Roads, Railways and Decentralization of Chinese Cities*

Nathaniel Baum-Snow[a]

Loren Brandt[b]

J. Vernon Henderson[a]

Matthew A. Turner[b]

and

Qinghua Zhang[c]

This version: September 17, 2011

Abstract: This paper investigates how the extent and configuration of Chinese road and railroad networks has shaped the spatial transformation and degree of compactness of Chinese urban regions in the last 20 years, a period in which central cities were experiencing strong population inflows but relative losses of industry to the urban periphery. We find strong evidence that the presence of radial roads and ring roads outside of the central city reduce central city population density. However radial roads have no effect on the spatial distribution of economic activity (GDP) in urban regions, though ring roads outside of central cities may contribute to industrial decentralization. Rather in a country where inter-city trade relies heavily on rails, rail networks have significant impacts on the extent to which economic activity decentralizes. Pseudo-random variation in historical transportation infrastructure provides identifying exogenous variation in more recent measures of such infrastructure.

J.E.L.: R4, O2

Keywords: China, Roads, Railroads, Infrastructure

---

* We are grateful to Inter Governmental Council grant #RA-2009-11-013 for generously funding this research. Baum-Snow and Turner thank the Lincoln Institute of Land Policy for additional support. Brandt and Turner are grateful to the Canadian Social Science and Humanities Research Council for funding. We also thank the many research assistants who helped on this project: Magda Besiada, Rong Zhang Wang, Jie Ciao, Huaihong Su, Yujin Cao, Hyunjoo Wang, Xiaolu Li and particularly Zhi Li and Zhi Wang. We are also grateful to Byron Moldofsky, the University of Toronto Cartography lab and the Neptis Foundation for their support and for their assistance with GIS data.

[a] Brown University

[b] University of Toronto

[c] Guanghua School of Business, Peking University, Beijing China

1. Introduction

In the early 1990's, China began rapidly building and upgrading its transportation infrastructure, particularly highways. From a low level, spending on transportation infrastructure grew at 15% a year to about $200 billion in 2007, much of which occurred in cities. This was accompanied by rapid migration of rural populations to cities and high rates of economic growth averaging over 10% a year. We investigate how the extent and configuration of Chinese road, railroad, and public transit networks affected transformation of urban form, in particular compactness and the decentralization of population and economic activity in Chinese cities during this period. Since decentralization of population and economic activity may precipitate infrastructure investments, we rely on exogenous variation in transportation networks that predate China's conversion to a modern, market based economy to estimate the causal effects of infrastructure on decentralization.

For our investigation we construct a unique data set describing population, economic activity and infrastructure in Chinese cities. These data integrate satellite images of lights at night from 1992 to 2009 with digitized national road and rail maps from 1962, 1990, 1999, 2005 and 2010. Our data also include census information by county from 1990, 2000, 2010, and information assembled and input from city and national urban yearbooks for GDP, investment and other variables for 1990-2008. We construct our data to describe a panel of constant-boundary Chinese central cities in 1990 for metropolitan areas defined in 2005. This is the first ever constant boundary panel data set describing major Chinese cities over the last 20 years of which we are aware.

We find strong evidence that the presence of radial roads reduces population density in central cities and that ring roads outside the central city additionally reduce central city population density. Since in the period studied population is moving into central cities, radial roads and ring roads outside the center retard the degree of centralization. Our estimates indicate that each additional radial highway significantly displaced at least 4.1 percent of central city population to suburban regions. Conditional on the radial and ring configuration of the highway network, total kilometers of roadways in or outside the central city do not affect central city population density. We find suggestive evidence that additional buses and trolleys in the central city increase center city population density. Together, these findings provide strong econometric evidence in support of the conventional wisdom (World Bank, 2002) that urban compactness is reduced by radial and ring road construction, but enhanced by public transport.

Our data also show that while a city's intra-prefecture railroad network does not affect central city population, it does affect the extent to which industrial production is centrally located. Why we do

not have employment by location data, we do have GDP data. Each additional radial railroad line causes a decline in central city GDP of about 12 percent and industrial sector GDP of 19 percent. Second, ring roads built outside the central city also contribute to the displacement of center city production to outlying areas. More radial rails with their sidings and more ring roads giving ex-urban access to rail networks encourage decentralization of production. However radial roads and the overall length of the road network do not cause decentralization of production in Chinese cities. That railroads, but not radial roads, affect the location of production probably reflects China's heavy historical reliance on railroads for long haul and short haul freight.

What is important about our investigation? Given the high costs of urban transport infrastructure investments, mayors and planners worldwide have two basic questions (World Bank, 2002). What is optimal transport infrastructure network for their city? What is the impact on their city form of building a radial highway, a ring road, or a rail line or expanding public transport modes? This paper helps answer the second set of questions. The answers have key economic implications. We note these implications as further motivation for the investigation.

