Delineating China's Metropolitan Areas Using Commuting Flows Data

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August 2022

Abstract

This paper provides the first delineation of China's commuting-based metropolitan areas (MAs) using a new source of commuting flows data at fine geographic levels. We find that the commuting-based MAs rarely cross prefectural boundaries and are small relative to those in other countries. This is consistent with the fact that commutes in China are overwhelmingly short and largely confined by administrative boundaries. We compare commuting-based MAs with other definitions of cities and show that different definitions lead to different system-of-city properties. Our preferred definition provides an approximation of local labor markets in China while balancing practical considerations such as the comparability with the official definition and the availability of statistics.

Keywords: Metropolitan areas, local labor markets, commuting flows
JEL Classification: R12, R23, R41

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1 Introduction

In the past four decades, China underwent one of the most massive waves of urbanization in human history. According to official statistics, the share of population that lived in urbanized areas increased from below 18% in 1978 to around 65% in 2021.[1] The contiguously built area increased by more than eight times during the same period. Cities of all sizes have substantially expanded boundaries by annexing nearby agricultural land, forming large areas that are interconnected via commuting, consumption, and other social economic activities.

Despite rapid urbanization, to this day, we know very little about the current urban system in China because there is no official definition of a city that matches its economic function. There are administrative definitions of cities, but they often contain substantial proportions of rural areas and sometimes even overlap with one another. As we describe in more detail in Section 2, the official definition of a city in China is often a misnomer and can easily cause confusion. Importantly, there is no existing definition of Chinese cities that mimics the concept of a local labor market—such as the metropolitan statistical areas (MSA) in the United States—and can be widely used in economic analyses.

A local labor market is typically defined as connected areas that include where people live and where they work. Defining cities as local labor markets thus relies heavily on commuting flows. There are no official statistics on commuting flows in China that (i) are available at fine geographical levels and (ii) cover the entire country.

This paper presents the first delineation of China's metropolitan areas (MAs) following a standard commuting flow-based approach and explores their characteristics. To this end, we use a novel source of data on commuting flows that are derived from frequent location information captured by smartphones. Specifically, we obtain access to the complete commuting flow matrix between any pair of townships (China is divided into about 40,000 townships) from one of China's leading companies that provide location services on mobile devices. The company not only runs a mobile digital map application that has millions of active users, but also is the main provider of location plugins for other mobile applications. The company uses the frequent location information sent by these applications to calculate each device's usual daytime and nighttime locations, which it refers to as work and home locations, respectively. These locations are then aggregated to generate commuting flows at the township pair level.

We have remote access to the commuting matrix that reflects the commuting patterns as of November 2017. Per the company's own calculation, the commuting data cover almost the en-

[1] Please refer to http://www.stats.gov.cn/ztjc/ztfx/ggkf40n/201809/t20180910_1621837.html and http://www.stats.gov.cn/tjsj/zxfb/202202/t20220227_1827960.html. Last visited in March, 2022. Urbanized areas are defined by administrative divisions. The official definition of urban residents typically include those who live in urban residential communities, and that of rural residents refer to those who live in villages. Villages and urban residential communities are much finer geographic units whose statistics are typically not available to the public. See Section 2 for more details.

tirety of China's workforce, thanks to the high smartphone penetration rate in China among the work-age population and the ubiquitous presence of the company's location services on mobile devices. We verify the quality of the commuting data by checking it against official statistics on population and employment. We also check commuting flows in selected areas where the population survey of 2015—the first nationwide survey that includes questions on commuting but nevertheless is small in sample size—has a sufficient number of observations with commuting information.

To delineate metropolitan areas, we adopt the iterative clustering algorithm proposed by Duranton (2015). The algorithm merges a geographic unit to another if the share of commuters from the former to the latter surpasses a predetermined threshold. Commuting flows are updated as units are merged, and the process repeats iteratively until no more units can be merged. It generates delineation of MAs similar to other definitions of cities that are based on a mix of commuting flows, population size, and population density criteria.

The algorithm gives us a set of township clusters. However, few statistics are available at the township level. In order for our delineations to be relevant statistically, we aggregate township clusters at the county level. Specifically, a county is assigned to a cluster if more than half of its population falls in the cluster. Finally, we impose minimum population and density restrictions as well as a requirement for contiguity and call the qualifying clusters China's metropolitan areas (MAs).

What remains to be decided for the algorithm is the threshold of commuting flows at which two townships are merged. After experimenting with different thresholds, we use commuting-based MAs with a threshold of 10% as our baseline delineation of China's MAs. The size distribution of MAs, and in particular the number of the largest MAs derived under the chosen threshold is the most consistent with the conventional knowledge of Chinese cities. Also, compared with other thresholds, commuting-based MAs with a 10% threshold have the best fit of Zipf's law.

Our preferred delineation suggests that China has about 500 MAs with a population of more than half a million. Together, they account for 15% of the nation's area and 55% of its population. The largest MA is Shanghai, which has 24.2 million residents. Beijing is the close second with 24 million residents. There are eight MAs with a population of more than 10 million and another 11 with a population between 5 and 10 million. The 50 largest MAs account for about 4% of the country's area and about 23% of its population .

One striking feature of Chinese MAs is that most of them lie within prefectural boundaries and are much smaller than their corresponding prefectural-level cities. Only one MA crosses a provincial boundary. This is consistent with the fact that commutes in China are overall short in both time and distance. The 2015 population survey shows that the median one-way commute takes 15 minutes. Barely 2% of workers have commutes that take more than one hour. The modes of transportation are mostly rudimental, with about 80% of commuters walking or using two-wheelers such as bicycles, electric scooters, and motorcycles.

The short commutes are echoed in our commuting flow data. The median township has 61% of its workers commute within its boundaries. The median within-county commuting flow is 88%. Cross-border commuting is more common in urban cores of large cities, though overall still relatively small.

All these patterns suggest that administrative boundaries impose substantial barriers to commuting. Gravity regressions show that at the national level, crossing the border of a prefectural-level city is equivalent to a 55 log point increase in distance in terms of hampering commuting flows; crossing a provincial border is equivalent to a 104 log point increase in distance. This is in stark contrast to commuting flows in the United States: Not only do commuting volumes decline more slowly with distance, but also crossing a state border in the U.S. reduces commuting flow in a magnitude that is equivalent to a mere 8 log point increase in distance.

Relatedly, we also find that China's MAs, relative to the size of the country, are small compared with those in other large populous countries. We construct commuting-based MAs in the United States, Brazil, and Mexico using the same algorithm and commuting share threshold. Compared with MAs in those countries, the largest MAs in China account for not only a smaller share of the nationwide population but also a smaller share of area.

We discuss policy distortions that may have contributed to the relatively small MAs in China. First, the way local labor markets are organized and local public goods are provided makes it difficult to live in one administrative unit while working in another. Access to jobs, healthcare, or housing mortgages is often tied to one's *hukou* location and where one works. When work and home locations fall into different jurisdictions, access to those basic needs quickly becomes complicated. Cross-jurisdiction public transportation is rare, adding to the difficulty in cross-border commuting. Under the current tax system, local governments lack the incentive to coordinate with each other. All these make the separation of workplace and residence across prefectural borders exceptions instead of conventions. Second, China's MAs are hierarchical: the size of an MA is highly correlated with its administrative rank. As administrative ranks are largely inertial, a city that has great growth potential but have a low administrative rank often finds itself constrained to grow and expand. Administrative hierarchy within a city also matters for the size of MA. There are few MAs being formed exclusively among county-level units that are not urban districts.

Finally, we compare sets of MAs generated by various commuting share thresholds with other definitions of Chinese cities, including three versions of the administrative definition and the nightlight-based definition. Of the three administrative definitions, the one that includes contiguous urban districts plus stand-alone county-level cities is highly correlated with our preferred commuting-based definition. Statistics for this set of cities are not readily available, but can be rather conveniently constructed using the county-level statistics. We investigate the system-of-cities properties of various MA definitions. Compared with other definitions, commuting-based

MAs has the best fit of Zipf's law. We also document substantial city size premiums along important dimensions.

China's rapid economic growth and urbanization has drawn wide-range interests in the study of its cities. Yet the literature has been limited by the lack of proper definitions of the subject of study. Most papers have used prefectural-level cities (e.g., Bosker et al., 2012; Chauvin et al., 2017; Baum-Snow et al., 2020; Fan and Zou, 2021). For example, Baum-Snow et al. (2020) estimate the effect of China's highways on prefecture-level economic activities such as population and GDP. Also using prefectural-level cities, Chauvin et al. (2017) find that Zipf's law does not hold for Chinese cities. A recent study by Dingel et al. (2021) defines China's MAs using satellite nightlight imagery and show that Zipf's law does hold for Chinese cities. Our paper is the first to define China's MAs that are based on commuting flows, which is closer to the how MAs are usually defined in many countries. We show that prefectural-level cities are poor proxies for commuting-based cities. We also find substantial differences between commuting-based MAs and those based on the nightlight. There are large areas that appear connected according to the nightlight, yet commuting flows in between are actually limited.

Recently, there is a renewed interest in the definition of cities, especially in developing countries where proper official definitions are often unavailable and where data are limited. Economists and geographers have devised various ways to do so. As noted by Duranton (2021), there is not a single best way to define a city. An approach can serve one purpose well while lack in others. One method is to delineate urban areas using certain building density criteria (Arribas-Bel et al., 2021; De Bellefon et al., 2021). For example, De Bellefon et al. (2021) compare a map of actual buildings to maps of counterfactual random redistributions of the same buildings, and define areas with significant excess building density as urban. Another method is to define metropolitan areas as a set of contiguous spatial units that contain economic activity. A unit is identified as having economic activity either if it contains built-up landcover classified from daytime satellite images (Baragwanath et al., 2021), or if its nighttime light intensity exceeds a given threshold (Dingel et al., 2021). This paper follows a widely accepted approach that defines MAs based on commuting flows. Similar approaches have been used in the U.S. to define the Core-Based Statistical Areas (CBSAs) (Office of Management and Budget, 2010) and commuting zones (Tolbert and Sizer, 1996), and to delineate MAs in Colombia (Duranton, 2015) and Japan (Adachi et al., 2020).

The prevalence of cellphone location data presents new opportunities for economists who are interested in studying the spatial dimension of economic activity and human interactions. Recent studies have exploited cellphone location data to study urban consumption (Miyauchi et al., 2021) and racial segregation (Athey et al., 2021). Compared with these studies, delineating cities using commuting flows are much less demanding on the frequency and accuracy of the location data. It is also worth noting that cellphone location data usually include only limited demographic characteristics and the social economic status of the user. Traditional surveys maintain an advantage along those dimensions. An increasing number of countries, including several developing countries such as Mexico, Brazil and China, are incorporating questions regarding commuting and mobility in their recent nationwide population surveys, which we use to corroborate the cellphone-based data.

The rest of the paper is organized as follows. Section 2 provides institutional background on China's administrative divisions and the official definitions of cities. Section 3 introduces and verifies the data. Section 4 describes the algorithm and the delineation of commuting-based MAs. Section 5 describes the characteristics of China's MAs. Section 6 compares commuting-based MAs with other MA definitions. Section 7 concludes.

2 Background

2.1 Administrative Divisions of China

It is helpful to illustrate how China is divided administratively because (i) our data are grouped in units of administrative divisions and (ii) delineations of MAs are only useful if they can be matched with official statistics, which in China are usually provided at various administrative levels. Table 1 shows a simplified version of administrative divisions of mainland China. There are four levels of local governments: provincial, prefectural, county, and township.[2] The provincial level units include 4 municipalities (*zhixiashi*), 22 provinces (*sheng*), and 5 autonomous regions (*zizhiqu*). There are no secondary level units under municipalities. Provinces and autonomous regions are divided into 333 prefectural-level units, including 293 prefectural-level cities (*dijishi*) and 40 prefectures (*diqu*, *zizhizhou*, *meng*). Municipalities, prefectures, and prefectural-level cities are divided into 2,851 county-level administrations, including 954 districts (*shixiaqu*), 366 county-level cities (*xianjishi*), and 1,531 counties (*xian*, *qi*, etc.). County-level units are further divided into around 40,000 township level administrations, including 8,122 subdistricts (*jiedao*), 21,927 towns (*zhen*), and 9,815 townships (*xiang*).

The Ministry of Civil Affairs is the government agency that oversees the classification of administrative units. It re-evaluates the classification periodically. Different types of units at the same administrative level are broadly divided by the population size and the urban rate. For example, compared with prefectures, prefectural-level cities are more populous and usually contain an urban core. Over the past few decades, as population grew and urbanization proceeded, most prefectural-level divisions have been relabeled from prefectures to prefectural-level cities. At the county-level, districts are contiguous units that form the urban core of a municipality or a

[2]Some refer villages (in rural areas) and communities (in urban areas) as the 5^{th} level of government. Villages and communities are officially part of the "basic level autonomy". Their governing bodies, villagers committees and residential committees, are self-governing organizations and are not part of the government, although in reality, higher-level governments have substantial authority over the organization and function of these committees. Village and community leaders are not in the formal ranks of government officials. Official statistics rarely reach the level of villages and communities.

prefectural-level city (prefectures in general do not contain districts), while county-level cities are on average more populous and urban than counties. At the township level, subdistricts are more likely to be found in urban settings, while townships are largely rural. However, the classifications are not absolute, nor are there clearcut population or density thresholds for various classifications. Districts are in general more urban, but they also contain towns and townships; counties are less urban, yet they typically have an urban core that consists of one or more subdistricts. Despite their different levels of urbanization, all three types of county-level administrations contain a mix of subdistricts, towns, and townships.

Table 1: Administrative Divisions of Mainland China

provincial level	**prefectural level**	**county-level**	**township level**
municipality		district county	subdistrict town township
province	prefectural city	district county-level city county	
	prefecture	county-level city county	
autonomous region	prefectural city	district county-level city county	
	prefecture	county-level city county	

2.2 The Anarchy of Chinese Cities

The term "city" is constantly misused in China's context. A source of the misconception is the confusing definition of "*shi*", the Chinese word for city, which corresponds to administrative units at various levels and are only loosely correlated with the economic meaning of a city: an economically connected area with dense population and an urbanized economy. There are in total 663 *shi* in China. They can be classified into three categories: municipalities (*zhixia-shi*), prefectural-level cities (*diji-shi*), and county-level cities (*xianji-shi*). They respectively correspond to provincial, prefectural, and county level administrative units. There are rural areas within a *shi*, and the collection of *shi* do not exhaust all urban areas in China. Counties that are not classified as *shi* typically contain an urban core as well. One particularly unappealing feature of using *shi* to define Chinese cities is that they could overlap with one another. For example, a prefectural-level city could contain one or more county-level cities.

