the size distribution between 2000 and 2010. In contrast, previous studies have highlighted an apparent move towards a more even distribution of city sizes in China.

Our analysis then adopts a *normative* standard, by using Pareto's Law as a benchmark to evaluate China's evolving urban system. Pareto's Law holds well in market economies, so the parts of China's urban system that deviate from Pareto's Law may be a legacy of the command economy era and both historic and current urban planning and land use policies. This normative analysis suggests that even though the largest cities look gigantic relative to other cities (for example, Shanghai with 20.2 million residents in 2010 is almost double the size of the 3rd largest city and triple the size of the 7th largest) they actually are too small according to the size they ought to be as the top ranked cities in the urban hierarchy. Thus, it is the very large cities that appear too small and have the most scope for absorbing more migrants in order to become the right size for their rank. In contrast, when judging from the standpoint of a Pareto distribution, there is almost no scope for small to medium cities to absorb more migrants despite policy biases and statements from political leaders in favor of directing migrants towards these small cities.

This result suggests that the focus of the Eleventh Five-Year Plan (2006-2010) on the development of metropolitan regions was broadly appropriate, but the current swing towards a pro-small policy bias is not. For example, rather the recent policy to make land outside of the largest cities as "permanent basic farmland" a better focus for rules on urban land expansion might be to more strictly regulate farmland conversion by small and medium-sized Chinese cities. Also, reforms to governance and public finance that see less tax revenue transferred from local to central government or fewer responsibilities left for local government to fund from their own budgets may reduce the reliance of these smaller cities on revenue from land auctions.

Finally, we note that in using Pareto's Law as a normative standard to judge China's city size distribution we are relying on this as a proxy for what city sizes look like in societies with a less distorted urban past than China. Of course, there is debate in many countries about which distribution best fits the urban hierarchy, with some studies suggesting Pareto's Law only fits the upper tail (e.g. Eeckhout 2004, 2009), and distributions such as the log-normal, q-exponential and double Pareto log-normal are often proposed (e.g. Anderson and Ge, 2005; Soo, 2007; Giesen et al, 2010). It would be an interesting question for future research to see if the normative result found here, that it is the very large cities in China that are best placed to accept more migrants, would also be found using these other distributions.

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Appendix Table 1. Details on the Four Sub-Samples Used in the Estimation

	Sub-Sample Name			
	NA 2000	U 2000	NA 2010	U 2010
Share of population from districts in all prefectures, that are in sub-sample	97.8%	97.9%	98.0%	97.8%
Actual City Size				
Minimum (threshold for inclusion in the sub-sample)	0.147	0.204	0.199	0.301
Median	0.386	0.552	0.571	0.698
Mean (used to divide cities into the six size classes in Tables 2 and 3)	0.666	0.975	0.979	1.407
Maximum	9.382	13.460	12.286	20.218
Predicted City Size (equation (2))				
Minimum	0.205	0.283	0.277	0.370
Median	0.356	0.501	0.500	0.676
Mean	0.722	1.074	1.126	1.571
Maximum	16.953	27.558	31.274	45.794
Stock of non-hukou migrants in 2010 (equation (3))				
Minimum			-1.523	
Median			0.166	
Mean			0.437	
Maximum			7.931	
Hypothetical extra migrants for exact Pareto distribution to hold according to NA or U				
Minimum			-0.176	-0.613
Median			-0.037	-0.008
Mean			0.150	0.168
Maximum			18.988	25.576

Notes: NA is the non-agricultural *hukou* registered population and U is the urban resident population. Each sub-sample has 251 observations, and represents the largest 87.5% of cities for each indicator and each year, except migration calculations that are based on the union of NA and U (*n*=244). Numbers are in millions.
Sources: MPS (2001, 2011); NBS (2003, 2011, 2012).

Chapter 5

Urbanization Economies in China: Nature, Location, and Effects

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Urbanization Economies in China: Nature, Location, and Effects

Abstract

The nature and location of urbanization economies and their effects on productivity per worker in China are examined. Unlike previous studies, more accurate resident-based measures of urban scale from the 2010 census are used. The size of urbanization economies is similar to those in other countries and they occur only in bigger cities and not in smaller towns, and operate only through tertiary sector activity. Efforts by government to disperse urbanization, through land use and migration restrictions, and by stimulating construction and manufacturing in China's counties are unlikely to create beneficial agglomeration effects.

Keywords: Agglomeration, Cities, Population, Productivity, Urbanization, China

JEL: R12, O15

5.1 INTRODUCTION

Spatial concentration of economic activity is an inherent feature of market economies (World Bank, 2009) and is socially beneficial since firms and workers are more productive in dense and populous urban areas (Puga, 2010). After three decades of market reforms in China, firms and workers are no longer trapped in place by either the central plan or by the *hukou* household registration system, allowing spatially concentrated patterns of development to emerge. This change is also reflected in the academic literature, with several recent studies estimating the size of agglomeration effects in China (e.g., Au and Henderson, 2006; Xu, 2009; Combes et al, 2015). These effects are the positive externalities due either to *localization economies* from firms being near to other firms in the same industry or to *urbanization economies* arising from the scale of an area and the diversity of its economy.

These existing studies rely on inappropriate measures of city scale, so findings need to be re-examined with better data. One problem is that sub-national population counts for China were not reliable before 2010 because they are for the population with local *hukou* registration (a *de jure* measure) and not the resident population (a *de facto* measure).[44] For example, Xu (2009) uses the local *hukou* registered population for cities from 1990 to 1997, ignoring urban residents who had their *hukou* registration from elsewhere; at the time these non-*hukou* urban

[44] Li and Gibson (2013) discuss this data problem, which biases even simple descriptive claims. For example, Au and Henderson (2006: page 557) say China had nine cities over 3 million and 125 of 1-3 million in 2000; a ratio of large to small cities (0.07) well below the global average of 0.27. But measured by residents in the 2000 census, China had 20 cities over 3 million and 89 cities of 1-3 million; a ratio of 0.23. The 2010 census has 38 cities with residents over 3 million versus 97 cities of 1-3 million, giving a large-to-small ratio of 0.39. Using the local *hukou* registered population rather than the resident population makes the ratio just 0.18.

residents numbered more than 100 million (Chan, 2012). Other statistical sources also are incomplete, perhaps because they continue to be collected and reported as they were when China was a state-run economy. For example, Au and Henderson (2006) measure city scale by employment but many private sector workers do not get counted in the data they use.[45] Combes et al (2015) use urban density rather than employment or population counts, but their survey data are from a sample frame that excludes those urban residents whose *hukou* registration is from elsewhere.

In light of these data issues, this paper uses 2010 census of population data to study the nature, location, and magnitude of urbanization economies in China using more accurate measures of city scale. Another contrast with existing studies is that we test for urbanization economies over the entire hierarchy of urban units in China while previous studies tend to concentrate on one particular type of urban unit. Our results suggest positive effects of urban scale on productivity that are of similar size to those found in other countries, but these effects occur only for urban districts (containing the core of prefectural cities) and not for county-level cities and smaller towns, and operate only through tertiary sector activity. Census data from 2000 and 2010 show that tertiary sector activity is ever more concentrated in the urban districts while secondary sector activity – especially construction and manufacturing – is moving into counties. Hence, these results imply that efforts to disperse urbanization towards counties and county-level cities

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[45] Au and Henderson use *City Statistical Yearbook* (*CSY*) data, where 'private sector' employment was titled as self-employed (with a very low share of the total) so employees are apparently excluded. Long-form census data on employment by sector in 2010 show that *CSY* substantially undercounts overall employment, with an average of only 43 percent of the employment for each city that the census reports in the same year.

will not generate beneficial agglomeration effects.

Understanding the nature of urbanization economies is one of the most policy-relevant research questions in China, where there is debate about whether small and medium-sized cities should be favored over expansion of existing mega-cities like Shanghai. Public policy in many places tries to foster agglomeration effects by luring mobile industry, by building clusters, or by attracting 'talent' (Combes et al 2011). But efforts to shape urban structure are especially salient in China. There is a long history of planning policies that affect city size and location and even in the early reform era policy aimed to limit growth of big cities and favor small ones. The 1990 'City Planning Law' (*Zhonghua Renmin Gongheguo Chengshi Guihua Fa*) mandated 'strictly controlling the size of large cities and developing medium-sized and small cities' (Xu, 2009). Many new cities in this era were simply relabeled counties; this experiment of creating cities was deemed a failure and was ended in the late 1990s (Fan et al, 2012). A period of more even-handed policy treatment followed, with the Tenth Five-Year Plan (2001-2005) seeking balanced development of large, medium-sized, and small cities and the Eleventh Five-Year Plan (2006-2010) emphasizing development of metropolitan regions. In tune with this more even-handed approach, the 1990 'City Planning Law' was replaced in 2008 by a new 'Urban and Rural Planning Law' (*Zhonghua Renmin Gongheguo Chengxiang Guihua Fa*) and the key phrase "strictly controlling the size of large cities" was dropped from the law (Fan et al, 2012).

But the policy pendulum is again swinging against the biggest cities. In 2014 President Xi Jinping announced *hukou* reforms to assist rural migrants into small towns and county-level cities but restrict their access to bigger cities: "…the overall principle is to fully remove *hukou* restrictions in towns and small cities, gradually ease restrictions in medium-sized cities, set reasonable conditions for settling in big cities, and strictly control the population of megacities".[46] In addition to ongoing *hukou* controls, big city growth also may be limited by land use controls. Citing food security concerns, land on the outskirts of the biggest cities like Beijing, Shanghai, and Guangzhou is being classified as "permanent basic farmland" to be used only for cultivation. In announcing these controls the Minister for Land and Resources, Jiang Daming, claimed that good farmland has been 'eaten by steel and cement'.[47]

In spite of this pro-small policy bias, millions of non-*hukou* migrants voting with their feet seem to prefer large cities.[48] Our analysis of the 2010 census of population reveals two population relocation processes: First, there is an agglomeration process where about 1400 locations lost people due to non-*hukou* migration and just over 400 locations gained people; three-quarters of the gain is from 43 cities with more than 0.5 million migrants each. The second process is urbanization without agglomeration, which sees migrants without non-agricultural *hukou* found in over 1000 dispersed urban locations.[49] The strength of the agglomeration process is shown by there even being some cities that are losing

[46] A report on the speech is here: http://english.peopledaily.com.cn/n/2014/0607/c90785-8738238.html.

[47] Details are in *Xinhua* 2014-11-04: http://news.xinhuanet.com/english/china/2014-11/03/c_133763130.htm

[48] Non-*hukou* migrants are people who move somewhere other than where their *hukou* registration is from without converting either their type of *hukou* (agricultural or non-agricultural) or their place of registration (*hukou suozaidi*).

[49] The number of urban migrants in each urban unit is calculated as urban residents in the 2010 census minus the number with non-agricultural *hukou* registration for that place and totals 216 million.

population, because increasingly mobile workers and firms judge these cities as unsuitable locations for realizing urbanization economies, contrary to what central planners might once have thought. Given this mis-match between where migrants go and where urban planning policy may try to direct them, research on the nature and location of urbanization economies in China may contribute to better policy settings.

The next section gives a brief review of prior studies of agglomeration effects in China. Section 3 discusses the data, paying attention to China's different spatial units. Results from the 2010 census of population are used to describe the agglomeration and urbanization processes in Section 4, with changes in the economic structure of various spatial units examined using long form census data on sectors of employment in 2000 and 2010. The econometric specification and the empirical results for the elasticities of output with respect to urban scale are discussed in Section 5. These results include comparisons between economic sectors, and between types of spatial units. The conclusions are in Section 6.

5.2 PREVIOUS LITERATURE

In one of the first and most widely cited studies for China, Au and Henderson (2006) found that output per worker had an inverted U-shaped relationship with city size in data from 205 cities in the 1990s.[50] The productivity cost of small cities (below the peak of the inverted U) exceeded that for oversized cities and these authors note that most Chinese cities were smaller than the peak point. This paper is the source of the often repeated claim that China has too many small cities, and foregoes agglomeration-based productivity gains as a result. But the

[50] Specifically they use data for urban districts within some prefectural cities.

data Au and Henderson (2006) use may not be the best for drawing these conclusions. They use city yearbooks that at the time only counted local *hukou* holders and did not include employees in private sector firms. But the GDP data reflected output of both private and state sector workers, and the consumption of both the locally registered *hukou* population and the city residents with *hukou* from elsewhere. Hence, the measured scale of cities should reflect both types of population and the employment denominator for GDP should cover all types of workers.

A similar miscounting problem likely affects results reported by Xu (2009), who finds positive effects of city population and density on productivity (GDP per worker) using city-level panel data for urban districts in 155 prefectural cities in the 1990s. City size is from the locally registered population rather than from the actual number of residents, so it greatly understates the size of cities with many non-*hukou* residents. The GDP per worker data also have problems since city yearbooks did not count all private sector employees. It is thus unclear if the estimate of peak productivity at a city size of four million people is valid, which may undermine Xu's conclusion that most of China's cities are too small to achieve this peak level of productivity.

One way to sidestep problems with the employment denominator is to use survey data on wages, which is the approach of Combes et al (2015). But findings in this study also may be distorted since the employment density variable is just for workers with local *hukou*, while the share of workers whose *hukou* is from elsewhere augments the 'native' density. The reason for separating these effects is unclear since non-*hukou* residents should be an intrinsic part of urbanization economies, but it may reflect limitations in the Urban Household Survey, which excludes non-*hukou* residents from the sampling frame. Aside from this concern, an important contribution is made by Combes et al (2015) in showing that workers in China do not appear to sort across cities, in terms of variation in the measured productive qualities of workers in cities of various sizes. [51] Consequently, micro data are not needed to control for cross-city variation in worker characteristics when urbanization economies are being estimated. This is advantageous since most survey data in China have gaps in sample frames due to the exclusion of non-*hukou* urban residents. Using city-level data rather than worker- or firm-level data is common in the literature on urbanization economies, and in the meta-analysis of Melo et al (2009) the choice of data type is shown to have no influence on results.

In addition to these estimates of urbanization economies, a related literature describes the agglomeration process in China, concentrating on changing patterns of industrial location. For example, Ge (2009) estimates location regressions to explain the share that a locality has in national employment for each manufacturing sector. This analysis suggests that industrial agglomeration is driven by foreign trade and investment, and is centered on the east coast in places with easy access to foreign markets. Two concerns with this study are that the spatial units used (provinces) are quite broad and may miss finer scale patterns, and that there is no attention to the services sector. Yet services may have large urbanization economies because the proximity of service

[51] Even in developed countries there may be limited sorting of workers due to the complementarity of different labor types within local labor markets (Albouy, 2008). Eeckhout et al (2014) find both the very high and the very low skilled sort into the biggest U.S. cities and so effects on average skill levels by city size may cancel out.

providers to consumers in denser cities allows greater substitution away from home production due to a lower time cost of buying services (Murphy, 2013). In contrast, locations for the production and consumption of goods are more easily separated and so goods producers may not benefit as much from locating in a larger, denser, more diverse urban area.

5.3 DATA DESCRIPTION

The data are from China's second and third administrative levels that are described in Appendix Table 1. In most of China the unit at the second administrative level is a prefectural city, *diji shi*. Every prefectural city has district(s), *shiqu*, and merging contiguous districts within a prefectural city gives urban cores that best correspond to a city proper (Roberts et al, 2012). Most prefectural cities also have counties that are largely rural (less than one-fifth of the registered population have non-agricultural *hukou*). Prefectural cities also may have county-level cities, which are closer in urbanization to counties than to districts. In parts of China, especially in the west and southwest, the equivalent to a prefectural city is a League, a Region, an Autonomous Prefecture or a Provincially Administered area; there are 76 of these compared to 287 prefectural cities. These other types of second-level units are distinguished by having no urban districts, and contribute only a small share of GDP (3%) and population (6%) so we ignore them in our analysis. Our estimation sample is the 287 (merged) districts, 321 county-level cities and 1262 counties.

The dependent variable for estimating urbanization economies is non-agricultural GDP per worker in 2010, which we have for all districts, counties and county-level cities. We also use breakdowns of GDP into the secondary sector (which is mainly manufacturing and construction) and the tertiary sector (services). The long form census given to 10% of all households provides details on industry of employment, for 20 industries in 2010 and 16 broader industries in 2000. These industries and our concordances between the two years are defined in Appendix Table 2. The scale measure used to estimate urbanization economies is the urban resident population in the 2010 census. Summary statistics in Appendix Table 3 show that this averages 1.3 million people for (merged) districts and 0.2 million for counties (including county-level cities). It is also notable that average GDP per worker in the secondary sector is twice as high as in the tertiary sector, while it is only 12% higher in districts than in counties.

Several control variables also are included in the regressions, and are summarized in Appendix Table 3. These controls include the average years of schooling of residents in 2010, the employment rate, and proxies for the industrial structure of each urban area (the ratio of secondary sector to tertiary sector GDP and the share of the primary sector in GDP). The control variables also include measures of domestic market potential (using the Haversine formula to calculate average population-weighted distances to all other districts and counties in China) and foreign market access (population weighted distance to the ten largest ports).[52] An instrumental variable for dealing with possible endogeneity in the urban scale of each county or district is also used, based on the count of people from

[52] These are Shanghai, Shenzhen, Ningbo-Zhoushan, Guangzhou, Qingdao, Tianjin, Xiamen, Dalian, Lianyungang, and Suzhou.

each area who had non-agricultural *hukou* registration ten years earlier.[53] We rely on four main sources for these data: the city statistical yearbook (NBS, 2011a), the statistical yearbook for regional economy (NBS, 2011b), the yearbook on registered *hukou* population (MPS, 2001, 2011), and the population census tabulations (NBS, 2003, 2012a).

5.4 CHINA'S AGGLOMERATION AND URBANIZATION PROCESSES

The 2010 population census reveals a process of funneling migrants from many source areas into just a few urban destinations. This is shown in Table 1, which classifies areas according to the scale of their in-migrant or out-migrant stocks, initially for the total population, and then in the bottom panel for just the urban population. The number of non-*hukou* migrants is calculated as:

$$M_i = PR_i - HR_i \quad (1)$$

where PR_i is the count of residents at location *i* in the 2010 census and HR_i is the number with *hukou* registration from location *i*. The number of non-*hukou* urban migrants (UM_i) is:

$$UM_i = U_i - NA_i \quad (2)$$

where U_i is the urban resident population for location *i* in the 2010 census and NA_i is the number of people who had non-agricultural *hukou* registration from that place in 2010. The estimates of HR_i and NA_i come from the Ministry of Public Security (MPS, 2011).

The funnelling noted above is seen in the top panel of Table 1; 110 million people came from over 1400 source areas to live in 460 destinations. This

[53] The justification for this variable, and its relationship to other identification strategies, is explained in Section 5.

relocation affects both agricultural and non-agricultural *hukou* holders since the type of *hukou* is not being considered; some of these migrants will have had non-agricultural *hukou* and made urban-to-urban moves. Another view of the funnelling process is seen within rows in the top panel of the table; 84 million non-*hukou* out-migrants are registered in 1099 different counties yet as many in-migrants are living in just 62 districts (focusing on those with at least 0.2 million migrants) and just seven districts are home to 41 million non-*hukou* migrants. Other evidence on spatial relocation of the population is shown by the fact that some urban areas are losing people, as shown in the right-hand columns in the bottom panel of Table 1. Specifically, there are almost 12 million fewer urban residents in some areas than the non-agricultural *hukou* counts for those places; these are cities that in some sense are in the 'wrong' place since already-urbanized people voted with their feet by moving out of them to find agglomeration benefits elsewhere.[54]

In contrast to the agglomeration process, once the focus is on just urban residents and the holders of non-agricultural *hukou* (bottom panel), the urbanization process is apparent. In this bottom panel the most numerous cell is for counties with from 0-0.2 million more urban residents than their number of non-agricultural *hukou* registrations. The people who urbanize by moving from a village to their county seat, or whose village is engulfed as the county seat expands are counted in this cell. We argue that this is a distinct process from the agglomeration process shown in the top panel where people have to, at the very

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[54] For example, the number of people with non-agricultural *hukou* for districts of Shantou city is 5.2 million but the urban resident population in 2010 was just 3.6 million, indicating a substantial out-migration.

least, leave their county to show up as a non-*hukou* migrant. Accounts of China's urbanization note that China has over 200 million rural-urban migrant workers, and this is confirmed in Table 1 by the total of 216.4 million non-*hukou* urban migrants. But little attention is paid to the unequal spatial distribution that results from migrants voting with their feet, shown in the top panel of the table. A lack of spatial awareness may contribute to misguided policies that encourage people to move to small urban locations thinking that it is urbanization that matters more than agglomeration.

Another way to consider differences between the two processes is in terms of scale. If we set an arbitrary rule that sites of agglomeration are urban areas that at least half a million people chose to move to, 46 districts and nine counties qualify. An average of 1.8 million in-migrants live in those 46 districts. For the county-level cities and county the average is 0.67 million. In contrast, the urbanization process shown in the other cells in the lower left part of Table 1 affects far more places – specifically, 1122 counties, 266 county-level cities and 215 districts – but the scale for each destination is tiny, averaging just 0.08 million in-migrants. Collectively the urbanization process is bigger (just over 60% of the 216 million non-*hukou* urban migrants are living outside the 46 districts we highlight as agglomeration locations) but far fewer people go to each of those small locations. Yet small places are the current target of China's land use and urbanization policy, encouraging migrants to settle in these places with an easier process of *hukou* conversion and with lower house prices (due partly to fewer land use restrictions).

Table 1. Agglomeration and Urbanization Processes, as Revealed by Stocks of Non-*hukou* (Urban) Migrants in the 2010 Census

	In-Migrants						Out-Migrants				
	≥ 3mil	≥ 1mil	≥ 0.5mil	≥ 0.2mil	≥ 0mil	Total	≥ 1mil	≥ 0.5mil	≥ 0.2mil	≥ 0mil	Total
						Non-*hukou* Migrants					
District	40.9	27.6	9.3	7.1	10.5	95.4			3.0	4.1	7.0
	(7)	(20)	(13)	(22)	(139)	(201)			(12)	(74)	(86)
County-level City			2.4	2.9	4.0	9.3			7.7	11.4	19.1
			(3)	(8)	(86)	(97)			(26)	(198)	(224)
County				1.3	3.1	4.4		1.9	27.4	55.1	84.4
				(4)	(159)	(163)		(3)	(94)	(1002)	(1099)
						Non-*hukou* Urban Migrants					
District	38.8	30.5	12.9	18.3	15.0	115.4	1.5	0.7	1.7	1.3	5.2
	(7)	(20)	(19)	(61)	(154)	(261)	(1)	(1)	(5)	(19)	(26)
County-level City			5.4	10.7	17.5	33.6		0.6	0.4	1.7	2.7
			(8)	(34)	(232)	(274)		(1)	(2)	(44)	(47)
County			0.6	8.2	58.6	67.4				3.7	3.7
			(1)	(30)	(1092)	(1123)				(139)	(139)

Notes: Non-*hukou* migrants are the resident population minus the registered population, calculated by Equation (1). Sums of non-*hukou* in-migrants and out-migrants do not balance because the ‘irregular’ prefectures such as Leagues and Provincially Administered areas are omitted from the table. The non-*hukou* urban migrants are the urban resident population minus the non-agricultural registered population, calculated by Equation (2). The table cells have the number of migrants, in millions, with the number of locations in ( ).

Sources: MPS (2011), NBS (2011a, 2012a).

The industrial composition of the workforce also shows the effects of public policy in encouraging urban growth in small places. In Table 2, long-form census employment data are used to compare 2000 and 2010. There was a 16.6 percentage point fall in agriculture's share of employment, with four industries increasing shares by about the same total amount. These industries, with percentage point increases in ( ), are: manufacturing (4.6%), construction (2.9%), transport (1.6%) and trade (5.5%). Some of these growing industries are moving away from possible agglomeration benefits; manufacturing and construction had declines in the shares of their employment in urban districts of about 10 percentage points while employment in counties rose, especially for construction. Indeed, 41 percent of all construction employment was in counties in 2010, compared with only 28% in counties in the 2000 census. Government-directed efforts at growing new cities in less urbanized regions typically require urban infrastructure and housing to be built, which may explain this dispersion of employment in the construction sector. Similarly, efforts of local governments to attract footloose manufacturing factories may account for the rise in the share of manufacturing employment in counties.

In contrast to dispersed construction and manufacturing employment, most large service industries in Table 2 show concentration of employment into urban districts. This concentration confirms that it is harder to separate the location of production and consumption for services than it is for goods, making services better candidates for urbanization economies (as seen below). Since China currently has a smaller services sector and a larger manufacturing sector than would be predicted from income levels (Ghani 2012), it is likely that future

Table 2. Distribution of Employment by Industry and Location, 2000 and 2010

	Employment Distribution by Industry			Distribution of Each Industry's Employment Across Spatial Units					
				---------------2010---------------			---------------2000---------------		
Industry	2010	2000	Change	District	County-level City	County	District	County-level City	County
Agricult	46.6%	63.2%	-16.6%	15.1%	19.4%	65.5%	15.7%	19.9%	64.4%
Mining	1.1%	1.1%	0.1%	41.9%	20.4%	37.7%	42.7%	22.7%	34.6%
Manufact	17.8%	13.1%	4.6%	50.9%	22.5%	26.6%	59.4%	20.1%	20.6%
Utilities	0.7%	0.6%	0.1%	57.9%	15.5%	26.7%	55.1%	16.6%	28.3%
Construct	5.7%	2.8%	2.9%	40.8%	18.7%	40.6%	50.9%	20.7%	28.4%
Transport	4.3%	2.6%	1.6%	55.5%	15.3%	29.2%	50.6%	18.6%	30.8%
Trade	12.4%	6.9%	5.5%	55.2%	16.5%	28.3%	55.0%	17.2%	27.8%
Finance	0.8%	0.6%	0.2%	70.1%	11.5%	18.4%	60.6%	13.7%	25.7%
Property	0.7%	0.2%	0.5%	81.2%	8.8%	10.0%	86.2%	6.9%	6.9%
Social Serv	2.7%	2.2%	0.5%	56.8%	15.9%	27.3%	64.5%	14.6%	20.9%
Research	0.7%	0.4%	0.4%	74.2%	10.4%	15.4%	76.6%	9.0%	14.5%
Welfare	4.0%	3.6%	0.3%	54.3%	14.8%	30.9%	46.5%	16.3%	37.2%
Govt	2.5%	2.6%	-0.1%	53.3%	14.2%	32.6%	46.4%	17.5%	36.1%
Total	100%	100%		35.2%	18.8%	46.0%	30.3%	19.3%	50.4%

Notes: Each industry is named and defined in Appendix Table 2, along with a concordance between the classifications in 2000 and 2010. Some industries are merged to allow the concordance; with 'Transport' being industries 6 & 7, 'Trade' being industries 8 & 9, 'Social Serv' being industries 12 & 15, 'Research' being industries 13 & 14, 'Welfare' being industries 16, 17 & 18, and 'Govt' being industries 19 & 20 in Appendix Table 2. Other than that, 'Agricult', 'Mining', 'Manufact', 'Utilities', 'Construct', 'Finance', 'Property' respectively refers to industries 1, 2, 3, 4, 5, 10, 11 in Appendix Table 2. Employment is defined as the population aged 16 or older working and receiving income (NBS, 2012c).
Sources: NBS (2003, 2012a).

employment growth will be greater for services than for manufacturing as China attempts to rebalance the structure of the economy. In some sense, therefore, the employment growth of the secondary sector in counties and county-level cities may reflect an anti-agglomeration urban planning approach that will not best exploit the urbanization economies that are estimated in the next section.