Dating to Marshall (1890), economists have recognized that dense central cites provide rich information environments, with agglomeration improving productivity, economic creativity and growth (Jacobs, 1969, Lucas 1988). However such environments in bigger cities come with higher land and labor costs and only particular industries sufficiently benefit from the richer information environment to pay those costs. As a result, in developed market economies, central cities typically house business and financial services and incubate small businesses, with standardized manufacturing found on the urban periphery and in small cities and towns (Kolko, 2000; Swartz, 1992). In contrast in developing countries, in the early stages of industrialization, manufacturing locates in these central cities, perhaps because learning and adaptation are critical to the successful transfer of technology from abroad and FDI requires the infrastructure and institutional support that may only be found in some central cities. In China a legacy of central planning accentuated this hypothesized process with large factories dominating the central city landscape. However as transferred technologies mature and economic growth proceeds, central city environments become expensive locations for standardized manufacturing; and, in a version of the product cycle (Duranton and Puga, 2001), industrial firms seek to decentralize to the urban periphery and beyond, where land and labor costs are lower.

In China one twist to this process was that the factories under Mao were allocated huge plots of central city land that became very valuable in the 1990s. Factories were permitted to cash in on their implicit holdings by vacating the center and developing those holdings for business and residential uses

(Zhu, 2004). A second twist is the economic reforms in the rural sector in the 1980s that predate urban reforms in the 1990s. These reforms facilitated rapid growth of a rural industrial sector, contributing to the relative decentralization process.

The urban literature suggests that migration of these factories to the urban periphery, growth of rural industry, and the consequent development of business and financial services in central cities depend substantially on the ability of the transportation network to connect peripheral locations to the rest of the local economy (Lee and Choe 1990, Lee 1982, Hansen 1987, Henderson, Kuncoro and Nasution 1996). Our results indicate the extent to which different configurations of road and railway networks help contribute to this transformation. Such transformation as facilitated by infrastructure investments may improve efficiency in production through better use of the rich information environments in central cities and operation of the urban version of the product cycle, thus promoting local economic growth.

However there is another perspective: the value of urban compactness per se. On the environmental side, compact cities are argued to enhance greenness, reducing energy costs and pollution (Kahn, 2006). In China an additional aspect involves the desire for food security. Policy makers are concerned with the preservation of agricultural land and expanding cities consume such land. Our results provide a basis for understanding the tradeoff between improved transportation infrastructure, compactness for environmental purposes, operation of the urban product cycle, and the use of agricultural land near cities. More generally, the construction of transportation infrastructure currently consumes about 3 percent of Chinese GDP. These enormous investments will shape Chinese cities and the lives of their residents for generations. By providing an understanding of how infrastructure affects the evolution of Chinese cities, we provide a foundation for infrastructure policies that will help or hinder the achievement of different objectives that mayors and planners may have.

In terms of the literature which is reviewed in the next section, here we note three important ways we improve on the existing literature relating infrastructure to urban form. First, the existing literature focuses almost exclusively on the United States in the late 20th century. We extend the literature by investigating the effects of transport infrastructure on urban form in a developing country context, that is, where automobiles are less prevalent[1], household incomes are much lower, and cities

[1] In 1990, car production was only 50,000 units. This increased to slightly more than 600,000 units by 2000, but a major portion of these sales were to institutions (as opposed to individuals). By 2010, car sales exceeded 10 million units, most of which were to individuals. (Zhongguo chiche gungye nianjian (China Automotive Industry Yearbook), miscellaneous years.)

are much denser than in the developed countries. Second, we provide a more sophisticated analysis of the role of transportation network design than has previously been conducted. Our examination of the effects of ring roads and the competing influences of roads and railways is entirely novel. The extant literature considers these networks independently and provides little insight into the effect of railroads on urban form. Third, our analysis is among the first to examine the relationships between transport infrastructure and the spatial distribution of various measures of GDP rather than simply population or employment within urban regions.

The validity of our conclusions concerning the effects of transport infrastructure investments on urban form relies on achieving pseudo-random variation in transport variables of interest. We generate such exogenous variation by using the configuration of urban transport infrastructure in 1962 as instruments for more recent transport infrastructure. The validity of this identification strategy depends crucially on the fact that Chinese roads and railways served very different purposes in 1962 than they do today. Roads existed primarily to move agricultural goods to local markets while railroads existed to ship raw materials and some manufactures between larger cities, to provincial capitals, and to an unusual extent even within metropolitan regions. Moreover, unlike since the mid-1990s there was very little commuting in 1962 in China and almost no individual choice of where to live or work. The liberalization of urban economies during the 1990's that both started the operation of urban land markets and moved industry to a competitive market basis means that 1990 is an appropriate starting point for our analysis.

The paper proceeds as follows. The next section discusses relevant literature and context. Section 3 describes the data. Section 4 presents our econometric model and discusses identification. Section 5 discusses our results and Section 6 concludes.