Many official statistics are available at the provincial and prefectural levels. Partly for this reason, it is conventional in the literature to treat municipalities and prefectural-level cities as local economies. Yet, there are several problems with this definition. First, although they are called "cities", they are not equivalent to urban areas since they contain vast rural areas. In fact, because there remain only a handful of non-city prefectures, municipalities and prefectural-level cities account for the vast majority of mainland China, which, however, has an official urbanization rate of only 64% in 2020. Second, it is questionable how much economic activity is interconnected within a prefectural-level city to the extent that it can be treated as an integrated city. Similarly, it is possible that economic connections extend beyond administrative boundaries.

A more sensible definition of cities based on existing official classifications includes collections of contiguous districts, which make up core urban centers of municipalities and prefectural-level cities. Few studies follow this definition.[3] Several remaining issues are with this definition. For example, it leaves out county-level cities, some of which are populous and highly urbanized. An alternative definition, seldom used in the literature, includes both contiguous districts and county-level cities. However, it is unclear how to treat a county-level city that is contiguous to the districts. Should it be included as part of the urban core or treated as a stand-alone city? If there are two neighboring county-level cities, what determines whether they should be counted as one city or separated cities? To answer these questions, it is necessary to have some consistent measures of connectivity both within and across administrative boundaries. Official statistics provide few clues on those fronts.[4] In Section 6, we compare our commuting-based MAs with these administrative definitions.

3 Data

3.1 Data Sources

We have access to the commuting flows data between all pairs of townships as of November 2017.[5] The data are collected by a leading provider of digital map and online navigation services in China. The company collects mobile devices' location information from its popular digital map application on mobile devices and from other applications that it provides location services to. From each device's location data, the company calculates its typical daytime and nighttime locations in the past three months, which it refers to as "workplace" and "home", respectively.

Given the wide coverage of the mobile applications and the frequency of the location records,

[3] A few exceptions include Au and Henderson (2006), Desmet and Rossi-Hansberg (2013), Baum-Snow et al. (2017), and Lin (2017).

[4] For the simplicity of presentation, in the remainder of the paper, we refer all provincial-level administrations (municipalities, provinces, and autonomous regions) as "provinces", all prefectural-level administrations (prefectural-level cities and prefectures) as "prefectures", all county-level administrations (districts, county-level cities, and counties) as "counties", and all township-level administrations (subdistricts, towns, and townships) as "townships".

[5] We access the data remotely by sending codes to an in-house engineer. We also have access to commuting flows between all pairs of townships as of November 2019 as well as flows between pairs of counties in both years. For the main analyses, we use the 2017 data because the latest supportive statistics we have are from 2017 or earlier. We cross-check the quality of the data in both years and in both levels of aggregation. Our main results and conclusions do not change if we use the data from 2019 or at the county level.

the data present a good approximation of actual commuting flows in China. The company's mobile application has about 600 million active users in mainland China. It is also the leading provider of location services used in other popular mobile applications. So its presence in mobile devices is ubiquitous. China also has a high smartphone penetration rate. The smartphone-to-population ratio was about 63% in 2020.[6] The rate is likely still higher among workers.

A typical device generates about 30 location records per day, more than enough to determine the typical daytime and nighttime locations over a period of three months. In addition, the median township in China covers about 70 km^2. The precision of smartphone GPS location data is much higher than that.

Table 2 presents summary statistics of the township-level commuting flow data in November 2017. The data cover 37,647 townships in mainland China. On average a township has 5,978 workers who commute (whose home and workplace are discernibly different). Excluding pairs of units with zero commuters in between (99.7% of all township pairs), there are 72 commuters between a typical pair of township units.

Table 2: Summary Statistics of the 2017 Township-level Commuting Flow Data

Variables	No. of Obs.	Mean	SD
Number of Commuters	37,647	5,978	26,620
Commuters Between (excluding zeros)	4,872,974	72	1,026

It is worth noting that the data track devices, not people. The data miss workers who do not have a smartphone, or users who do not allow their smartphones to track locations. The data may include some non-workers who possess a smartphone and have daily routines in whereabouts, such as students who commute between home and school, and retirees who have regular itineraries. The company uses other information from the device to infer the demographics of the user; it generates its own estimation of population and employment at the township and county levels.[7] As we show below, counts of population and workers from the commuting flows data match well with official statistics.

The commuting flows data based on smartphone locations are novel since there are no data on commuting in China at the national level. A few large cities, such as Beijing and Shanghai, imple-

[6]https://newzoo.com/insights/rankings/top-countries-by-smartphone-penetration-and-users/. Last visited in December, 2021. The monthly report of July 2017 by the Ministry of Industry and Information Technology (MIIT) indicates a higher ratio at about 86%, with 1.2 billion mobile Internet users (https://www.miit-icdc.org/info/1010/3003.htm, in Chinese. Last visited in March, 2022).

[7]For example, college students can be identified as those who commute within the boundaries of the campus because most Chinese college students live on campus. We have access to the imputed employment (sum of commuters by workplace) and population at the township and county levels, but not data from individual devices. We also do not have the distribution of imputed demographics.

ment household travel surveys periodically. But there is no such survey at the national level. Even at the city level, such surveys are typically limited in size. For example, the 2015 household travel survey in Beijing, one of the largest surveys of this kind in China and covering more than 50,000 households, was a one-in-200 sample and surveyed residents in only 698 out of 2,109 geographic units (transportation analysis zones) that divided up Beijing. The traditional surveys are usually residence-based and likely under-represent migrant workers, who according to some estimates account for more than 30% of the residents in China's largest cities. The population survey of 2015 (mini-Census) is the first nationally representative survey to include questions on commuting. But its sample size is too small to calculate credible commuting flows at fine geographic levels. We use the population survey and other statistics to cross-check the quality of the commuting flows data.

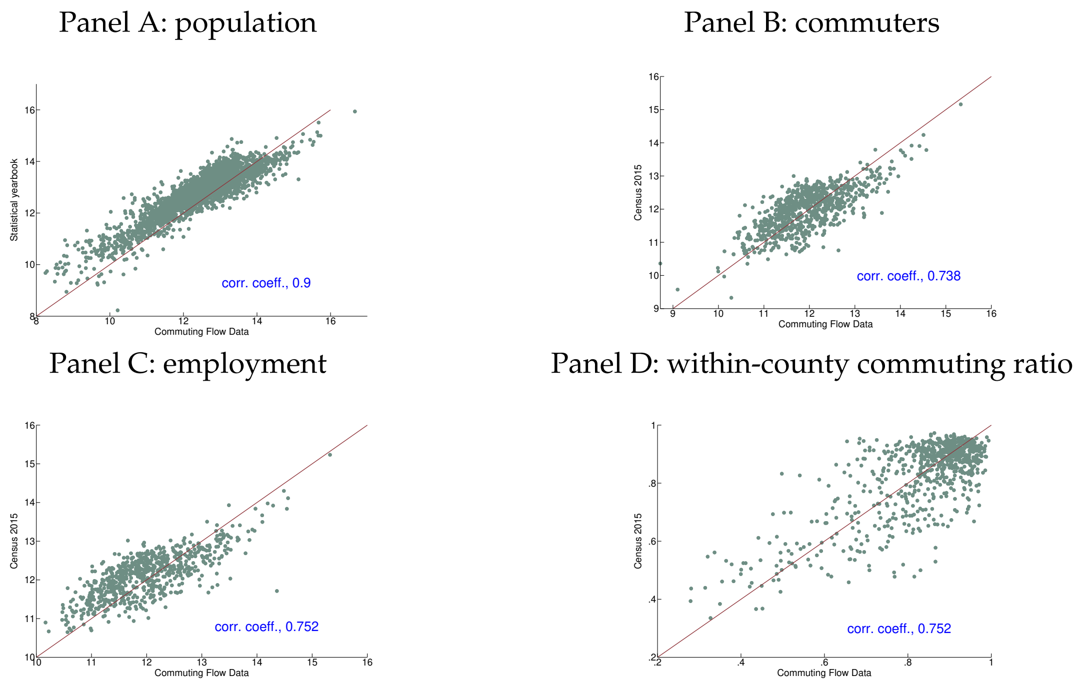
3.2 Data Verification

We check the quality of the commuting flows data by comparing them with nationwide population surveys and official statistics along several important dimensions. Because official statistics at the township level are scarce, we aggregate our data at the county level.

We compare the population (in log terms) from the commuting flows data (x-axis) and the official population count from the 2017 statistical yearbooks. Panel A of Figure 1 shows that the two measures are highly correlated and similar to each other (tightly distributed along the 45 degree line).

We use the individual level sample of the 2015 population survey to construct statistics related to commuting. The sample is relatively small with about 1.5 million observations (roughly 1 in 1000). The survey includes a set of questions on commuting, including commuting time, the mode of transportation, and the townships of residence and workplace. The census follows a residence-based stratified sampling procedure and does not cover all counties. To reduce the measurement error in the comparisons, we restrict the sample of county-level units to those with at least 500 observations. They largely correspond to counties with more than half a million population. There are 197 such units in the sample.

Figure 1: Commuting Flow Data Quality Check



Note: Each dot represents a county. The x-axis represents county characteristics constructed from the commuting flows data; the y-axis represents the counterpart from official statistics. Official statistics for Panel A are from the 2017 Statistical Yearbook; those for Panels B, C and D are from the 2015 population survey. Panel A plots log county population. Panel B plots the log number of commuters by residence. Panel C plots the log number of employment by workplace. Panel D plots the share of commuters who commute within the county. Panels B and D restrict the sample to counties with more than 500 observation in the 2015 population survey, while Panel C restricts the sample to those with more than 250 worker observations. Correlation coefficients are shown in each panel.

For each unit we define three commuting-related measures that have counterparts in our commuting flow data. The first measure is the number of commuters by the county of residence, defined in the census data as employed workers who report a positive time of commuting. The second measure is the number of workers by the county of workplace. Most employment statistics in China are residence-based, and reflect how many workers *live* in each place. Although the population survey is also residence-based, information on where the worker works allows us to recover how many people *work* in each county.[8] The third measure is the share of workers who commute within the same county. Panels B, C, and D of Figure 1 plot the log numbers of commuters, log employment, and within-county commuting ratios, respectively, from the population survey and the commuting flow data. The two versions of the same measurement line up closely along the 45 degree line. The correlation coefficients are high in Panel A, while relatively lower in Panels B to D as there are only less than 200 counties for comparison.

[8]We restrict workplace counties to those with more than 250 worker observations. This is consistent with the 500-observation restriction we make to counties by residence because the employment-to-population ratio is roughly 0.5.

4 Delineation of China's Metropolitan Areas

4.1 Algorithm

We follow the iterative aggregation algorithm proposed by Duranton (2015). The algorithm groups pairs of spatial units based on the commuting flow between them. In essence, unit A is aggregated to unit B if the share of workers who reside in A and work in B exceeds a pre-determined threshold. After each round of aggregation, commuting flows among the aggregated set of spatial units are updated, and a new round of aggregation proceeds according to the same criteria. This process is repeated until no further units can be aggregated.

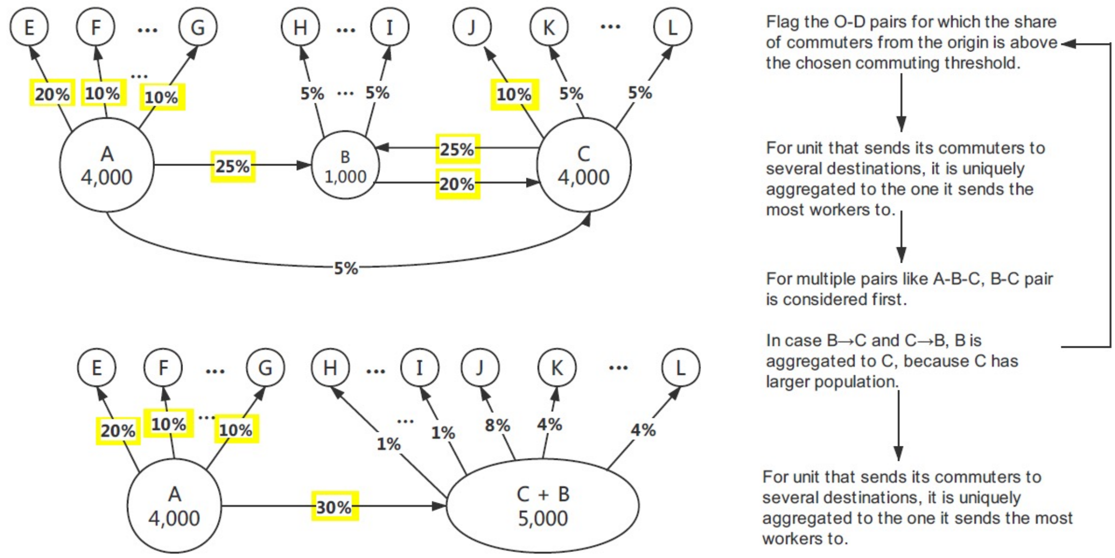
Figure 2 illustrates the algorithm. The top graph shows the initial commuting flows. The direction of the arrow points from the unit of residence towards the unit of workplace. The number in the circle indicates the number of workers who reside in the unit, and the number next to each arrow indicates the size of the commuting flow. For example, the graph indicates that 20% of workers who reside in B work in C. Suppose the threshold of commuting flow is chosen at 10%, the top graph highlights flows that are above this threshold.

The algorithm sets the following rules to ensure that in each round a spatial unit is involved in at most one aggregation. First, if a unit sends its commuters to several destinations, it is uniquely aggregated to the one to which it sends the most workers. In this example, A is aggregated to B as 25% of the commuters who reside in A work in B, though the commuting shares from A to E, F, G also exceed 10%. Second, the unit with a smaller population is aggregated to the larger one in case there are two-way aggregations. In this example, the algorithm proceeds with B being aggregated to C, although C is supposed to be aggregated to B in the same round. Third, if there is a chain of aggregations in the same round, the last aggregation "link" is chosen to be executed. As illustrated in Figure 2, if in the same round A is aggregated to B and B to C, the algorithm first aggregates B to C. Also, in each round, the aggregation of pairs of spatial units is executed sequentially when more than one origin unit is merged to the same destination unit.

The spatial units and commuting flows are updated after each round. The bottom graph of Figure 2 shows that now 30% of workers who reside in A work in the aggregation of B and C. The next round would involve further aggregating A into $B + C$.

Notice that 10% of workers who reside in C work in J. However, once B and C are aggregated, the combined unit only sends 8% of its workers to J, so $B + C$ will not be further merged with J. On the other hand, consider an alternative scenario where A sends 5% of its workers to B and another 5% to C. In the initial round, A will not be slated to merge with either B or C. But once B and C are merged, A sends 10% of its workers to the agglomerate, which is above the threshold. These examples illustrate the underlying mechanism of the algorithm: large employment centers are first grouped together; while the agglomerate becomes even larger employment centers, it further groups nearby units.