5.5 ECONOMETRIC ESTIMATES OF URBANIZATION ECONOMIES

We use local area GDP estimates and the 2010 census counts to relate output per worker to the size of the local urban population, letting the relationship vary between the sub-sample of counties (including county-level cities) and of districts:

$$\ln(GDP_i/N_i)^d = \alpha^d + \beta^d lnU_i^d + \theta_j^d C_{ji}^d + \varepsilon_i^d \quad (3a)$$

$$\ln(GDP_i/N_i)^c = \alpha^c + \beta^c lnU_i^c + \theta_j^c C_{ji}^c + \varepsilon_i^c \quad (3b)$$

where superscripts indicate if variables and coefficients are from the model for districts (*d*) or for counties (*c*), GDP_i/N_i is non-agricultural GDP per worker for area *i*, and U_i is the urban resident population there.[55] The parameter of interest is β, the elasticity of output per worker with respect to urban scale, which shows the urbanization economies.[56] The regressions include a rich set of covariates to deal with omitted variable bias. The control variables in C_j include dummies for each province, average years of schooling (to control for labor quality differences), employment rates (to control for labor utilization), proxies for the industrial

[55] Studies of urbanization economies sometimes use wages to measure productivity, especially with micro data (e.g. Glaeser and Mare, 2001; Combes et al, 2010). Micro data for China typically omit the non-*hukou* migrants and city average wage data do not cover all private sector workers. We therefore use GDP per worker to measure productivity, and use urban resident population to proxy for city scale following studies such as Sveikauskas (1975) and Rosenthal and Strange (2004).

[56] We do not follow Au and Henderson (2006) in using non-agricultural employment to proxy for city scale. While the right employment variable (from long form census counts, in our case) helps measure worker productivity, urbanization economies are really about the overall size of an urban area. A larger population may improve matches between workers and firms, and may let workers more narrowly specialize and raise their productivity (Puga, 2010).

structure of each area (*msgdp* and *gdp1*), and measures of domestic market potential and foreign market access.

But even with control variables included, the literature has a concern that the error term, ε_i may correlate with U_i due to 'endogenous quantity of labor bias' (Combes et al, 2011). Rather than firms and workers becoming more productive in a more populous area, it may be that being more productive – for whatever reason – causes an urban area to grow. To deal with this, studies typically use historical population as an instrumental variable (IV). The idea is that what affected population location in the agrarian past is different to what affects it today, but location patterns persist due to durability of housing and urban infrastructure.[57] China's command economy era means one does not need the distant past to find causes for the patterns of population location that differ from current causes. Under central planning China was too rural and had too many people in the interior, with regional self-sufficiency upheld for military reasons and to simplify planning. Also, the early Soviet-style focus on heavy industry favoured the northeast region, which was poorly situated compared to the coastal southeast once an outward-oriented strategy was adopted in the reform era. The factors affecting the planned urban ('non-agricultural') population in a given location in the command economy era are less relevant to location decisions in the market era, so the exclusion restrictions needed by a valid instrumental variable are plausible. It is possible to observe the 'echo' of the planned economy urban

[57] Ciccone and Hall (1996), Combes et al (2008) and Mion and Nattichioni (2009) use long lags of population as instruments, while Rosenthal and Strange (2008) and Combes et al (2010) also use geological characteristics. All of these studies find almost no endogenous quantity of labor bias, with elasticities of urban scale hardly changing in the IV estimates (see summaries in Puga, 2010, page 207; Combes et al, 2011, page 261).

structure in modern data, since *hukou* status is inherited. So based on this reasoning, our instrumental variable is the non-agricultural *hukou* population for each location, as of the year 2000.

The main results of equations (3a) and (3b) are in Table 3, with more details in Appendix Table 4. In a pooled OLS regression the elasticity of output per worker with respect to urban scale is 0.09 (Table 3, column 1). But once we let coefficients differ between the sub-samples of districts and counties the effect of urban scale on productivity is seen to be almost three times as large for districts as for counties and county-level cities. The difference in coefficients between the county sub-sample and district sub-sample is statistically significant ($p<0.01$) according to a Chow test. The finding that urbanization economies are three times as large in districts as in counties persists when IV estimation is used (column (3)). The diagnostic tests for the IV models show that the number of people with non-agricultural *hukou* registration for each area, ten years earlier, is a very strong instrumental variable (first-stage F=2432). Using this instrument slightly raises the urbanization elasticities, by between one-fifth and one-tenth.[58]

In contrast to the small effect from using IV estimation, introducing the full set of control variables (in column (4)) reduces the elasticity of urban scale by one-half for districts, while for counties and county-level cities the elasticity becomes negative and statistically insignificant. The results for the control variables (in Appendix Table 4) suggest that the industrial structure of each urban area is a highly significant covariate, as are average school years and employment

[58] This corroborates the common finding in the literature that endogenous quantity of labor bias has minor effects.

Table 3. Effects of Urban Scale on 2010 GDP per Worker, for Different Spatial Units and Economic Sectors

	Non-agricultural Sector				Secondary Sector		Tertiary Sector	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	OLS	OLS	IV	IV	IV	IV	IV	IV
U	0.090							
	(0.013)***							
U^d (districts)		0.149	0.181	0.088	0.142	-0.008	0.226	0.151
		(0.037)***	(0.039)***	(0.038)**	(0.054)***	(0.052)	(0.031)***	(0.034)***
U^c (counties)		0.057	0.064	-0.028	0.025	-0.073	0.098	0.014
		(0.019)***	(0.022)***	(0.019)	(0.031)	(0.025)***	(0.018)***	(0.017)
α^d		4.506	5.218	-0.619	5.799	-4.131	4.232	0.583
		(0.483)***	(0.326)***	(2.456)	(0.445)***	(3.375)	(0.258)***	(2.225)
α^c		4.673	4.707	-0.479	4.672	-3.498	4.756	0.974
		(0.477)***	(0.472)***	(0.980)	(0.643)***	(1.346)***	(0.374)***	(0.888)
Constant	4.423							
	(0.275)***							
Full controls				Yes		Yes		Yes
Adjusted-R^2	0.29	0.99						
IV *F* statistic			2432	2235	2432	2235	2432	2235
Chow *p*-value		0.00	0.00	0.00	0.00	0.00	0.00	0.00

Notes: U is (log) resident urban population for districts (*d*) or counties and county-level cities (*c*). All models include province fixed effects. Other controls include *AYS*, ER, msgdp, gdp1, *DMP*, and *FMA* (defined in Appendix Table 3) used for the models in columns (4), (6) and (8) with detailed results in Appendix Table 4. The IV models use the (log) non-agricultural *hukou* population in 2000 as an instrument for *U*, and the IV *F* statistic is the Cragg-Donald first-stage *F* statistic for the instrument. The Chow *p*-value is for testing the null hypothesis that coefficients for the county-level model are the same as for the district-level model.

N=1870, with 287 districts and 1583 counties (1262 counties and 321 county-level cities). Standard errors are in parentheses. *significant at 10%; ** at 5%; *** at 1%.

rates in counties, while domestic market potential in counties and district average school years are weakly associated with average output per worker. Controlling for all of these factors, the IV estimate of the elasticity of output per worker with respect to scale for urban districts is 0.088; as a reminder, these are the core of prefectural cities and average 1.3 million residents. In contrast, county-level cities and urban areas in counties average just 0.2 million urban residents and seem to provide no urbanization economies. Whatever else may be achieved by planners trying to steer rural migrants into these smaller urban areas, the results in Table 3 give no reason to expect any increase in local non-agricultural productivity by making these non-core urban areas bigger.

The output-scale elasticity of 0.088 for urban districts also has another implication, based on its similarity to findings in the literature for other countries. For example, Melo et al (2009) report an average elasticity of urban scale of 0.08, based on 264 estimates from 34 studies across the world. Similarly, an early study by Sveikauskas (1975) has an elasticity of output per worker with respect to local population of 0.06, while the Rosenthal and Strange (2004) survey puts the elasticity between 0.03-0.08. The (merged) districts of China's prefectural cities best match the urbanized parts of the metropolitan statistical areas used in other countries (Au and Henderson, 2006) so the elasticity reported here may be comparable to these results. If urbanization economies for China are of similar size to those in countries where the city size distribution has been less distorted by mobility restrictions and planning policies, it suggests that China's contemporary city size distribution may be less malformed and may cause smaller productivity losses than is often claimed.[59] Indeed, a related study suggests that most of China's cities are close to their productivity-maximizing scale, with the number of workers in cities that are too small about the same as the number in cities that are too big (Li and Gibson, 2015).

In addition to showing the location of urbanization economies, the results in Table 3 help to reveal something about the nature of these effects in China. When output per worker in the secondary sector is considered separately from the tertiary (services) sector, it is apparent that urbanization economies operate only through tertiary sector activity. In the models using the full set of controls, output per worker in the secondary sector has no relationship with urban scale for districts, and has a negative relationship (with an elasticity of -0.07) for counties (column (6)). In contrast, for output of the tertiary sector, the scale elasticity is 0.15 for districts and is highly significant, while there is no significant effect of urban scale on tertiary sector productivity in counties and county-level cities (column (8)). Thus, to the extent that positive externalities due to urban scale exist in China, they appear to be a feature of the services sector only but even in that sector they only occur in the bigger urban areas that make up the core of prefectural cities.

5.6 CONCLUSIONS

In this paper we contribute to the growing literature on agglomeration effects in China, using data that are more reliable than those available to previous studies. It is only since China's 2010 census that accurate estimates of the urban population

[59] For example, the urban scale elasticity from survey data on Chinese wages in Combes et al (2015) is about three times what is found with similar data in other countries. This large elasticity implies China is not yet fully exploiting available agglomeration benefits due to having too many undersized cities.

and of total employment are available. Since measures of local population scale are crucial for estimating urbanization economies, having these more reliable data makes it timely to re-examine previous results. Our data also are more comprehensive than those used in prior studies, covering the entire urban hierarchy, and coming from 287 prefectures that provide 97 percent of China's GDP. Prior studies have used samples with more limited spatial coverage and focus on only one type of urban unit, or else use survey data that omit major population groups, such as the non-*hukou* urban residents.

Our results show that effects of urbanization economies on China's non-agricultural GDP per worker are of similar size to what is found in other countries, with an elasticity of urban scale of about 0.09. The similarity to what is found elsewhere may count against the argument that a legacy of China's command economy era, and especially its *hukou* restrictions on population mobility, is that it does not reap the full agglomeration benefits that it might with a different urban structure. Indeed, even the simple descriptive claim that China has too many small cities relative to large ones can be questioned, since this claim is based on incorrect measures of city scale that use the number of people with local *hukou* registration (a *de jure* measure) rather than the actual number of residents (a *de facto* measure).

Our focus on the resident population shows that an important reshaping of China's economic geography is under way, due in part to the effects of non-*hukou* migrants who have voted with their feet. The total of 216 million non-*hukou* urban migrants enumerated in the 2010 census represents two processes; a funnelling towards 46 urban districts that accounts for about two-fifths of the total, which we argue is an agglomeration process, and a more dispersed urbanization towards 1612 districts, counties, and county-level cities which we argue is not an agglomeration process. A comparison of 2010 and 2000 census employment by industry data suggest that the dispersed urbanization operates especially through the secondary sector, with increasing shares of construction and manufacturing employment located in counties. In contrast, the services sector increasingly concentrates into the larger urban districts. There may be a mismatch between people's choices, as revealed by their funnelling into a few big cities, and a pro-small bias in China's urban planning policy that encourages migrants to settle in smaller, dispersed, urban areas through an easier process of *hukou* conversion and fewer land use restrictions.

Notwithstanding this pro-small policy bias, the econometric evidence is that agglomeration effects in China occur only in urban districts (the urban core of prefectural cities) and do not occur in county-level cities or counties. Moreover, it is only in the tertiary (services) sector where there are positive agglomeration effects, with the secondary sector (manufacturing and construction) not showing a positive effect of urban scale on productivity. Specifically, our results suggest that a ten percent increase in scale for the urban districts of prefectural cities raises output per worker by 1.5 percent in the tertiary sector. In contrast, increases in urban scale for counties and county-level cities have no effect on output per worker in the tertiary sector and are associated with lower secondary sector output per worker. These patterns imply that the recent efforts of local and central government in China to encourage a dispersed form of urbanization, by stimulating construction and manufacturing activity in counties, is unlikely to create beneficial agglomeration effects. A more even-handed urban planning approach that is not biased against the biggest cities is needed if China is to make the most of the potential productivity gains from its on-going urban transformation.

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Appendix Table 1. Shares of Various Administrative Divisions in National Population and GDP, and Urbanization Rates, 2010

Admin Level *(Chinese Name)* (Number)	Registered Population	Resident Population	Non-agricultural Population	Urban Population	GDP	Non-agricultural Rate	Urban Rate
Prefectural City *(diji shi)* (287)							
District (*shiqu)* (287)	28.0%	34.8%	54.8%	53.9%	54.3%	66.7%	77.8%
County-level City (*xianji shi)* (321)	17.4%	16.8%	15.4%	15.1%	18.1%	30.0%	45.1%
County (*xian)* (1262)	47.1%	41.5%	24.9%	26.5%	24.2%	18.0%	32.2%
League *(meng)* (3), **Region** *(diqu)* (17), **Autonomous Prefecture** *(zizhi zhou)* (30)							
County-level City (49)	1.3%	1.4%	1.7%	1.5%	1.0%	42.4%	55.8%
County (358)	5.2%	4.7%	2.3%	2.3%	1.7%	15.0%	24.2%
Provincially Administered *(shengxia)* (26)							
County-level City (14)	0.7%	0.6%	0.8%	0.6%	0.5%	37.4%	46.5%
County (12)	0.3%	0.2%	0.3%	0.2%	0.1%	31.5%	36.8%
Total	100.0%	100.0%	100.0%	100.0%	100.0%		
Prefectural city	92.5%	93.1%	95.0%	95.5%	96.7%		
League, Region, Autonomous Prefecture	6.5%	6.1%	4.0%	3.8%	2.7%		
Provincially Administered	1.0%	0.8%	1.0%	0.7%	0.6%		

Notes: Prefectural cities include Beijing, Tianjin, Shanghai and Chongqing, which are at provincial level but are similar to prefectural cities (according to NBS, 2011a). A prefectural city's districts are contiguous areas, which collectively represent its city proper (Roberts et al, 2012). County-level cities here include Chongqing's 10 districts (Puling, Wansheng, Shuangqiao, Changshou, Jiangjin, Hechuan, Yongchuan, Nanchuan, Wanzhou and Qianjiang), Wuhan's 4 districts (Caidian, Jiangxia, Huangpi and Xinzhou according to NBS, 2011a), and Kunming's 1 district (Dongchuan). Counties here include banners (*qi*, 49), autonomous banners (*zizhi qi*, 3), and forestry area (1). There are 13 prefectural cities, Wuhai (Inner Mongolia), Xiamen (Fujian), Laiwu (Shandong), Ezhou (Hubei), Shenzhen, Zhuhai, Foshan, Dongguan and Zhongshan (Guangdong), Haikou and Sanya (Hainan), Jiayuguan (Gansu) and Karamay (Xinjiang) having neither county-level cities nor counties. Registered Population is from the 2010 *hukou* household registration system administered by the Ministry of Public Security, in which a household is given either "agricultural" (*nongye*) or "non-agricultural" (*fei nongye*) *hukou* by the local police station at the place of *hukou* registration. Resident Population is the population in the 2010 Population Census conducted by the National Bureau of Statistics of China, of which Urban Population includes households residing in urban areas in districts, county-level cities and counties while Rural Population includes the rest (NBS, 2012b&c). Non-agricultural Rate is the ratio of the non-agriculture population to the registered population while the Urban Rate is the ratio of the urban population to the resident population.
Sources: MPS (2011, noting that the reported registered population for districts and counties of five prefectural cities Fuyang, Suzhou, Bozhou, Liuan and Chaohu in Anhui province are incorrect and have been corrected by the authors according to NBS, 2011a,b&c), NBS (2011a,b&c, 2012a).

Appendix Table 2. Industry of Employment Definitions in 2010 and 2000 Long Form Census of Population

ID	2010	2000
1	Agriculture, Forestry, Farming, Fishery	Agriculture, Forestry, Farming, Fishery
2	Mining	Mining
3	Manufacturing	Manufacturing
4	Electricity, Gas, Water Provisions	Electricity, Gas, Water Provisions
5	Construction	Construction
6	Warehousing, Postal Services	Transportation, Warehousing, Postal, Telecommunication Services
7	Transportation, Computer, Software	
8	Information, Wholesale & Retail Trades	Wholesale & Retail Trades, Accommodation & Food Services
9	Accommodation & Food Services	
10	Finance	Finance & Insurance
11	Real Estate	Real Estate
12	Rental, Leasing, Business Services	Social Services
13	Scientific Research, Technical Services, Geological Survey	Scientific Research, Technical Services
14	Water Conservation, Environment, Public Facility Management	Water Conservation, Geological Survey
15	Resident Services	
16	Education Services	Education, Culture, Arts, Sports, Radio, Film, Television
17	Health Care, Social Security, Social Welfare	Health Care, Sports, Social Welfare
18	Culture, Sports, Entertainment	
19	Public Administration, Social Organizations	State Agencies, Party Agencies, Social Organizations
20	International Organizations	Others

Notes: The long form census is filled in by 10% of households. Compared to the usual census forms it has extra questions related to occupation, industry, marital status, family, and housing; ID is industry identification number.
Sources: NBS (2003, 2012a).

Appendix Table 3. Variable Definitions and Summary Statistics

Variable	Definition	Districts		Counties	
		Mean	Std. Dev.	Mean	Std. Dev.
Dependent variables					
GDP/N	Non-agricultural GDP per worker (thousand yuan) in 2010	110.6	49.5	98.6	67.8
	Secondary sector GDP per worker (thousand yuan) in 2010	163.9	95.4	154.5	165.2
	Tertiary sector GDP per worker (thousand yuan) in 2010	79.7	34.4	68.3	38.3
Independent variables					
U	Urban resident population (millions) in 2010 census	1.26	2.09	0.18	0.14
AYS	Average years of schooling of residents in 2010	9.86	0.94	8.36	0.68
ER	Employment rate (employed workers/residents aged 16+) in 2010	0.62	0.08	0.72	0.07
msgdp	Manufacturing to service ratio (secondary GDP/tertiary GDP) in 2010	1.43	0.91	1.70	1.15
gdp1	Primary sector share in GDP (primary GDP/GDP) in 2010	0.07	0.07	0.21	0.11
DMP	Domestic market potential (distance to other districts/counties, kilometers)	1192	343	1154	313
FMA	Foreign market access (distance to 10 largest Chinese ports, kilometers)	1175	450	1165	405
IV	Instrument (non-agricultural *hukou* population in 2000, millions)	0.62	0.95	0.08	0.06

Notes: There are 287 districts and 1583 counties (including 321 county-level cities).
Sources: MPS (2001); NBS (2011a&b, 2012a).

Appendix Table 4. Detailed Results for Control Variables in Models Reported in Columns (4), (6) and (8) of Table 3

	GDP/N					
	Non-agricultural Sector		Secondary Sector		Tertiary Sector	
	District	County	District	County	District	County
	(1)	(2)	(3)	(4)	(5)	(6)
	IV	IV	IV	IV	IV	IV
U	0.088	-0.027	-0.007	-0.067	0.150	0.014
	(0.027)***	(0.019)	(0.035)	(0.027)**	(0.026)***	(0.017)
AYS	0.506	1.087	1.154	1.334	0.106	0.937
	(0.289)*	(0.158)***	(0.377)***	(0.219)***	(0.275)	(0.143)***
ER	0.019	0.756	-0.661	0.845	0.835	0.845
	(0.314)	(0.167)***	(0.409)	(0.231)***	(0.299)***	(0.151)***
msgdp	0.192	0.130	0.265	0.249	-0.042	-0.113
	(0.021)***	(0.010)***	(0.027)***	(0.014)***	(0.020)**	(0.009)***
gdp1	-2.321	-1.967	-2.269	-1.725	-2.626	-2.103
	(0.371)***	(0.126)***	(0.484)***	(0.174)***	(0.353)***	(0.114)***
DMP	0.146	0.282	-0.187	0.257	0.502	0.485
	(0.269)	(0.164)*	(0.351)	(0.227)	(0.256)**	(0.148)***
FMA	0.346	-0.093	0.549	-0.097	0.049	-0.258
	(0.260)	(0.162)	(0.340)	(0.224)	(0.248)	(0.146)*
Observations	287	1583	287	1583	287	1583
IV *F* statistic	1587	3751	1587	3751	1587	3751

Notes: Variables in *italics* are in logarithms. Each regression also includes province-level fixed effects (30 for districts, 29 for counties and county-level cities). The IV is the (log) non-agricultural *hukou* population in 2000. IV *F* statistic is the Cragg-Donald first-stage *F* statistic for the instrument. The number of observations includes the 287 districts and 1583 counties (1262 counties and 321 county-level cities). Standard errors are in parentheses. *significant at 10%; ** at 5%; *** at 1%. Variable definitions and summary statistics are shown in Appendix Table 3.

Chapter 6

Shining Light on Erroneous Use of China's Sub-national Data

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Shining Light on Erroneous Use of China's Sub-national Data

Abstract

This paper uses measures of city area derived from night lights as an arbiter to compare two different types of local population data for China; a *de facto* measure based on census counts of where people actually reside, and a *de jure* measure based on police records of where they are registered to live under China's *hukou* system. One would conclude that expansion of urban areas is driven by income growth with no independent role played by local population growth, if the *de jure* population from the *hukou* registration data is used as a proxy measure for city-level population. In contrast to this conclusion, which we consider to be an artefact, if the more appropriate *de facto* population measure based on census counts of where people actually reside is used, there is a strong effect of local population growth on urban expansion and no apparent effect of income growth.

Keywords: China

JEL: R12, O15

6.1 INTRODUCTION

Researchers who work with sub-national data for China face an important but largely ignored data problem. The most widely available population counts for provinces, prefectures, cities and counties are not counts of residents, as in most other countries. Instead they are counts of people whose address for their household registration (*hukou suozaidi*) is from within that locality. Many people now live thousands of miles away from their place of *hukou* registration so this is a *de jure* count of where people are legally registered to live rather than a *de facto* count of where they actually live. These counts are reported in annual yearbooks put out by China's statistics office but are based on data from the Ministry of Public Security – China's police force – since Chinese are meant to (but do not) stay registered at local police stations.

The "counting errors" from treating the *de jure* count of *hukou* holders as the *de facto* local population may substantially distort economic analysis since population counts are central to many branches of applied economics. In urban economics, the size of cities is important for understanding the scope for higher productivity due to agglomeration effects from workers and firms locating in larger, denser environments. In development and welfare economics, and in studies of inequality, interest is usually in income or output *per capita* since comparing totals for unequally populated areas is not informative. In this regard, there is a literature on the accuracy of China's economic statistics (e.g. Holz, 2004; Chow, 2006) but almost no attention is paid to the errors in the population denominator of *per capita* indicators.

Yet for the first three decades of the reform era in China, local GDP was divided by the count of people with local *hukou* registration for a particular sub-national area rather than by the count of local residents. It is not the *de jure* population whose production and consumption goes in to local GDP, so this was a biased measure, and the bias grew with the rising tide of migration as millions left their place of *hukou* registration. By 2010, the census counted over 220 million of these non-*hukou* migrants; one-third of China's urban residents. A clear distortion from using these biased data is in regional inequality statistics, which seemed to rise from 1990 until 2004, when a fall coincided with China investing heavily in lagging regions (Fan et al, 2011). Both the apparent rise and the turning point are statistical artifacts due to provincial GDP figures initially being denominated by the count of people with *hukou* registration from each province and then switching to using the number of residents as a denominator (Li and Gibson, 2013).[60]

The risk of distorted analyses from erroneous use of China's local population data goes well beyond studies of regional inequality. The bias from using the wrong population will vary with the level and growth of local GDP, since non-*hukou* migrants are attracted to richer, faster growing, areas, so time-series of *per capita* variables for sub-national areas are affected. Such data are widely used, in part because China is unusual in reporting GDP statistics for the third sub-national level (counties and urban districts, which are below prefectures, which are below provinces). With sub-national GDP data so finely grained, they

[60] There was also a double-counting problem because some provinces switched before others, so someone may have been in the denominator of GDP *per capita* for two different places at the same time; as a resident of one province and in the *hukou* registered population of a province that was slow to switch to reporting output per resident. In some years up to 26 million people were double-counted (Li and Gibson, 2013).

are increasingly used by researchers, even to validate proxy measures for local economic growth applied elsewhere (Storeygard, 2013). For example, of 464 economics journal articles with ‘China’ and ‘city’ and ‘economic growth’ as keywords or in the title, 45% were published in the last four years.[61]

It is not just a denominator bias that results from the *de jure* population being treated as a *de facto* population. Any study that relies on how big are sub-national units, in either population or employment terms, is likely to be biased. For example, the often repeated claim that China has too many small cities is an artifact of measuring cities by how many local *hukou* holders there are, rather than by how many residents they have.[62] The employment size of cities is likewise biased since *City Statistical Yearbook* (*CSY*) data omit most private sector employees; long-form census data in 2010 show that *CSY* reports an average of only 43% of the employment for each city that the census counts (Li and Gibson, 2015). While surveys are not inherently biased, since they can define residency by how long someone lives in a locality rather than just relying on their *hukou* status, China’s lack of a complete sample frame threatens survey validity. The main urban and rural household surveys by China’s National Bureau of Statistics (NBS) are based on *hukou* registration rather than on the census and so non-*hukou* migrants are omitted from the sample frame. Hence, many surveys provide an incomplete picture of modern China.