2. Literature and Context

A recent literature investigates the effects of infrastructure on the allocation of resources across and within regions. Michaels (2008) and Chandra and Thompson (2000) investigate the effects of U.S. interstate highways on the development of rural U.S. counties and Duranton, Morrow and Turner (2011) examine the effects of the interstate highway system on trade between cities. This literature shows that the interstate system has a modest effect on inter-regional trade flows and composition in the late 20th century U.S. Donaldson (2010) examines the impacts of railroads in late 19th and early 20th century India and finds large effects on trade and welfare. Faber (2010) examines the effect of Chinese intercity roads on the economic development of rural Chinese prefectures and finds large effects. Puga and

Nunn's (2010) investigation of the effects of topography on economic development suggest an important role for transportation costs, and hence, indirectly, for transportation infrastructure. In each of these papers, the authors address the possibility that economic activity causes infrastructure rather than vice-versa.

A smaller literature examines how within city transportation infrastructure affects the development of cities. This literature began with Baum-Snow (2007) which finds that limited access radial highway caused economically important decentralization in U.S. metropolitan areas. Following this paper, Duranton and Turner (2011a) find that kilometers of interstate highways in a city have economically important impacts on the growth rate of population and employment in cities. Duranton and Turner (2011b) find that driving within a city depends sensitively on the extent of the interstate highway network in the city, and slightly less sensitively to the extent of other roads. Cheung, Hsu and Zhang (2011) replicate this result using Japanese data. All of these papers rely on exogenous variation to identify the effect of roads on their particular outcome variable of interest and all investigate wealthy western countries. To our knowledge only Deng et al. (2008) investigate the effect of roads on the developmentWhile-1.c)5(m(o)-pJ5nr6(w)(f7)-3(t) -3(4-6(e 011-1(t oeTJ2e 5(e a(r)TJ2e TJ2tut o26 on)5()TJ2 b6 oy3(t)2(e)-x

urbanized areas in our study area of China. Panel C shows trends in GDP and industrial GDP for the 108 prefectures for which we could build data.

Evidence in Table 1 indicates that throughout our study period, population grew much more quickly in central cities than in suburban regions. Panel A shows that aggregate population growth was 56% in central cities relative to just 5% in city hinterlands, with slightly more rapid growth in both regions during the 1990s than after year 2000. These high city population growth rates are driven by the mass migration of Chinese peasants from the countryside that almost certainly ranks as the largest migration in human history.[2] Chinese cities have had to struggle to accommodate the migrants and consequently have utilized administrative barriers to migration to try to stem flows to the biggest cities. Given the rural-urban gap in income, these barriers impose high costs on the rural population. This study will contribute to understanding how transport infrastructure can aid cities in successfully handling such large influxes of rural migrants.

This context is in stark contrast to the post-WWII United States experience. While the recent expansions of western cities mostly involved stable or declining central populations and sprawling hinterland population, Chinese cities remain relatively compact. Car ownership nationally remains low and motorcycles and scooters are banned from most central cities. It is probably more apt to compare modern China to U.S. cities circa 1925, rather than 2000. Like the U.S. circa 1925, the Chinese economy today relies heavily on railroad transportation, fostered by the heavy reliance on railroad transport in China in the Maoist era[3]. Indeed, while the ratio of total ton-distance carried by railroads versus trucks is currently about 1.4 in the USA in China it is about 2.6.(cite)

In contrast to population, Table 1 shows that lights increased more quickly in suburban then urban regions, with some modest decentralization of economic activity. In the full sample of 264 observations, lights grew by 106% in central cities and 174% in prefecture remainders between 1990 and 2010. For the smaller common sample of 108 areas for which we have consistent GDP data broken out by sector for the 1990-2005 period, overall suburban GDP also grew slightly more quickly than central city GDP at 588% and 527% respectively. This relative suburban growth in economic activity was partly driven by more rapid industrial sector growth in these regions. Industrial GDP grew by 773% in suburban regions relative to 413% in central cities between 1990 and 2005. These GDP numbers reflect the very high rates of economic growth experienced during our study period.

[2] Recent estimates put the stock of migrants at between 175-200 million.

[3] Cite 1980 world bank report.

While the context during our study period of cities rapidly growing with huge numbers of migrants is clearly quite different from the sprawling U.S. cities of the post-WWII period examined in much of the literature, estimates of the effects of highway rays are remarkably similar. Baum-Snow (2007) finds that each highway ray causes about a 6 percent decline in central city population within the first 20 years of construction, a number within standard error bands of estimates reported in this paper. This consistent evidence from very different contexts indicates the fundamental importance of transportation infrastructure for understanding the spatial structures of urban areas and how they evolve.