Figure 2: Illustration of Clustering Algorithm



The algorithm is similar to the hierarchical clustering algorithm that is used in defining commuting zones in the United States (Tolbert and Sizer, 1996). The algorithm also generates results similar to other definitions of cities or local markets that use a mix of commuting flows, population size, and population density criteria. In the U.S., core-based statistical areas (CBSAs) consist of larger metropolitan statistical areas and smaller micropolitan statistical areas. A CBSA is centered around an urban core of a sufficiently large size. An outlying county is aggregated into a CBSA if either of the following criteria is met: (i) at least 25% of the workers living in the outlying county work in the CBSA core; or (ii) at least 25% of the employment in the county is accounted for by workers who reside in the CBSA core. The second criterion captures the “reverse commuting” of those who live in the core city while work in the outskirts. Dingel et al. (2021) apply the iterative clustering algorithm with a threshold of 25% to the U.S. counties. The resulting metropolitan areas are highly similar to CBSAs.

4.2 Criteria and Baseline Results

We apply the algorithm with various thresholds to the 2017 township-level commuting flows and get sets of township clusters. Because statistics at the township level are rare, we further aggregate the clusters at the county level. A county is assigned to a cluster if more than 50% of its population are in townships that fall into the initial delineation of the cluster. The algorithm gives us something akin to commuting zones—clusters of counties that are connected via commuting flows. We impose contiguity restrictions so noncontiguous clusters will be taken as separate commuting clusters.[9] We further apply restrictions on population size and density to obtain clusters that we call metropolitan areas (MAs). We restrict the county clusters to those that have a combined population of at least 500,000 and a population density that is more than 100 persons per km^2. 100 per km^2 is about the 25th percentile of the county population density, and 500,000 is about the average county population. Those restrictions are of course arbitrary. Few clusters have a population density below the cutoff. Since we define MAs as aggregations of counties, it is natural to restrict an MA to be larger than a typical single county.[10]

This approach has several advantages. First, township-level commuting flows allow us to delineate MAs at a fine geographical level. Because cross-border commuting shares are low, had we used the county-level commuting flows, the vast majority of counties would not be part of any cluster. Yet many such stand-alone counties are large in size, often with a population exceeding one million. It is not clear whether we should classify those large stand-alone counties as MAs. Defining clusters at the township level allows us to identify single-county MAs that have an interconnected urban core with more than half of the county's population. Second, aggregating clusters at the county level allows existing statistics to be matched to MAs. Third, this approach is flexible. We provide the original township level clusters, researchers can generate alternative definitions of MAs that suit their research setting.

One remaining critical decision to make is on the threshold of the commuting flows. Naturally, a higher threshold leads to smaller MAs. The relationship between the number of MAs and the threshold is less clear. A lower threshold makes it less restrictive to form an MA, thus increasing the number of MAs. But as the threshold is further lowered, separate MAs identified under a higher threshold tend to be connected, and the total number of MAs likely starts to decline.

There is also no theoretical guidance on what is the "right" threshold. The choice ultimately depends on the local setting and the geographic level one is working with; naturally, it is more demanding for a larger geographic unit to cross a given commuting flow threshold. The definition of CBSAs in the United States is most closely approximated by a threshold of 25% (Dingel et al., 2021). Duranton (2015) uses 10% as the preferred threshold for MAs in Colombia. Dingel et al. (2021) use 10% as the preferred threshold for MAs in Brazil. The delineation of the U.S. CBSAs is based on counties, which have an average population of 100,000 and an average area of about 3,000 km^2. The delineations in Colombia and Brazil are based on municipalities. An average municipality in Colombia has a population of 45,000 and an area of 1,000 km^2. An average municipality in Brazil has a population of about 40,000 and an area of 1,500 km^2. The average Chinese

[9] The contiguity restriction has negligible effects on the set of commuting clusters. Only two clusters contain noncontiguous parts under the 10% commuter-share threshold in 2017.

[10] A 2014 standard by China's State Council classifies cities by residential population in urban areas: greater than 10 million (megacity), 5 to 10 million (extra-large), 1 to 5 million (large), half a million to one million (medium), and below half a million (small). Please refer to the "Notice of the State Council on Adjusting the Standards for Categorizing City Sizes" (http://www.gov.cn/zhengce/content/2014-11/20/content_9225.htm, in Chinese. Last visited in March, 2022).

township has a population of 38,000, but is much smaller by area, covering an area of 260 km^2.[11]

Table 3: Metropolitan Areas under Various Definitions

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
	commuting flow							administrative			nightlight
MA pop.	commuter share cutoff (%)							muni.	urban	(9) +	brightness
(million)	2	5	10	15	20	25	30	+ pref.	distr.	cnty-cities	cutoff=30
$\geqslant 10$	19	15	8	3	0	0	0	14	7	7	9
5 - 10	13	14	11	4	0	0	0	78	11	11	11
1 - 5	61	120	170	172	103	43	14	157	144	203	226
0.5 - 1	100	206	348	414	404	292	189	7	90	260	492
total	193	355	537	593	507	335	203	256	252	481	738
% of pop.	65	58	55	47	31	18	11	89	39	54	75
% of area	27	19	15	12	10	7	4	34	8	12	21

Note: The table shows the distribution of MAs according to various definitions. Columns 1 through 7 report MAs defined by commuting flows with various thresholds. Columns 8 through 10 show three administrative definitions of MAs. Column 11 shows MAs defined by nightlight brightness as in Dingel et al. (2021). Clusters with more than 500,000 residents are reported. MAs are also restricted to those with a density over 100 persons per km^2.

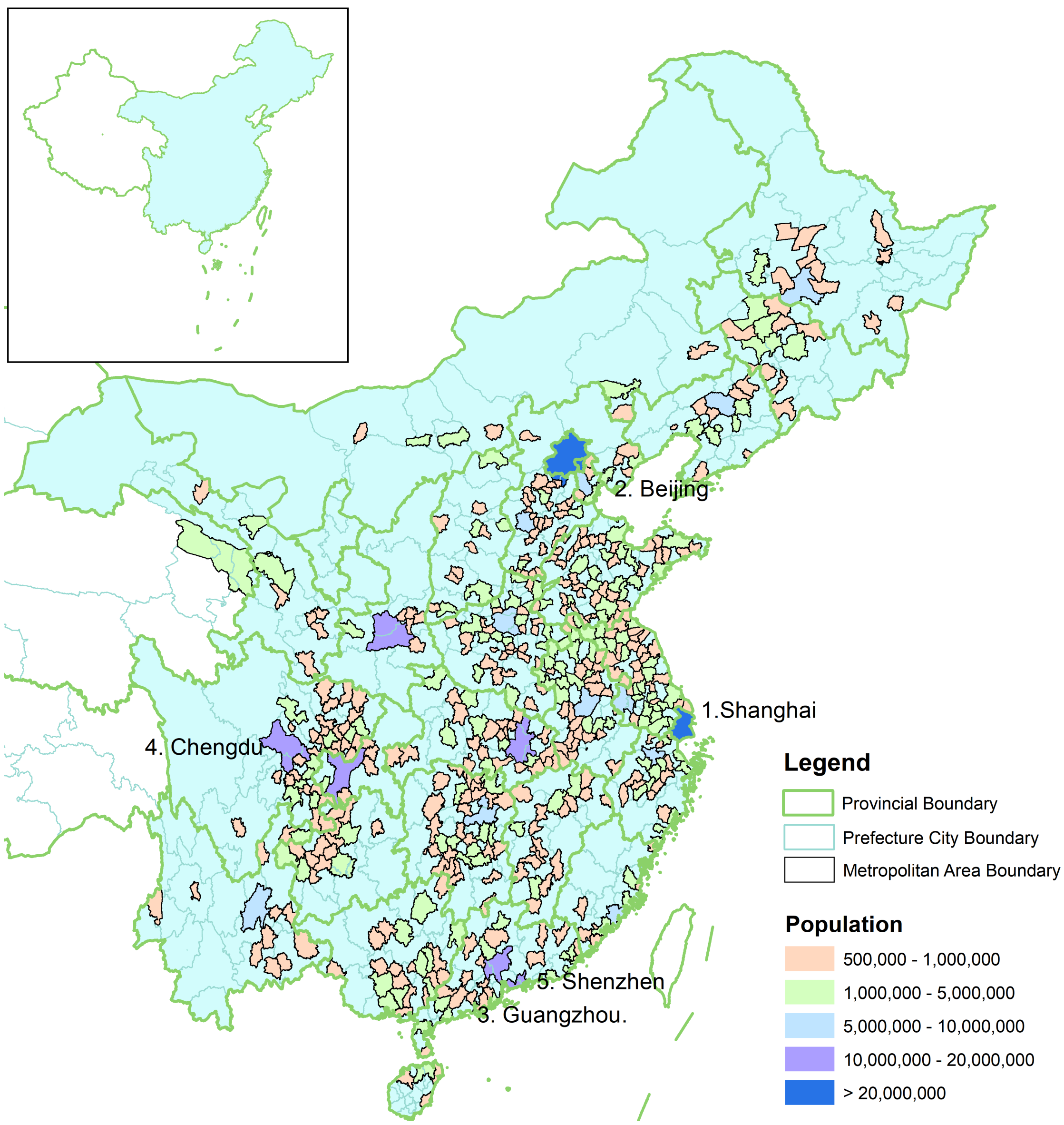
We experiment with varying thresholds ranging between 2% and 30%. The first seven columns of Table 3 reports the summaries of MAs according to various thresholds. As the threshold increases, the number of large MAs declines. The number of MAs that have a population of more than 10 million is 19 when the threshold is 2%, 15 at 5%, 8 at 10% and zero if the threshold is higher than 20%. The total number of MAs (after applying restrictions on overall population and population density) first increases with the threshold and then declines.

The last two rows report the MAs' aggregate shares in the nationwide population and area. When the threshold is 2%, the 193 MAs account for 65% of the population and 27% of the area. At 10%, the 537 MAs account for 55% of the population and 15% of the area. At 25%, the 335 MSAs account for 18% of the population and 7% of the area.

Our preferred delineation is the one with the 10% commuting flows threshold. The reason is several fold. First, the size distribution of MAs, and in particular the number of largest metropolises obtained under this threshold are most consistent with the conventional knowledge about cities in China. As can be seen in Appendix Figure A.1, using thresholds smaller than 10% tends to generate unreasonably large MAs; using thresholds larger than 10% tends to identify too few MAs. Second, commuting-based MAs with a 10% threshold have the best fit of the Zipf's law (see Section 6.2.1 for details).

[11] In all these cases, the median is smaller than the mean, in both area and population.

Figure 3: County-Level Delineations of Metropolitan Areas in mainland China: 10% Commuter-Share Threshold, 2017



Note: The map shows metropolitan areas in central and eastern China according to our preferred definition. Only two MAs in West China are not shown here. In this definition, MAs are obtained by intersecting township-based commuting clusters under the 10% commuter-share threshold with county units and then applying contiguity requirements as well as population and density restrictions. The 2017 population data are from the statistical yearbooks.

Figure 3 shows the map of our preferred commuting-based MAs. The green lines and the blue lines are the provincial and the prefectural-level city boundaries, respectively. MAs are color-coded according to their population sizes. The map zooms in on the central and eastern China as there are only two MAs in the rest of Mainland China. China's northern plains (including Hebei, Beijing, Tianjin, and Shandong), the Yangtz River Delta (including Shanghai, Jiangsu, Zhejiang, and Anhui), the Pearl River Delta (Guangdong), the central south (Henan, Hubei, and Hunan), and the Sichuan Basin (between Chengdu and Chongqing) are heavily urbanized.

The largest MAs in Mainland China are Shanghai, Beijing, Guangzhou, Chengdu, and Shenzhen, each with more than 10 million residents. Shanghai and Beijing each has more than 20 million residents. Appendix Table A.1 lists the top 10 MAs by population according to this definition. The MAs on the list are also conventionally perceived as the largest cities in China.

5 Characteristics of China's Metropolitan Areas

5.1 Few MAs Cross Prefectural Boundaries

The most striking pattern as shown in Figure 3 is that most MAs lie within prefectural boundaries and are much smaller than their corresponding prefectures. 18 out of 537 MAs cross prefectural borders, and only one (Beijing) crosses a provincial boundary.

Appendix Figure A.2 zooms in to the four major regions around the largest MAs—Beijing (upper left), Shanghai (upper right), Guangzhou & Shenzhen (lower left), as well as Chengdu & Chongqing (lower right), respectively. Most of commuting-based MAs, except a few largest ones, cover only part of the corresponding prefectures. The Beijing MA aggregates a couple of counties that administratively belong to Hebei Province. Simiarly, the Guangzhou MA and the Shenzhen MA cross prefectural borders and include counties that belong to Foshan City and Huizhou City, respectively.

This may be partly due to the fact that commutes in China are short in both distance and time. The 2015 population survey shows that the median one-way commuting time among all workers is 15 minutes. Only 8% of workers report commutes that cost more than 30 minutes, and barely 2% have commutes that take more than an hour. The modes of transportation are mostly rudimental. 41% walk to work; 36% use two-wheel vehicles such as bicycles, electric scooters, and motorcycles; 8% use automobiles, and 10% ride public transit.[12] The 2015 population survey also shows that cross-border commutes are rare. 29% of workers commute outside the township of residence, and only 12% commute outside the county of residence.

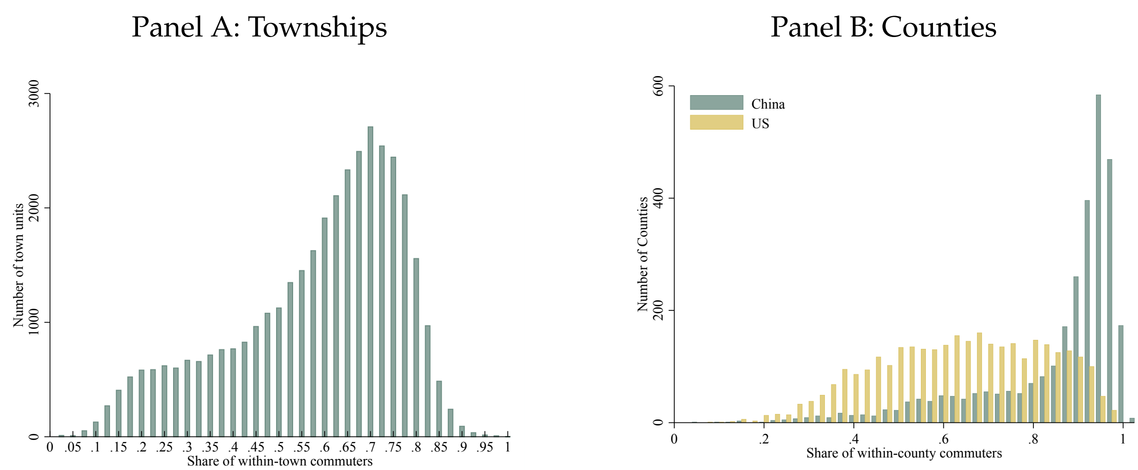
These numbers align with the commuting flows based on the smartphone location data. Figure 4 Panel A shows the distribution of the share of commutes that are bounded within a township. The median township has 61% of its workers commute within its boundaries. In about two-thirds of townships, more than half of the workers live and work in the same township. These numbers suggest that the vast majority of Chinese townships are self-contained labor markets. Panel B shows that cross-county commuting is even less common. The median within-county commuting

[12] Non-agricultural workers, who account for 68% of the workforce in 2015, have slightly longer commuters. Median one-way commuting time among non-agricultural workers is also 15 minutes. 11% have commutes that cost more than 30 minutes and 3% cost more than 60 minutes. 31% walk, 38% use two-wheelers, 11% use automobiles, and 15% take public transportation. There is an "others" category in the modes of transportation, which accounts for about 5% of the commuters.

ratio is 88%, the 25th percentile is at 72%, and the 75th percentile at 91%.[13]

The comparison of the commuting patterns between China and the United States suggests that the administrative boundary effect is much stronger in China. The U.S. is among the most mobile countries and its sprawling cities render long commutes. The average one-way commute in the U.S. was 27.6 minutes in 2019, compared with 18 minutes in China.[14] We then compare the distribution of within-county commuting ratio between these two countries. Chinese and U.S. counties are rather comparable geographically. Both countries have about the same land area and are divided into about 3,000 county-level units. Commuting across county borders is much more common in the United States, as is visibly evident from the much flatter distribution in Figure 4 Panel B. The median within-county commuting ratio is 66% in the U.S., the 25th percentile is at 52%, and the 75th percentile at 80%.