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[61] Specifically, a search of EconLit (May 11, 2015) reveals that there were 23 papers published in all of the 1990s, 74 published between 2000 and 2005, 159 from 2006 to 2010, and 208 from 2011 to 2014.

[62] Au and Henderson (2006, p.557) claim China had nine cities with over 3 million people and 125 in the 1-3 million range in 2000. This ratio of large to small cities (0.07) was well below the global average of 0.27. But measuring cities by residents, as counted in the 2000 census, China had 20 cities over 3 million and 89 cities of 1-3 million, giving a ratio of 0.23; more than three times higher than Au and Henderson report and just below the global average.

To see how widespread is the failure to account for these features of China's sub-national data, we surveyed empirical articles on China published in three groups of economics journals: 'blue-ribbon' journals, [63] development journals,[64] and regional and urban journals.[65] We studied articles published from 2005, after the switch to reporting GDP *per capita* on a resident population basis. Since the NBS also reports total GDP for sub-national units, a researcher could, thereafter, derive a yearly average resident population for each locality from the ratio of the two numbers.[66] In contrast, the most widely used population data are year-end counts of the number of people with *hukou* registration from each locality.

Of the 94 articles that we surveyed, just 15 correctly interpreted China's sub-national data while the other 84% made various errors. The most common error was for sub-national areas to be measured with the wrong population or employment data, followed by using *per capita* data calculated with the wrong denominator for the interpretation placed on the variables. The results summarized in Appendix Table 1 show that there is a little better understanding in the development journals, but no trend for an improved interpretation of the data over time. The 79 articles that incorrectly interpreted the data are cited an average of 84 times each (in *Google Scholar*) so any errors in the results they report may contribute to widespread misunderstanding of modern China. Given that we

[63] *American Economic Review*, *Review of Economic Studies*, and the *Review of Economics and Statistics*.
[64] *Journal of Development Economics*, *World Development*, and the *Journal of Comparative Economics*.
[65] *Journal of Urban Economics*, *Regional Science and Urban Economics*, and the *Journal of Economic Geography.*
[66] However, such estimates are still not as reliable as the census counts of residents (see Section 2, below).

surveyed only nine journals, if we extrapolate to all economics journals it is likely that there are hundreds of articles that misinterpret China's sub-national data.

Given the on-going problems in the literature on China, the goal of this paper is to shine more light on the erroneous use of China's sub-national data. A few prior studies also cover some of the points that we make (e.g., Chan, 2007; Li and Gibson, 2013) but we go beyond just comparing results using resident population counts for local areas with results using the *hukou* registered population. Such comparisons shows inconsistencies, with results for the resident population counts presumed to be more correct, but have no independent arbiter of truth showing which data are right. In this paper we use satellite-detected luminosity as just such an independent measure. Night time lights also are used by Pinkovsky and Sala-i-Martin (2014) to sift between conflicting data (survey estimates of consumption versus consumption from the national accounts) so our paper builds on an existing approach to assessing data quality.

Specifically, we run a statistical 'horse race' between two models of the growth in urban area (as shown by night lights) for over 200 Chinese cities, between 2000 and 2010. One model uses the change in the *hukou* registered population for each city while the other uses the change in the urban resident population, as recorded by China's population censuses. The focus is on urban area because an existing literature models this, and the key paper (Deng et al, 2008) is the most cited article in our survey of regional and urban economics journals. That paper used a first differenced model of the change in urban area between 1995 and 2000 (as detected by Landsat) for 2200 counties and found that local GDP growth explained all of the urban expansion, with no independent effect of local population growth. If population growth does not affect urban area, cities should be becoming denser rather than more sprawling were it not for the effects of income growth. Yet this densification is contrary to what is often asserted about China (e.g., World Bank, 2014), and is contrary to what is implied by trade-offs between food security and urbanization that China's policy makers claim to face.[67]

The problem with the Deng et al (2008) study is it uses the *hukou* registered population for each county, as provided by the Ministry of Public Security, as the measure of local population. But there is no reason why urban area would expand when this *de jure* population rises, since more and more people live away from their place of *hukou* registration. Using the wrong population variable to measure how populous are sub-national areas is the most common error in our survey of the literature using China's sub-national data. Thus, testing for distorted findings on this specific topic may inform about the potential for distorted analysis, more generally, from failure to recognize this data problem.

The next section briefly reviews "counting errors" in China's sub-national statistics. The errors mean that it is only for census years (2000 and 2010) that researchers can be confident of population data (and therefore *per capita* variables) for sub-national areas. For other years, what is reported as a resident population will often be a registered population count, exaggerating the

[67] For example, China recently announced strict controls to stop big cities expanding on to farmland, with the Minister for Land and Resources, Jiang Daming, justifying these controls by claiming that good farmland has been 'eaten by steel and cement' (for details, see http://news.xinhuanet.com/english/china/2014-11/03/c_133763130.htm).

population of migrant-sending areas and understating it for migrant-receiving areas. Section 3 describes the urban area estimates we use, and the population and GDP data. Results in Section 4 include non-nested tests comparing regression models of urban area that rely on the two types of population data. The conclusions are in Section 5.

6.2 A REVIEW OF THE COUNTING ERRORS

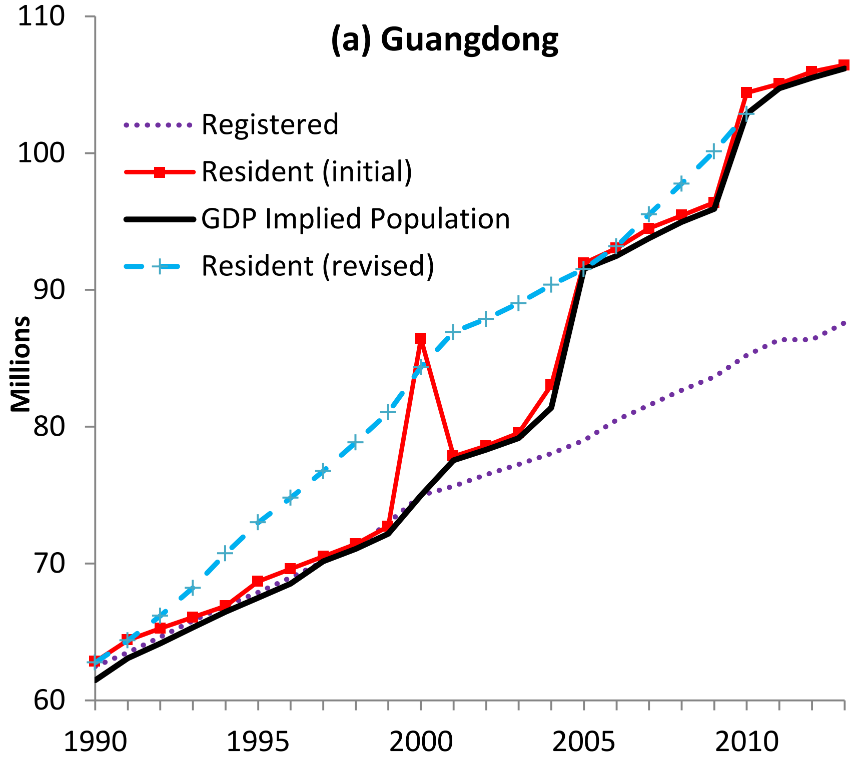
The main problems in China's sub-national population and GDP *per capita* data can be seen by examining four time series; shown in Figure 1a for a migrant-receiving province (Guangdong) and in Figure 1b for a migrant-sending province (Anhui). These series, in increasing order of complexity, are:

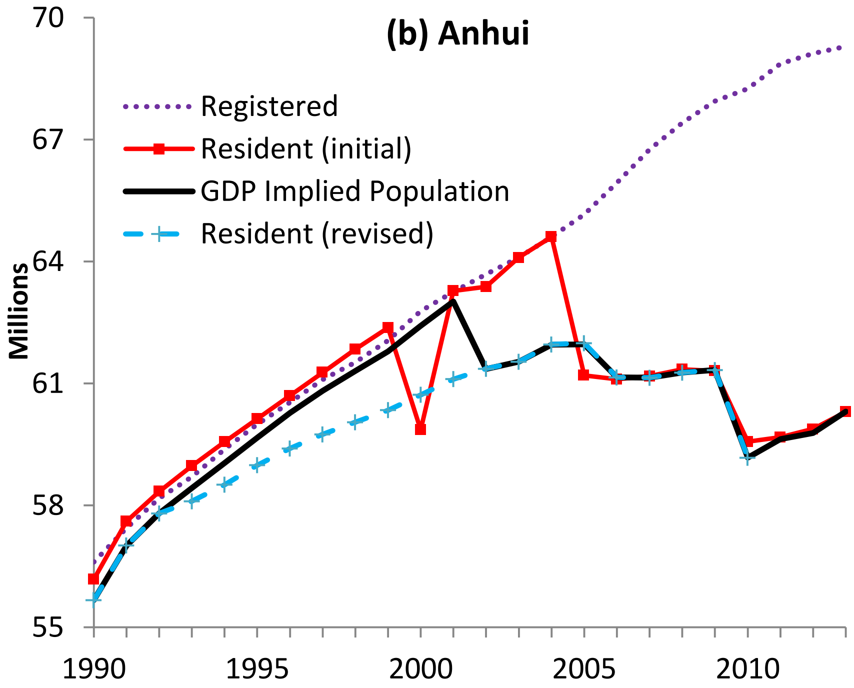
- Registered population - the year-end registered population for each province, as reported in various editions of what is now called the *China Population and Employment Yearbook* but with the original source of the data being the Ministry of Public Security.
- Resident (initial) population - the estimated year-end resident population, also reported in the *China Population and Employment Yearbook*. Most of these data come from the annual National Sample Survey on Population Changes (a 0.1% sample) except in years with a population census (1990, 2000, 2010) or microcensus (2005; 1% national sample).
- GDP implied population – the population values underlying reported GDP *per capita*, derived by dividing provincial GDP by provincial GDP *per capita*, where both series are published on the NBS website for each province.

- Resident (revised) population – in 2011 the NBS combined resident population counts from the 2010 census with economic census data, using a trend-deviation interpolation method to backdate estimates of GDP, the resident population, and GDP *per capita* on a resident population denominator basis. That exercise has not been carried forward, so the series only runs from 1990 to 2010, and the exercise was only carried out for provinces so similarly corrected data are not available for prefectures, counties, or urban districts.

The time series for the registered population grows fairly smoothly, since it reflects deaths and births (*hukou* status is inherited), and, rarely, some *hukou* conversions. From 1990 to 1999, what China's statistical publications report as the resident population almost exactly tracks the *hukou* registered population in both provinces. But the (initial) resident population figures for 2000 show a sharp movement away from the time series of registered population. The census showed that Guangdong had 14 million more residents than was estimated the year before by the 0.1% National Sample Survey on Population Changes, while for Anhui the resident count was almost three million less. These census counts are plugged into the resident population time series by the NBS and the sharp peaks and troughs for the year 2000 do not reflect anything done by us to the data. The reported resident population for Anhui the year after the census fell back to the time series of registered population, which it tracks until the 2005 microcensus revealed 3.4 million fewer people living in Anhui than was reported the year before. The patterns are reversed for Guangdong, although the resident population series never fully returned to the time series of registered population after the 2000 census (but

Figure 1: Four Time Series of Provincial Population Estimates





it still dropped by 8.4 million people from 2000 to 2001). The sharp jumps in the Guangdong population in 2005 (by 9 million) and 2010 (by 8 million) correspond to the extra residents found in years with a microcensus and a full census.

These volatile time series of what is reported as a resident population are repeated for all of China's provinces, with migrant receivers having patterns like Guangdong and senders having patterns like Anhui. In years without a census or microcensus, the number of non-*hukou* migrants is inaccurately estimated by the National Sample Survey on Population Changes and statistical offices in some provinces appear to just use the number of registered *hukou* holders provided by the Ministry of Public Security as a proxy for the resident population. Consequently, research relying on estimates of how populous is each province is likely to be distorted unless it is limited to years with a microcensus or census. This problem is magnified when researchers use sub-provincial units like prefectures, urban districts, or counties because there are more non-*hukou* migrants for smaller units; a person migrating from the countryside to the capital city of their province is not defined as a non-*hukou* migrant at the provincial level, but is at the prefectural or county level. Moreover, there are no revised resident population estimates for sub-provincial areas, unlike the series created by the NBS in 2011 for backdating provincial resident population estimates from 2010 to 1990.

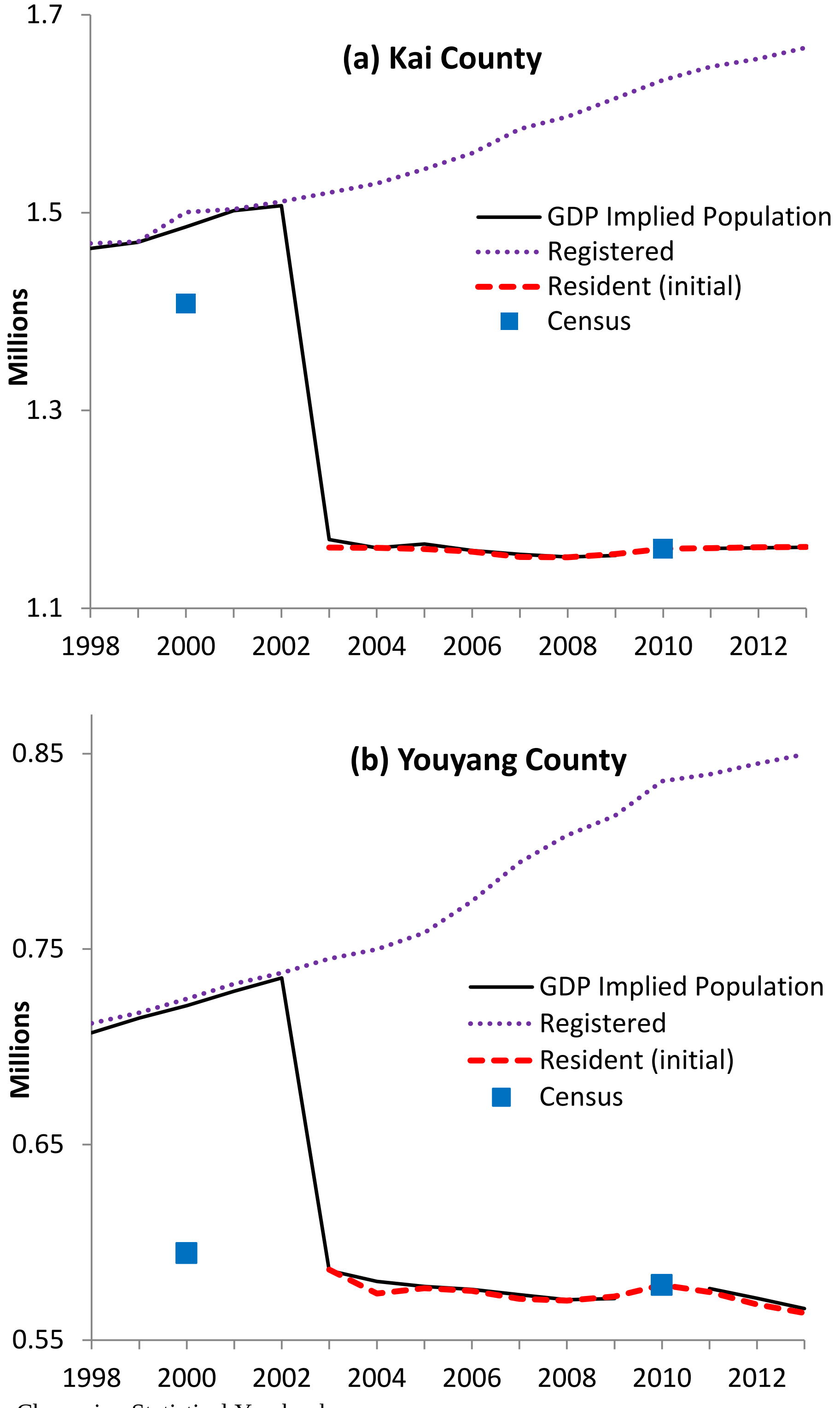
The time series of the GDP implied population shows four problems that may bias results using GDP *per capita* data. First, the denominator is the *hukou* registered population, rather than the number of residents, up until 2001 (Guangdong) or 2002 (Anhui). Accordingly, *per capita* GDP of migrant-sending provinces was ever more understated, since the denominator was increasingly too large, while the reverse bias occurred for migrant-receiving provinces. Second, once provinces switch from using the number of *hukou* registrations as the denominator, the GDP *per capita* of migrant-senders rises since the denominator is now smaller, with a fall in GDP *per capita* (relative to trend) for migrant-receivers since their population denominator increases. Lo and behold, inequality between the coast (migrant-receivers) and the interior (migrant-senders) appears to fall, but this may just be an artifact of the switch in the denominator. Third, there is scope for a double count, since some provinces stopped using the number of *hukou* registrations as a denominator before other provinces made this switch; in the intervening years a migrant might be in the denominator of GDP for two provinces at once and at the peak there were 26 million people in this double-counted group. Finally, the fact that the GDP implied population still jumps in years with a census or microcensus (e.g., 2005 and 2010) suggests that the *per capita* GDP data are not yet accurately capturing the resident population in non-census years.

The problems with local population data are even more complex for sub-provincial areas, since there is variation in statistical practice between provinces. For example, some provinces do not report a time-series of resident population estimates for prefectures or counties, even for the period since 2005 when such estimates have been reported at the provincial level. The counting problems shown in Figure 1 also occur for these sub-provincial areas but two factors make the likely bias due to these problems worse at this finer spatial scale: first, there are no retrospective corrections to the resident population estimates, along the lines of what the NBS did in 2011 for provinces (as shown in Figure 1 for the 'resident (revised)' series). The second factor is that the switch to denominating GDP by the resident population rather than by the registered population entails proportionately much larger breaks in the time-series at the sub-provincial level.

We illustrate this point using population time-series for two counties from Chongqing in Figure 2, where the registered population, the resident (initial) population, and the GDP implied population are defined in the same way as for Figure 1. In 2003 the statistics yearbooks for Chongqing changed the denominator for reporting GDP *per capita* from a *hukou* registered population basis to a resident population basis, leading to apparent falls in population for these two counties of between 21% and 22%. In contrast, at the provincial level the largest drop in implied population from the switch in GDP denominator is for Sichuan, which seems to drop by only 7% (albeit, amounting to eight million people) between 2003 and 2004.

The sharp fall in apparent population (and rise in GDP *per capita*) for migrant-sending counties when provincial statistics offices switched their GDP denominators is clear in Figure 2. But even with the more appropriate resident-based denominators used recently, a further problem is seen for Kai county (as an example of the same problem in many other counties). The resident population time series for Kai county varies by only 0.9% around its mean between 2003 and 2013 and the mean is just 0.2% away from the census count for 2010. But the 2003-2013 time series is 18% below the resident population count from the 2000 census, and it is unlikely that the resident population would fall so sharply between 2000 and 2003 and then stabilize. In contrast, the resident population

Figure 2: Time Series of County Population Estimates



Source: Chongqing Statistical Yearbooks.

Note: No GDP per capita data is reported for 2010 for these counties.

time series for Youyang county appears more plausible, with a range over 2003-13 that is 3.9% of its mean, where that mean is almost exactly equal to the 2010 census count and is just 3.5% below the 2000 census count. The trend in the resident population time-series for Youyang county seems reasonably consistent with the change in the census counts, unlike for Kai county.

We have examined population time series for many other counties, and also for urban districts ('cities') and for prefectures, and we find similar examples of inconsistencies. This evidence suggests that for many sub-provincial areas the resident population counts outside of Census years cannot be considered accurate. These estimates come from a 0.1% sample as part of the National Sample Survey on Population Changes and the likelihood of this survey accurately counting non-*hukou* residents is much less than what can be expected from the complete census enumeration. It would be a mistake, however, to use this evidence to advocate for using the registered population data, which do maintain a consistent definition over time; this *de jure* population series is not a sensible choice for economists to use since it does not correspond to the number of people who are consuming or producing local output. Instead, our review of the counting errors in China's sub-national population data leads us to advocate for restricting the scope of any analysis to relying on changes in local populations between censuses, which is what we do in the remainder of this paper for 2000 and 2010.

6.3 DATA AND MODEL SPECIFICATION

The estimates of urban area in 2000 and 2010 are from Gibson, Li and Boe-Gibson (2014) and are based on remotely-sensed night lights from the Defense Meteorological Satellite Program's Operational Linescan System (DMSP/OLS).

The starting sample for the analysis by Gibson et al (2014) was 260 cities that had data available on built-up area, GDP, and registered population for at least 15 of the 20 years from 1993 to 2012.[68] Towards the end of that sample period, the lit area for some of these administratively defined cities could not be distinguished from the lit area of their neighbors, for cities in larger agglomerations like the Pearl River delta and the Yangtze delta. To provide consistent time series, any cities whose night lights eventually join are merged for all years (1993–2012) and after this aggregation, the number of cities in the sample dropped to n=225 (but they continue to cover the same total area). The population and GDP data used in the current analysis are aggregated in the same way, for both 2000 and 2010.

Unlike other sources of remote sensing data, such as Landsat, estimates of urban area based on night lights require a threshold level of brightness to be set to exclude low-lit areas of sparse development. Cross-validation exercises by Gibson et al (2014) showed that thresholds of 50% and 65% of the maximum luminosity level were appropriate for China's cities.[69] When these thresholds are used a few dimly lit cities drop out of the sample, especially in earlier years when cities were smaller and less brightly lit, and especially for the higher threshold. Other deletions were of any cities whose lit area was less than one square kilometer, which is below the resolution of the most widely used night lights data from

[68] Specifically, these cities are districts (*shiqu*), which are the best proxy for an urban core in China (Roberts et al, 2012). Gibson et al (2014) show that estimates of built-up area reported in *City Statistical Yearbooks* understate trend expansion rates in urban area, most probably because local governments under-report land conversions (World Bank, 2014). Thus just the urban area estimates detected from night lights are used in the current study.

[69] These thresholds correspond to DN values of 32 and 41. Although it is a semantic point, we prefer to talk about a fraction of the maximum luminosity that is recorded by DMSP/OLS (DN=63) to emphasize that these remote sensing observations give a relative rather than absolute measure of brightness, due especially to lack of on-board recording of amplification changes and to inter-satellite differences. Any errors due to these features are captured in the intercepts of our first-differenced models and so should not affect the analyses.

DMSP/OLS (for non-ephemeral lights). After these deletions, the sample sizes are 221 cities if using the 50% light threshold to define contiguously lit areas as urban, and 203 cities if using the 65% threshold. City areas measured at these thresholds both correlate closely with Landsat estimates for the year 2000, with Pearson correlation coefficients of 0.86.[70] Thus it is expected that using night lights derived measures of city area as an arbiter for comparing registered population and resident population should also be informative about likely bias in published results that rely on city areas as measured from Landsat data. It is also expected that by using two different luminosity thresholds to measure cities it should allow an assessment of the robustness of any inferences based on the test results.

The summary statistics in Table 1 show that city area in 2010 had approximately tripled compared with the year 2000, when either detection threshold is used. The summary statistics also show that average city-level GDP, as reported in the *City Statistical Yearbooks*, was roughly five times as high in 2010 as in 2000. These are nominal GDP estimates and since the modelling uses first differenced models the intercept will capture the effects on nominal variables of changes in the general price level. The city-level population counts are the urban resident population from the censuses and the year-end non-agricultural *hukou* registered population from the Ministry of Public Security. In both years the resident population counts are over 40% higher, due to the non-*hukou* residents, and it is this difference between the two types of population estimates

[70] We thank Dr Xiangzheng Deng of the Chinese Academy of Sciences for providing us with these Landsat estimates of city area for the year 2000. Similar estimates have not yet been processed for 2010.

Table 1. Variable Definition and Summary Statistics

Variable	Definition	Observation	Mean	Std. Dev.	Min	Max
		---------------2000---------------				
NA	Non-agricultural population (million)	225	0.74	1.61	0.09	20.07
U	Urban resident population (million)	225	1.08	2.64	0.13	29.42
A65	Night light area at 65% threshold using satellite 15 (km^2)	205[a]	155.32	636.10	0.77[c,d]	7609.59
A50	Night light area at 50% threshold using satellite 15 (km^2)	222[b]	194.46	768.76	0.75[c]	9383.45
GDP	Gross domestic product (billion yuan)	225	20.75	67.49	1.27	795.32
		---------------2010---------------				
NA	Non-agricultural population (million)	225	1.09	2.73	0.12	33.44
U	Urban resident population (million)	225	1.56	4.54	0.15	49.60
A65	Night light area at 65% threshold using satellite 18 (km^2)	225	441.61	1883.09	0.79[c,d]	24706.03
A50	Night light area at 50% threshold using satellite 18 (km^2)	225	577.96	2306.13	2.37	30320.72
GDP	Gross domestic product (billion yuan)	225	106.15	391.93	4.03	4442.01

Notes: [a] 20 observations with missing areas. [b] 3 observations with missing areas. [c] 1 observation with area <1 km^2. [d] Different two observations.
Sources: NBS (2001a, 2003, 2011a, 2012) and DMSP/OLS.

that is at the heart of our tests whose results are reported in the next section.