3. Data

3.1 City and Prefecture Geography

We describe the geography of Chinese cities analogously to metropolitan areas in the United States. That is, we describe the boundaries of Chinese metropolitan areas using counties as building blocks. The Chinese administrative unit corresponding to the US county is divided into three different classes: rural counties (Xian), county cities (Xianji Shi), and urban districts (Qu). As their names suggest, rural counties are typically rural, county cities contain small to midsize towns, while urban districts are the components of larger cities. Loosely, urban districts correspond to urban counties in the U.S. making up metropolitan areas, while rural counties and county cities correspond to the residual set of US rural counties. To ease exposition, we often refer to all of the Chinese county equivalent units as `counties'.

Unlike the U.S., there is an administrative unit intermediate between the county and the state or province. These units are called prefectures (Shi). The urban districts in a prefecture comprise the prefectural city.[4] This unit is an administrative city and is the nearest possible Chinese analog to the US metropolitan statistical area. These prefectural cities are our primary unit of study.[5] [6] The extant literature sometimes treats the prefecture or county as a `city' for statistical purposes (e.g. Deng et al 2008, Faber 2010). We study a set of 264 prefectures in primarily Han provinces of China that have a prefectural level city in 2005. Our study area contains about 85% of China's population. Figure 1a illustrates our study area, prefecture boundaries, and the boundaries of central cities in 1990. We exclude the less developed territories in the West because data availability is much poorer in these

---

[4] If the prefecture consists entirely of rural counties then it does not contain a prefectural city.

[5] In four cases, Beijing, Shanghai, Tian Jin and Chongqing cities are treated administratively as provinces rather than prefectures.

[6] Unlike MSAs, prefectural cities are sometimes disjoint. The unlabelled area in red borders adjacent to Beijing in the south-east in Figure 1b actually belongs to Chengde.

regions. As illustrated in Figure 1a, prefectural cities in 1990 are typically much smaller than prefectures; and, as illustrated in Figure 1b for the Beijing area, they often consist of many counties. Neither counties nor prefectures appear to be defensible as statistical cities. Ours is the first study to develop data for China to analyze population allocation between a central city—the historical prefecture city -- and the surrounding prefecture area.

Over the course of our study period, the boundaries of a number of counties and prefectures changed and new prefectural cities were created. We require data describing constant boundary prefectures and prefectural cities. We construct such data by describing prefectural cities in 1990 as a collection of 2005 counties. That is, our 1990 prefectural cities consist of all year 2005 counties that were designated as urban districts in 1990 (or which contained 1990 counties with this designation).[7] These 1990 prefecture cities are what we call our central cities. We are able to follow these same constant boundary central cities through the four cross-sections covered by our data, 1990, 2000, 2005 and 2010, during the post-1990 period of reforms in the urban sector and rapid urban growth.[8] Of the 264 prefectures with cities in 2005, 48 were created or experienced boundary changes after 1990.

In addition to numerous boundary changes, many counties also experienced changes in administrative status, as illustrated in Figure 1b. 95 of the 264 year 2005 prefectural level cities did not exist as prefectural cities in 1990. That is, in 1990 these 2005-definition prefectures did not contain a single urban district. For these cities we define the 1990 central city boundaries to correspond to those of the 2005 county containing the prefecture's CBD. (We discuss our method of locating these CBDs below). We call such cities ”promoted” cities, i.e., their administrative status was promoted. Since these cities are newer than vintage 1990 prefectural cities, in some of our empirical work we distinguish between “promoted” and “incumbent” cities. Of the promoted cities, 6 experienced boundary changes between 1990 and 2005 that had to be handled in our data construction while 39 incumbent cities experienced boundary changes.

We are primarily interested in understanding the way that infrastructure contributes to the ongoing rural to urban migration. Chinese restrictions on internal migration impose larger barriers to population migration from one prefecture to another than from the rural to the urban part of a prefecture. This fact, together with the fact that the set of prefectures corresponds to the set of cities, suggests that the rural portion of prefectures represents the `hinterland' from which prefectural cities

[7] See data appendix for more detail on this.
[8] This approach is driven by the necessity of developing a way to track changes to administrative boundaries over time and the availability of electronic boundary files.

draw a large portion of their migrants.[9] Thus, our analysis will be primarily interested in two geographical units, constant boundary 1990 prefectural cities, the ”central city”, and the surrounding prefecture from which it draws migrants.

It remains to describe infrastructure, population, and economic activity for our panel of prefectural cities and prefectures. We rely on three primary types of data: tabular data from the census and city and provincial yearbooks for 1990, 2000 and 2005; a series of large scale national road maps from 1924, 1962, 1980, 1990, 1999, and 2005; and satellite data describing 1992 land use and land cover along with `lights at night' data for 1992, 2000 and 2005. We also use a digital map of post roads from the mid 18th century, coastline and river maps, data describing the location and size of the walls surrounding ancient Chinese cities, weather station data, and a digital elevation map. The remainder of this section provides more detail.

3.2 Satellite Data

We have six satellite images of China. First is the 1992 land cover data (USGS 1992). For each 1 km square cell in a regular grid covering the whole extent of China, these data report one of about 21 land cover classification codes. In particular, they record whether land is in urban or agricultural use.[10] We use these data to calculate the share of agricultural land in the prefecture and in the central city.