Figure 4: Within-unit Commuting Ratio



Note: Graphs show the number of townships and counties by the share of within-unit commuters. For China, the data are from smartphone location data in November 2017. For the U.S., data are from the 2011-2015 5-Year Commuting Flows constructed by the U.S. Census Bureau using data from the American Community Surveys.

To better describe how distance and administrative boundaries affect commuting flows, and how they differ in China compared with the U.S., we estimate the following gravity regression:

$$\ln Comm_{od} = \lambda_o + \lambda_d + \rho \ln Dist_{od} + \mathbf{D}_{od} \cdot \rho + \varepsilon_{od}. \tag{1}$$

$Comm_{od}$ is the number of commuters between the place of residence o (origin) and the place of work d (destination). λ_o and λ_d are origin and destination fixed effects, respectively. $Dist_{od}$ is the linear distance between the centroids of the origin and the destination. $\mathbf{D}_{od}$ is a set of binary

[13] Appendix Figure A.3 shows the distribution of within-unit commuting for counties and districts, respectively. The ratio of within-unit commuting is much lower in districts, but the median is still around 70%.

[14] http://www.census.gov/newsroom/press-releases/2021/one-way-travel-time-to-work-rises.html. Last visited in January, 2022.

variables indicating whether o and d belong to the same administrative unit, be it a county, a prefecture or a province (or a state).

The first four columns of Table 4 report the results of estimating equation 1 using counties from China and the United States, respectively. The first two columns show that distance imposes a substantial barrier to commuting in China. The elasticity of the commuting flow between pairs of Chinese counties with regard to distance is between -2.3 and -2.5. Conditional on distance, administrative boundaries impose further restrictions to commuting. Everything else equal, if two counties are in different prefectures, the commuting flow in between will be lower by a magnitude that is equivalent to a 55 log point increase in distance. Crossing a provincial boundary is equivalent to an additional 49 log point increase in distance. In total, if two counties are in different provinces, the commuting flow in between would be 236 log point lower than if they are in the same prefecture.

This is in stark contrast with the commuting patterns among U.S. counties, shown in Columns 3 and 4. The distance elasticity is only about half of that in China (-1.178 vs. -2.274), which may reflect better transportation infrastructure (e.g., denser road network) and higher car ownership. What is more striking is that crossing state boundaries imposes little additional barrier to commuting. Commuting flows decline by a merely 10 log points at the state border, which is equivalent to about 8 log point increase in distance.

We also estimate the gravity regression on the 334 townships in Beijing, which has one of China's most connected urban areas. The last two columns of Table 4 show that distance still imposes a substantial barrier within Beijing, although somewhat smaller than the nationwide pattern at the county level. What is more surprising is that district borders impose substantial barriers to commuting even within Beijing, considering that urban planning, design of road network and public transit are all highly coordinated at the municipality level. Beijing's 16 districts typically have much weaker power to act on their own than prefectures in a province or counties in a prefecture. This suggests that large barriers imposed by administrative boundaries go beyond reasons with regard to geography and transportation.

The overall limited commuting, the large distance elasticity, and the substantial border effects all confirm that China's local labor markets are confined by administrative boundaries. This explains why there are few MAs that cross prefectural or provincial boundaries.

Table 4: Gravity Model of Commuting Flows

	Dependent variable: log number of commuters					
	counties in China		counties in the U.S.		townships in Beijing	
Variables	(1)	(2)	(3)	(4)	(5)	(6)
log distance	-2.490	-2.274	-1.194	-1.178	-1.727	-1.449
	(0.005)	(0.005)	(0.006)	(0.006)	(0.025)	(0.031)
= 1 if same prefecture		1.247				
		(0.009)				
= 1 if same province/state		1.110		0.097		
		(0.006)		(0.023)		
= 1 if same district						1.022
						(0.068)

Note: Commuting flows between townships and counties in China are from smartphone location data in November, 2017. County-level commuting flows in the United States are from the 2011-2015 5-Year Commuting Flows constructed by the U.S. Census Bureau using data from the American Community Surveys. The sample includes origin and destination pairs with positive numbers of commuters. Origin and destination fixed effects are included in all columns. Robust standard errors are in parentheses.

5.2 China's MAs Are Relatively Small

There have been debates on whether Chinese cities are too small as China imposes various restrictions (e.g., the *hukou* policy) to prevent cities, especially its largest metropolises, from getting too large. Based on patterns of real wage distribution against city sizes, Au and Henderson (2006) conclude that Chinese cities are indeed smaller than their optimal sizes. However, they use the administrative definition of cities, which we have shown is an imperfect measure. Their main sample includes only about 200 cities. In addition, the paper is based on data in the late 1990s. Since then, China's large cities experienced substantial growth despite restrictions. The conclusion may have changed as a result.

Here we compare the concentration of population in clusters defined by commuting flows in China with similarly constructed clusters in the United States, Mexico, and Brazil that feature few restrictions on city size.[15] For the United States, commuting flows are at the county level and are from the 2011-2015 American Community Surveys. For Brazil, commuting flows are at the municipality level and are from the 2010 Population Census. For Mexico, commuting flows are at the municipality level and are from the 2015 Population Census. For each country, we apply the clustering algorithm on commuting flows with the threshold set at 10%. For China, we apply the algorithm at the township level (then assigning each county to a cluster) as well as at the county level. Intuitively, it is more demanding to meet the commuting threshold for larger geographic units. Therefore, the county-based clusters are smaller than the township-based. We then rank the

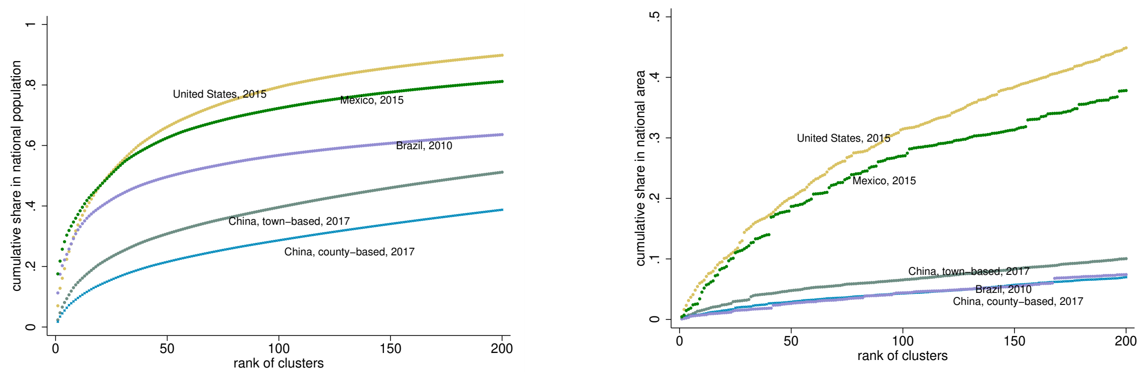
[15]Those countries have publicly available commuting flow data. They are also large countries in both population and area. Brazil and Mexico have similar income levels as China.

clusters by population.

Figure 5: The Size Distribution of Commuting-Based Clusters in China and Selected Countries

Panel A: population

Panel B: area



Note: Top 200 commuting-based clusters with the largest population in each country and year as indicated. Clusters are ranked from the largest to the smallest by population. Each line represents the cumulative share of the nation's population (Panel A) or area (Panel B). Clusters are all formed using the same 10% threshold. For China, commuting flows are from smartphone location information in the three months ending in November 2017. Two sets of clusters are formed. The first set is based on commuting flows at the township level, and a county is assigned to a cluster if more than 50% of its population are in that cluster. The second set is based on commuting flows at the county level. For the United States, clusters are formed using county-level commuting flows, with data from the 2011-2015 American Community Surveys. For Brazil, clusters are formed using municipality-level commuting flows, with data from the 2010 Population Census. For Mexico, clusters are formed using municipality-level commuting flows, with data from the 2015 Population Census. There are 2,855 counties in China, 3,108 counties in the United States, 5,567 municipalities in Brazil, and 2,443 municipalities in Mexico. All clusters are not subject to population or density restrictions.

Figure 5 Panel A plots the cumulative shares of the 200 largest clusters in each country's population. Large clusters in the United States account for a substantial share of the nationwide population. The largest metropolitan area in the U.S. — the New York City Area — has a population of about 23 million and accounts for about 7% of the U.S. population. The 15 largest clusters in the U.S. account for 41% of the nation's population. Clusters in China are much smaller. Its largest cluster, a 16-county area around Shanghai, has a population of 24 million, but that only accounts for up to 1.7% of China's population. The 15 largest clusters in China account for only 18% of the nationwide population. Clusters in Mexico and Brazil, measured as their shares in the nationwide population, are relatively smaller than those in the U.S., but still much larger than those in China.

China's MAs are relatively small in area as well. Figure 5 Panel B shows that the cumulative density of area is also much higher in the United States and Mexico than that in China. The top 15 clusters in the U.S. account for 8% of the nationwide area, while the top 15 clusters in China account for a mere 2%, though China and the U.S. have a similar land area. Clusters in Brazil, on the other hand, are comparable to those in China in terms of their share in the nationwide land area.[16]

[16] Appendix Figure A.4 plots the cumulative shares of population (Panel A) and area (Panel B) for all commuting-

One may point out that China is not directly comparable with those countries. Its population is 4.2 times that of the United States, 6.7 times that of Brazil and 10.8 times that of Mexico. To make the comparison more meaningful, we choose two out of the six traditional economic regions of China that both have a similar population size at less than 400 million as the U.S. East China centers around the Yangtz River Delta and includes Shanghai, Jiangsu, Zhejiang, Anhui, Fujian, Jiangxi, and Shandong, while South Central China centers around the Pearl River Delta and includes Henan, Hubei, Hunan, Guangdong, Guangxi, and Hainan. Appendix Figure A.5 shows the cumulative shares of the 200 largest clusters in each region's population (Panel A) and area (Panel B). Relative to those in the U.S., clusters in these two regions are still smaller in both population and area.[17]

5.3 Policy Distortions

China imposes various restrictions on worker's mobility, which also affects the size of its cities. We discuss two types of policy distortions in China that restrict the growth of cities. First, administrative boundaries impose serious barriers for cities to grow. Second, Chinese cities are hierarchical, and the size of the city is highly correlated with its administrative rank. The administrative hierarchy may impose barriers on cities, especially those lower in the administrative hierarchy, to expand and grow.

5.3.1 Administrative Boundaries

Most Chinese MAs are largely confined within administrative boundaries (Figure 3). Figure 4 and Table 4 show that administrative boundaries impose severe restrictions to commuting. According to our preferred definition, only 18 out of 537 MAs cross a prefectural border, and merely one (Beijing) crosses a provincial border. In contrast, 36 out of the 100 largest commuting-based MAs (10% threshold at the county level) in the U.S. cross a state border. Of the 10 largest MAs in the U.S., there are seven cross-state MAs.

Local governments in China impose various rules that make it difficult to live in one juridiction while work in another. First, both labor market and local public goods are strongly linked to one's *hukou* location. Many jobs, both in the public sector and the private sector, are only offered to people with local *hukou*. Li et al. (2020b) find that *hukou* discrimination explains one third of the wage gap between local and migrant workers. In the meantime, access to public schools priori-

based clusters. Similar conclusions hold. For example, clusters in the top 20 percentile in the United States account for over 80% of the population and over 40% of the area; while clusters in the top 20 percentile in China account for 40% of the population and about 15% of the area.

[17] Population increasingly concentrates in larger clusters over time. Appendix Figure A.6 Panel A shows that the share of population in the largest clusters in the U.S. increased substantially between 1970 and 2015. There is also an increase in population concentration in the largest clusters in China between 2017 and 2019. The concentration of population in large MAs often accompanies expansion of these MAs in area. In the United States, the share of area accounted for by those large labor markets increased substantially between 1970 and 2015, reflecting the large-scale suburbanization and urban sprawl in the second half of the 20th century. Expansion in area is also observed for China between 2017 and 2019, though at a much smaller scale.

tizes families with local *hukou*, children without a local *hukou* either need to pay a hefty fee to be enrolled at a local public school, or are only eligible to be enrolled at private schools, which often cost more and are of lower quality.

Secondly, some social programs—such as government-provided healthcare and government-backed housing mortgage fund—are tied to where one works, not where one lives. Medical insurance can only be used in drug stores and medical facilities in the jurisdiction of one's workplace. Similarly, housing mortgage supported by the housing provident fund, typically featured an interest rate lower than that of the commercial housing mortgage, is only available to formal employees in the local jurisdiction.

Third, public transportation networks typically do not extend beyond administrative boundaries.[18] There have been numerous reports about the insufficient public tansit supply for commutes across jurisdictions, e.g., between Beijing and nearby townships in Hebei Province, where many who work in Beijing live.[19] Local governments, in particular those adjacent to the largest metropolises such as Beijing and Shenzhen, often lack the incentives to serve commuters who work in other prefectures and thus coordinate in cross-border transit. Under the current tax revenue sharing schemes, personal income tax is shared between the central government and the local government of the jurisdiction one works. China has yet to impose a property tax, so cross-border commuters contribute little to the coffer of local government where they live.

5.3.2 Administrative Hierarchy

One salient feature of China's MAs is that the size of the MA is highly correlated with its administrative rank. Appendix Table A.1 lists the 10 largest commuting-based MAs ranked by populatioin. All of them are municipalities or provincial capitals except for Shenzhen, which itself is the most successful Special Economic Zone. In 25 out of 27 provinces, the largest MA in the province is the corresponding provincial capital. In 163 out of 229 prefectures that contain more than one MA, the largest MA is the one that consists of the prefecture's core urban districts.