6.4 RESULTS

The first-differenced models of the change in urban area between 2000 and 2010 are reported in Table 2. In columns (1) and (3) the results are for models that follow the approach of Deng et al (2008) in using a *de jure* population concept, which in this case is the number of non-agricultural *hukou* registrations from each city. These models give results that are quite similar to what is reported by Deng et al (2008), which is that local GDP growth explains the urban expansion, with no independent effect of local population growth. Specifically, the elasticity of urban expansion with respect to growth in local GDP is about 0.2, while the elasticity with respect to the change in local population is not significantly different from zero.

The results are very different when the *de facto* urban resident population from the census counts is used as the measure of local population in the models (in columns (2) and (4) of Table 2). For these models, the elasticity of urban area with respect to population change ranges from 0.38 to 0.43, and these elasticities are precisely measured while there is no statistically significant effect of local GDP change on urban expansion. In other words, the expansion in the area of these cities between 2000 and 2010 can be explained by population growth with no independent effect of rising incomes, if the population whose growth is measured is the resident population rather than the *de jure* population provided by the *hukou* registration system. Thus the finding of Deng et al (2008) that urban expansion in China was due to income growth rather than population growth appears to be an artifact of using the wrong type of local population data for what

Table 2. Effects of Economic and Population Growth on Expansion of Urban Land Area in China 2000-2010 by First Difference Models

	Dependent variable: $\Delta\ln(A)$			
	Night Light 65% Threshold		Night Light 50% Threshold	
	(1)	(2)	(3)	(4)
	OLS	OLS	OLS	OLS
$\Delta\ln(GDP)$	0.190	0.064	0.191	0.031
	(0.108)*	(0.110)	(0.103)*	(0.104)
$\Delta\ln(NA)$	-0.072		-0.161	
	(0.139)		(0.133)	
$\Delta\ln(U)$		0.380		0.431
		(0.186)**		(0.175)**
Constant	1.054	1.122	0.983	1.061
	(0.159)***	(0.158)***	(0.153)***	(0.151)***
Observations	203[a]	203[a]	221[b]	221[b]
Adjusted R^2	0.006[c]	0.025[c]	0.008[c]	0.028[c]
F stat[d]	1.59	3.57**	1.84	4.17**
Cox-Pesaran stat[e]	-11.41***		-7.13***	
	H_0:(1) / H_1:(2)		H_0:(3) / H_1:(4)	
Cox-Pesaran stat[e]	0.23		-0.41	
	H_0:(2) / H_1:(1)		H_0:(4) / H_1:(3)	

Notes: Standard errors are in parentheses; * significant at 10%; ** at 5%; *** at 1%. [a] 20 observations with missing areas and 2 observations with area <1 km^2 are excluded. [b] 3 observations with missing areas and 1 observation with area <1 km^2 are excluded. [c] First-differences models have small adjusted R^2, which is consistent with Deng et al (2008, Table 3, page 111). [d] Tests for the hypothesis that all coefficients (excluding the constant) are zero. [e] Tests for non-nested models.

the modeling task required. Notably, this is the most common type of mis-interpretation of China's sub-national data in our survey of the literature (see Appendix Table 1).

The reversal of results in Table 2 once the *de facto* resident population is used makes intuitive sense. There is no reason to believe that the number of people whose *hukou* registration is from a particular place is a suitable proxy measure for local population in modern China, given the massive and rising tide of non-*hukou* migration. The unsuitability of this proxy measure is especially apparent when seeking to explain urban area expansion, since the uncounted non-*hukou* urban residents also need dwellings to live in, roads to drive on, and offices, shops and factories to work in. All of these activities by non-*hukou* residents require land being converted from agricultural use to urban use and so the *de facto* population is the one that should be expected to be related to the increase in city area.

However we also back up this intuitive reasoning with a more formal testing procedure, by using the Pesaran (1974) version of a Cox likelihood ratio test of the validity of one linear model, H_0 as opposed to its non-nested alternative H_1. The test can be described in general terms, as follows:

$$H_0\text{: } y = x_0 b_0 + u_0$$

$$H_1\text{: } y = x_1 b_1 + u_1$$

where x_0 and x_1 are matrices of n observations on explanatory variables that are not linear combinations of one and other, b_0 and b_1 are corresponding parameter vectors, u_0 and u_1 are random errors with zero mean and variance-covariance matrices $\sigma_0^2 I$ and $\sigma_1^2 I$ (I is an identity matrix of order n). Constructing the test statistic involves six steps, where in what follows we use the notation $M_i = I - x_i(x_i'x_i)^{-1}x_i', i = 0,1$:

(i) Regress y on x_0 to form $\hat{y} = x_0\hat{b}_0$

(ii) Regress the fitted values from (i), $x_0\hat{b}_0$, on x_1 to form residuals: $M_1 x_0 \hat{b}_0$

(iii) Calculate the sum of squared residuals from (ii), $\hat{b}_0' x_0' M_1 x_0 \hat{b}_0$

(iv) Regress the residuals from (ii) on x_0

(v) Calculate the sum of squared residuals from (iv), $\hat{b}_0' x_0' M_1 M_0 M_1 x_0 \hat{b}_0$

(vi) Calculate the test statistic $N = \sqrt{s/\hat{v}}$ which is N(0,1) under H_0, where:

$$s = (n/2)\ln\{\hat{\sigma}_1^2 / [\hat{\sigma}_0^2 + (1/n)(\hat{b}_0' x_0' M_1 x_0 \hat{b}_0)]\}$$

$$\hat{v} = (\hat{\sigma}_0^2 \hat{b}_0' x_0' M_1 M_0 M_1 x_0 \hat{b}_0) / (\hat{\sigma}_0^2 + \hat{b}_0' x_0' M_1 x_0 \hat{b}_0)^2$$

and where $\hat{\sigma}_0^2, \hat{\sigma}_1^2$ are SSE_0/n and SSE_1/n, where SSE is sum of squared errors.

The decision procedure for the test is to reject H_0 for negative (since this is a lower tail test) values of $\sqrt{s/\hat{v}}$ exceeding the critical value from the standard Normal tables. After testing H_0 versus H_1, the procedure is reversed with H_1 replacing H_0 in the above steps.

The results reported in the last rows of Table 2 provide strong support in favor of using the *de facto* resident population to explain the expansion of urban areas between 2000 and 2010. When the model that uses a *de jure* population concept (the number of local *hukou* holders) is used as H_0 it is decisively rejected in favor of H_1, the model based on the resident population (with the test statistic significant at $p<0.01$ regardless of whether using a 50% or 65% luminosity threshold). But when the test procedure is reversed, with the model using the *de facto* population as H_0 the Cox-Pesaran statistics are insignificant, indicating that the *de facto* population model is not rejected against the *de jure* population alternative.

6.5 CONCLUSIONS

This paper uses measures of city area derived from night lights as an arbiter to compare two different types of local population data for China; a *de facto* measure based on census counts of where people actually reside, and a *de jure* measure based on police records of where they are registered to live under China's *hukou* system. Our review of the economics literature shows that it is the *de jure* measure that is most typically used in published studies, even when it would be more sensible to use the *de facto* measure that relates to the population who actually consume and produce local output. Treating the *de jure* measure as if it were a *de facto* local population constitutes what we have called a "counting error" and in the example we provide, this counting error substantially distorts the conclusions that are drawn from the data.

Specifically, one would conclude that expansion of urban areas is driven by income growth with no independent role played by local population growth, if the *de jure* population from the *hukou* registration data is used as a proxy measure for city-level population. Indeed, this is the conclusion reached in the study by

Deng et al (2008), and this conclusion is likely to have influenced views about China since the Deng et al paper is the most highly cited of all the articles we surveyed within the urban and regional economics category. In contrast to this conclusion, which we consider to be an artefact, if the more appropriate *de facto* population measure based on census counts of where people actually reside is used, there is a strong effect of local population growth on urban expansion and no apparent effect of income growth. The outcome of non-nested tests strongly favours using the resident-based *de facto* population rather than the *de jure* population from the number of local *hukou* registrations. We offer these results as an example of the distorted inferences that are likely to result from the erroneous use of China's sub-national population data.

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Appendix Table 1. Number and Percentage of Papers with Wrong Interpretation

Year	Blue Ribbon	Development	Regional/Urban
2005-2006	2*	11****	3
	100%	79%[d,e,e]	100%
2007-2008	1	9*	2*
	100%	90%[d]	100%
2009-2010	3	10**	2
	75%[c]	77%[d,e,e]	100%
2011-2012	1	10***	4
	100%	91%[c]	80%[d]
2013-2015	5**	12*	4
	83%[c]	75%[a,b,d,e]	100%

Notes:
1. Year is publication year. The starting year is set to be 2005 because NBS started to switch to use resident population to calculate GDP per capita in 2005. Detailed information on this NBS official switch can be found in Li and Gibson (2013).
Blue Ribbon 3 journals include American Economic Review, Review of Economic Studies, and Review of Economics and Statistics.
2. Development 3 journals include Journal of Development Economics, World Development, and Journal of Comparative Economics.
3. Regional/Urban 3 journals include Journal of Urban Economics, Regional Science and Urban Economics, and Journal of Economic Geography.
4. Papers with wrong interpretation are defined either as if they use unreliable historical population, employment, or GDP per capita data for provinces, prefectures, districts, county-level cities or counties from yearbooks, or as if they solely use NBS annual household survey data that only sample people with local *hukou* and therefore exclude non-*hukou* migrants unless they acknowledge this exclusion would bias their results. The total is 79.
5. * denotes a paper with wrong interpretation solely using NBS annual household survey data without acknowledgement on the non-*hukou* migrants exclusion bias. The total is 15 (included in the 79).
6. Papers solely use population census data (denoted by a if using census 2010; denoted by c if using census 2000 or earlier), NBS revised provincial historical GDP per capita based on census 2010 (denoted by b), NBS annual household survey data with acknowledgement on the non-*hukou* migrants exclusion bias (denoted by d), or other data free of the NBS population/employment counting error e.g. from World Bank, other NBS firm-level surveys etc. (denoted by e) are treated as papers with correct interpretation, which is used to calculate the percentage of papers with wrong interpretation. The total is 15. There is only one paper using census 2010 (most reliable on population and employment), which is Li and Gibson (2013).
7. The total of papers reviewed is 94. Detailed references and reviews in excel sheets are available from authors upon requests. The review is completed on 7th May 2015. There are only 3 papers in 2015, which all fall in the Development journal group (2 in World Development and 1 in Journal of Comparative Economics), and of which one is with correct interpretation (in World Development, denoted by e) while the other two are with wrong interpretation (in World Development and Journal of Comparative Economics, respectively using unreliable provincial historical employment and GDP per capita data from yearbooks).

Chapter 7

Conclusion

In the last two decades the internal migration of hundreds of millions of Chinese has dramatically reshaped China's economic geography. However a complete understanding of this reshaping is currently lacking because China's statistical system has not fully coped with this massive internal migration. While Chinese are meant to stay registered at local police stations under the *hukou* household registration system, many do not. Consequently data on the *de jure* population that is provided every year from Ministry of Public Security statistics becomes an increasingly poor guide to where Chinese actually live. Yet from an economic point of view it is important to know how many people live in each sub-national area, whether that be for provinces, prefectures, urban districts or counties, since it is the people who actually live in an area who produce and consume local output.

This thesis is all about the "counting errors" that can result when *de jure* population estimates from the *hukou* registration system are wrongly treated as if they were *de facto* population counts for the size of each local area in China. The empirical research reported in the thesis is made possible by the availability of population census data every ten years, which can be contrasted with the annual estimates of the local resident population, which in many cases are based on poor approximations from the registered population statistics. Since population data are widely used in economic analysis due to reliance on *per capita* variables, the error of mistaking statistics based the *de jure* population for estimates of the *de facto* population could show up in many parts of the economics literature.

Indeed, as shown in chapters 2-6, when the most reliable local resident population and employment counts from China's 2010 (and 2000) population census are used, the existing empirical evidence on five topics is extensively challenged. First, in Chapter 2, which is published as Li and Gibson (2013), much of the apparent increase in inter-provincial inequality in China from 1990 onwards disappears once local GDP per resident and resident population counts are used. Most prior studies used *per capita* GDP figures that initially were based on the *hukou* registered population for each province, which increasingly overstated the population (and understated the GDP *per capita*) of migrant sending provinces while causing the opposite for migrant receivers. A further distortion occurred as provinces switched to denominating GDP by the resident population, with the change in denominator causing an apparent turning point in the inequality statistics that corresponded with China's investment in lagging regions. Thus, the common accounts of both the rising inequality and the turning point (e.g. Fan et al, 2011) may be nothing more than statistical artefacts.

A second example is provided in Chapter 3, which is published as Li and Gibson (2015a). The use of more complete data on city-level employment, from the long form census given to ten percent of households in 2010, shows that Chinese cities are much closer to their peak scale and have much smaller losses in net output per worker from being away from the peak point than is suggested by earlier studies. Amongst these earlier studies, the key paper is by Au and Henderson (2006), who use employment data in the city statistical yearbooks which appears to be incomplete because many private sector workers are not counted (and this error is likely related to the population counting errors since the non-*hukou* residents of cities are much more likely to work in the private sector). Thus, it may again be nothing more than a statistical artefact that China has too many small cities and foregoes agglomeration-based productivity gains as a result, despite this being an often repeated claim in the literature.

A third example of a challenge to the existing literature is in Chapter 4, which is available as a working paper in Li and Gibson (2015b). Compared with what is estimated when using the local resident population count, if instead the local *hukou* population count is wrongly used as a measure of city size it makes the city size distribution in China seem more even, and gives larger exponents when a Pareto distribution is estimated. The reason is that non-*hukou* migrants increasingly congregate into a few larger cities and if cities are measured with a *de jure* population variable that ignores the non-*hukou* migrants this pattern is missed. Thus, the existing literature on the size distribution of cities in China, which argues that they are becoming more evenly sized over time (e.g. Anderson and Ge, 2005), may mislead because the measure of city size used (from the *hukou* registration statistics) does not correspond to where people actually live.

A fourth challenge to the existing literature concerns the size of urbanization economies due to agglomeration effects in China. A variant of the claim that China has too many small cities is made by Combes et al (2015) who argue that urbanization economies in China are three times higher than in Western countries which is a claimed consequence of the malformed city size distribution in China. But the China's Urban Household Survey used in Combes et al (2015) excludes non-*hukou* urban residents from the sampling frame and so the results may not be reliable. In Chapter 5, which is published as a working paper by Li and Gibson (2015c), estimates of urbanization economies are made using census estimates of the size of each city (in terms of urban residents), and also using long-form census data on the industrial and spatial distribution of employment. These urbanization economies occur only for urban districts, and not for counties or county-level cities, and are only found for tertiary (services) sector activity and not for the secondary sector of manufacturing and construction. Notably, the urbanization economies are similar in magnitude to what is found in Western countries, which may count against the idea that China is foregoing agglomeration-related benefits due to having too many small cities.

The fifth and final example of a challenge to the existing literature concerns the effect of local population change on the expansion of urban area, which is often termed *sprawl*. In Chapter 6, which is a working paper of Li and Gibson (2015d), it is shown that changes in the local *hukou* population between 2000 and 2010 does not have any explanatory power when modelling local urban land area expansion in China at the city level, while local economic growth has all of the explanatory power. This pattern is exactly what is found in Deng et al (2008) who use county-level data and related urban area expansion from 1995 to 2000 to county GDP growth and growth in the *hukou* registered population for each county. However, the exact reverse pattern is found once a more appropriate measure of local population growth is calculated using the urban local resident population counts from the 2000 and 2010 census. Thus it is likely that the published finding about the non-importance of local population growth for explaining urban sprawl in China is also an artefact of relying on a *de jure* population variable rather than a *de facto* population variable.

These five examples serve as a cornerstone in the small literature that reminds analysis on various other economic issues for China of the need for caution in use of local population and employment counts. For example, two recent papers published in *World Development* by Shi and Huang (2014) and by Elliott and Zhou (2015) respectively study infrastructure and wage issues topics related to China, but both incorporate exactly the interpretations of China's sub-national population and GDP *per capita* data that are suggested in Li and Gibson (2013). Indeed, Li and Gibson (2013) clearly show in detail at provincial level where and how big the error of sub-national population counts is in China's statistical system. Relatedly, Li and Gibson (2015a) explicitly indicate that the incomplete local employment count reported in China's statistical yearbook averages just 43% of the complete local employment count recorded for the same cities by the China's population census. Even more specifically and at finer scales, Li and Gibson (2015c) explicitly show where and how big the stock of non-*hukou* urban residents is among all districts, count-level cities and counties in China. Those are all very helpful guides for future economic analysis on China.

While this thesis mainly aims to make a contribution to the economic literature on China, there also are important and timely policy implications of the five main papers. China's urban population and its rate are forecasted to further reach 1050 million and 76% by 2050 (UN World Urbanization Prospect 2014). This is an increase of 292 million and 22% on top of that in 2014. One way that China can undergo catch-up urbanization is for a few existing cities to join Beijing and Shanghai as mega-cities. But central and local governments may also try to foster the growth of new cities in currently less urbanized or laggard regions. The latter dispersed urbanization strategy is especially pertinent in China while it is also true elsewhere[71]. Examples include initiatives such as the "county-to-city upgrading system" (see Li and Gibson, 2015b), the "new rural countryside program", the "west China development project", the "northeast China revitalization campaign", and the "rise of central China plan" (see Li and Gibson, 2013). A new effort in this dispersed strategy was launched in 2012 under the heading of 'townification' (*chengzhenhua*) which can be considered as in-*situ* urbanization where rural towns become urbanized. While it is also true elsewhere,[72] China particularly is averse to a concentrated urbanization strategy given the long-standing and still ongoing pro-small bias in its urban policy (see Li and Gibson, 2015b).

Despite that policy bias, the five main chapters in this thesis collectively give the mutual policy implication that China shall go for the concentrated urbanization strategy rather than the dispersed one. Some of the evidence which might be thought to oppose this recommendation is likely to be misleading since it is based on incorrect local population and employment counts. First, some studies

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[71] Public policies in many countries try to foster new agglomeration economies by building clusters, by attracting 'talent' or by luring large industrial facilities (Combes et al, 2011)
[72] Urban policies commonly attempt to limit the growth of large cities in many countries (particularly developing countries), which often take the form of barriers to labour mobility and zoning restrictions on new constructions (Duranton, 2008).

(e.g. Fan et al, 2011) suggest that the leveling off of regional inequality in China in the early 2000s reflects the good effects of massive state-led infrastructural investments in western China in the period. But an alternative explanation of Li and Gibson (2013) is that the apparent leveling off over those years is just a statistical artefact caused by the switch in population denominator for GDP from a registered population basis to a resident population basis. Thus, the active state intervention to close the apparent regional gaps, which cost hundreds of billions of dollars, may not have been effective after all and was perhaps not actually necessary. Second, as shown in Li and Gibson (2015a), the reshaping of China's economic geography by the hundreds of millions of non-*hukou* urban residents evidently is producing an urban system that does not have productivity losses that are as large as previously reported in highly-cited studies such as Au and Henderson (2006). Thus, the suggestion in Au and Henderson (2006) that China shall actively foster the growth of small cities is not necessary at all. Indeed, the "county-to-city upgrading system" had failed to improve local economic performance of those relabeled counties and ended in the late 1990s.

Third, in Chapter 4 when Pareto's Law is used as a normative standard, only the very largest cities in China appear to have scope to absorb more non-*hukou* urban residents. This contrasts sharply with the pro-small and anti-large bias in China's urban policy. Indeed, the analysis in Chapter 4 finds that over time, Chinese cities are moving away from the middle of the city size range with many joining the bottom range while some joining the top range, which implies the divergence of city size distribution in China as opposed to the common findings of convergence in extant city size distribution studies on China (e.g. Anderson and Ge, 2005).

Further evidence in favour of a concentration urbanization strategy comes from Chapter 5, where it is shown that agglomeration effects in China occur only in already agglomerated areas, and operate mainly through economic sectors that require a large nearby market such as services. Thus, the dispersed urbanization strategy will entail a high opportunity cost in terms of foregone productivity in China. Yet, even with the much larger estimated agglomeration effects, Combes et al (2015) wrongly suggest that there are potentially high efficiency losses in China due to Chinese small and medium-sized cities being with too few people. Indeed, Li and Gibson (2015c) clearly show that the locations of agglomeration economies in China are only the very existing largest cities according to the choices of hundreds of millions of non-*hukou* urban residents in China. Thus, the policy implications in Combes et al (2015) and Au and Henderson (2006) may be misleading. In particular, the sharp increases of secondary sector employment in Chinese county-level cities and counties found between 2000 and 2010 (as reported in Li and Gibson (2015c)) is evidence of how China's urban policy has been misguided in following a dispersed strategy, since there is no likelihood that sending manufacturing and construction out to rural counties and small county-level cities will generate any useful agglomeration benefits.

The fifth policy implication concerns urban land area expansion, which relates to food security and environmental concerns. The population densities of the very largest Chinese cities are lower than those of other mega-cities elsewhere in the world, and over time their relative density is falling further (Du et al, 2013).

As shown in Chapter 6, urban land area expansion of Chinese cities should be best modelled by using the *de facto* resident population and not the *de jure* registered population. So further study on this critical environmental and economic issue is likely to be misleading if it follows the strategy of the previous literature, of wrongly treating the *hukou* registered population as a measure of where people actually live.

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Appendix 1

Spatial Price Differences and Inequality in the People's Republic of China: Housing Market Evidence

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Spatial Price Differences and Inequality in the People's Republic of China: Housing Market Evidence

Abstract

The large literature on regional inequality in the People's Republic of China (PRC) is hampered by incomplete evidence on price dispersion across space, making it hard to distinguish real and nominal inequality. The two main methods used to calculate spatial deflators have been to price a national basket of goods and services across different regions in the country or else to estimate a food Engel curve and define the deflator as that needed for nominally similar households to have the same food budget shares in all regions. Neither approach is convincing with the data available. Moreover, a focus on tradable goods such as food may be misplaced because of the emerging literature on the rapid convergence of traded goods prices within the PRC that contrasts with earlier claims of fragmented internal markets. In a setting where traded goods prices converge rapidly, the main source of price dispersion across space should come from nontraded items, and especially from housing given the fixity of land. In this paper we use newly available data on dwelling sales in urban PRC to develop spatially-disaggregated indices of house prices which are then used as spatial deflators for both provinces and core urban districts. These new deflators complement existing approaches that have relied more on traded goods prices and are used to re-examine the evidence on the level of regional inequality. Around one-quarter of the apparent spatial inequality disappears once account is taken of cost-of-living differences.

Keywords: Housing, inequality, prices, spatial, People's Republic of China
JEL: E31, O15, R31

A1.1 INTRODUCTION

The large literature on regional inequality in the People's Republic of China (PRC) is hampered by the limited evidence on price dispersion across space, which makes it difficult to distinguish real inequality from nominal inequality. Like statistical agencies in most countries, the PRC's National Bureau of Statistics (NBS) does not publish a spatial price index that allows cost-of-living comparisons over space. Instead, the focus is on the temporal Consumer Price Index (CPI), which is reported at both the national and the provincial level. There are also separate CPIs for rural and urban areas at both national and provincial levels. These indices allow rates of change in the consumer price level to be compared across different locations but do not allow comparisons of absolute price levels or of the cost of living between locations.

However, there are good reasons to suspect that price levels and the cost of living vary over space. A higher price level is expected in more productive, richer economies (Balassa 1964, Samuelson 1964). The same pattern likely holds within countries because typically productivity growth is stronger in the traded sector than in the nontraded sector. If wages in the traded sector rise with productivity while nontraded sector wages are pegged to those in the traded sector (both sectors compete for workers in the same labor market), then prices of nontraded items will grow faster than productivity and will rise in real terms. The overall price level is an average of traded and nontraded prices so that in the context of regions of the PRC, one can expect a higher overall price level in export-oriented, coastal provinces in which nominal income is higher, such as Guangdong, than in poorer, inland provinces such as Yunnan.

The implications of this pattern are worth emphasizing in the PRC where there is substantial debate about the impacts of economic reform on inequality. A common claim in the literature is that spatial inequality rose in the reform era, especially when policy neglected the rural sector (Fan, Kanbur, and Zhang 2011). This claim has fuelled initiatives to help seemingly laggard regions catch up to seemingly advanced regions, including the West China Development Project (Lai 2002), the Northeast China Revitalization Campaign (Zhang 2008), and the Rise of Central China Plan (Lai 2007). Just a subset of these initiatives saw more than one trillion yuan ($180 billion) of state-led infrastructural investment directed to western region of the country (Yao, 2009). But without reliable measures of spatial price differences, it is not clear how much of the reported spatial inequality (and its claimed increase) is simply due to regional price variation and how much reflects differences in real incomes.

In this paper, we use newly available data on dwelling sales in urban PRC to develop spatially-disaggregated indices of house prices which are used as spatial deflators for provinces, urban prefectures, and urban core districts. Since we account for only one source of cost-of-living variation over space, the impacts on inequality that we find when using these deflators should be considered a conservative, lower bound. Our approach contrasts with the two main methods previously used to calculate spatial deflators in the PRC where either a national basket of goods and services has been priced in different regions or a food Engel curve has been estimated and a deflator derived as that which is needed for nominally similar households to have the same food budget shares in all regions. Neither approach is convincing with the data available in the PRC, as we explain below. Moreover, a focus on traded goods such as food may be misplaced because of the emerging literature on the rapid convergence of prices within the PRC that contrasts with earlier claims of fragmented internal markets.

It is increasingly reasonable to expect integrated goods markets in the PRC, and for goods prices to obey the law of one price (net of transport costs), but the same is not true of housing services. Because of the fixity of land supply, accounting for regional differences in housing service prices is fundamental to the calculation of spatial differences in the cost of living. While other services are also considered nontradable, the long-run supply of their dominant factor of production can spatially adjust to reduce interregional price differences. For example, if haircuts are relatively more expensive in urban areas of the Pearl River Delta, hairdressers might be expected to migrate to that region to increase the supply and reduce the regional price premium. There is no similar migration possibility for land—the presence of abundant land (relative to the population) in western regions and consequently relatively low house prices can do nothing to moderate the high cost of housing in Beijing.