Henderson, Storeygard and Weil (2011) show that lights at night are a good proxy for GDP at the national level. As we will see, this also appears to be the case for smaller units in China. We rely on six `lights at night' images of China (NGDC 1992-2009). These images are for 1992, 2000, 2005, and 2009. Sometimes there is more than one satellite recording lights at night and we have sets of lights data each for 2000 and 2005. Since what is recorded differs slightly by sateliite because of the different characteristics of the satellites' sensors, we utilize the same satellite (F15) in both years. Lights at night data are first processed so that their projection and grid cells align with the 1992 landcover data (USGS 1992). For each cell, these data report an intensity of nighttime lights ranging from 0-63. The codes 0-62 indicate intensity, while 63 is `a topcode'. We note that the topcode occurs very rarely in China (although it is common in western countries).

We first use the 1992 lights at night data to identify the central business district in each central city. To accomplish this, we select the brightest cell in each city. In that this does not lead to single cell, we break ties by summing the total light in successively larger rings surrounding each brightest cell.

[9] Chan (2005) estimates that in the 1990's, about 50% of urbanization in prefectures is transformation of local rural populations into urban ones, 20% is from natural growth of cities and 30% from in-migration of rural populations into cities.

[10] Urban land is code 1, agricultural land is 2-6.

Figure 2a illustrates the resulting CBDs for Beijing and four nearby central cities. White-gray areas show three intensities of light from the 1992 lights at night data and dots identify CBD's. As the figure demonstrates, our algorithm identifies points that `look' like the most central point of the 1992 lights data. In Figure 2b we show lights at night for the same area in 2009. Apart from the fact that lights grow enormously over 17 years, 1992 city centers seem to also serve 2009 well. In Figure 4 below we also see that these points tend be centrally located in the central cities' road networks. As a further check on the location of these CBDs we calculate the corresponding CBD for each of our different lights data sets and find that the location of the CBD is very stable. We also compare the location of our 1992 CBDs with the locations of old walled cities and find that they are almost always within a few kilometers of an old walled city, and if they are not, it is usually because the old walled city is at one sub-center while our calculated CBD is at another.

Having identified the central point of each central city in this way, for each of the four lights at night data layers we next calculate total lights contained in each prefecture, in each central city drawn to 1990 boundaries, and in a 10km disk centered on the central business district.

3.3 Demographic and GDP Data

We build demographic information at the 1990 definition city proper and 2005 definition prefecture level using data from the 1990, 2000 and 2010 Chinese censuses of population. In 1990, we primarily use data aggregated to the city proper, rural county or county city level. We base year 2000 demographic information on a 1% sample of the 2000 census micro data with rural county or urban district identifiers. Our 2010 census data is the 100% count aggregated to urban district and rural unit levels, but it only partially covers the country, encompassing 182 prefectures in our sample.

Information on output is reported for many city propers and some prefectures back to 1990. Because of less complete prefecture level GDP data than city proper data, we make only scant use of prefecture level GDP data. For 1990, we get GDP and industrial sector GDP information from various national and provincial printed data year books. Some of the cities included in these year books were county level cities not yet promoted to prefectural level cities. In 2000 and 2005 we use output information from the University of Michigan's Online China Data Archive at the rural county, county city or city proper levels or printed year books that also break out data to the urban district level for a few cities. Because we do not have a comprehensive source for GDP information disaggregated below the city proper level, we are forced to exclude from our sample some cities that expanded geographically over time when studying effects of transport infrastructure on output. This restriction plus the lack of data availability for some cities in 1990 leaves us with a sample of 203 when examining effects of

transportation on GDP and 186 when examining its effects on industrial sector GDP. For this reason, our use of lights at night as an alternative GDP measure is valuable as its use presents no potential sample selection difficulties.[11]

3.4 Infrastructure

To describe the Chinese road and railroad network, we digitize a series of large scale national road maps. Mechanically, this involves scanning large paper maps, projecting the resulting image, and electronically tracing each of the transportation networks of interest. The resulting tracings are our digital road or railroad maps. We rely on national maps rather than more detailed provincial maps to ensure consistency within a cross-section. To have some consistency across time, to the extent possible, we selected maps from the same publisher drawn using the same projection and with similar legends. However details of what roads are recorded and the definitions of when a road is a " highway" change overtime.

In this way we are able to construct digital maps for railroad and highway networks for each of the following years: 2010 from SinoMaps Press (2010), 2005 from SinoMaps Press (2005); 1999 from Planet Maps press (1999); 1990 from SinoMaps Press (1990); 1980 SinoMaps Press (1982); 1962 from SinoMaps Press (1962), and 1924 by Jiarong Su, published by China's Modern Map Press of Peking University.We also use a map of mid 18th century post roads. This map describes the imperial postal relay system, which connected the capital (Beijing) with the provincial capitals.[12] The left panel of Figure 3 presents an image of Beijing taken from our 2005 map. The right panel shows the resulting electronic map the 2005 railroad and national road network.