The strong correlation between administrative rank and city size is a prevalent phenomenon throughout China's history and the relationship seems causal. Bai and Jia (2020) study the sizes of Chinese cities over hundreds of years. They find that cities that were designated as provincial capitals became bigger, while those that were deprived of the capital city status subsequently lost population and the size of their economy shrank. Similar patterns are present in many other countries. Ades and Glaeser (1995) find that capital cities in autocratic countries tend to be much larger

[18] Transportation cost is one of the major determinants of city size as in the canonical urban model. China used to feature inadequate road network, low car ownership, and bus-dominated transit services. The urban transportation infrastructure has experienced rapid improvements only in the recent two decades. We find that MAs with rail lines put into operation between 2017 and 2019 are more likely to witness an urban growth during the same period. Out of 33 MAs with new rail lines, 22 (67%) increase in area by incorporating adjacent county units, much higher than MAs that did not have transit rail lines being added (27%).

[19] For example, https://www.chinanews.com.cn/sh/2018/11-15/8677138.shtml (in Chinese). Last visited in March, 2022.

and more developed than other cities in the country. They hypothesize that political capture and political rent are potential explanations.

Cities that are ranked lower administratively may get unfavorable policy treatments that are not necessarily related to their market advantage. Economic geography have changed substantially in China during the past few decades. An outward economy has made coastal and port cities economically more important, while provincial capitals are mostly inland cities. Thus it is striking that the largest cities in a province remain largely unchanged. In fact, for a Chinese city to expand and grow, it is necessary to obtain an "administrative hat", such as being designated as a "special economic zone" or a "coastal port city".

Another feature of Chinese system of MAs that stems from its hierarchical nature is that there are few MAs being formed exclusively among county-level units that are not urban districts. According to our delineations, there are essentially two types of MAs. The first type mostly consists of urban districts. Sometimes a large MA also includes nearby non-district counties. The second type includes stand-alone non-district counties that have an urban core that is large enough and meets the population and density criteria. Out of the 537 MAs according to our preferred definition, there is not a single MA that consists of more than one county (or a county-level city) and does not include an urban district. The only way for a county or a county-level city to be in a multi-county cluster is to be part of the urban core of a prefecture or a municipality.

This suggests that administrative hierarchy within a city matters for city sizes. As China is gradually urbanizing and cities expand, the Ministry of Civil Affairs periodically reclassifies counties and county-level cities that are adjacent to an urban core as districts, both as a result and a cause of urbanization. The reclassification is highly correlated with the pattern of how commuting-based MAs expand, which provides another piece of suggestive evidence that administrative decision, or at least administrative approval, plays a large role in city growth in China. One possible mechanism is that, only when counties are converted into districts could they be included in the city's urban planning.

We use the commuting flows matrix from November 2019 and delineate the MAs using the same set of criteria as we did for the 2017 matrix. We assemble a dataset of county-to-district conversions that took place between 2015 and 2019.[20] Comparing MAs in 2017 and those in 2019 we find that being reclassified as a district is highly correlated with being added to a nearby urban cluster between 2017 and 2019. Six out of 30 (20%) counties that were converted to a district between 2015 and 2019 became part of an MA between 2017 and 2019, a much higher probability than counties that did not have a relabeling (less than 10%).

[20] We extend the period back to 2015 because it may take time for the reclassification to have observable effects.

6 Comparison with Other Definitions

In this section, we compare our preferred delineation of MAs with various versions of the administrative definition and the nightlight-based definition. Among different versions of the administrative definition, we show the one that includes contiguous urban districts as well as stand-alone county-level cities is most similar to our preferred commuting-based definition. We argue that this version of the administrative definition provides a rule-of-thumb approximation of the commuting-based MAs. We then check system-of-cities properties under various different definitions.

6.1 Correlation among Various Definitions

We first compare the distributions of MAs between the commuting-based definition with the 10% threshold (Column 3 of Table 3) and different versions of the administrative definition (Columns 8-10 of Table 3). Column 8 shows the size distribution of cities according to the widely-used administrative definition that defines municipalities (provincial-level administrative units) and prefecture-level cities as MAs. The 256 units that meet the population size and density bars account for 34% of the country's area and 89% of its population. Since the rural area still accounted for about 40% of the national population in 2017, this definition of cities includes much of the rural areas and is thus unlikely to be a good definition of metropolitan areas.

Column 9 provides an alternative administrative-based definition that uses the contiguous urban districts, which form the urban core of a municipality or a prefectural-level city. 252 such MAs cover about 8% of the country's area and 39% of its population. While they represent China's most dense areas, they miss possible urban clusters in counties and county-level cities as well as counties that have been closely connected to the urban core.

Column 10 reports a revised version that further includes 229 county-level cities (subject to meeting population and density criteria). The inclusion of county-level cities does not change the tally of the largest MAs. About 60 county-level cities have more than one million residents, while most of them have a population between 500,000 and one million. According to this definition, there are 481 MAs in China, which collectively account for 54% of the population and 12% of the area.

The administrative definition that we believe best fits the economic definition of a city is the one presented in Column 10. This definition generates the size distribution of MAs that is the closest to that of our preferred commuting-based MAs. Both definitions indicate that there are around 500 MAs in China, which collectively account for 12%-15% of the area and 54%-55% of the population. That population ratio is also close to the official urbanization rate, which is reported to be 64% in 2020 according to the population census conducted in that year. The similarity between the two definitions should not strike as surprising, as we have exhibit the unique properties of China's commuting-based MAs: they are largely confined within administrative boundaries and rarely form multi-county MAs beyond contiguous urban cores. Another way to think about the similarity is that the administrative definition of cities presented in Column 10 can be justified as commuting-based local labor markets with the 10% commuting flows threshold.

We also report MAs delineated based on nightlight in Column 11 of Table 3. We use the 2017 VIIRS satellite nightlight data and follow a similar strategy as in Dingel et al. (2021).[21] The nightlight imagery suggests an urbanization rate higher than that of our preferred delineation. The total 738 MAs it identifies account for 21% of China's area and 75% of its population. This approach also delineates a few large clusters of urban areas in China, including 9 megalopolises (Appendix Figure A.7). According to this definition, the top two MAs roughly cover the entire Yangtze River Delta and the Pearl River Delta, with a population of 91.6 million and 55.0 million, respectively. Similarly, Dingel et al. (2021) identify the Pearl River Delta as the largest metropolitan area in the world using the 2010 nightlight data, which is formed through the process that "several original centers that over time merge across boundaries" (World Bank, 2015). However, we find although the nightlight seems to be connected in these regions, patterns from commuting flows clearly identify multiple clusters.

We then compare MAs that are based on commuting flows with other definitions by calculating the correlation coefficients in log population and log area between different definitions. Specifically, for each MA according to the commuting flows definition with a certain threshold, we match it with the corresponding MA in the alternative definition. MAs in different definitions do not perfectly match one-on-one. To match MAs to different administrative definitions, we first rank MAs within each administrative unit under that definition by population, and match the largest MA to that administrative unit. If an MA covers multiple administrative units, it is assigned to the unit that contains the largest share of the MA's population. Commuting-based MAs and nightlight-based MAs are matched using the administrative definition of urban districts plus county-level cities as the base.

Figure 6 reports the correlation coefficients. Overall, correlation coefficients for log population between different definitions as in Panel A are high, typically above 0.6 except for the MAs defined as urban districts.[22] The correlation coefficient is typically the highest when the threshold for the commuting flow is chosen at 10%. Commuting-based MAs with 10% cutoff are most correlated with those that include urban districts and county-level cities. The correlation coefficient for that pair is almost 0.9. In other words, if one intends to use one of the administrative definitions, the

[21] Dingel et al. (2021) use the DMSP satellite imagery from 2010. The sources of satellite nightlight data have changed between 2010 and 2017. We use the converted 2017 VIIRS data that are consistent with the DMSP data (Li et al., 2020a) and choose 30 as the nightlight intensity threshold—the preferred choice by Dingel et al. (2021).

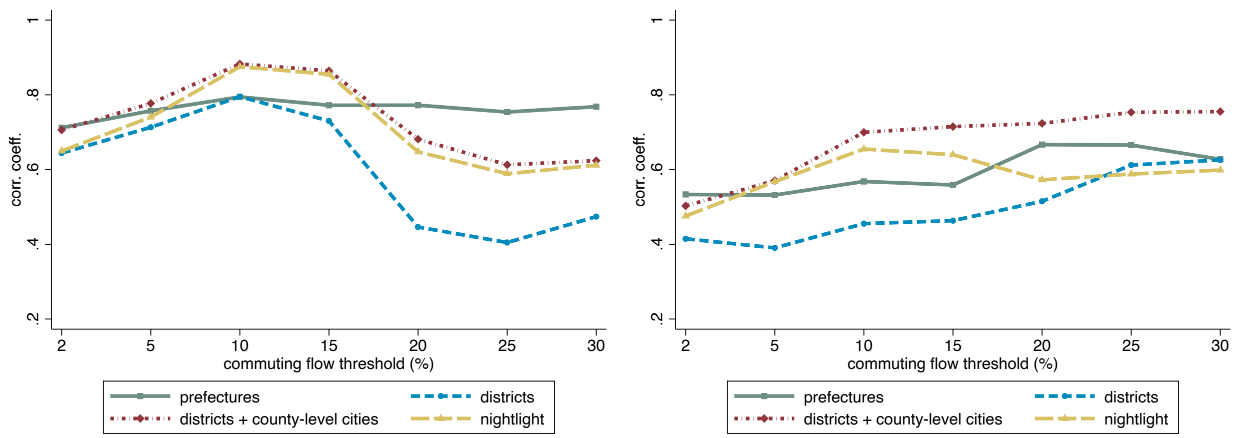
[22] A high correlation coefficient means that larger MAs in one definition is also typically larger in another definition. It does not mean that the MAs have similar population sizes. Table 3 provides additional evidence on the size distribution of MAs according to different definitions. Appendix Figures A.8 and A.9 show scatter plots of commuting-based MAs of various thresholds against the corresponding MAs by other definitions. Those graphs confirm that MAs defined as urban districts plus county-level cities are most consistent with commuting-based MAs with a 10% threshold.

one includes county-level cities and contiguous districts in municipalities and prefectural-level cities not only makes the most intuitive sense, but also can be largely justified by our preferred commuting-based definition. Panel B shows the correlation coefficients for log area. These correlation coefficients, between 0.4 and 0.8, are generally lower than those for log population.

Figure 6: Correlations across Various MA Definitions

Panel A: population

Panel B: area



Note: The graphs show the correlation coefficients between MAs based on commuting flows (with various thresholds) and other definitions: municipalities plus prefectural-level cities, contiguous urban districts, contiguous urban districts plus county-level cities, and MAs based on continuous nightlight. Panel A shows correlation coefficients for log population, and Panel B shows those for log area. Here we do not impose the population and density restrictions.

Correlation coefficients, however, do not tell us whether different MA definitions agree on a spatial unit being urban (part of an MA) or not. So we compare our preferred commuting-based MAs with other definitions by introducing Jaccard similarity indices, which measure the extent to which different MA definitions overlap on maps (De Bellefon et al., 2021). We first calculate urban Jaccard similarity as the ratio of spatial units that are urban in both maps to those that are urban in either of the two maps. Table 5 reports the values of urban Jaccard similarity. Of the three administrative definitions, the one including urban districts and county-level cities has the highest similarity with commuting-based MAs of 0.386, higher than 0.378 (which includes municipalities and prefectures) and 0.284 (which includes urban districts). Nightlight-based MAs perform better than the official definitions with a similarity index of 0.593. If we measure the overlap in population rather than area, urban Jaccard indices increase for all MA definitions, indicating that these definitions have a higher consistency with commuting-based MAs on more populated counties.

Table 5: Jaccard Similarities Between Commuting-Based MAs and Other Definitions

	MA definitions			
Similarity indices	muni + pref	urban distr.	distr. + cnty-cities	nightlight cutoff=30
Urban Jaccard (area)	0.378	0.284	0.386	0.593
Urban Jaccard (population)	0.584	0.478	0.552	0.688
Refined Urban Jaccard (area)	0.202	0.115	0.224	0.511
Refined Urban Jaccard (population)	0.393	0.379	0.438	0.590

Note: The table shows the Jaccard similarities between commuting-based MAs with a 10% threshold and other definitions. Urban Jaccard similarity is calculated as the ratio of spatial units that are urban in both maps to those that are urban in either of the two maps. Refined Urban Jaccard similartiy is stricter as it takes only spatial units that belong to the same urban area as the numerator. "Area" measures the overlap in area, while "Population" measures that in population.

Of the 2,855 county units in Mainland China, 2,211 are defined as urban by our preferred commuting-based MAs, 2,179 as urban by the administrative definition that includes municipalities and prefectural cities, 894 by the definition including urban districts, 1,115 by the definition including urban districts plus county-level cities, and 1,475 by the nightlight-based MAs. These numbers, together with urban Jaccard similarities, tell us a few things. First, there is a large discrepancy between commuting-based MAs and the definition of municipalities and prefectural cities, though they have the similar number of urban units. Second, the definition that includes urban districts plus county-level cities still misses counties that either have close commuting linkages to urban districts or are stand-alone MAs with a large urban core. Third, nightlight-based MAs have a higher similarity because they capture part of the above county units.

A similar urban Jaccard similarity may imply different partitions of MAs, e.g., a large interconnected MA vs. a couple of independent MAs. This is well illustrated by the nightlight-based MAs in the Pearl River Delta and those with the commuting-based definition. We thus calculate refined urban Jaccard similarity (city Jaccard similarity as in De Bellefon et al. (2021)), which is stricter as it takes only spatial units that belong to the same urban area as the numerator. MAs across definitions are matched in the same way as we calculate the correlation coefficients. As seen in Table 5, refined urban Jaccard indices, though overall lower than urban indices, confirm that of the three administrative definitions, MAs including urban districts and county-level cities are most similar to our preferred commuting-based MAs. Nightlight-based MAs again show a higher similarity than the administrative definitions. However, as mentioned earlier, the similarity between commuting-based and nightlight-based MAs are quite poor for the largest metropolises.

6.2 System-of-city Properties under Different Definitions

6.2.1 Zipf's Law

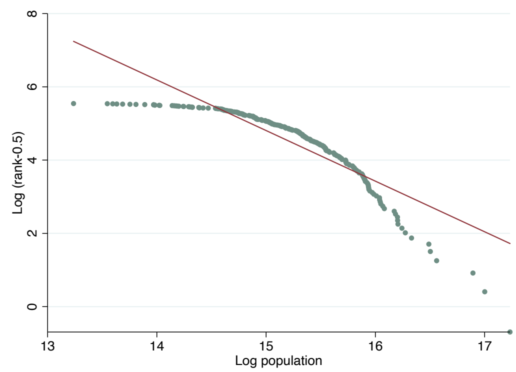
A prevailing pattern of the city size distribution is the log-linear relationship between population and the population rank, often referred to as Zipf's law (Gabaix and Ioannides, 2004). Figure 7 Panel A shows that cities defined as municipalities and prefectural-level cities present a poor fit of the log-linear relationship, which suggests that there are fewer large cities than what Zipf's law would predict. Chauvin et al. (2017) find the same pattern. They suggest that China's system of cities is still on the way towards a steady state, while large cities suffer from distortions from urban planning and population restrictions.