Our focus on housing costs as the main driver of spatial cost-of-living differences is supported by previous studies in other countries. According to Moulton (1995, 181): “the cost of shelter is the single most important component of inter-area differences in the cost-of-living.” Similarly, Massari et al. (2010) find housing prices account for almost 70% of cost-of-living differences between northern and southern Italy. Our approach is perhaps most closely related to Jolliffe (2006) who examines how adjusting for cost-of-living differences between metropolitan and nonmetropolitan areas in the United States causes a complete reversal of the poverty ranking of these areas. In order to measure poverty using spatially deflated data, Jolliffe (2006) uses the fair market rent (FMR) index which consists of just two components: housing expenses (with a weight of 0.44) and all other goods and services (weight of 0.56). This index assumes that cost-of-living variation over space reflects variation in housing prices only and that there is no variation over space in the prices of all other goods and services.[73]

Although our results are most clearly relevant to scholars interested in the PRC, they also may have broader applicability. A growing international literature examines the impact of accounting for spatial price differences, especially those generated from urban housing markets, on apparent trends in nominal outcomes. For example, Moretti (2013) finds a more rapid rise in the cost of living experienced by college graduates compared to high school graduates accounts for one-quarter of the 1980–2000 increase in the nominal college premium in the US. This cost differential occurs because college graduates have increasingly congregated in urban areas with expensive housing (using monthly rent as a proxy for the user cost of housing).[74]

Similarly, Albouy (2012) shows how accounting for the higher real cost of living in US urban areas with more expensive housing provides revealed-preference estimates of the quality of life that are more consistent with popular "livability" rankings and stated preferences. The same effect is present in Russia, where Berger, Blomquist, and Peter (2008) estimate housing value and wage

[73] Specifically, the FMR is based on housing prices for the poor, defined as the cost of gross rent (including utilities) at the 40th percentile for standard quality housing.
[74] In a related paper using the same housing cost data, Moretti (2010, 4) notes that empirical results are not sensitive to measuring housing costs by using the price of owner-occupied homes instead of using rental costs.

equations to impute implicit prices for city amenities. In their study, house values and nominal incomes are correlated over space and the implied quality of life rankings generated by the housing and labor markets are consistent with observed internal migration flows. The importance of housing markets for measured inequality and quality of life is emphasized by this literature.

The remainder of the paper is structured as follows. Section II reviews the literature in three areas that help to inform this study: spatial deflation studies, market integration studies, and housing market studies. Section III describes the data that we use to create housing-related spatial deflators for the PRC. One concern with using dwelling prices as an indicator of cost-of-living differences is that dwelling quality may vary systematically across space, so that in Section IV we discuss the nature of real estate development in the PRC and provide some empirical evidence on the importance of location effects relative to dwelling characteristics in determining housing prices. Another concern is that dwelling prices may capture more than just the costs of shelter, hence we also contrast our approach with studies that rely on rental costs and describe recent trends in tenure patterns in urban areas of the PRC. The calculation of the deflators is described in Section V and the results are contrasted with other spatial deflators for the PRC. The impact of using the deflators when measuring spatial inequality is discussed in Section VII, while the conclusions are discussed in Section VII.

A1.2 PREVIOUS LITERATURE

The approach we use here, of constructing spatially real income by deflating only for housing costs, relies on literature for the PRC that is drawn from three distinct areas: spatial deflation studies, market integration studies, and housing market studies. Our overall goal is to contribute to the literature on spatial inequality in the PRC by examining the impact of using various deflators on estimates of spatial inequality. We reviewed the spatial inequality literature in a recent study (Li and Gibson 2013), where the focus had been on the misunderstanding that results from ignoring the fact that for most of the reform era, statistical authorities in the PRC denominated local GDP by the number of people with *hukou* household registration from each place rather than the number of people actually residing in each place (so that measured inequality mechanically increased as the number of non-*hukou* migrants rose). In the current study we use the adjustments to the population denominators created by Li and Gibson (2013) but otherwise do not address population issues and instead pay attention to the impact of adjusting for spatial cost-of-living differences.

A1.2.1 Spatial Deflation Studies

The most widely used spatial deflators for the PRC appear to be those of Brandt and Holz (2006).[75] The authors use provincial price data from 1990 to calculate the cost of national rural and urban expenditure baskets (containing 40–60 items) and a population-weighted combined basket. The prices had originally been collected by statistical authorities for the purpose of calculating a temporal index (the CPI) for each province, so that they do not necessarily refer to the same quality of items across provinces. Rural prices were not available for all products consumed in rural areas, so provincial capital city prices were instead used for items constituting just over 40% of the average rural household budget. Since there were no prices for nontraded services, average labor wages in township and

[75] This paper has 152 Google Scholar citations as of March 2013.

village enterprises (TVE) were used as a proxy. Finally, the analysis lacked data on either rent, land prices, or real estate prices, therefore construction costs per square meter of rural household buildings were used in their place with the "quantity" of housing services in the basket set at 0.5625 m^2—chosen to give an expenditure that was equivalent to nationwide per-capita rural household living expenditures on housing.

Brandt and Holz (2006) then use the annual rate of change in the CPI for each province to form annual spatial deflators for each province from 1984 to 2004. This time series is also used by other researchers studying inequality (e.g., by Sicular et al. 2007, Li and Gibson 2013) since it allows easy updating by just using published data on the annual rate of change in each province's CPI. Despite the simplicity, there are potential problems in using a temporal index to update a spatial index so as to create a panel of deflators. An example of such bias comes from Russia: Gluschenko (2006) compares a spatial price index calculated for period t using spatial prices for the same period, with an index for period t that is extrapolated from a spatial price index for period t_0 using local CPIs to update prices from t_0 to t. The direct method gives a spatial price index for each province whose range is 44% of the national mean price level, but the indirect method gives a much wider range, of 72%.

The example from Russia shows that CPI-updated price levels may not adequately proxy for cross-spatial price levels. More generally, it may not be possible to construct panel price indexes that are unbiased across both space and time (Hill 2004). The problem is that bilateral index formulas such as for the Laspeyres index used by Brandt and Holz (2006) are unlikely to give transitive results when extended to a multilateral situation. For example, consider a price index calculated for three regions (Beijing, P_B; other urban areas, P_U; and rural areas, P_R) with base weights that differ in each region. A direct comparison between the rural price level in period t_2 and Beijing prices in period t_0 will not give the same result as constructing an indirect comparison via the third region in an intermediate time period, t_1.That is,

$$P_{R2,B0} \neq P_{R2,U1} \times P_{U1,B0}$$

Instead, transitivity requires use of a multilateral index method, such as the Geary-Khamis (GK) method that underlies the Penn World Table or EKS (Eltetö, Köves, and Szulc) type methods.[76]

Another issue with the deflator formed by Brandt and Holz is the use of a national basket rather than letting consumer responses to relative prices and other differences induce regional variation in the structure of consumption. While sensitivity to consumer responses is a claimed feature of the "no-price" Engel curve method described below (Gong and Meng 2008), it is not required that methods using disaggregated price data ignore variation in the structure of consumption. For example, Deaton and Dupriez (2011) use unit values from household surveys to calculate spatial price differences in two other large countries—India and Brazil—using multilateral Törnqvist indexes that are the

[76] These methods compare each country (or region) with an artificially constructed average country (or region). Typically they use the Paasche price index formula to make each of these bilateral comparisons with the artificial country as the base and tend to suffer from substitution bias because the price vector of the base artificial country (region) is not equally representative of the prices faced by all of the countries (regions) in the comparison. EKS methods impose transitivity in the following way: first, they make bilateral comparisons between all possible pairs of countries and then take the *n*th root of the product of all possible Fisher indices between *n* countries. Deaton and Dupriez (2011, 4) note that multilateral price indexes required for spatial work are typically not consistent with the inflation rates in local CPIs and so need to be calculated regularly, not just once, and updated by the local CPIs.

geometric average of price relativities between each region and the base region, weighted by the arithmetic average of the budget shares for the two regions. Hence, variation in the structure of consumption, as captured in budget shares for each region, is accounted for by this type of spatial price index. The results for these two countries show a 20% range in average food prices between the cheapest and most expensive regions in India, while in Brazil there is almost no price gradient, reflecting the higher incomes in Brazil and hence greater importance of processed foods which likely have much smaller price margins between regions than do unprocessed foods.[77]

Gong and Meng (2008) use an Engel curve approach to estimate spatial price deflators for each province using data from the Urban Household Income and Expenditure Survey from 1986 to 2001.[78] Their deflator is defined by what is needed for nominally similar households to have the same food budget shares in all regions following an idea first proposed by Hamilton (2001) for measuring bias in a temporal CPI. These authors find implied regional cost-of-living differences from the Engel curve that are considerably larger than those calculated from pricing a fixed basket using either provincial average prices or household-level unit values. The difference from fixed basket results was most apparent during the mid- to late-1990s when social welfare reforms altered coverage and subsidies for public health, education, and housing. In terms of inequality, when no adjustment was made for spatial price differences, Gong and Meng (2008) find

[77] Relatedly, supermarkets are more important in Brazil (and also in the PRC) than in India, and the growth in the importance of supermarkets assists with spatial convergence in food prices (Reardon et al. 2003).

[78] In contrast to the later work of Almås and Johnsen (2012), Gong and Meng (2008) do not create a panel price index of time–space deflators, and instead the food Engel curves are estimated separately for each year.

that the mid-1990s saw the most significant increase in regional income inequality, but after using the deflator derived from their Engel curve results, they find regional income inequality to actually increase the most in the late 1980s.

Almås and Johnsen (2012) use a similar Engel curve approach with data from just 2 years (1995 and 2002) for rural areas in 19 (of 31) provinces and urban areas in 11 provinces. Rather than estimating a spatial cost-of-living index year by year, they attempt to make incomes comparable over both time and space using a single set of Engel curve estimates. They claim that the CPI understates price changes in rural areas and overstates them in urban areas: the deflator derived from the Engel curve suggests a 44% rise in the rural cost of living from 1995 to 2002 and zero change in the urban cost of living compared to CPI increases of 8% and 11%, respectively. This closes the rural-urban gap in terms of price levels, with the rural cost of living rising from 60% of the urban level in 1995 to 87% of the urban level by 2002. Thus, the real income figures calculated with their deflator show a greater rise in inequality and a more modest fall in poverty than is implied by making no spatial adjustment and using the CPI for temporal deflation.

The studies that use a food Engel curve to back out regional differences in the cost of living (or more generally the bias in any spatial or temporal deflator) are one strand in a broad literature that relies on observable proxies for well-being to calculate implicit compensation for people living in different circumstances (such as family size and structure, or location). For example, Timmins (2006) uses internal migration data from Brazil under the logic that moves reveal preferences over locations that differ in terms of nominal incomes and the cost of living and can thereby reveal spatial differences in the cost of living. Lanjouw and Ravallion (1995) use child anthropometric indicators (stunting and wasting) in addition to food share to indicate well-being when anchoring their calculation of allowances for household size economies (effectively, the inverse of the compensation needed by people living in smaller households to be as well off as those in larger ones at the same per capita consumption). Subjective data on self-rated welfare can also be used. Krueger and Siskind (1998) and Gibson, Stillman, and Le (2008) use survey questions that compare feelings of being better off in the present or the past to adjust for possible biases in the CPI, and the same method could be used to make spatial comparisons.

The problem with all of these approaches is that it is simply an assertion that the welfare indicator—whether food budget shares, anthropometrics, and so forth—does indeed identify people who are equally well off. At least since Nicholson (1976), a long literature has argued that food share is not a good indicator of well-being. Consider the example of using food share to calculate the exact amount of money needed for parents to maintain their consumption while providing for a child: Since child consumption is concentrated more on food than is adult consumption, food share would be higher even if exact compensation had been given, and this higher food share would wrongly indicate the need for further (over)compensation.

In the context of the food Engel curve estimates for the PRC, there is a substantial difference between provinces and between urban and rural areas in the proportion of household members who are children. The data from the latest wave of the China Health and Nutrition Survey (CHNS) show 0–15 year old children comprise just 3% of the average household in urban areas of Liaoning province but comprise 16% of the average rural household in Guangxi. Food shares will thus be higher in Guangxi even if there were no differences in the cost of living, but the Engel method will not necessarily recognize this.[79] Consequently there are reasons to doubt the reliability of spatial deflators produced by this method.

A1.2.2 Market Integration Studies

Many authors consider the PRC an example of a developing country with segmented markets and much less integration than developed countries (Gong and Meng 2008, Xu, 2002). In the early reform period, this description may have been apt since economic interaction between provinces had been minimized during the planned economy era, making the PRC more like a cluster of independent economies rather than a large, spatially integrated economy.

But the surprising claim of some influential studies is that market integration declined even more during the reform period. According to Young (2000, 1128)

> (T)wenty years of economic reform … resulted in a fragmented internal market with fiefdoms controlled by local officials whose economic and political ties to protected industry resemble those of the Latin American economies of past decades.

[79] Adding demographic variables to the Engel curve regression may not help since there is no reason for these effects to operate as just intercept-shifters. The literature using food Engel curves to study bias in temporal deflators is more credible since it typically restricts attention to a particular household type (say, two adults with two children) and the change in household structure over a decade or so is much less than the differences over space, yet all of the regional differences are rolled into a catch-all term that is assumed to be due to just cost-of-living differences.

The claimed reason for the seemingly perverse fragmentation of the internal market while the PRC opened up internationally is that devolution of powers saw local government revenue linked to local industry protection, leading to interregional trade wars. Apparent confirmation comes from Poncet (2005) who examined "border effects" between provinces by comparing volumes of intraprovincial and interprovincial trade. The trade-reducing impact of provincial borders appeared to increase between 1992 and 1997, from which the study concluded that the domestic economy was fragmented and that "rather than a single market, (the PRC) appears as a collection of separate regional economies protected by barriers" (Poncet 2005, 426).

A critical reappraisal shows that the evidence from Young (2000) is not robust and that the PRC is comparable to the US in terms of being a relatively integrated, large economy (Holz 2009). For example, Young showed a rise in the (natural logarithm of the) interprovincial standard deviation of (the natural log of) prices of various consumer and agricultural goods, which was taken as evidence of trade barriers segmenting markets. But this calculation was neither robust to inflation nor to the growth in product variety in the reform period. Once Holz (2009) accounts for these factors there is no trend in interprovincial price dispersion, and the range of variation matches that in intercity data for products in the US. Similarly, Young found a convergence in the output structure of each province during the reform period, taken as evidence of provinces duplicating each other's industries rather than allowing regional specialization. The degree of convergence in the composition of value-added across US states in the same period was approximately the same as for provinces in the PRC, but there were no claims of rising interstate trade barriers in the US at that time.

In keeping with the reappraisal by Holz (2009), a number of more recent studies find the PRC to be a relatively well integrated market economy. Fan and Wei (2006) apply panel unit root tests to data on monthly prices for a group of 93 industrial products, agricultural goods, other consumer goods, and services in 36 major Chinese cities, finding that prices do converge to the law of one price. Similarly, Ma, Oxley, and Gibson (2009) use spot energy prices in 35 major cities to test for convergence with their panel unit root tests indicating that the energy market is integrated in the PRC. Huang, Rozelle, and Chang (2004) examine prices for rice, maize, and soybeans from almost 50 locations in 15 provinces on the eve of the PRC's accession to the WTO. These authors find most market pairs to be integrated (and this integration to extend down to village level) and market integration to be substantially higher than even 5 years earlier.[80] A longer term perspective on grain prices found that on the eve of the industrial revolution, market integration in the PRC was as high as it was in most of the advanced areas of western Europe (Keller and Shiue 2007a), while contemporary markets are even more integrated. Keller and Shiue (2007, 107) conclude that for the PRC "in the late twentieth century local and national prices essentially move one-to-one." Thus, it is mainly the central planning era that deviated from the pattern being a normal, relatively integrated, large economy.

[80] Rising integration is also apparent in the labor market. Since 1997, urban wages in China's interior provinces have risen at a faster rate than in coastal regions—although the absolute wage gap continues to grow (Li et al. 2012).

Another way to examine market integration is to test how long it takes prices to converge following idiosyncratic shocks. For example, Parsley and Wei (1996) find convergence rates to purchasing power parity of 5 quarters for tradable goods and 15 quarters for services, for a sample of 48 cities in the US. When the comparable approach is used in the PRC, convergence rates appear to be much faster. Lan and Sylwester (2010) study the prices of 44 products in 36 PRC cities and estimate half-life divergences from the law of one price that average just 2.4 months. This is approximately twice the speed of adjustment found in the US, leading these authors to conclude: "(O)ur findings suggest that prices within China converge to relative parity extremely quickly" (Lan and Sylwester 2010, 231).

A recent review of product, labor, and capital market integration in the PRC summarizes the evidence as showing: "(P)roduct markets became more integrated over time, as regional trade increased and product prices were increasingly similar throughout the country" (Chen, Goh, Sun, and Xu 2011, 73). Given this similarity over space of the prices of tradable goods, the focus of many of the previous spatial deflation studies summarized above may be misplaced. In an environment where traded goods prices converge rapidly, the main source of price dispersion across space should come from the nontraded components of consumption and especially from housing, given the fixity of land. We therefore briefly review the literature on spatial variation in house prices before turning to the data that we use to develop housing-related deflators.

A1.2.3 Housing Market Studies

In the planned economy era, government agencies such as work units provided all urban housing. Rents were low and the dwelling one was allocated depended on administrative criteria such as job rank (Bian et al. 1997). Housing reform was launched in 1988 with privatization and creation of an urban housing market as the aim (State Council 1988). Thereafter, commodity houses built by private developers could be bought on the housing market (Huang and Clark 2002). For the first decade of reform, a dual track system developed with large numbers of commodity houses bought by work units and then distributed to workers at discounted prices (Huang 2003). In 1998, the State Council abolished the old housing system completely, and thereafter any provision of subsidized housing by work units was strictly banned (State Council 1998, Huang 2003). Since then, the urban housing system has become totally market oriented.

In contrast to the urban sector, rural houses were self-funded, self-built and self-renovated by residents, and remain so until now (Liu 2010). The right to use rural residential land (*nongcun zhaijidi shiyongquan*) is evenly distributed and free of charge for village collective members. Land is collectively owned by the village and the occupant is not allowed to mortgage or trade the land, although transfers within the village collective community are permitted. The occupant may build new houses or renovate old houses with their own funds for all kinds of needs such as marriage, tourism (*nongjiale*, akin to a motel, for urban tourists to taste rural life), family workshop, and handicraft production (Liu 2010). Thus, the rural housing system enables rural residents to satisfy their housing needs at much lower cost than is incurred by urban residents in the current era. Though rural self-built houses are generally large and cheap, they are poor in quality relative to urban housing in terms of housing attributes such as the energy source for cooking, bath facilities, and individual toilets (Logan et al. 2009).

The reforms have led to a large literature on urban housing in the PRC, with early studies on determinants of home ownership (Huang 2003, Pan, 2004). But after the full marketization of urban housing in 1998, the focus shifted to affordability due to the sharp increases in house prices. For example, the Shanghai Housing Price Index (SHHPI) of the China Real Estate Index System (CREIS) rose by 63% within 2 years from January 2001 (Hui and Yue 2006). Liu et al. (2008) document poor housing affordability in Beijing during the 2000s using the house price to income ratio (PIR) and the home affordability index (HAI). The PIR is defined as the ratio of the average market value of a typical dwelling to the average annual household income and the HAI measures the ability of a household with an average income to pay back a mortgage on a typical home. In a more comprehensive study, Xiang and Long (2007) calculate PIR and HAI indices for 34 major cities and find Beijing, Shanghai, Shenyang, Xiamen, and Haikou to have poor housing affordability, while the inland cities of Hohhot, Changsha, Chongqing, and Urumqi are relatively better.

In addition to affordability, the other focus of recent literature on the urban housing market is price determination. Zhang and Tian (2010) study sales of new dwellings in 35 major cities between 1995 and 2006, finding stable long-run intercity price relativities, which implies that the urban housing market in the PRC is segmented and that specific local economic characteristics matter. Deng et al. (2012) examine land auctions for 35 major cities from 2003 to 2011 to construct a model of land supply and also for use in a hedonic model of dwelling prices, finding that house prices are driven by the land market rather than by construction costs. Zheng et al. (2009) estimate a hedonic house price regression for 35 major cities and find significant location effects in determining prices. Wu et al. (2012) use a similar model but examine the role of intracity locational factors (e.g., distance to city center). Overall, this research indicates the importance of location in determining dwelling prices in urban PRC, with the most plausible source of inter-area variation coming from land prices.

A1.3 DATA

For our main analysis, we use administrative data on the average selling price for new residential dwellings that real estate developers are required to report to the NBS. Specifically, every transaction for new housing sales is meant to be reported (both monthly and annually, directly to the NBS through an electronic portal). These are the most commonly used data for studies of the PRC urban housing market (Zheng et al. 2009). Since most of the housing market is new construction rather than repeat sales (Deng et al. 2012), an index derived from prices of new units is broadly representative. The average selling price is given for each province in the *China Real Estate Statistics Yearbook* (NBS 2011a), while for urban prefectures the statistic is found in the *China Statistical Yearbook for Regional Economy* (NBS 2011c). For urban core districts (which are more consistently urban than the prefecture they belong to), the numbers are reported for 2009 (but not 2010) in the *China Urban Life and Price Yearbook* (NBS 2010).[81]

[81] Subsequent editions of the *China Urban Life and Price Yearbook* after 2010 do not report house price data for urban core districts, hence we use the 2009 values as reported in 2010.

We obtain data on average GDP for every province, every urban prefecture, and every urban core district from the *China Statistical Yearbook for Regional Economy* (NBS 2011c) and the *China City Statistical Yearbook* (NBS 2011b). These same two sources provide information on the value of total urban real estate investments on residential assets (IRA). The data on the resident population, which are needed for correct calculation of per capita values (rather than using the misleading registered population figures), are year-end 2010 figures for provinces from NBS (2011c) and are 1st November 2010 figures for prefectures and districts as reported in the county-level tabulations of the 2010 Census of Population (NBS 2012).

In addition to these data provided by the NBS, we gathered our own data on sales prices and attributes of new apartment units from www.Soufun.com, which is the largest real estate listing site in the PRC. In conjunction with the CREIS, Soufun.com co-publish the *China Real Estate Statistical Yearbook*. For the primary data collection, we only considered the dominant type of urban residence which is a private apartment in a complex. We did not consider subsidized public rental housing, economically affordable housing, and high-grade apartments and villas, which are just minor components of the urban housing system. According to the *China Real Estate Yearbook 2011*, of 8.82 million new urban housing units sold in 2010, just 2.5% were high-grade apartments or villas and 3.7% were economically affordable housing. The other 94% were standard private apartments, and so our primary data collection concentrated on this dominant form of urban housing.

A1.4 THE PRC URBAN HOUSING MARKET AND PRICE DETERMINANTS

If dwelling quality varies systematically over space, then it may interfere with using published average new dwelling selling prices as an indicator of standardized housing costs for urban areas. However, real estate development in the PRC is organized such that systematic quality differences between cities are unlikely, since many apartment complexes in different cities are developed by the same national-level real estate development companies (sometimes even using the same names for their complexes in each city). While each complex may have dozens of multistory towers, each containing more than 50 individual housing units, within a complex there are only a few (typically less than 10) floor plans available and the selling price in terms of yuan per square meter varies little across the individual units. But there is considerable variation in selling price between complexes in different areas, including between different districts of the same city. For example, Beijing has 16 city districts, and complexes in different Beijing districts may have prices that vary by up to CNY30,000 (US$4,800) per square meter. This variation is consistent with the finding of Deng et al. (2012) that variation in new dwelling prices is driven by the land market.

In order to verify if dwelling quality varies systematically over space, we gathered data in February 2013 on sales prices for 150 new apartments in three cities. Each city is from a different level of the administrative hierarchy: (i) Beijing is a municipality-level city with an equivalent status to a province; (ii) Nanjing is the capital of Jiangsu province and is one of 15 subprovincial cities, which have much greater autonomy and higher status than prefecture-level cities;

while (iii) Changsha is a prefecture-level city and the capital of Hunan province. The data collection was restricted to these three cities because advertisements from most of the 323 cities in Soufun.com lack data on key attributes (both unit and complex characteristics). The majority of advertisements list only the average selling price of all units in a complex, but for the three selected cities, the unique price (per square meter) for every apartment in a complex is consistently listed. Furthermore, the advertisements always list the complex opening date, completion date, and the proportion of units sold to date (the sales ratio) only for these three cities, while for other cities these data are missing. Previous research has found that these factors play a significant role in determining new apartment prices because they represent changing pricing behaviour of the real estate developer at different stages to completion of an apartment complex (Wu et al. 2012). We sampled prices from 3 to 5 complexes for each of the 13 districts of Beijing, 5 to 8 complexes from each of the nine districts of Nanjing, and 5 to 12 complexes from each of the five districts of Changsha.

The data used for the hedonic apartment price regression are described in Appendix A. For some characteristics, apartments in Nanjing and Changsha appear to have more desirable qualities than those in Beijing, with more green space and a higher proportion of the complex area being green space (despite the complexes in Nanjing and Changsha rising higher, on average, than those in Beijing). Also, the listings for Changsha are for slightly newer complexes than for Beijing, as seen from the fewer months elapsed since the complex was opened for sale and the greater number of months to completion of the complex. On the other hand, the apartments in Beijing in the sample are larger than those in Changsha, which is likely to be a desirable characteristic showing up in higher prices even when we concentrate on the price per square meter. The apartment complexes from Beijing also have a higher car park ratio (the number of car parks per dwelling)—note that these are rented or sold separately, while most observations for Nanjing and Changsha leave this attribute blank so it is unclear if car parking is bundled with the price of the apartment in those cities. Overall, there is no clear sign that Beijing apartments have better quality relative to those in the other two cities. For example, the new trend in the real estate market in urban PRC of developers selling decorated new houses rather than unfinished ones is just as apparent in all three cities.

The results of the hedonic house price regressions are shown in Table 1. The dependent variable is the logarithm of the price (in thousands of yuan) per square meter so that the relative difference in prices is not directly shown by the regression coefficients on the dummy variables for each city. Instead, the coefficients must be transformed into percentage differences using $percentage\_difference = (e^{\hat{\beta}} - 1) \times 100$, which shows that the price per square meter is 84% higher in Nanjing than in Changsha, and 256% higher in Beijing without controlling for any attributes of the apartment (first column of Table 1). The results in the second column of the table use the attributes of each apartment but do not consider the location. Despite having 15 characteristics that are potentially related to selling prices, these explain slightly less of the variation in prices than just using location dummy variables.