With these digital maps in hand, we calculate the total kilometers of each transportation network within each prefecture and each 1990 central city. To measure road capacity in 1999 or 2005, we use the 2 types of highways indicated on the national map whereas for 2010, with its finer classification, we use the top two of 3 categories to capture higher grade express highways. We also use the digital maps to calculate a radial road (or railroad) index, which measures the capacity of a given network to carry traffic outward from the CBD, and ring road (or railroad) index, which measures the capacity of a given network to carry traffic circumferentially around the CBD.

---

[11] Because boundary changes resulted in some rural counties being counted as part of 1990 "city propers", we also need a measure of GDP for these rural counties in 1990. For these few rural counties, we impute GDP using information on value added and agricultural employment.

[12] These routes were plotted (and then digitized) by Tuanhwee Sng on the basis of the description of the routes provided in the Yongzheng edition of the "Collected Statutes of the Qing Dynasty Through Five Reigns". Yongzheng was the 5th of the Qing Dynasty and ruled between 1722-1735.

To calculate our radial road index, for each central city we draw rings of radius 5km and 10km around the CBD. We then count the number of times a particular transportation network crosses each of the two rings. Our index of radial roads is the smaller of these two counts of intersections. Thus, this index measures the number of radial segments a particular network provides, while excluding segments which do not come sufficiently close to the center.

The left panel of figure 4 illustrates this algorithm. In this figure, the green areas represent central cities, the locations of CBDs are given by dots, the 2010 highway network is represented by red lines and the two relevant rings for each city center in black. From the left panel of figure 4, we see that for Beijing and the 2010 highway network, our radial road index is value is 6, which is what one would choose if doing the calculation by eye.

Calculating the ring road index is more involved. Our goal is to generate an index number which reflects the capacity of a particular city road network to move traffic in a circle around the CBD. We proceed quadrant by quadrant. The right panel of figure 4 illustrates the calculation of our ring road index for the 2010 national road network for the Southwest quadrant of 3 cities. To begin for any city, we draw two rays from the CBD, one South and one Southwest (not West). We next restrict attention to intersections which lie between 5 and 10km from the center. In the figure, these are areas bounded by the two black circles. We next identify all intersections of each ray with the road network within the rings. In this case, for Beijing there is one each. The southwest quadrant ring road index for the 5 to 10 km ring is the minimum of these two counts of intersections, which is still one each. For the other cities shown the minimum is zero. To finish our calculation of the ring road index in the 5 km to 10 km annulus centered on the CBD, we replicate this calculation for each of the four quadrants and sum the resulting quadrant by quadrant index numbers. Thus, a one unit increment in this index reflects a single road traveling about 90 degrees around the center while remaining between 5 and 10km from the center. We replicate this calculation for roads that lie between 10 and 15 km from the CBD and 15-25 km from the CBD. For the empirical work, we sum the results of these three calculations and restrict attention only to roads which lie outside the central city. Intersections between the rays and the road network which occur nearer to the CBD than 5km are not counted as contributing to the network's ring road capacity. As a practical matter, such intersections are almost always generated by radial roads.

3.4 Supplemental data sources and summary statistics

We also use several supplemental data sources. We use a digital elevation map with 90m sq. resolution to calculate the range in elevation in each prefectural city and prefecture. We also use the digital elevation map to calculate an index of the roughness of the topography in these units. [13]

To calculate coastline and river distance, we calculate the distance from the CBD of each city to the nearest point on the Chinese coastline. To determine the location of the coastline we use an extract from the ESRI world oceans file. To calculate river distance, we calculate the distance from each CBD to the nearest major river. [14]

To construct climate data, we obtain weather station data for each of 194 Chinese weather stations over the period 1971 to 2000 and construct yearly averages or totals from these data. With this done, each prefectural city is assigned the climate associated with the weather station nearest to its CBD. [15] Summary statistics for most variables used in the analysis are reported in Table A1.

4. Empirical strategy

4.1 Econometric model

Our goal is to determine how the configuration and extent of the railroad and road networks affect the population level and the level of economic activity within constant boundary central cities. We begin by conceptualizing a static economic model that describes the allocation of economic activity across space within a prefecture as in Mills (1967). In such a model, we take the prefecture level of economic activity as given and are interested in understanding transportation's role in determining its allocation between the central city and suburban regions, whose spatial configurations are determined by our data. Define y_{tA} to be the outcome variable of interest, typically population or a measure of economic activity, t takes the values 1990, 2000, 2005 or 2010 and indexes the different time periods in our study while A indexes administrative units, prefecture "p" and central city "c". We denote vectors of control variables by $\mathbf{x}$ and use the same subscript convention.