However, Zipf's law holds well for other definitions of MAs. Figure 7 Panel B shows that our preferred definition of MAs exhibit a near perfect linear relationship between log population and log population rank. The linear relationship explains over 99% of the variation. Panel C shows that defining cities as contiguous urban districts results a decent approximation of Zipf's law. Panel D shows that the log-linear relationship holds if county-level cities are included in the list of MAs. Panel E shows that the log-linear relationship holds for nightlight-based MAs using the 2017 data, which is consistent with the finding in Dingel et al. (2021) who use the 2010 satellite nightlight.

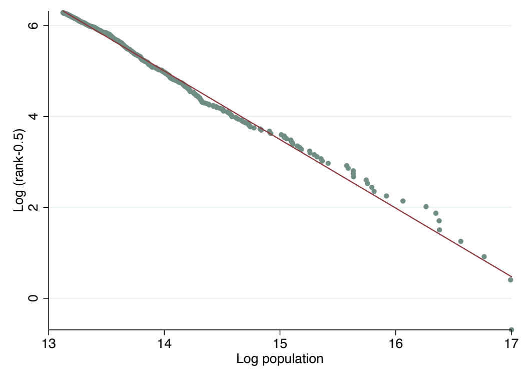
Appendix Figure A.10 shows the relationship between log population size and log population rank using commuting-based MAs of alternative thresholds. Setting the threshold at 15% or 20% yields systems of MAs that largely fit the Zipf's law, though not as well as setting the threshold at 10%. Thresholds that are either too small or too large lead to poorer approximations of the log linear relationship. This to some extent justifies our use of 10% threshold as the baseline delineation.

Figure 7: Zipf's Law according to Various MA Definitions

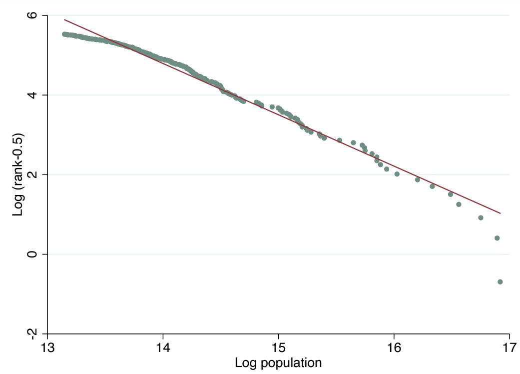
Panel
A: municipalities and prefectural-level cities



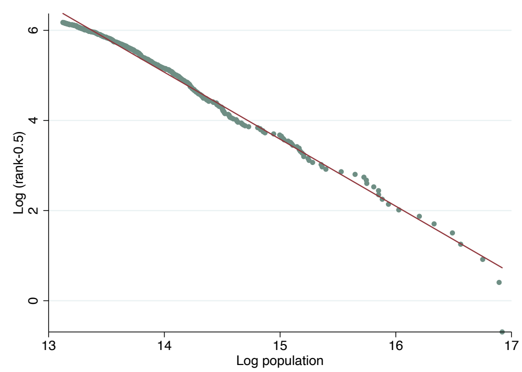
Panel B: commuting-based, 10% cutoff



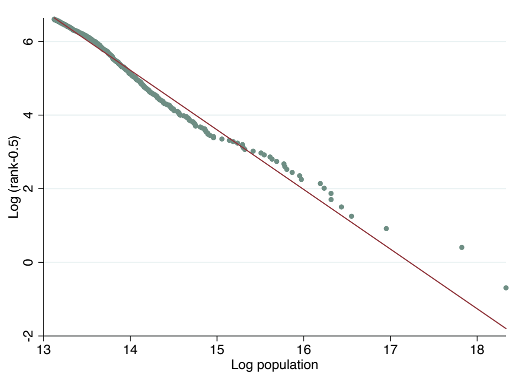
Panel C: urban districts



Panel D: urban districts + county-level cities



Panel E: nightlight-based, 30 cutoff



Note: The graphs show the log linear relationship between population rank and population size according to different definitions of MAs. In Panel A, the slope is -1.508 (the standard error is 0.006), and the $R-$squared of the fit is 0.992. In Panel B, the slope is -1.381 (the standard error is 0.043), and the $R-$squared of the fit is 0.800. In Panel C, the slope is -1.289 (the standard error is 0.014), and the $R-$squared of the fit is 0.970. In Panel D, the slope is -1.486 (the standard error is 0.007), and the $R-$squared of the fit is 0.988. In Panel E, the slope is -1.620 (the standard error is 0.008), and the $R-$squared of the fit is 0.982. The same size and population density restrictions are applied to all MA definitions.

6.2.2 City Size Premium

Large metropolitan areas are typically places where skill concentrates (Costa and Kahn, 2000; Moretti, 2004; Bacolod et al., 2009; Davis and Dingel, 2020) and where wage, productivity and housing prices are higher (Au and Henderson, 2006; Baum-Snow and Pavan, 2013; Davis and Dingel, 2019; Eckert et al., 2020). In this subsection, we collect data from various sources and report city-size premiums in skill and occupation composition, share of migrants, housing price, wage, and productivity (total factor productivity) according to various definitions of MAs. We show that while city-size premiums are ubiquitously positive across all definitions, the magnitudes of the premiums differ by definition.

We first estimate the city size premium in the share of college graduates. We construct the share of population with a college degree (at least 15 years of education) at the MA level using the 2015 population survey. The first row of Table 6 shows that the size premium in skill is substantial. According to the commuting-based definition with our preferred threshold, doubling the size of the city is associated with a 7.2 percentage point (p.p.) increase in the skill share. The nationwide sample average of the 2015 population survey is merely 12.34%. The city size premium in skill is the highest according to this commuting-based definition of MAs. Other definitions, including those based on prefectures and urban districts, yield smaller size premiums.

Higher skill shares in larger cities reflect more jobs in high-skill occupations in these cities. To show that, we build the crosswalk between occupations in the 2015 population survey and the International Standard Classification of Occupations (ISCO-88). High-skill jobs, defined as those in managerial, professional, technical and associated professional occupations (ISCO 1, 2 and 3), accounted for 6.59% of all the jobs in China in 2015. The second row of Table 6 indicates that the magnitude of city-size skill premiums in occupation composition is the highest using the commuting-based MA definition. Doubling the MAs' population size is associated with a 2.8 p.p. increase in the ratio of high-skill jobs.

Larger MAs also attract more migrants. Using the 2015 population survey, we calculate the share of migrants in each MA, where migrants are defined as those whose *hukou* registrations are outside the MA of residence. The nationwide sample average is 25.43%. The third row of Table 6 shows that doubling the population size of commuting-based MAs is associated with an 11.1 p.p. increase in the share of migrants. The premium is 10.0 p.p. when MAs are defined as urban districts plus county-level cities and 3.0 p.p. when they are defined as municipalities plus prefectural cities.

Large cities typically feature high housing prices. We estimate housing price premiums at the city center as in Combes et al. (2019).[23] We scrape second-hand housing prices at the neighborhood level in 2017 from a home sale listing website (soufun.com). We regress log housing prices

[23] Housing price premiums would be lower if we do not control for distance to the MA center, but the variation in the magnitude across different MA definitions remains.

on a set of housing characteristics including distance to the city center, the building age, and floor-to-area ratio as well as a set of MA fixed effects. The value of those fixed effects indicates the housing price at the MA center after controlling for distance to the center and adjusting for differences in housing quality. The fourth row of Table 6 shows that the size-premium of the housing price varies across different definitions of MAs. As the size of the city doubles, the housing price increases by around 43 to 55 percent depending on which MA definition to use.

We also check the relationship between city size and worker's wage as well as firm productivity. There is no recent publicly-available nationwide dataset in China that contains wage information that would allow us to calculate the residual wage at the MA level. We instead use the population survey in 2005, which asks respondent's monthly income. Similarly, we regress log wage on a set of personal characteristics such as age, gender, *hukou* status, industry and occupation as well as MA fixed effects. The fixed effects estimates refer to the MA-level wage after adjusting for differences in industry, job, and individual characteristics. The fifth row of Table 6 reports that doubling the size of the MA is associated with a 6.3% increase in monthly income according to the commuting-based definition, and a 13.4% increase if MAs are defined as urban districts.[24,25]

We calculate firm TFP using the 2006 Survey of Chinese Manufacturing Firms, where the TFP is measured as the Solow residual. We regress log firm TFP on a set of industry fixed effects as well as MA fixed effects, and then regress the MA fixed effects estimates on log MA population. The last row of Table 6 shows that the average firm productivity is about 4.6%-9.4% higher in a city that is twice the size, according to various MA definitions.

[24]This difference can largely be explained by the fact that a municipality or prefectural-level city may contain multiple commuting-based MAs that have the similar wage level but varying population sizes. The wage premium increases to 10.4% if we restrict the sample to the largest commuting-based MA within each municipality/prefecture.

[25]Using the 2005 population survey, Combes et al. (2015) find that the OLS estimates of log wage on the ratio of migrants to unskilled workers at the city level are 0.193, 0.123, and 0.053, respectively for high-skilled urban natives, low-skilled urban natives, and rural migrants. Our estimates in the third and the fifth rows of Table 6 imply larger gains from migration, which can partly be explained by the increasing variation in migrant shares with respect to the city size from 2005 to 2015.

Table 6: City-size Premium

	Mean	CB	NB	UD	UD+CC	PR
share of college graduates	12.34%	0.072	0.057	0.050	0.059	0.023
	(0.329)	(0.005)	(0.004)	(0.006)	(0.006)	(0.006)
# obs	1,354,988	341	473	239	368	256
share of workers in high-skill occ.	6.59%	0.028	0.020	0.015	0.020	0.005
	(0.248)	(0.002)	(0.002)	(0.0023)	(0.002)	(0.003)
# obs	1,354,988	341	473	239	368	256
share of migrants	25.43%	0.111	0.086	0.091	0.100	0.030
	(0.345)	(0.010)	(0.008)	(0.011)	(0.011)	(0.014)
# obs	1,354,988	341	473	239	368	256
log housing price at the MA center	9.565#	0.429	0.450	0.548	0.478	0.437
	(0.839)	(0.053)	(0.044)	(0.053)	(0.056)	(0.085)
# obs	102,351	121	98	117	121	117
log wage	6.740#	0.063	0.074	0.134	0.100	0.077
	(0.645)	(0.018)	(0.013)	(0.016)	(0.017)	(0.019)
# obs	593,908	231	275	204	290	249
log TFP	5.626	0.076	0.062	0.073	0.046	0.094
	(1.074)	(0.028)	(0.027)	(0.026)	(0.026)	(0.030)
# obs	286,810	525	721	251	478	256

Note: Each cell in Column "Mean" reports the nationwide sample average of the variables and the associated standard error. # The mean housing price is 20,916 RMB, and the mean monthly wage is 1,061.2 RMB in the sample. Each cell in Columns "CB" to "PR" reports the estimated coefficient associated with log population and the associated robust standard error, where the outcome variable is indicated in the first column. These five columns correspond to five different ways of defining MAs: CB stands for commuting-flow based MAs; NB stands for nightlight-based MAs; UD stands for urban districts in a municipality or a prefectural-level city; UD+CC includes also county-level cities in addition to urban districts; PR stands for municipalities plus prefectural-level cities. Data for the outcome variables come from the following sources. Share of college graduates, share of workers in high-skill occupations, and share of migrants are from the 2015 population survey. The share of college graduates is calcuated as the share of population who receive at least 15 years of education. The share of workers in high-skill occupations are the ratio of those in managerial, technical and associated professional occupations. Migrants are defined as those whose *hukou* registrations are outside the MA of residence. Log housing price at the MA center at the neighborhood level in 2017 is scraped from soufun.com, adjusting for housing characteristics. Log monthly wage is from the 2005 population survey, adjusting for industry, job, and individual characteristics. Log TFP is calculated as the average Solow residual of 2-digit industries using the firm-level data from the 2006 Survey of Manufacturing Firms.

7 Conclusions

Using novel commuting flows data at fine geographical levels, this paper defines commuting-based metropolitan areas in China following a standard clustering approach that takes into consideration both boundary accuracy and the availability of statistics. Overall, Chinese commuting-based MAs rarely cross prefectural boundaries and are small relative to those in other comparable countries. This is consistent with the fact that commuting in China is largely short and administrative boundaries impose severe barriers for commuting. We further discuss two types of policy distortions that may have hindered the growth and expansion of China's MAs.

We compare our preferred commuting-based MAs with other definitions. We find a version of the administrative definition that includes contiguous urban districts as well as stand-alone county-level cities is most similar to our preferred delineation of commuting-based MAs. Although some of the largest metropolises seem continuously urbanized according to nightlight satellite images, commuting links within these regions remain modest. We also show that using different MA definitions deliver different implications. Zipf's law hold for all definitions of MAs except the one that defines cities as municipalities and prefecture-level cities. Chinese MAs exhibit large size premiums along important dimensions, such as the share of college graduates, the ratio of high-skill occupations, average wage, housing price, and the total factor productivity. However, the magnitudes differ across various MA definitions.

The commuting-based MAs defined in this paper offer the first delineation of Chinese cities according to a city's most important economic functions—to provide employment opportunities and to house its residents. The delineation of commuting-based MAs is a useful tool for policy-makers. The provision of public goods, such as public transit and public housing, can be greatly improved from the perspective of commuting-based MAs. In a similar spirit, place-based policies need to target MAs instead of administratively defined units.

This paper shows the potential of new sources of big data in generating policy-relevant measures of social economic conditions in a timely, granular, and high-frequency manner. We believe our definition of commuting based MAs would provide a useful tool for researchers who are interested in questions related to Chinese cities and local labor markets.