Table 1: Effect of Location and Dwelling Characteristics on House Prices in Urban PRC

	Natural log(price of apartment unit in CNY1,000 /m^2)		
	(1)	(2)	(3)
Beijing=1, otherwise=0	1.270		1.190
	(15.28)***		(13.85)***
Nanjing =1, otherwise=0	0.610		0.716
	(7.34)***		(9.59)***
Unit characteristics			
Apartment area (m^2)		0.005	0.002
		(4.75)***	(2.60)**
Number of bedrooms		-0.432	-0.191
		(5.80)***	(3.82)***
Number of bathrooms		0.348	0.283
		(4.38)***	(5.50)***
Number of living rooms		0.030	0.127
		(0.29)	(1.89)*
Decorated=1, otherwise=0		0.337	0.256
		(3.93)***	(4.71)***
Level (floor) in complex		-0.011	-0.005
		(1.44)	(0.97)
Complex characteristics			
Land area (1,000 m^2)		-0.002	-0.001
		(2.13)**	(1.62)
Total number of floors		-0.002	0.003
		(0.34)	(0.83)
Floor area ratio		-0.104	0.072
		(2.57)**	(2.51)**
Green area (1,000 m^2)		0.005	0.003
		(2.07)**	(1.56)
Green area / total area		-3.035	-0.466
		(4.18)***	(0.95)
Car park ratio		0.006	0.018
		(0.06)	(0.29)
Months after opening		-0.008	-0.012
		(1.09)	(2.48)**
Months to completion		-0.017	-0.019
		(2.79)***	(4.79)***
Sale ratio		0.043	0.060
		(0.39)	(0.70)
Constant	1.945	4.039	1.584
	(33.08)***	(11.04)***	(5.48)***
R-squared	0.61	0.59	0.84

* = significant at 10%, ** = significant at 5%, *** = significant at 1%, m2 = square meter.

Note: Absolute value of t statistics in parentheses for regressions where N = 150. The omitted location is Changsha.

Source: Authors' computations from data in housing sample collected by authors in February 2013 from www.Soufun.com.

When the location effects and characteristics are put together, the hedonic regression explains 84% of price variation, and after controlling for all of the characteristics of the particular apartment and its complex, the relative price differences are fairly similar to what they were without the controls. Specifically, the (conditional) price per square meter is 105% higher in Nanjing than in Changsha and 229% higher in Beijing. While the price premium is slightly smaller for Beijing than when using the raw data, it is somewhat larger for Nanjing and this reflects the fact that, at least for these three cities, there is no systematic quality gradient whereby apartments in cities with higher priced real estate have more desirable attributes of either the unit or the apartment complex. In the absence of the sort of apartment-specific data that we used in the regression, we proceed to use raw data on average selling prices for all cities and we treat the spatial variation in these raw prices as mainly reflecting the fixity of land supply rather than systematic variation in quality.

A1.4.1 Rental Equivalence Approach

Before turning to the evidence on average selling prices of new dwellings, we discuss an alternative approach to forming standardized housing costs—the rental equivalence method. In some OECD countries, temporal price indices for the services provided by owner-occupied dwellings are based on the imputed value of shelter for owners that are calculated as equivalent to what they forgo by not renting out their homes. In the case of the CPI for the US, this measure was adopted in 1983 in place of the previous measure based on house prices, since it was argued that prices did not accurately reflect the costs of shelter since they also include the use of a house as an asset. There is no guarantee that the rental equivalence method produces lower costs than do price methods, and indeed in the US between 1983 and 2007, the monthly principal and interest payment needed to purchase a median-priced existing home increased by only one-half as much as the increase in shelter prices indicated by the rental equivalence method.[82] But to maintain consistency with temporal deflators, many spatial cost-of-living studies in the US rely on rents rather than on house sales prices (e.g., Moretti 2013).

Despite the arguments for the rental equivalence approach, three reasons lie behind our decision to use the selling prices of new dwellings. First, we note that in some OECD countries (e.g., New Zealand) the price of housing services for owner-occupiers in the CPI is based on new housing sales, with the value of the net increase in the stock of owner-occupied housing during the reference period providing the expenditure weights. These components reflect the change in the price of housing acquired by the owner-occupier segment of the household sector, which is analogous to the approach that we use below and is particularly applicable to the situation in urban areas of the PRC since so much of the market is supplied by new housing rather than resale of existing dwellings.[83] Second, observed rents in urban areas of the PRC may not be an appropriate basis for pricing the rental equivalence of owner-occupied dwellings because of the low share of rented dwellings (Ahmad 2008). Finally, in contrast to the situation for prices of new dwellings, there are no comprehensive statistics on rents reported by the NBS on a spatially disaggregated basis so that any attempt to implement the

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[82] These figures come from the Bureau of Labor Statistics online publication "Common Misconceptions about the Consumer Price Index: Questions and Answers" available at: http://www.bls.gov/cpi/cpiqa.htm.

[83] Even urban dwellings built as recently as the 1979–1999 period are being dismantled to make way for new development because they do not meet the standards of modern urban affluence in the PRC (since they are either too small or lack desirable facilities). See "Most Homes to be Demolished in 20 Years," *China Daily*, 7 August 2010. Available at: http://www.chinadaily.com.cn/china/2010-08/07/content_11113982.htm.

rental equivalence approach would be limited in scope and so could not inform national-level estimates of inequality. Moreover, when considering variation in house prices and rents over space, the same fundamental driver—land prices—affects both, whereas for the temporal variation studied by much of the literature, factors such as interest rates may create a wedge between house prices and rents.

A1.4.2 Trends in Urban Tenure

To help put our choice of using selling prices rather than rents in context, we describe here the trends in urban tenure based on data from the "long form" population census (answered by 10% of the population, which we gross up to total population counts). The available data are reported at county or district level so we categorize according to the urban population as a percentage of the county or district population and restrict attention to the most urbanized counties and districts (being 70% or more urban), distinguishing "highly urbanized" with 70%–90% urban from "very highly urbanized" with ≥ 90% urbanized. In total, there were 71 million urban households in 2000 and 103 million in 2010 under these definitions.

The first trend is that the share of urban households living in self-built accommodation has fallen considerably, from over one-quarter of the total in 2000 to just one-sixth by 2010 (Table 2). This trend is most apparent in very highly urbanized areas, where households in self-built dwellings declined by 3 million over 10 years and are now under 10% of the total (down from 19% in 2000). This pattern most likely stems from rising land values—for example, Wu, Gyourko, and Deng (2012) calculate that real, constant quality land values in Beijing rose by 800% from 2003 to 2010. Under such land price pressures, self-built dwellings are likely to be undercapitalized in the sense of being too small and having inadequate facilities relative to a new dwelling that would be appropriate for such land values. The flip side of the falling share of self-built dwellings is a rising share of purchased dwellings, which are the majority form of tenure (Table 2). Moreover, the rate of new construction, of approximately 8 million new standard private apartments each year, is equivalent to about one-sixth of the existing stock of purchased urban dwellings. The preponderance of new stock in the owner-occupied portfolio means that our focus on the price of new apartments is appropriate.

Table 2: Number of Urban Households of Various Tenure Types (millions)

	Census 2000 (long form)			Census 2010 (long form)		
Dwelling Tenure Type	Highly Urbanized	Very Highly Urbanized	Total	Highly Urbanized	Very Highly Urbanized	Total
Self-built	9.3 (40.2%)	9.0 (18.8%)	18.3 (25.8%)	12.1 (28.2%)	5.9 (9.9%)	18.0 (17.5%)
Purchased	8.1 (35.0%)	23.0 (48.0%)	31.0 (43.7%)	17.8 (41.5%)	33.2 (55.4%)	51.0 (49.6%)
Rented	4.7 (20.4%)	13.4 (28.1%)	18.2 (25.6%)	11.1 (25.8%)	17.9 (29.9%)	29.0 (28.2%)
Total Households	23.1	47.8	70.9	42.8	60.0	102.8

Note: "Highly urbanized" refers to counties or districts where more than 70%, but less than 90%, of the population are urban residents. "Very highly urbanized" refers to counties or districts where 90% or more of the population are urban residents. There are 583 counties or districts in the 2000 census in these categories and 596 in the 2010 census. The column total number of households includes "other tenure types" which are not reported in the table.

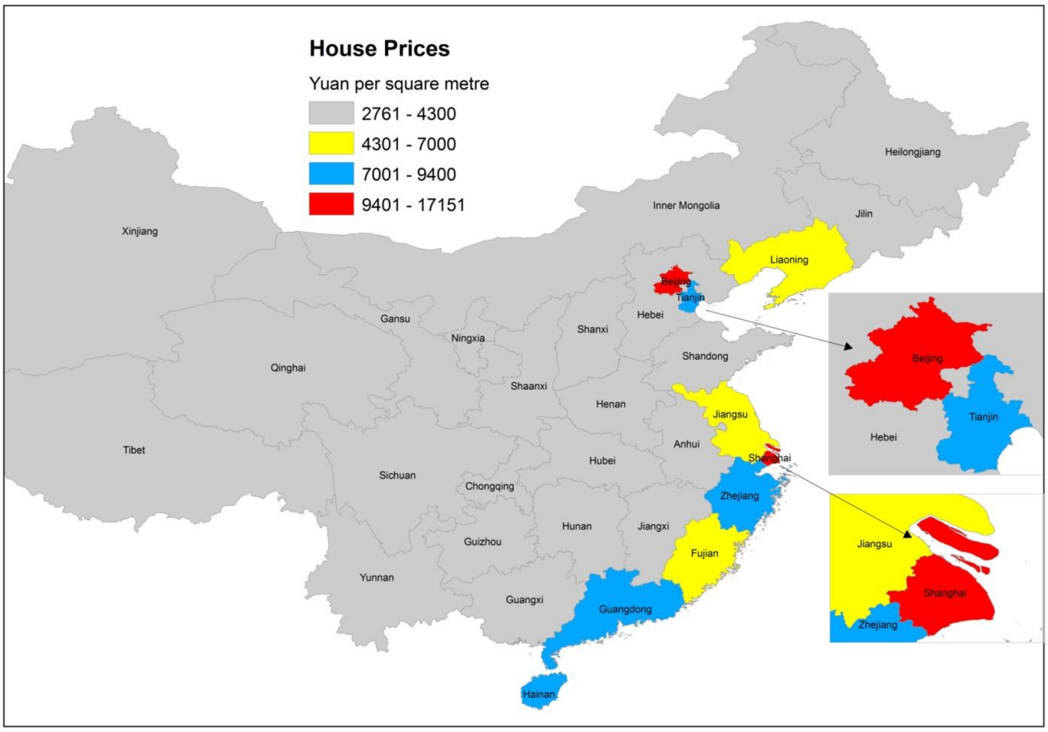
Source: NBS (2003, 2012).

The final tenure category in Table 2 is renters, who have also seen a rise in numbers, although only half as large as the increase in the number of purchasers. However, what is not shown in Table 2 is that that rental sector in urban areas of the PRC is quite different from the owner-occupied sector, mainly housing poor rural–urban migrant workers (Wu 2012) and youth (Zhu 2013, Ouyang, 2011) in dwellings that are older and of lower quality than the dwellings that are being purchased. For example, we gathered data on apartment rentals in Beijing from Soufun.com and found the listed dwellings to have an average age of 10 years, greater than the age of the dwellings that were for sale.

A1.5 HOUSING PRICES AND ESTIMATED DEFLATORS

Since there is tentative evidence that purchased new apartment quality does not vary systematically between cities, we go ahead and use data from the *China Real Estate Statistics Yearbook* (NBS 2011a), *China Statistical Yearbook for Regional Economy* (NBS, 2011c), and the *China Urban Life and Price Yearbook* (NBS 2010) on the average selling price in 2010 (provinces and urban prefectures) and 2009 (urban core districts) of new residential dwellings. We note that these data are for the urban sector, and our expectation is that these prices vary over space most especially because of intercity land price variation. For this reason we do not consider rural housing since rural residential land use rights are not determined by market forces and also because the data available for rural households are just the construction costs (building materials) which we consider to be traded goods and therefore less likely to vary over space than do urban house prices. The distinction between the urban and rural housing sectors is clearly seen in the way that the statistical system reports the relevant data—rural household expenditure on new dwelling construction is defined as consumption expenditure in the *China Rural Statistical Yearbook 2011* (NBS 2011d) while urban household expenditure on house purchases are defined as a separate category apart from consumption expenditure in the *China Urban Life and Price Yearbook 2010* (NBS 2010).

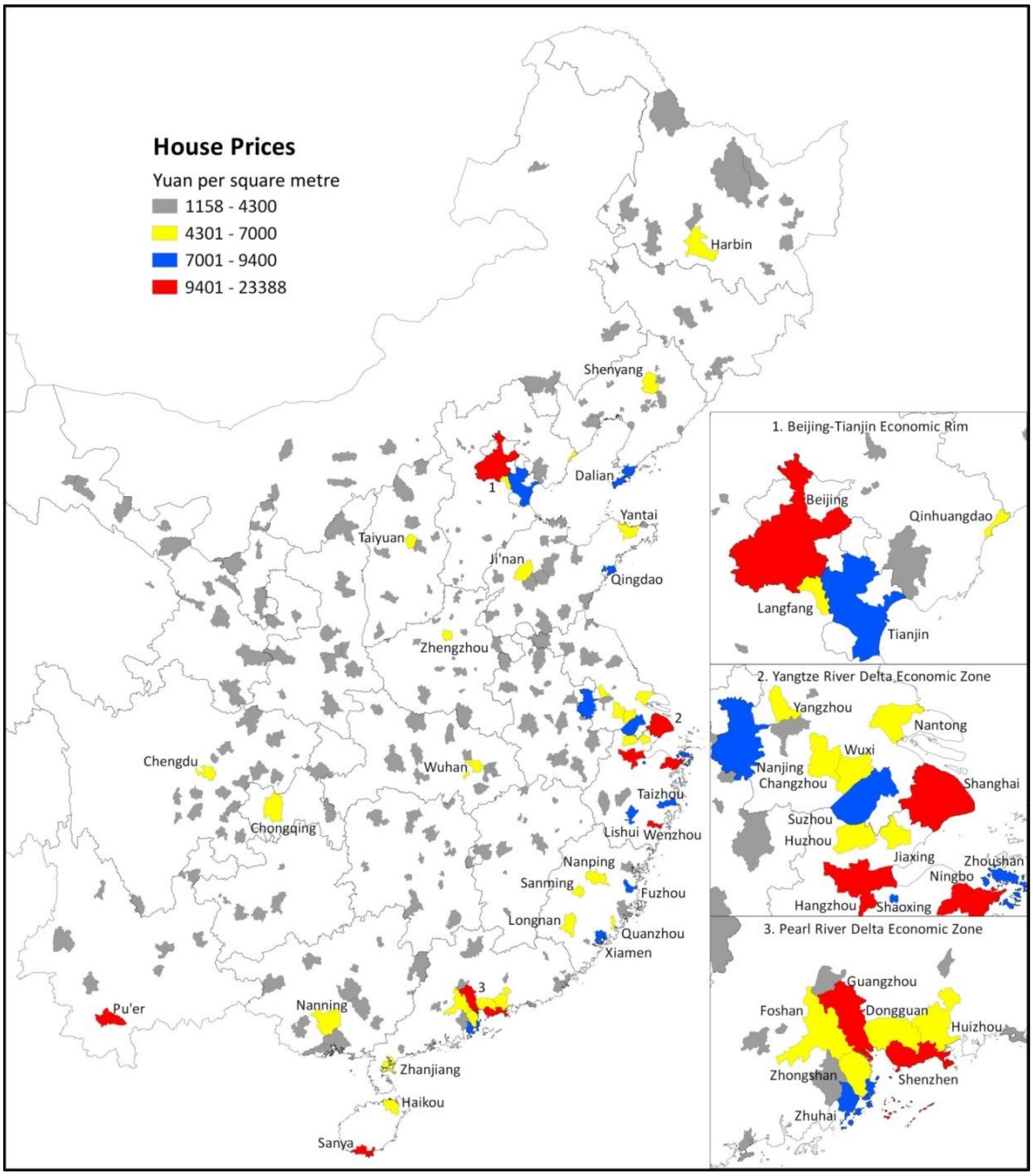
Figure 1: Provincial Average Prices for New Urban Housing, 2010



Source: NBS (2011a).

The average prices for new urban housing in 2010 are displayed in Figure 1, at provincial scale. The highest prices are found in Beijing (CNY17,150 per square meter) and Shanghai (CNY14,290 per square meter). The next highest category of prices (CNY7,001–CNY9,400 per square meter) are only one-half as expensive as those in Beijing, and are found in Tianjin, Zhejiang, Guangdong, and Hainan. In general, the highest prices are found in a continuous belt of provinces along the coast between Jiangsu and Hainan and in the Gulf of Bohai. All of the remaining provinces fall into the lowest price category, which includes all interior provinces plus the coastal province of Shandong.

Figure 2: Average Prices for New Housing in Urban Core Districts, 2009



Source: NBS (2010).

There is considerable heterogeneity within provinces since many of them are as large and as populous as independent countries. Therefore, Figure 2 provides a finer-scale view of urban house prices, reporting the average value in 2009 for each of the 288 core urban districts. These core districts lie within prefecture-level and subprovincial cities, but are more consistently urban than the full area of the prefecture, which often includes rural counties. In order to concentrate on the region where most core urban districts are located, the map truncates Xinjiang, Tibet, and Qinghai in western China. This region contains only two urban districts—Karamay and Urumqi (both in Xinjiang). It is apparent that there are a number of cities in interior provinces such as Chengdu, Harbin, Ji'nan, Taiyuan, and Wuhan with much higher prices than revealed by the provincial average. Pu'er in Yunnan even falls into the highest price category shared by cities such as Guangzhou, Hangzhou, and Shenzhen, in addition to Beijing and Shanghai. Conversely, it is also apparent that there are cities in the coastal provinces with much lower prices than some cities in the interior. Consequently, the variation in the cost of living will be more accurately portrayed at subprovincial levels.

In order to measure cost-of-living differences over space, we calculate a Törnqvist price index for each province (and also for each urban prefecture and urban core district):

$$T = \exp\left[\sum_{j=1}^{J}\left(\frac{S_{kj}+S_{ij}}{2}\right)\ln\left(\frac{P_{ij}}{P_{kj}}\right)\right]$$

where s_{ij} is the average share that item j has in consumption in region i, and s_{kj} is the average budget share in region k, which is the base region, while P_{ij} and P_{kj} are the prices of item j in region i and in the base region. The Törnqvist index uses the arithmetic average of the budget shares in the base region and in region i to weight the logarithm of the price relativities between those two regions. These weighted price relativities are then summed over all *J* items that comprise the budget.

Our working assumption is that only house price variation contributes to cost-of-living differences, so as to form a lower bound for the impact of deflation on spatial inequality. Since it is assumed that prices do not vary spatially for all other components of the budget, the index formula reduces to the log house price relativity between Beijing (base region) and region *i*, weighted by the average importance of housing in Beijing and region *i*. There are no micro data on household budget shares on housing that can be disaggregated to subprovincial levels so we instead use national and regional accounts data. Spatially disaggregated annual investments in urban residential assets are published by the NBS, and since the urban housing market is dominated by new housing stock rather than repeat sales (Deng et al. 2012), this annual investment should be a good proxy for the component of regional income set aside for housing provision. However, one further adjustment is needed because of the famously low share of final consumption in GDP for the PRC, which varies across provinces because of differing intensities of net exports. We therefore use the ratio of annual investments in urban residential assets to final consumption expenditure as our proxy for the budget shares in the Törnqvist formula.[84]

[84] The share of final consumption expenditure in GDP is not available for prefectures and urban districts, so we use the share for the province that the prefecture or district is part of, as an approximation.

Table 3: Residential Investment, Final Consumption Expenditure, Average New House Prices, and Deflation Indices at Province Level, 2010

Province	FIRA	FCON	HP	Tornqvist	DINXB&H
Beijing	0.11	0.56	17151	1.00	1.00
Tianjin	0.06	0.38	7940	1.15	1.19
Hebei	0.09	0.41	3442	1.40	1.52
Shanxi	0.05	0.44	3338	1.29	1.28
Inner Mongolia	0.07	0.39	2983	1.39	1.40
Liaoning	0.13	0.40	4303	1.43	1.40
Jilin	0.08	0.41	3495	1.36	1.42
Heilongjiang	0.06	0.53	3492	1.28	1.38
Shanghai	0.07	0.55	14290	1.03	0.99
Jiangsu	0.08	0.42	5592	1.24	1.30
Zhejiang	0.07	0.46	9332	1.11	1.34
Anhui	0.13	0.50	3899	1.40	1.45
Fujian	0.07	0.43	6077	1.21	1.37
Jiangxi	0.06	0.47	2959	1.33	1.43
Shandong	0.06	0.39	3809	1.30	1.42
Henan	0.07	0.44	2856	1.37	1.50
Hubei	0.07	0.46	3506	1.32	1.35
Hunan	0.07	0.47	3014	1.35	1.24
Guangdong	0.06	0.47	7004	1.16	1.12
Guangxi	0.09	0.51	3382	1.35	1.35
Hainan	0.20	0.46	8800	1.23	1.09
Chongqing	0.14	0.48	4040	1.42	1.64
Sichuan	0.09	0.50	3985	1.32	1.42
Guizhou	0.07	0.63	3142	1.30	1.27
Yunnan	0.09	0.59	2893	1.36	1.20
Tibet	0.01	0.64	2761	1.21	1.22
Shannxi	0.09	0.45	3668	1.36	1.26
Gansu	0.05	0.59	2938	1.28	1.29
Qinghai	0.06	0.53	2894	1.32	1.17
Ningxia	0.11	0.49	3107	1.43	1.31
Xinjiang	0.05	0.53	2872	1.30	1.29

FIRA = investments in urban residential assets as a fraction of GDP, FCON = final consumption expenditure as a fraction of GDP, HP = average selling price of urban commercial new house units (yuan per square meter), Tornqvist = deflation index used by authors, DINXB&H = deflation index of Brandt and Holz (2006) updated to 2010.

Sources: Authors' computations from data in NBS (2011a and 2011c).

Table 3 contains the provincial Törnqvist indexes calculated under these assumptions along with the input data used. The base region is Beijing and the index values are interpreted as the factor by which nominal GDP per capita in region *i* has to be multiplied to translate it into Beijing prices. On average, GDP per capita in provinces outside of Beijing has to be raised by 30% to make it comparable to GDP per capita at Beijing prices. The deflator ranges from 1.03 for Shanghai—whose residents face housing prices almost as high as in Beijing—to 1.42 for Chongqing and 1.43 for Liaoning. It is notable that the lowest average housing prices do not always give the lowest calculated price index because the importance of housing also matters. For example, house prices are low in Gansu but the inflation factor is lower than average because of the relatively low importance of provision for residential housing in regional income.

The last column of Table 3 reports the deflator from Brandt and Holz (2006) using the national basket, which is updated to 2010 using movements in each province's CPI. The Brandt and Holz deflator is more variable than the Törnqvist index, with an unweighted coefficient of variation across provinces more than one-third higher than for the Törnqvist index. This pattern is consistent with Gluschenko (2006), who found that calculating a spatial deflator just once and updating it with the local CPIs can overstate the spatial variation in prices. Nevertheless, the overall level of adjustment needed to put GDP outside of Beijing into Beijing prices is quite similar, with an average inflation factor of 32%. The cross-province patterns of the deflators also are quite similar, with a Pearson correlation coefficient of 0.71 and a rank-correlation of 0.63.

A1.6 IMPACTS OF DEFLATION ON SPATIAL INEQUALITY

Our overall goal in carrying out the analysis reported here is to examine how much difference is made to estimates of spatial inequality in the PRC when using deflators derived just from variation in housing costs. The results are summarized in Table 4, which reports three measures of inequality—the Gini coefficient, the Theil index, and the weighted coefficient of variation (CoV)—for three levels of geography (province, urban prefecture, and the urban core districts within urban prefectures).[85] The nominal values that are deflated are GDP per resident in 2010, which takes into account the various corrections to both GDP statistics and population denominators that are summarized in Li and Gibson (2013). We restrict attention to 2010 because of the need for census data to provide correct counts of the resident population (rather than the *hukou*-registered population) for subprovincial spatial units.

If no account is taken of spatial variation in the cost of living, the level of spatial inequality is overstated by up to 35% (for interprovincial analysis, using the Theil index). This is two-thirds larger than the impact of spatial deflation found by Li and Gibson (2013) who use the deflator from Brandt and Holz (2006), updated to 2010 with the rise in each province's CPI. Since the current analysis assumes that prices for all goods other than housing are set on perfectly integrated markets, it should provide a lower bound to the impact of spatial

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[85] The Theil index is: $T_w = \sum_{j=1}^{m} (p_j / P)(y_{wj} / \mu)\ln(y_{wj} / \mu)$ where m=31 provinces (or 288 prefectures or urban core districts), p_j is the population of the j^{th} province (or prefecture or district), P is overall population, y_{wj} is GDP *per capita* of the j^{th} province (or prefecture or district), and μ is the overall population-weighted mean of GDP *per capita* for all provinces. The (weighted) coefficient of variation is: $CoV = \sqrt{\sum_{j=1}^{m} (p_j / P)(y_{wj} - \mu)^2} \Big/ \mu$. The Gini coefficient is: $G = \left(\sum_{i=1}^{m} \sum_{j=1}^{m} p_i p_j \left| y_{wi} - y_{wj} \right|\right) \Big/ 2\sum p_i^2 \mu$.

deflation if a "full" deflator was used which considered all components of consumption.

Table 4: Interregional Inequality in GDP per Capita with and without Spatial Deflation

	THEIL	THEIL(D)	CoV	CoV(D)	GINI	GINI(D)
Province	0.08323	0.06147	0.42332	0.35521	0.22672	0.19790
Prefecture	0.17442	0.14105	0.62303	0.55361	0.33106	0.29865
Districts	0.11026	0.08512	0.46545	0.40836	0.26059	0.22552

THEIL = Theil index, GINI = Gini coefficient, CoV = population weighted coefficient of variation, (D) = inequality measure on GDP per resident with spatial housing cost deflation.