---

[13] Let y be the elevation of the subject pixel and x_1 to x_8 the elevations for the eight adjacent pixels. For each y in a given jurisdiction we calculate $r(y) = \sqrt{\sum_{i=1}^{8}(y - x_i)^2}$. Our roughness index is the mean of $r(y)$ over all pixels in the jurisdiction. This index, which is similar to the mean standard deviation in elevation between each pixel and its neighbors is used in Burchfield et al (2006) and in was developed in Riley et al. (2006). This index provides an intuitive index of roughness and is particularly simple to calculate with GIS software.

[14] Our map of Chinese rivers is downloaded from the China Earthquake Geospatial Research Portal at *http://cegrp.cga.harvard.edu/data.* Our map reports four different classes of river and is produced by the China National Fundamental GIS. We use only the largest rivers of the four types reported.

[15] China Meteorological Data Sharing Service System, URL: http://cdc.cma.gov.cn/.

Our data describes the road and railroad network in each of several years. For each year and network we calculate three measures, total km, radial road index and ring road index. Let r_{tA} denote one such measure of roads. As before, the subscript t indicates the year of the network and, if necessary, the subscript A indicates the spatial extent for which the measure is calculated, prefecture or central city. To describe a vector of network measures we use $\mathbf{r}$.

We will usually be interested in first differences of our variables, and to denote this we use the symbol Δ_t where 1990 is always taken as the base year and t indicates the terminal year. Thus, $\Delta_{2000} y_p$ denotes $y_{2000,p} - y_{1990,p}$, the change from 1990 to 2000 in outcome variable y measured at the prefecture level.

One simple way to try to estimate the effect of transportation infrastructure on urban density would be the following `levels' equation,

(1) $$\ln y_{tC} = A_0 + A_1 \mathbf{r}_{tA} + A_2 \ln y_{tP} + B_0 \mathbf{x}_t + \delta + \varepsilon_t,$$

where δ and ε_t represent unobserved constant and time varying prefecture specific variables that determine central city population. If y is population for example, then this estimation predicts central city population as a function the infrastructure variables of interest, total prefectural population, and additional controls that would include additional factors that may influence y and be correlated with r. Inclusion of the control ln y_{tP} is central to our analysis. With this control included, the coefficient of interest A_1 indicates the percentage of central city economic activity displaced to prefecture remainders for each additional unit of transport infrastructure. Without the control for ln y_{tP}, we would not be able to differentiate whether the estimated relationship between ln y_{tC} and transportation infrastructure comes through additions to the whole economy or displacement within or across prefectures.

A necessary condition for estimates of equation (1) to provide estimates of the casual effect of infrastructure on density is that our infrastructure variables be conditionally uncorrelated with the two error terms. That is, $Cov(\mathbf{r}, \delta + \varepsilon \mid .) = 0$. This condition is unlikely to hold. In particular, we are concerned that historically productive or attractive city centers will be allocated more roads. In this case, the coefficient of the infrastructure reflects this unobserved attractiveness rather than a causal effect of infrastructure.

As a first response to this problem, we take first differences. This gives,

(2) $$\Delta_t \ln y_C = A_0 + A_1 \Delta_t \mathbf{r}_A + A_2 \Delta_t \ln y_P + B_0 \Delta_t \mathbf{x} + \Delta_t \varepsilon \ .$$

By taking first differences, we remove time invariant components of the error term. This means that the necessary condition for estimates of equation (2) to provide estimates of a casual effect of infrastructure on density is that our infrastructure measures be conditionally uncorrelated with the remaining error terms. That is, that

(3) $$Cov(\Delta_t \mathbf{r}, \Delta_t \varepsilon \mid .) = 0 .$$

This condition is arguably weaker than the corresponding condition for the levels equation.

A number of comments about this equation are in order. First, while our 1990, 1999, 2005 and 2010 measures of roads are nominally the same, there is in fact very little resemblance between a highway in 2010 and a `national road' we call a highway in 1990. In particular, any 1990 highway near a major city was almost universally a two-lane road. If this 1990 road is recorded as a highway in 2010, it would either have been subject to substantial widening and improvement over our study period or an entirely new highway would be built alongside the old road. Thus, we hope to more accurately measure the change in highways over our study period by treating the initial stock as zero rather than as the quantity we record on our maps. Thus, for measures of the road network, our measure of changes to the road network is simply its level at t. For railroad networks, quality changed less during our study period and we will use a different approach detailed below.

Second, the error term in equation (3) consists only of time varying shocks. Thus, it is important to include time varying controls. However, in some specifications we also include as level control variables that describe some city and prefecture characteristics in 1990. While none of these variables is time varying, and hence should drop out of our first difference equation, we include them because they may predict time varying shocks, e.g., flat central cities grow faster than bumpy ones or as discussed below central cities with bigger surrounding agricultural populations in 1990 have more migrants to draw upon. .

This leaves us with,

(4) $$\Delta_t \ln y_C = A_0 + A_1 \Delta_t \mathbf{r}_A + A_2 \Delta_t \ln y_P + B_0 \Delta_t \mathbf{x} + B_1 \mathbf{x}_{1990} + \Delta_t \varepsilon \;.$$

where we typically take the 1990 level of road variables to be zero as noted above.