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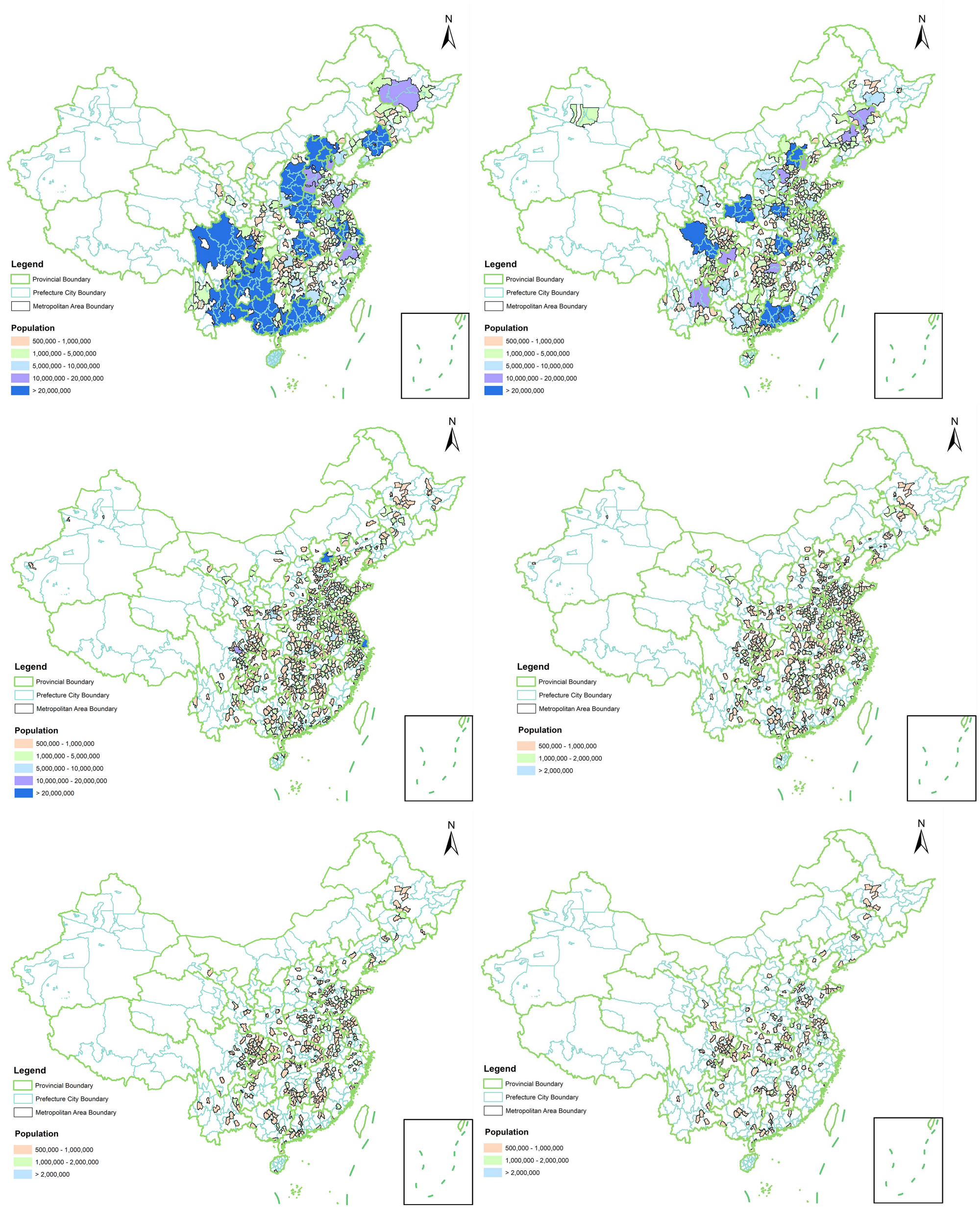
Online Appendix (Not for Publication)

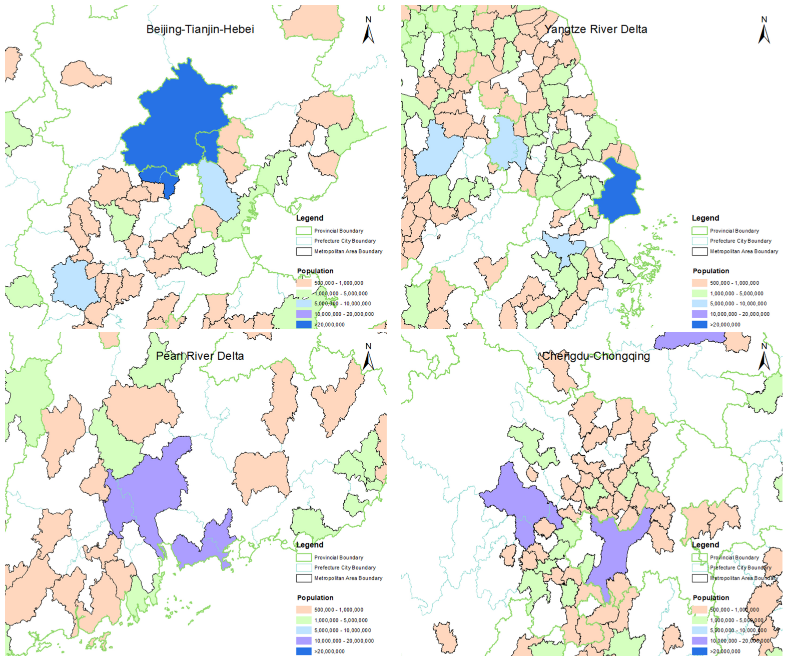
A Additional Figures and Tables

Figure A.1: County-Level Delineations of Metropolitan Areas in mainland China: Various Commuter-Share Thresholds, 2017



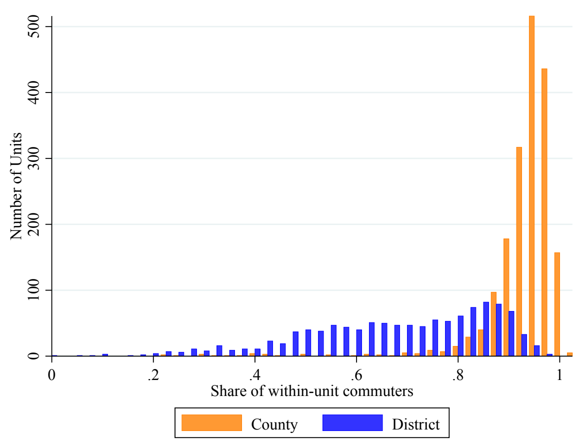
Note: Metropolitan areas are obtained by intersecting township-based commuting clusters under various commuter-share threshold with county units and then applying contiguity restrictions as well as population and density restrictions. Upper left, 2% commuter-share threshold; upper right, 5%; middle left, 15%; middle right, 20%; lower left, 25%; lower right, 30%. The 2017 population data are from the statistical yearbooks.

Figure A.2: County-Level Delineations of Metropolitan Areas in Major Regions of China: 10% Commuter-Share Threshold, 2017



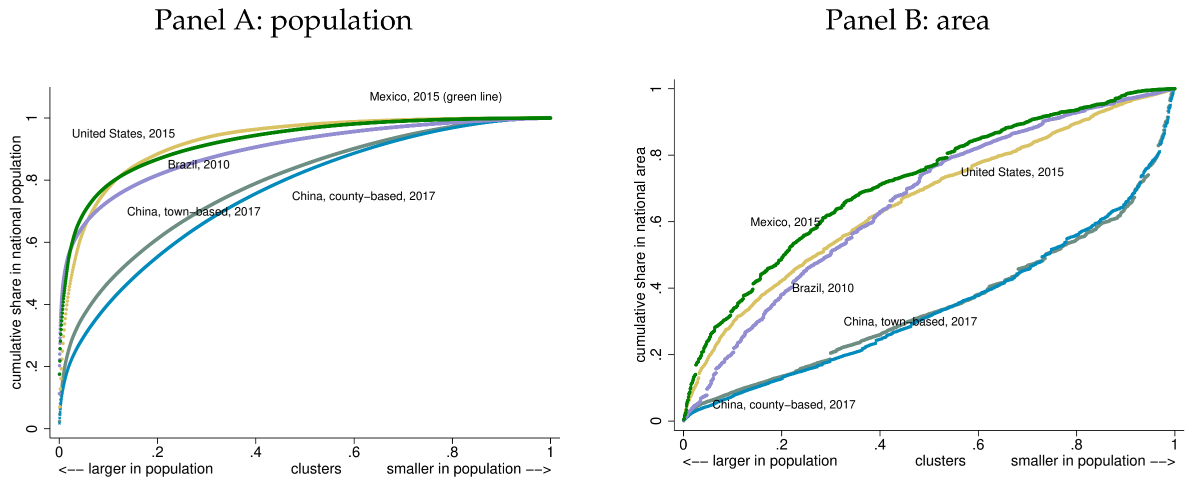
Note: Metropolitan areas are obtained by intersecting township-based commuting clusters under the 10% commuter-share threshold with county units and then applying contiguity restrictions as well as population and density restrictions. Upper left, Beijing-Tianjin-Hebei; upper right, Yangtze River Delta; lower left, Pearl River Delta; lower right, Sichuan Basin. The 2017 population data are from the statistical yearbooks.

Figure A.3: Within-unit Commuting Ratio: County vs. District



Note: Graphs show the number of counties and districts by the share of within-unit commuters using smartphone location data in November 2017.

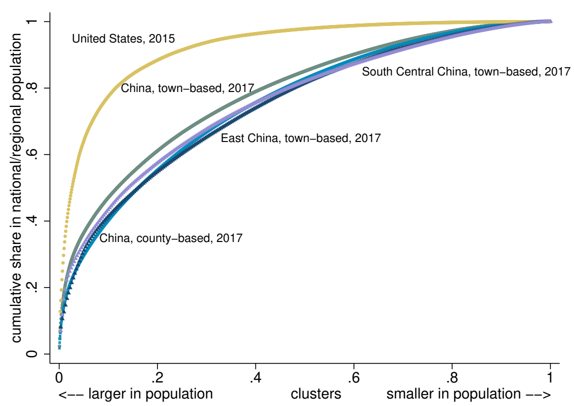
Figure A.4: The Size Distribution of All Commuting-Based Clusters in China and Selected Countries



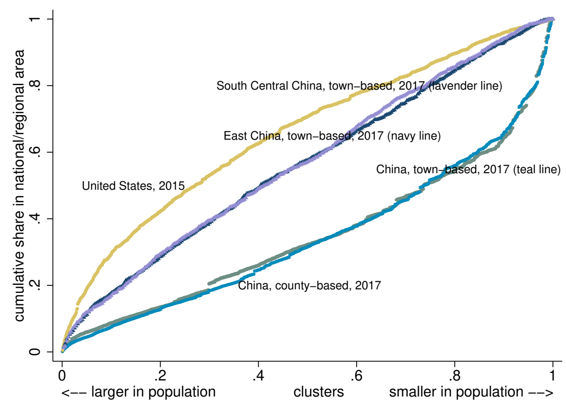
Note: All commuting-based clusters in each country and year as indicated. Clusters are ranked from the largest to the smallest by population. The x-axis indicates the percentile of the distribution of cluster population size. Each line represents the cumulative share of the nation's population (Panel A) or area (Panel B). Clusters are all formed using the same 10% threshold. For China, commuting flows are from smartphone location information in the three months ending in November 2017. Two sets of clusters are formed. The first set is based on commuting flows at the township level, and a county is assigned to a cluster if more than 50% of its population are in that cluster. The second set is based on commuting flows at the county level. For the United States, clusters are formed using county-level commuting flows, with data from the 2011-2015 American Community Surveys. For Brazil, clusters are formed using municipality-level commuting flows, with data from the 2010 Population Census. For Mexico, clusters are formed using municipality-level commuting flows, with data from the 2015 Population Census. There are 2,855 counties in China, 3,108 counties in the United States, 5,567 municipalities in Brazil, and 2,443 municipalities in Mexico. All clusters are not subject to population and density restrictions.

Figure A.5: The Size Distribution of All Commuting-Based Clusters in Selected Regions of China

Panel A: population

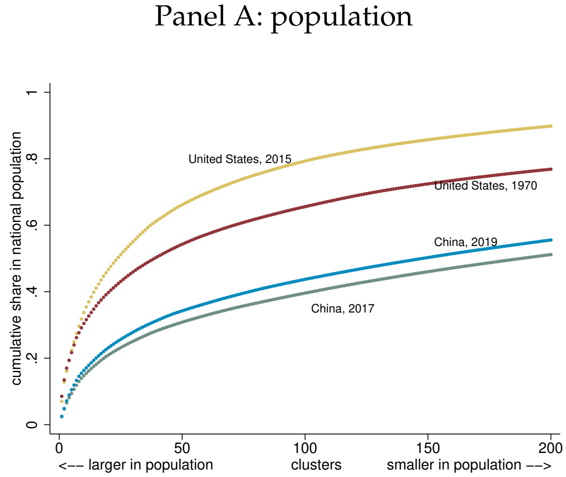


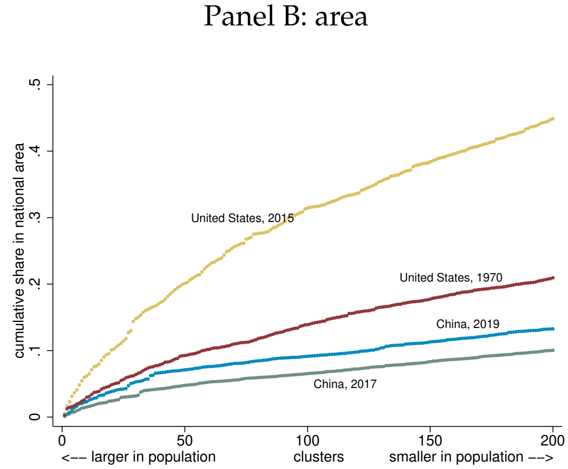
Panel B: area



Note: All commuting-based clusters with the largest population in each country/region and year as indicated. Clusters are ranked from the largest to the smallest by population. Each line represents the cumulative share of the nation or the region's population (Panel A) or area (Panel B). Clusters are all formed using the same 10% threshold. For China, commuting flows are from smartphone location information in the three months ending in November 2017. Two sets of clusters are formed. The first set is based on commuting flows at the township level, and a county is assigned to a cluster if more than 50% of its population are in that cluster. The second set is based on commuting flows at the county level. Two regions in China are also shown here, including East China (Shanghai, Jiangsu, Zhejiang, Anhui, Fujian, Jiangxi, and Shandong) and South Central China (Henan, Hubei, Hunan, Guangdong, Guangxi, and Hainan). For the United States, clusters are formed using county-level commuting flows, with data from the 2011-2015 American Community Surveys. All clusters are not subject to population or density restrictions.