Note: Results are for 31 provinces, 288 prefectures, and 288 prefecture-merged districts (prefecture urban cores).

Source: Authors' computations from data in NBS (2010; 2011a, b and c; 2012).

The lowest proportionate overstatement from not deflating comes when studying urban prefectures. This most likely reflects the fact that these spatial units have the highest apparent level of inequality amongst the various levels of disaggregation presented in Table 4, due to their heterogeneity. An urban prefecture may contain rural counties and this lack of a consistently defined urbanity gives higher apparent inequality between these "urban" units, and so correcting for spatial price differences has less impact. The more defensible level of subprovincial analysis is the urban core district within an urban prefecture, since this excludes rural counties. At this level of geography, spatial inequality is overstated by 14% (using the weighted coefficient of variation) to 30% (using the Theil index) if differences in the urban cost of living are not taken into account.

A1.7 CONCLUSIONS

In this paper we use newly available data on dwelling sales in urban PRC to develop spatially-disaggregated indices of house prices which are used as spatial deflators for provinces, urban prefectures, and urban core districts. Since we account for only one source of cost-of-living variation over space, the impacts on inequality that we find when using these deflators should be considered a conservative, lower bound. Previous approaches to forming spatial deflators for the PRC have focused more on traded goods prices, but our interpretation of the recent evidence is that these adjust quickly to parity levels and so are unlikely to cause long-run cost-of-living differences between areas. In contrast, the fixity of land makes housing the most likely source of price dispersion across space.

It would be ideal to generate regional components of house prices that hedonically adjust for all components of dwelling quality, but such data are not available beyond a limited number of cities. Nevertheless, our limited analysis suggests that systematic variation in the quality of new dwellings between cities is unlikely, making the published data on the average price of newly constructed urban dwellings a potentially useful source of information on spatial cost-of-living differences. When we use this information to adjust nominal GDP per resident we find that around one-quarter of the apparent spatial inequality disappears once account is taken of cost-of-living differences. Since there are good theoretical reasons for expecting a higher price level in nominally richer areas, our results provide a caveat to concerns about the degree of spatial inequality experienced in the PRC.

Our results are consistent with literature from other countries which finds that apparent patterns in nominal outcomes may weaken or reverse once account is taken of spatial price differences emanating from urban housing markets. The current research may help compare spatial (real) inequality in the PRC to that in other countries, but we believe that any altered inferences due to the deflation we propose are most relevant to temporal comparisons. The legacy of central planning and the *hukou* registration system meant that urbanization and urban housing development in the PRC were much less advanced at the beginning of the reform era than would be expected. Consequently, the spatial cost-of-living differentials now being caused by the urban housing market (reflecting the fixity of land) are likely to have grown from a very low base, making interpretation of trends in nominal inequality in the PRC atypically sensitive to assumptions about spatial and temporal differences in the cost of living.

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Appendix A: Comparison of House Prices and Attributes (means)

	Beijing	Nanjing	Changsha
Unit price (CNY1,000 /construction m^2)	29.93	13.93***	7.13***
Unit characteristics			
Area (m^2)	152.69	131.60	115.69***
Number of bedrooms	2.64	2.78	2.74
Number of bathrooms	1.76	1.40**	1.54
Number of living rooms	1.88	1.94	1.94
Decorated=1, otherwise=0	0.36	0.26	0.32
Level (floor) in complex	3.86	7.56***	7.18***
Complex characteristics			
Land area (1,000 m^2)	149.10	198.65	198.76
Total number of floors	13.74	20.24***	25.78***
Floor area ratio	2.42	2.28	3.51***
Green area (1,000 m^2)	47.73	84.55	87.15**
Green ratio	0.32	0.39***	0.42***
Car park ratio	1.08	0.88**	0.97
Months after opening	15.14	12.42	11.98**
Months to completion	1.94	4.72	5.50**
Sales ratio	0.23	0.78***	0.45***
Observations	50	50	50

CNY = yuan, * = significant at 10%, ** = significant at 5%, and *** = significant at 1% for testing difference in mean compared with Beijing.

Sources: Housing sample collected by authors in February 2013 from www.Soufun.com.

Appendix 2

Economic Growth and Expansion of China's Urban Land Area: Evidence from Administrative Data and Night Lights, 1993-2012

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Economic Growth and Expansion of China's Urban Land Area: Evidence from Administrative Data and Night Lights, 1993-2012

Abstract

The relationship between economic growth, expansion of urban land area, and the broader issue of cultivated land conversion in China has been closely examined for the late 1980s and 1990s. Much less is known about recent urban expansion and if effects of economic growth on this expansion have changed over time. This paper updates estimates of urban expansion for China and examines the relationship with city economic growth for 1993-2012. To see if patterns are robust to different types of evidence, administrative data on the area of 225 urban cores are compared to estimates of brightly lit area from remotely sensed night lights. The trend annual expansion rate in lit area is 8% and was significantly faster in the decade to 2002 than in the most recent decade. Expansion is slower according to administrative data, at just 5% per annum, with no change in unconditional expansion rates between decades while conditional expansion rates decline. The elasticity of area with respect to city economic output is about 0.3. Over time, expansion of urban land area is becoming less responsive to growth of the local non-agricultural population.

Keywords: Economic growth; Land conversion; Luminosity; Urbanization; China

A2.1 INTRODUCTION

The relationship between economic growth, expansion of urban land area, and the broader issue of cultivated land conversion in China during the late 1980s and 1990s has been examined in a series of national-level studies [1-3]. Urban land area expanded 3 percent for every 10 percent increase in local economic output (county Gross Domestic Product [GDP]) and GDP growth fully accounted for all urban expansion from 1995 to 2000. This income elasticity of urban area is less than that in a global sample of cities [4], indicating the dense nature of urban development in China.

Yet despite these findings, recent policy discussion suggests that urbanization in China relies excessively on land conversion and land financing, causing inefficient urban sprawl [5]. Moreover, recent studies of particular regions argue that the urban form is becoming more dispersed [6] and urban sprawl has increased since the beginning of the 21st century [7], which is after the period analyzed in the existing national-level studies. These more recent studies use the term 'sprawl' in the sense of Brueckner [8] as meaning the excessive spatial growth of cities.

Understanding how the rate of urban expansion, and its driving forces, change over time matters to urban planners [3]. Competition for land between urban and other use is very important in China. Land for agricultural and forestry production is concentrated in monsoon-affected East China, where agricultural soils account for 30% of total land surface; more than 20% higher than in West China [9]. Since the most rapid economic and urban growth has also been in East

China, there are concerns that rates of land conversion may be so high as to endanger aspects of sustainable development, such as food security [5].

The current study provides updated national-level evidence on urban expansion in China, and on the effects of local economic growth and population change on this expansion. The 1993-2012 period is examined. Tests are conducted to see if trend expansion rates and the relationship between local economic growth and city area change between the two decades studied. Two types of data are used to see if patterns are robust to different sources of evidence. The first is administrative data from various *Yearbooks* (documented more fully in Section 2 below) that annually report area and various socio-economic indicators for all urban districts in China. There are doubts about *Yearbook* data on urban area supplied by local governments since land sales account for up to one quarter of their revenue and not all sales are sanctioned by upper levels of government. For example, in the secondary market an entity who obtains land use rights from a local government may rent or mortgage that land to others and this often involves a change in land use that is not registered with the authorities [10].

The second source of data is remotely sensed night lights. Artificial light is commonly present wherever urban areas occur, and even though night light provides a potentially less accurate measure than the Landsat data used by the prior national-level studies [1-3], lights have the advantage of being low-cost and up-to-date. Night lights should be especially useful for studying urban growth in China since almost all households were electrified by the start of the study period, with urban electrification rates of 94% in 1992 and 95% by 1999 (rural electrification rates were just as high) [11]. Thus it is not the case that lit areas were catching up to the urban boundary due to rising electrification rates, as may have occurred in other developing countries such as India.

In addition to the search for robustness from using two different sources of data on urban area, and the timeliness of the current study, one other feature is worthy of mention. There are up to 20 years of annual data (and 32 satellite-year observations) for each city in the sample. Repeated information over time allows use of panel data to account for unobservable factors like environmental conditions (e.g., slope and soil) and local variation in the implementation of urban policy. Even though these factors may reflect the historical legacy of a city, and may be related to current land area, their omission from our study does not cause bias. With repeated information over time, one can use ‘fixed effects’ to control for unobserved factors, allowing unbiased estimation [3]. Also, panel data methods allow satellite fixed effects be used to ameliorate effects of random measurement error in estimates of urban area caused by various shortcomings of the DMPS-OLS sensors for urban mapping. Of the 11 shortcomings considered in the literature [12], the lack of on-board calibration and failure to record gain changes when the signal is amplified to enhance visual interpretation of clouds may introduce the largest temporal errors.

A2.2 DATA AND METHODS

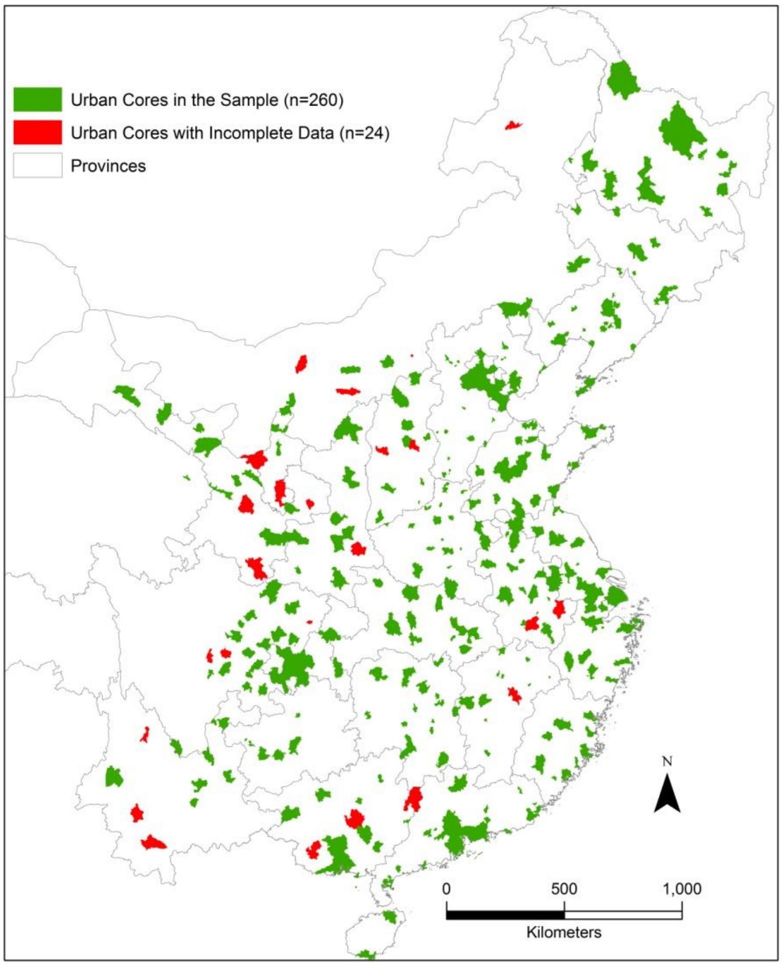
This is a national-level analysis covering urban districts (*shiqu*) of almost all prefectural cities in China. In the 2010 census, China’s 287 prefectural cities had 95% of the non-agricultural population, with the rest in other types of spatial units, such as Banners, Leagues, and Autonomous Regions. The westernmost provinces of Xinjiang and Tibet had just three prefectural cities with urban districts (Lhasa, Karamay, and Urumqi) and data for these cities is either absent in some official tabulations or reflects a skewed economic structure [13]. We therefore excluded areas west of Gansu when using national-level databases. The main sources for these databases were various issues of the City Statistical Yearbook [14], *Hukou* Yearbook [14], and 50 Years of Cities [16]. These data are referred to as coming from *Yearbooks*, to distinguish them from the estimates obtained from remote sensing.

A prefectural city typically includes rural counties and county-level cities along with urban districts. The district (or adjacent districts for multi-district prefectures) best proxies for an urban core [17]. These urban cores will be referred to as 'cities' in what follows and in this usage it does not mean the entire prefectural city. Some districts had been upgraded from previously being Banners, Leagues, Regions or Autonomous Prefectures and did not always have a continuous time series of data. The *Yearbooks* provide estimates since 1993 and currently run to 2012, so a threshold was set that a city needed data for at least 15 of these 20 years to be in the sample; this excluded 24 of the urban cores. Figure 1 shows the 24 cities excluded, and the remaining 260 cities.

In addition to *Yearbook* data, remotely sensed night lights from the Defense Meteorological Satellite Program's Operational Linescan System (DMSP/OLS) are used. These are available for download from http://ngdc.noaa.gov/eog/dmsp/downloadV4composites.html for six satellites: F10 (1992-94), F12 (1994-99), F14 (1997-03), F15 (2000-07), F16 (2004-09), F18 (2010-12). There is a long history of using satellite-detected luminosity to measure urban area [see, for example, 17-25]. The data from DMSP/OLS are reported in relative brightness terms, as a 6-bit Digital Number (DN) ranging from 0-63. A threshold level of brightness can be set to exclude low-lit areas of sparse development. The stable lights annual composite from DMSP/OLS covers 1992-2012, but to match with the time-series of *Yearbook* data the sample is restricted to 1993-2012. Tests of whether expansion rates for 1993-2002 differ from those for 2003-2012 are conducted.

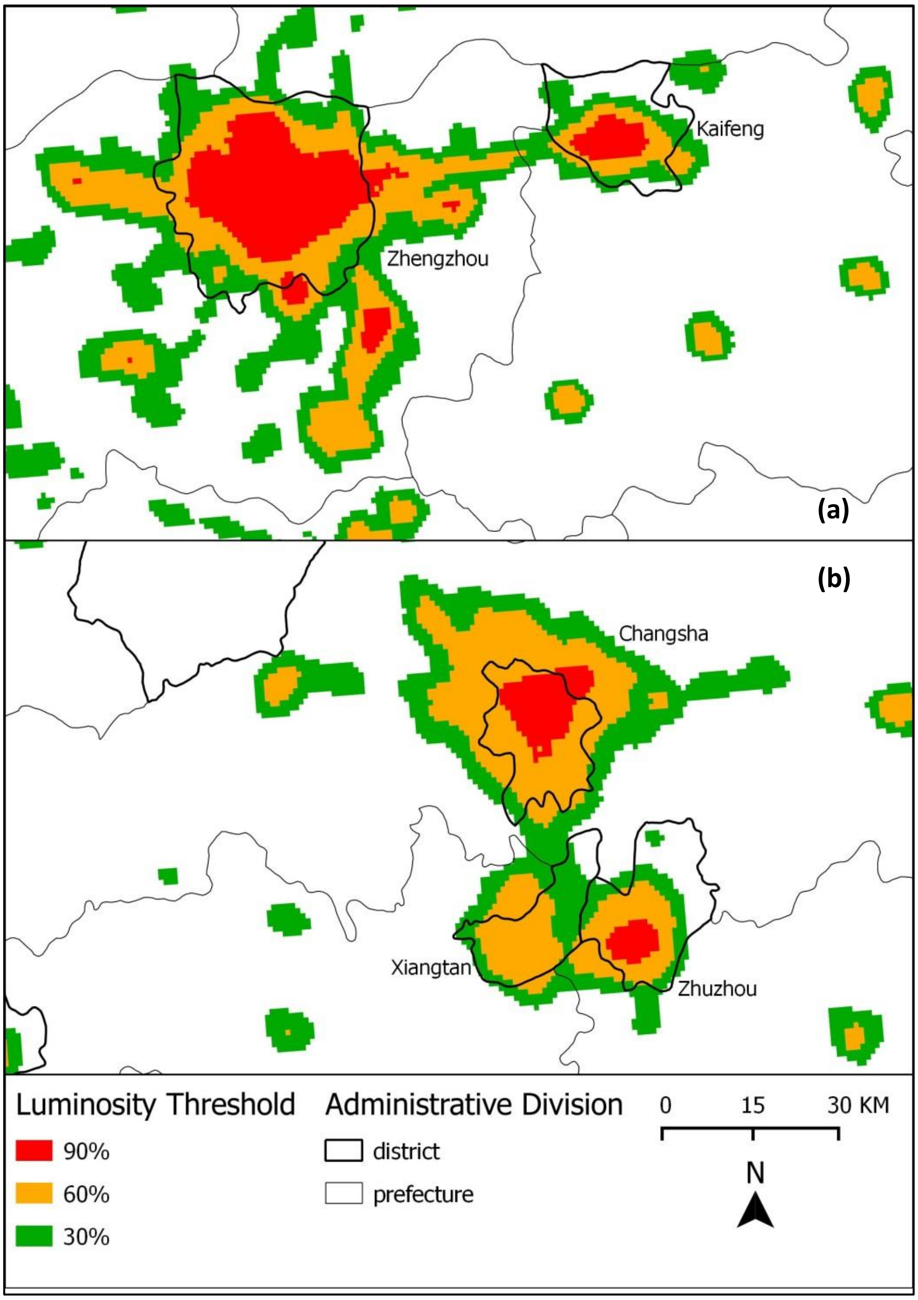
Prior national-level studies of urban expansion and land conversion in China mostly rely on Landsat data [1-3]. In comparison to Landsat, the DMSP stable lights data tend to make agglomerations appear larger. The composites produced by averaging several overlapping input pixels are approximately 1000 times larger than Landsat TM pixels, so sub-pixel light sources are attributed to an expanded area [22]. The reflectance of light from surrounding water and non-urban land (e.g., due to snow or ice) gives a blooming effect [21]. Also, uncertainty in geo-location that gets compounded by averaging over multiple nights causes exaggeration [23]. But the proportionate effects are small for medium to large settlements [24]. The urban cores studied here had an average resident population of 1.6 million and a minimum population of 0.2 million in the 2010 census, so errors for cities of this scale should be relatively small. Also, there is a strong linear trend between night lights and traditional measures of urban area in China [25]. The results reported below use both administrative data on urban area and night lights to indicate if the findings on urban expansion rates and their driving forces are robust.

Figure 1. Location of urban cores in the sample and urban cores excluded due to incomplete data



A key decision with night lights is the brightness threshold to classify a pixel as urban. A lower detection threshold makes urban area seem larger and cities may merge if linked by built-up corridors along major transport routes. Figure 2 gives examples of this effect for some cities in Central China. In this figure, and the results below, the digital numbers are in percent of the maximum value (DN=63), to stress that they are relative rather than absolute values. In Figure 2 the thresholds are 90%, 60%, and 30%.

Figure 2. Examples of the effect of luminosity thresholds on apparent urbanized area and the number of distinct urban cores, from (a) Henan, and (b) Hunan, China (Satellite F18 2012)



These thresholds work as follows: starting from the center of each city where lights are brightest and moving outwards, as the algorithm finds pixels less illuminated than the threshold it begins searching in a different direction. If the algorithm finds no adjacent pixels lit above the threshold except those already scanned closer to the city center, it sets a boundary. Prior studies of night lights in China use specific DN thresholds that are as low as 5, 8 and 12 [24] and as high as 27 to 62 [26]. The thresholds in Figure 2 correspond to DN values of 56, 37 and 19. There is no consensus on the particular threshold to use, so criteria for choosing a threshold are considered below and two thresholds are chosen, to ensure results are not sensitive to the threshold used.

In Figure 2a, nearby cities of Zhengzhou and Kaifeng (64 kilometers apart) form a single urban area if a lower luminosity threshold is used because a highly lit corridor about five kilometers wide joins them. At higher thresholds they shrink into separate 'islands' and at 90% even a city of 8 million like Zhengzhou has substantial areas not classified as urban. The example in Figure 2b has three nearby urban cores joined when a 30% luminosity threshold is used, but these become distinct cores at 60% (plus a small 'island' detaches from Changsha). A very high detection threshold causing some cities to disappear entirely is also illustrated; the city of Xiangtan has an apparent area of 200 km^2 at a luminosity threshold of 60% but it disappears at 90% because its lights are not bright enough, even though it has a population of two million.

The tradeoff between high and low thresholds is shown more generally in Figure 3. The total area for cities in the sample is on a log scale for 1993, 2002 and 2012 at thresholds from 30% to 100%. The slope changes at about 90% but at lower thresholds each percentage (0.6 DN points) raises apparent urban area by 3.8% in 1993 and 2.5% otherwise. The diamond-shaped markers in Figure 3a show total area according to the *Yearbooks.* In 1993, a luminosity threshold of 65%

gives the best match with *Yearbook* data, while in the later years the best match is at 85% and 90%. The rise in the threshold that best matches *Yearbook* data implies that *Yearbook* estimates of urban area rise slower than luminosity-based estimates. Specifically, between 1993 and 2012 the area estimates in the *Yearbooks* tripled, while lit area increased by a factor of 7.5 at a 65% luminosity threshold, and by more at higher thresholds. The likelihood is that *Yearbook* data on urban area are under-estimated due to the incentives facing local governments [10]. This under-estimate has been observed by the remote-sensing literature where it is suggested that the differences reflect limitations in the techniques used to gather the *Yearbook* data [26].

Returning to the question of choice of luminosity threshold, anything above 65% gives a smaller area in 1993 than what the *Yearbook* data show. Local governments are unlikely to overstate urban area, given concerns from higher levels of government about converting farm land [10]. Thus, we do not use any luminosity thresholds above 65%, since these give a smaller urban area at the start of our study period than what the *Yearbooks* report. High thresholds also make less brightly-lit cities drop out of the sample (Figure 3b). But the number of observations also falls at low thresholds as nearby cities clump into single units. Luminosity thresholds from 50% to 65% maximise observations and give similar estimates of area at the start of the period to what *Yearbook* data show. To see if patterns are robust to different ways of measuring areas, the results use city area reported in *Yearbooks*, and also use area estimates from night light at luminosity thresholds of 50% and 65%.

Figure 3. The effect of varying luminosity thresholds for detecting urban boundaries on (a) apparent urban area, and (b) the number of cities separately distinguished

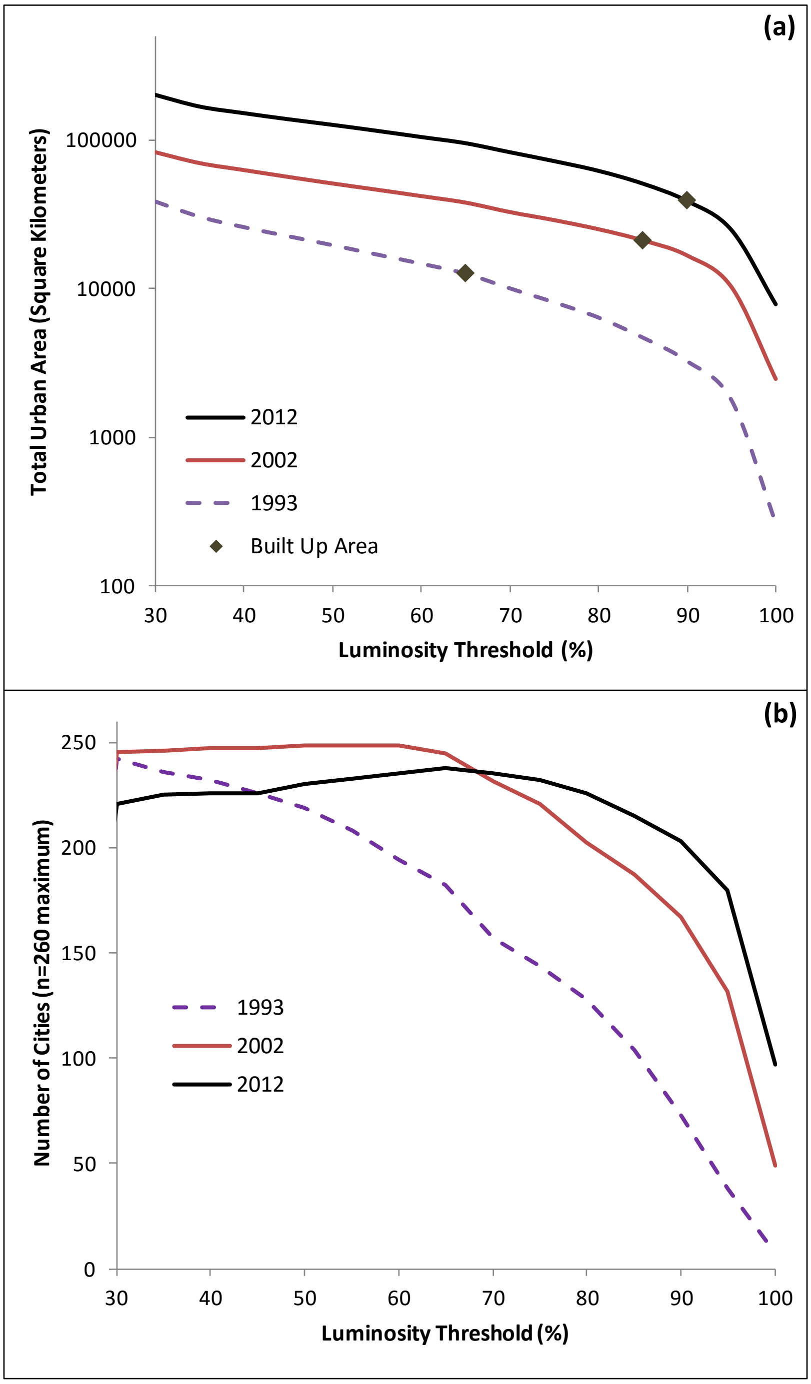
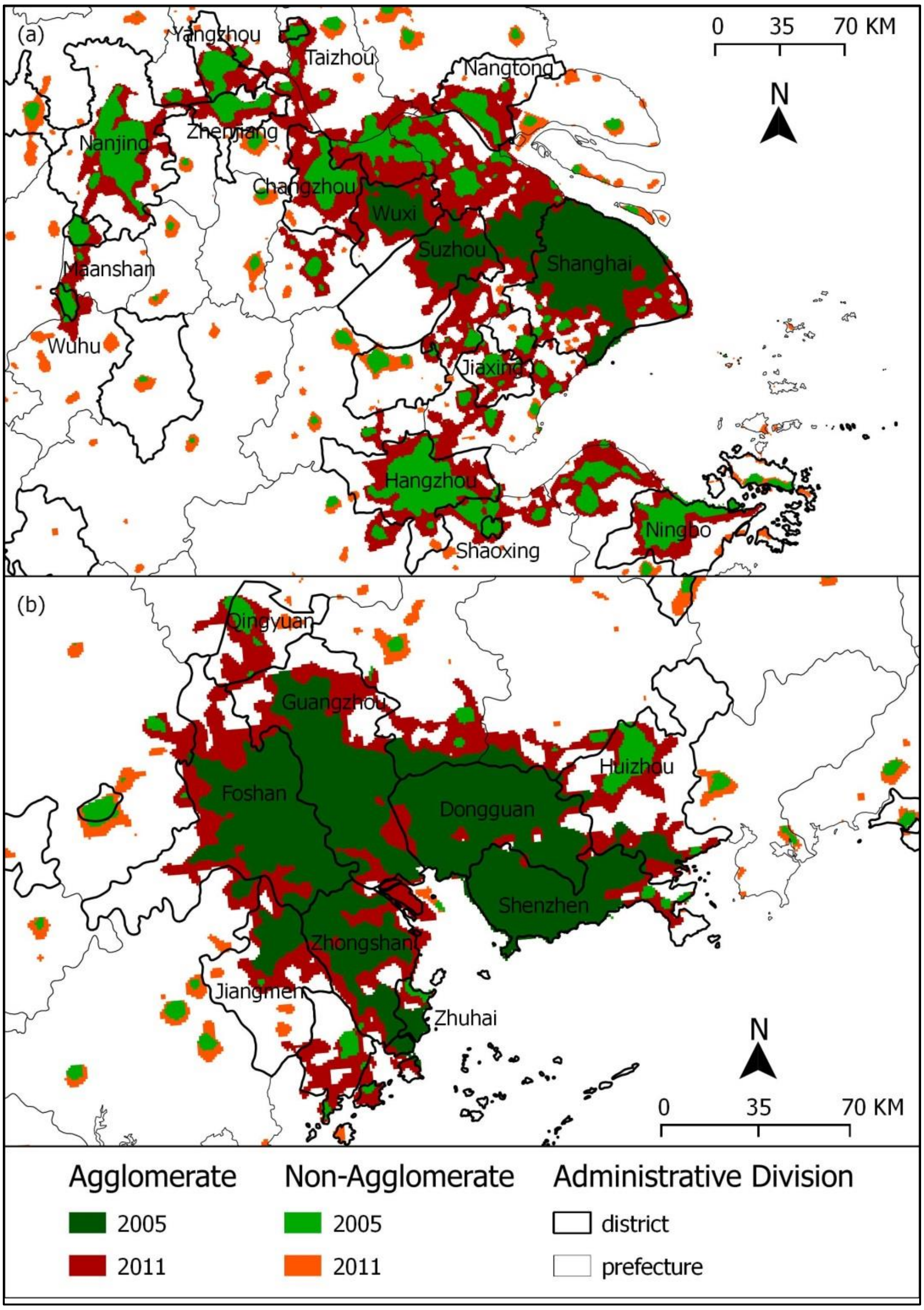


Figure 4. The joining of initially separate cities in the (a) Yangtze delta and (b) Pearl River delta



When cities clump into a single unit the time series of lit area is interrupted. Figure 4 shows (**a**) the Yangtze delta and (**b**) the Pearl River delta. By 2011 the separate cities in each delta had joined at a luminosity threshold of 50%

but several of them were separate in earlier years, as shown for 2005. To provide consistent time series, any cities that eventually join together at the 50% luminosity threshold are joined for all years (1993-2012) and for all three samples – the estimates from *Yearbook* data, and the lit area estimates from the 50% and 65% thresholds. This gives consistent samples across years and data sources. After these merges, the number of cities in the sample drops from n=260 to n=225 (but they continue to cover the same total area).