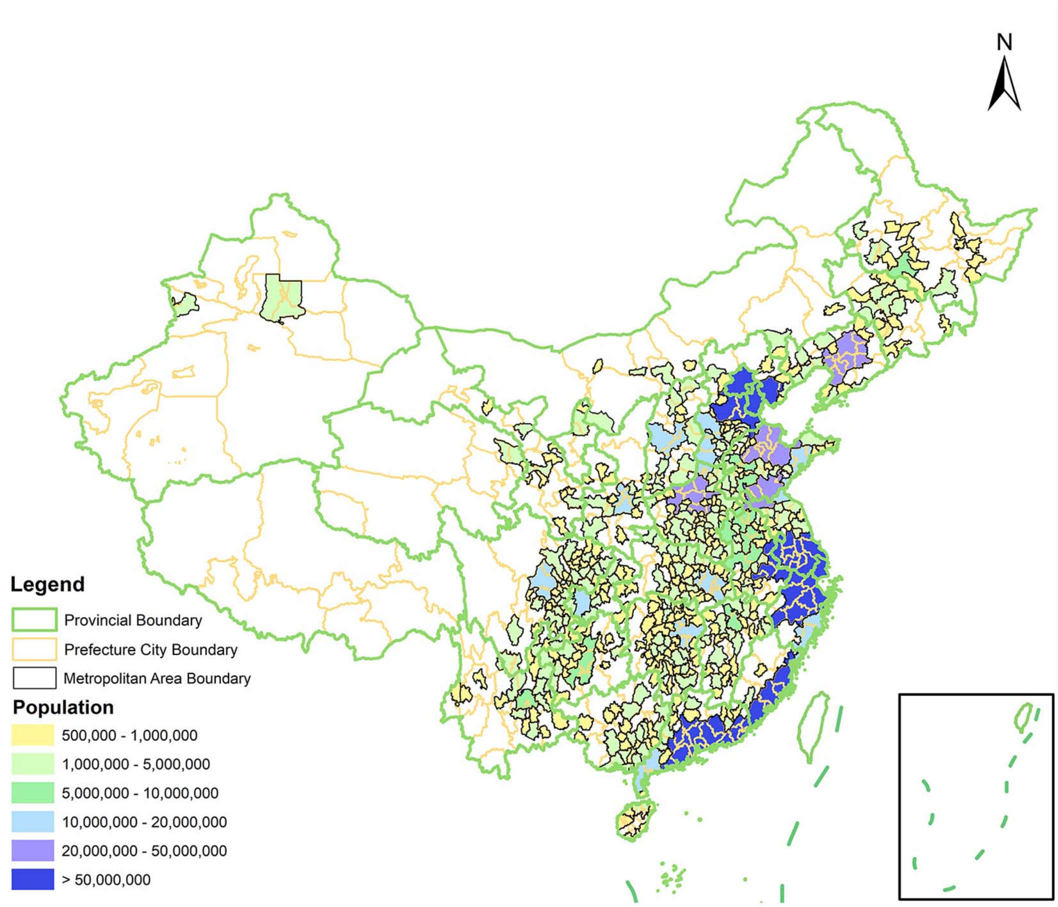
Figure A.6: The Size Distribution of Commuting-Based Clusters in China and the United States, Seclected Years





Note: Top 200 commuting-based clusters with the largest population in each country and year as indicated. Clusters are ranked from the largest to the smallest in population. Each line represents the cumulative share of the nation's population (Panel A) or area (Panel B). Clusters are all formed using the same 10% threshold. For China, township level commuting flows are from smartphone location information in the three months ending in November 2017 and November 2019. A county is assigned to a cluster if more than 50% of its population are in that cluster. Two sets of clusters are formed in 2017 and 2019, respectively. For the United States, clusters are formed using county-level commuting flows, with data from the 2011-2015 American Community Surveys and the 1970 population census. All clusters are not subject to population and density restrictions.

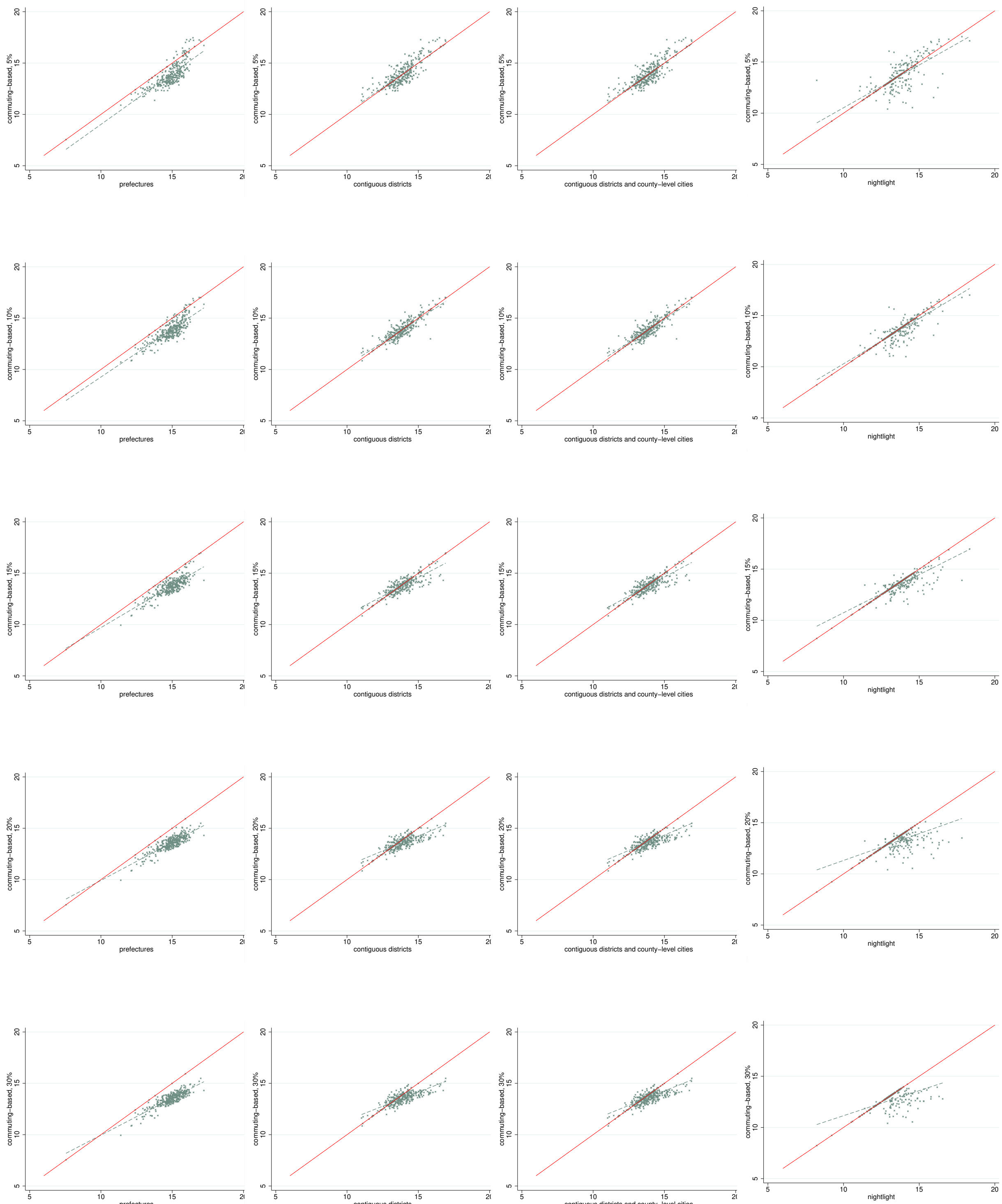
Figure A.7: County-Level Delineations of Metropolitan Areas in mainland China: 30 Nightlight Intensity Cutoff, 2017



Note: Nightlight-based metropolitan areas are obtained by intersecting contiguous bright areas with county units. We use the converted 2017 VIIRS nightlight data with an equivalent DMSP 30 cutoff.

Figure A.8: Correlations between Commuting-based MAs and Other Definitions: Population

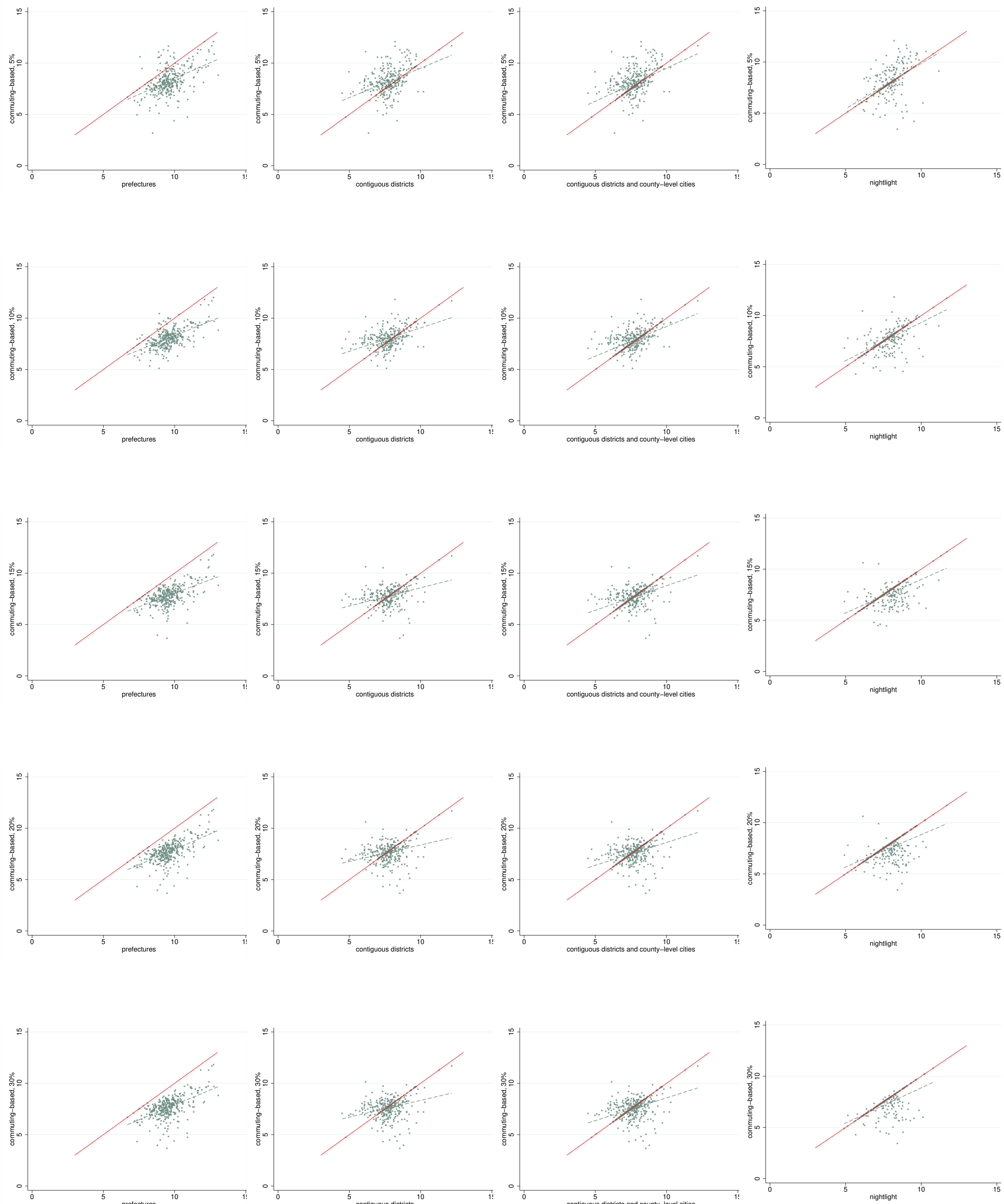
Col A: prefectures   Col B: districts   Col C: + cnty cities   Col D: nightlight



Note: Correlations in log population between commuting-based MAs and those according to other definitions. Each column corresponds to an alternative definition. Each row corresponds to a different threshold for commuting flows. Here we do not impose the population and density restrictions.

Figure A.9: Correlations between Commuting-based MAs and Other Definitions: Area

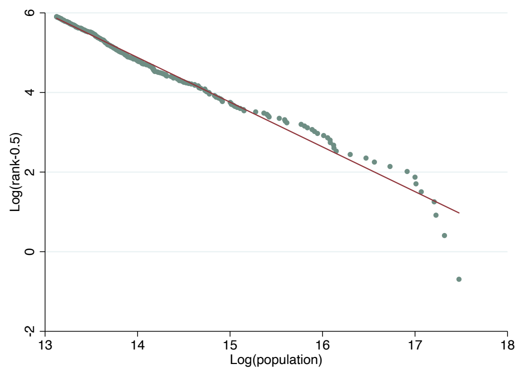
Panel A: prefectures | Panel B: districts | Panel C: + cnty cities | Panel D: nightlight



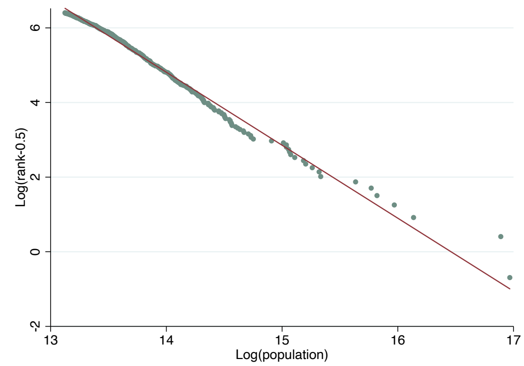
Note: Correlations in log area between commuting-based MAs and those according to other definitions. Each column corresponds to an alternative definition. Each row corresponds to a different threshold for commuting flows. Here we do not impose the population and density restrictions.

Figure A.10: Zipf's Law

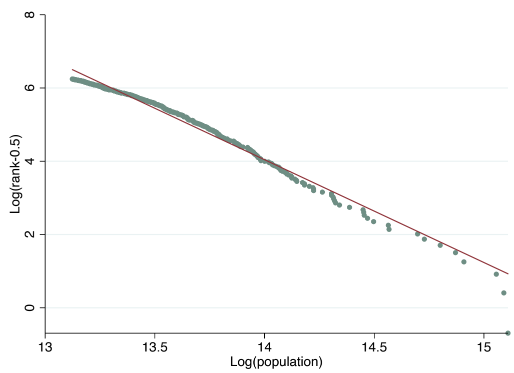
Panel A: 5%



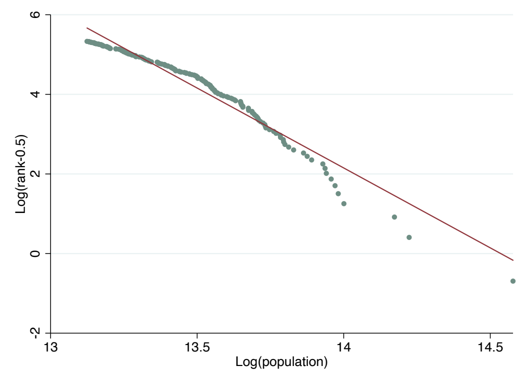
Panel B: 15%



Panel C: 20%



Panel D: 30%



Note: The graphs show the log-linear relationship between MA's population rank and its population size. Each panel corresponds to a different threshold for commuting flow shares. Panels A to D use a threshold of 5%, 15%, 20%, and 30%, respectively.

Table A.1: The Top 10 Metropolitan Areas By Population

Name	Rank	By Metropolitan Areas Population (million)	Area (km^2)	No. of Counties
Shanghai	1	24.2	8058.5	16
Beijing	2	24.0	19115.5	21
Guangzhou	3	19.1	9266.7	14
Chengdu	4	15.6	16410.1	20
Shenzhen	5	13.0	3142.1	10
Chongqing	6	12.9	13965.6	13
Wuhan	7	12.6	11955.4	17
Xi'an	8	11.6	16660.2	23
Tianjin	9	9.5	3660.1	11
Zhengzhou	10	8.2	7916.5	12

Note: The table reports the 10 largest MAs by population, according to our preferred commuting-based definition of MAs. The last column reports the number of county-level administrative units in each MA.