The final modeling issue is how to deal with temporal measurement error in night light data. The DMSP/OLS sensors lack on-board calibration and no record is kept of gain changes (when the signal is amplified to help the US Air Force detect clouds). These features introduce temporal variability into the record from a given satellite. Also, in years that two satellites are in orbit (e.g., 1994 and 1997-2007) a stable lights composite from one satellite's passes over a given area during the year will not be the same as the composite for the same area from the other satellite. This 'noise' is undesirable but random error in a dependent variable does not cause estimator bias and is unlikely to overwhelm the 'signal' in the data from the true but unknown expansion of the urban area.

One way to deal with inter-satellite variation is to average values in years with two satellites [27]. Another is inter-calibration, with regression adjustment to DN data prior to use in an analysis [28]. For the most widely used calibrated data, the F12 satellite in 1999 is treated as 'truth' because it has the highest DN values across years and satellites. Regressions of these 1999 DN values on a polynomial of DN values from other years and satellites for each pixel on the island of Sicily (which is assumed to be temporally stable) are used to generate sets of coefficients

[23]. The DN values from the other years and other satellites are then plugged into this regression to adjust the raw DN values to match the values from F12 in 1999. This calibration can also be done for a particular country or region and has been done for China [26]. But whether local or global, calibration relies on untested assumptions about temporal and spatial homogeneity. Moreover, subsequent analysis of adjusted values should take account of the fact that these are predictions from a regression, and so when they are treated as data, the standard errors should be adjusted for the two-stage estimation.

In contrast to these methods, this study does not average and does not calibrate. Instead, the (log) area of urban core *i* in year *t*, as measured by satellite *s*, is modeled with a fixed effects regression:

$$\ln A_{its} = \beta_0 + \beta_1 T + \delta_s D_s + \gamma_i D_i + \varepsilon_{its} \quad (1)$$

where T is a time trend, D_s is a set of fixed effects for each satellite, D_i is a set of fixed effects for each urban core, and ε_{its} is a random error. The $\hat{\beta}_1$ gives the percentage change in area for a one unit increase in T, and so is the best estimate of the trend annual rate of expansion, after controlling for the characteristics of each city and the idiosyncratic characteristics of each satellite. Unlike averaging observations in years with two satellites, which gives equal weight to both, the regression approach uses data-determined weights (the size of the $\hat{\delta}_s$). The measurement errors in the A_{its} should be random, conditional on D_s, so they go into the residuals, $\hat{\varepsilon}_{its}$ and do not bias coefficient estimates (but do create heteroscedasticity, so robust variance estimators should be used).

Equation (1) can also be extended to test if the growth rate is changing over time, using either a quadratic trend model or a piecewise linear trend. A dummy variable for the second decade in the study period D_t can be interacted with the time variable to give a piecewise trend:

$$\ln A_{its} = \beta_0 + \beta_1 T + \lambda(T \times D_t) + \gamma D_t + \delta_s D_s + \gamma_i D_i + \varepsilon_{its} \quad (1a)$$

A test of the null hypothesis λ=0 is a test of whether the trend annual rate of expansion is changing over time, while the annual expansion rate for the second period is calculated as: $\hat{\beta}_1 + \hat{\lambda}$.

The fixed effects regression can also be further extended to allow for time-varying covariates. The two covariates considered here are city economic output (GDP) and non-agricultural population (POP).

$$\ln A_{its} = \beta_0 + \beta_1 T + \beta_2 \ln GDP_{it} + \beta_3 \ln POP_{it} + \delta_s D_s + \gamma_i D_i + \varepsilon_{its} \quad (2)$$

With fixed effects for both cities and satellites included, the estimated elasticities from equation (2) are unlikely to be biased by the presence of unobserved factors that affect city area and correlate with local economic output or local population. In order to examine how these elasticities change over time, the dummy variable for the second decade in the observation period, D_t can be added to the model and interacted with the time-varying covariates and with the linear time trend.

A2.3 RESULTS

A2.3.1 Trend Expansion Rates for Urban Cores

The results of estimating equation (1) are reported in Table 1. The main results use a luminosity threshold of 65%, and a sensitivity analysis uses a threshold of

50%. These cities are expanding at a trend annual rate of 8.3% at the preferred threshold for defining a pixel as part of the urban core. The expansion rate is slightly less (8.0%) if the 50% luminosity threshold is used, which is to be expected since the lower detection threshold gives a larger apparent urban area to start with and so subsequent growth rates are then lower. At these trend rates of expansion, China's urban cores would be expected to double in area after nine years. However, the rate of city expansion appears to be slowing down, which is shown in Table 1 by the statistically significant negative coefficient on the squared term for a quadratic time trend (Panel B). This slowing of the expansion rate is also shown by the negative deviation term when a piecewise trend is estimated (Panel C). Specifically, allowing the time trend to differ from the first decade (1993-2002) to the second decade (2003-2012), there is a statistically significant fall in the annual rate of expansion of at least six percentage points between the periods. Thus, while the rate of area expansion for these cities in the first decade was around eleven percent per annum, in the second decade it was only around five percent per annum.

The results in Table 1 control for fixed characteristics of cities and of satellites. Both sources of variation in the apparent area of a city-satellite-year cell matter, given the statistically significant *F*-test results for the joint hypotheses that each set of fixed effects can be excluded from the model. These results are in the columns headed "cities" and "satellites". One sensitivity analysis that does not seem to matter is if sample values are weighted to reflect the fact that some observations represent more than one of the original urban cores (in cases where two or more cities merge into one as seen in Figure 4). Unreported results for urban areas as defined at the 65% luminosity threshold that use weights are very similar to what is in Table 1; the linear trend is 8.4% rather than 8.3% and the two values for the piecewise trend are 11.5% and -7.3% rather than 11.6% and -7.5%.

Table 1. Average trend expansion rates for urban cores in China, 1993-2012

	65% threshold	Fixed Effects = 0		R^2	50% threshold	*Yearbook* data on area
		Cities	Satellites			
Panel A: Linear Trend						
Trend Expansion Rate (% per annum)	8.3% (25.1)***	583***	125***	0.908	8.0% (26.6)***	5.1% (29.6)***
Panel B: Quadratic Trend						
Linear term	12.70 (6.69)***	571***	122***	0.909	8.65 (5.34)***	-0.87 (1.26)
Squared term × 100	-0.32 (6.65)***				-0.21 (5.29)***	0.02 (1.34)
Panel C: Piecewise Trend						
Trend 1993-2002	11.6% (18.0)***	565***	152***	0.910	10.9% (19.6)***	4.5% (17.3)***
Deviation 2003-2012	-7.5% (8.4)***				-5.7% (7.4)***	0.5% (1.4)

Note: The trends are estimated from variants of equation (1), with the fixed effects for cities and satellites not reported. The *t*-statistics for the trends in ( ) and *F*-statistics for the joint tests of the fixed effects=0 are from robust standard errors. Statistical significance at the 90%, 95% and 99% level is denoted by *, **, ***. N=225 urban cores.

While the results using the two luminosity thresholds are quite consistent with each other, they are rather different to the results obtained when using the *Yearbook* data on urban area. The linear trend model suggests an annual rate of expansion in *Yearbook*-reported urban area for these 225 cities of just 5.1% rather than the trend annual increase of 8.3% that the luminosity data suggest. This slower growth rate implies a doubling time of 15 years rather than the nine years that the night lights data show. The supposition in the literature is that local governments may have incentives to under-report land conversion to urban uses [10]. The empirical pattern that the *Yearbook* estimates of urban area are less than what remote sensing data indicate [26] is supported by our findings, since the rate of expansion is less when using the *Yearbook* data. In addition to the difference in the trend annual rates of expansion, when the *Yearbook* data are used with the quadratic and piecewise trend models, there is no evidence of a slowing in the growth rate of city land area in the later years of the observation period. However, it should be noted that this inconsistency, compared with the robust finding from the night light data of a slowdown in the expansion rate for the decade since 2002, is less apparent once other covariates are added to the models, as discussed in the next section.

A2.3.2 The Elasticity of Urban Area With Respect to City Economic Output

The area of these urban cores that is reported in *Yearbook* data increases by 2.7% for every ten percent rise in city GDP and by 3.7 percent for every ten percent rise in the non-agricultural *hukou* population of the city (Table 2, column 1). This sensitivity of urban area to growth in the local population is quite different to the existing results from national-level studies for China, where it appeared that local population growth had no impact on the rate of expansion [2,3]. If a time trend is included in the regression, it substantially reduces the elasticity of urban area with respect to city GDP but not with respect to the non-agricultural population of the city. As for changes in the elasticities over time, the results in columns (3) and (4) show that urban area was more elastic with respect to economic output and less elastic with respect to local population in the period after 2002 than before then.

The trend rate of urban expansion, conditional on population and local economic output also was significantly lower in this second decade of the observation period. This fall in the (conditional) expansion rate is in keeping with the main result of a slowing expansion rate that was found in Table 1 using night light derived measures of city area.

Table 2. Effects of GDP and population on expansion of urban area in China, 1993-2012

	Dependent variable: ln (area, city *i* year *t*) from *Yearbook* data			
	(1)	(2)	(3)	(4)
ln (GDP for city *i* in year *t*)	0.266 (15.94)***	0.175 (5.38)***	0.160 (6.99)***	0.085 (2.07)**
ln (non-agricultural population)$_{it}$	0.367 (5.50)***	0.366 (5.65)***	0.431 (6.96)***	0.432 (7.27)***
Time trend (t=1,2,3,…T)		0.014 (3.06)***		0.019 (3.89)***
ln (GDP)$_{it}$ × D_t [D_t =1 if year>2002]			0.122 (5.24)***	0.160 (4.91)***
ln (non-agricultural population)$_{it}$ × D_t			-0.107 (3.51)***	-0.144 (3.71)***
Time trend × D_t				-0.013 (2.40)**
R^2	0.945	0.946	0.947	0.948

Note: Fixed effects for cities and the overall intercept are not reported. The *t*-statistics in ( ) are from robust standard errors. Statistical significance at the 90%, 95% and 99% level is denoted by *, **, ***. *N*=225 urban cores, and 3967 observations.

The estimated elasticities and their change over time appear to be quite different when city area is measured using night lights rather than using administrative data. Specifically, there appears to be no effect of the locally registered non-agricultural population on urban area (Table 3, row 2). The elasticity of area with respect to city GDP is 0.37, with cities measured at a luminosity threshold of 65%, (Table 3, column 1). These economic output and local population elasticities are quite similar to those reported by Deng and colleagues [2] when using Landsat 5 data on urban areas in the 1990s.

Table 3. Effects of GDP and population on expansion of urban area in China, 1993-2012

	Dependent variable: ln (lit area, city *i* year *t*) with 65% threshold			
	(1)	(2)	(3)	(4)
ln (GDP for city *i* in year *t*)	0.373 (11.95)***	0.109 (2.38)**	0.307 (6.93)***	0.154 (3.08)***
ln (non-agricultural population)$_{it}$	0.094 (0.94)	0.100 (0.90)	0.168 (1.57)	0.157 (1.41)
Time trend (t=1,2,3,…T)		0.062 (8.46)***		0.093 (11.60)***
ln (GDP)$_{it}$ × D_t [D_t =1 if year>2002]			0.033 (0.67)	0.113 (2.24)**
ln (non-agricultural population)$_{it}$ × D_t			-0.158 (2.57)**	-0.237 (3.80)***
Time trend × D_t				-0.097 (9.11)***
R^2	0.904	0.907	0.907	0.912

Note: Fixed effects for cities and satellites and the overall intercept are not reported. The *t*-statistics in ( ) are from robust standard errors. Statistical significance at the 90%, 95% and 99% level is denoted by *, **, ***. For the *N*=225 urban cores there are 6229 city-satellite-year observations.

When a dummy variable for the second decade is interacted with the other variables, there is no change over time in the elasticity of land area with respect to GDP but a statistically significant fall in the elasticity with respect to non-agricultural population (Table 3, column 3). Once a piecewise time trend is added, the second decade shows significantly slower expansion rates than the first decade, conditional on GDP and population. This result is consistent with the finding in Table 1 of a slowdown in the expansion rates in the most recent period. The large fall in the elasticity of land area with respect to local population in the most recent period is still apparent with the time trend included, while the elasticity with respect to GDP appears to rise somewhat (but still is less than 0.3 for 1993-2012).

Table 4. Sensitivity analysis for elasticities using urban core area with a 50% luminosity threshold

	Dependent variable: ln (lit area, city *i* year *t*) with 50% threshold			
	(1)	(2)	(3)	(4)
ln (GDP for city *i* in year *t*)	0.324	0.093	0.259	0.095
	(11.64)***	(2.25)**	(6.61)***	(2.06)**
ln (non-agricultural population)$_{it}$	0.115	0.120	0.186	0.183
	(1.36)	(1.28)	(2.01)**	(1.87)*
Time trend (t=1,2,3,…T)		0.054		0.077
		(8.84)***		(11.74)***
ln (GDP)$_{it}$ × D_t [D_t =1 if year>2002]			0.068	0.114
			(1.59)	(2.54)**
ln (non-agricultural population)$_{it}$ × D_t			-0.145	-0.187
			(2.72)***	(3.48)***
Time trend × D_t				-0.058
				(7.25)***
R^2	0.939	0.942	0.941	0.944

Notes: See Table 3. For the N=225 urban cores there are 6357 city-satellite-year observations using the 50% threshold.

The patterns of the estimated elasticities and their changes over time are very similar when urban areas are measured with a 50% luminosity threshold as a sensitivity analysis (Table 4). While the elasticity of land area with respect to local population is more precisely estimated in this sensitivity analysis, the magnitude is roughly the same as in Table 3 with urban expansion appearing relatively insensitive to growth in local population. The slowdown in the trend rate of expansion, conditional on population and GDP, remains apparent. Indeed, this significant slowdown in the trend rate of expansion in the second decade of our study is a common finding across Tables 2-4, and so it is a feature of both the night light data and *Yearbook* data. Other patterns from these two data sources are quite different; for example, in terms of the trend expansion rates. Thus, the fact that the slowdown in expansion over time is shown by both types of data is a notable finding that is presumed to be more robust than if it was apparent only with one type of data.

A2.4 DISSCUSSION AND CONCLUSIONS

The cities studied in this paper are home to the majority of China's urban population. The land area of these cities reflects the demand for living space of this urban population, along with land needs of commercial and urban industrial development. The increase in China's urban population and the rising affluence of that population will see continued expansion of urban area. It is therefore important that agencies concerned with land use and land conversion are aware of the most recent and comprehensive patterns, rather than basing decisions on earlier evidence or more limited case studies.

The current national-level analysis finds consistent evidence that the rate of spatial expansion for these cities is slowing down, and this pattern holds across several different ways of measuring urban area and of modeling expansion. Specifically, if one looks at the expansion of urban land area conditional on local economic output and local population, then all three measures of urban area studied here show a sharp fall in the expansion rate in the decade since 2002. If unconditional expansion rates are studied, then two out of the three indicators of city land area show this slowdown.

This lower expansion rate in the most recent decade may reflect the effects of policy that aimed to direct urbanization elsewhere, such as to county-level cities. For example, the 1990 'City Planning Law' (*Zhonghua Renmin Gongheguo Chengshi Guihua Fa*) mandated 'strictly controlling the size of large cities and developing medium-sized and small cities' and a short-lived county-to-city upgrading system was attempted [29]. This national-level policy, and possible effects of local competition for mobile industry, helped fuel rapid growth in the construction sector that was especially apparent outside of the core urban districts whose spatial expansion is analyzed here. For example, the share of the working age population employed in the construction sector doubled between the 2000 and 2010 censuses. Where that construction sector employment was located also shifted [30]; for urban districts the contribution to total construction sector employment fell from 52% to 42%, while for counties it rose from 29% to 41%. With so much construction employment moving into counties over this decade, it is plausible that the rate of expansion of urban area in counties was increasing even as expansion rates slowed in the urban cores that house most of China's urban residents.

An additional factor that may have slowed expansion of urban core areas is the effects on China of the Global Financial Crisis (GFC). At the provincial level, the GFC seems to have reduced inequality, with income growth in export-oriented coastal areas slowing [31], and millions of workers moving back to their homes in interior provinces [32]. This demand shock in the middle of the second decade studied here may have reduced the rate of urban expansion in the rapidly growing coastal provinces and possibly shifted the location of expansion towards less urbanized areas in the interior.

In keeping with the existing evidence [2-3], the econometric results reported here suggest that rising income is an important driving force for the expansion of urban areas in China. Nevertheless, the rate of response of land area to local economic growth is fairly modest; the elasticity of 0.3 is well below the global average for the income elasticity of urban land area. Consequently, it remains true that urban areas in China are relatively densely populated when judged by the standards of the rest of the world. While there was some evidence of a more elastic response of land area to economic growth in the second decade of the period studied here, that change was from a low base and was most visible for the *Yearbook* data on built-up area, which exhibits different trends than the night lights derived measures of city area. Moreover, there are grounds for doubting the accuracy of *Yearbook* data, given the possible incentives for local officials to under-report land conversion. A continued monitoring of the response of urban land area to local economic growth would be a useful contribution of future research.

The fall over time in the elasticity of urban land area with respect to local population is not a result that would be expected, based on recent discussions of urban policy in China [5] and recent case study evidence [6]. If rising city population is not translating into expanded city land area, it must be the case that the population density of cities is rising, rather than becoming more dispersed as is often asserted. A possible reason for this unexpected result is that the *hukou* registered non-agricultural population for each city is becoming a less reliable count of the actual number of city residents because of the growing number of non-*hukou* migrants [31]. The count of *hukou* holders is used in this study, and in the previous national-level studies [2-3] because it is the only city-level population count reported annually. It would be a useful topic for future research to form *de facto* measures of city size based on counting residents rather than the *de jure* measures based on the *hukou* count, and to test which is the better predictor of city land area. It is helpful for urban planners to find the best way to count people for use in forecasting the future land needs for China's growing urban population.

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Author Contributions

The first and corresponding author John Gibson designed the research and wrote the initial text of the paper. Chao Li and Geua Boe-Gibson were responsible for the processing and analysis of the remote sensing data, and the production of the maps. Chao Li gathered all of the administrative data from the various *Yearbooks*. All authors read and approved the final manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

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Appendix 3

Co-Authorship Forms

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Co-Authorship Form

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chapter 2

Li, C. & Gibson, J. (2013). Rising regional inequality in China: fact or artifact? World Development 47(1), pp. 16-29.

Nature of contribution by PhD candidate	Data Collection, Empirical Analysis, writing of Initial Draft, Presentation at one conference
Extent of contribution by PhD candidate (%)	55

CO-AUTHORS

Name	Nature of Contribution
John Gibson	Positioning of paper in literature appropriate to where it published (World Development), interpretation of the key data issues, guidance on the empirical analysis, writing and revision assistance

Certification by Co-Authors

The undersigned hereby certify that:

- the above statement correctly reflects the nature and extent of the PhD candidate's contribution to this work, and the nature of the contribution of each of the co-authors; and
- in cases where the PhD candidate was the lead author of the work that the candidate wrote the text.

Name	Signature	Date
John Gibson	John Gibson	20/7/15

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Chapter 3

Li, C. & Gibson, J. (2015). City Scale and Productivity in China. Economics Letters, 131, pp.86-90.

Nature of contribution by PhD candidate: Data Collection, Empirical Analysis, Writing of Initial Draft, making poster for one conference

Extent of contribution by PhD candidate (%): 60

CO-AUTHORS

Name	Nature of Contribution
John Gibson	Recrafting a former full length paper into Economics Letters length, guidance on the estimation and structure

Certification by Co-Authors

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Chapter 4
Li, C. & Gibson, J. (2015). Pareto's Law and city size in China: only very large cities are too small! working paper 05/15. University of Waikato.

Nature of contribution by PhD candidate	Data Collection, Empirical Analysis, writing of Initial Draft.
Extent of contribution by PhD candidate (%)	60

CO-AUTHORS

Name	Nature of Contribution
John Gibson	Assistance with writing and revision, presentation at one conference

Certification by Co-Authors

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chapter 5
Li, C. & Gibson, J. (2015). Urbanization Economies in China: Nature, Location and Effects. Working paper 04/15. University of Waikato

Nature of contribution by PhD candidate	Data collection, Empirical Analysis, writing of Initial Draft.
Extent of contribution by PhD candidate (%)	55

CO-AUTHORS

Name	Nature of Contribution
John Gibson	Assistance with writing and revisions, presentation at two conferences

Certification by Co-Authors

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chapter 6
Li, C. & Gibson, J. (2015). Shining Light on Erroneous Use of China's Sub-National Data. Working Paper 07/15. University of Waikato.

Nature of contribution by PhD candidate	Data collection, Empirical Analysis, Writing of Initial Draft, presentation at one conference.
Extent of contribution by PhD candidate (%)	55

CO-AUTHORS

Name	Nature of Contribution
John Gibson	Guidance on estimation, assistance with writing, provision of city area estimates from an earlier study.

Certification by Co-Authors

The undersigned hereby certify that:

- ❖ the above statement correctly reflects the nature and extent of the PhD candidate's contribution to this work, and the nature of the contribution of each of the co-authors; and
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Appendix 1
Li, C. & Gibson, J. (2014) Spatial Price Differences and Inequality in the People's Republic of China. Asian Development Review, 31(1), pp. 92-120.

Nature of contribution by PhD candidate	Data Collection, Empirical Analysis, Writing of Initial Draft.
Extent of contribution by PhD candidate (%)	50

CO-AUTHORS

Name	Nature of Contribution
John Gibson	Invite for the paper, presentation at ADB, guidance on data collection, writing and revision contribution

Certification by Co-Authors

The undersigned hereby certify that:

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Appendix 2
Gibson, J., Li, C. & Boe-Gibson, G. (2014) Economic Growth and Expansion of China's urban Land area: Evidence from Administrative Data and Night Light, 1993-2012, Sustainability, 6(11), 7850-786

Nature of contribution by PhD candidate	Data Collection, Map production, Presentation at one conference, Empirical analysis in sections.
Extent of contribution by PhD candidate (%)	40

CO-AUTHORS

Name	Nature of Contribution
John Gibson	Design of the study and writing and revisions (jointly with CL)
Geua Boe-Gibson	Remote sensing analysis to produce the city area estimates.

Certification by Co-Authors

The undersigned hereby certify that:

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Name	Signature	Date
John Gibson	John Gibson	20/7/15
Geua Boe-Gibson	G Boe	20/7/15