We are concerned that our infrastructure variables are endogenous in this equation. That is, there are likely to be unobservables correlated with changes in transport that affect changes in the outcome of interest. For example cities that are centralizing more because they are drawing in migrants due to good economic shocks may have more road construction. To resolve this potential problem, we rely on instrumental variables estimation. In particular, we require variables, which satisfy

(5) $Cov(\mathbf{z}, \Delta_t \mathbf{r}_A \mid \Delta_t \mathbf{x}, \mathbf{x}_{1990}, \Delta_t \ln y_P) \neq 0.$ and $Cov(\mathbf{z}, \Delta_t \varepsilon \mid \Delta_t \mathbf{x}, \mathbf{x}_{1990}, \Delta_t \ln y_P) = 0$

That is, conditional on controls, we require variables which predict our endogenous variables but are otherwise uncorrelated with the error term in our structural equation.

Given such variables, and letting $\bar{\mathbf{r}}_A$ denote the first stage predicted value of $\mathbf{r}_A$, we can estimate the system of equations

(6) $\Delta_t \ln y_C = A_0 + A_1 \Delta_t \bar{\mathbf{r}}_A + A_2 \Delta_t \ln y_P + B_0 \Delta_t \mathbf{x} + B_1 \mathbf{x}_{1990} + \Delta_t \varepsilon$.

$$\Delta_t \mathbf{r}_A = C_0 + C_1 \Delta_t \ln y_P + C_2 \Delta_t \mathbf{x} + C_3 \mathbf{x}_{1990} + C_4 \mathbf{z}_t + \mu.$$

to obtain estimates of the causal effect of transportation infrastructure on central city density. This is essentially the same estimation strategy as is conducted in Baum-Snow (2007).

The estimation strategy given in (6), which uses historical transport data as IVs, is the primary method we use to estimate the effect of highways on Chinese urban decentralization. However, our examination of railways suffers from the limitation that the first condition in (5) is not satisfied. That is, the railways built after 1990 are not well predicted by earlier railroad infrastructure. Therefore, we are forced to resort to measuring railroad capacity as its initial level r_A rather than its change over time. As is discussed in more detail in the following sub-section, this is not a serious limitation given the heavy level of state control still in force on location patterns as of 1990.

One remaining consideration that presents itself as potentially important when utilizing an IV estimation strategy is the potential existence of heterogeneous treatment effects (Angrist & Imbens, 1994). We emphasize that our IV estimates of the effects of transport infrastructure are identified essentially from comparing outcomes in locations that received more infrastructure to less infrastructure because they had more predicted infrastructure based from the 1962 network, conditional on control variables. Ideally, the prefectures that provide identification are representative of the full population of prefectures, and therefore our estimated treatment effects are close to the average treatment effect for China overall.

4.2 Instrument validity

Our estimation strategy hinges on finding variables that only affect outcomes of interest through their shaping of recent transport networks conditional on appropriate control variables, satisfying condition (5). We follow Duranton and Turner (2011a,b) by relying on historical transportation networks to predict modern networks. To be valid instruments, such historical variables must not predict recent central city growth except through their influences on the location and configuration of the modern

transport network conditional on control variables. This means that instruments cannot be correlated with unobserved variables that themselves influence the post-1990 evolution of central city economies.

We have historical transport network data for 1980, 1962, 1924, and 1700. For each of these historical networks we construct ring and radial road indices and measure the extent of the network for each city. We first investigate the ability of these historical variables to predict their modern counterparts, e.g., 1962 rays to predict 1999 rays. Overall, we find that the 1962 road measures are good predictors of their modern counterparts, but that the earlier networks are not. While modern networks clearly follow routes laid out by the 1700 and 1924 networks, these networks are not extensive enough to predict the modern networks in a statistical sense.

Determining the set of appropriate control variables requires understanding the processes by which the 1962 transport networks were established and how these processes could relate to modern forces driving changes in urban form. For roads, one of the hallmarks of Sino-Soviet planning was to minimize commuting. The housing stock was nationalized during this 1950s and urban residents lived increasingly adjacent to their work locations. Because little commuting occurred as of 1962, the road transport network was oriented almost entirely toward the movement of goods. However, because the little long-distance trade within the country that existed in 1962 moved almost exclusively by rail, there was little need for long distance roads. Most roads were local, with construction decisions made locally. Therefore, the vintage 1962 road network generally consisted of unimproved roads connecting rural farming regions to nearby cities. Indeed, there were almost no paved roads in 1962 and only about half of roads were passable in rainy weather (Lyons, 1985).

While we do not have systematic information on anything except transport infrastructure from before 1990, the relative population, and particularly agricultural population of regions changed little as there was very little migration before 1990. Therefore, relating 1962 rays to 1990 observables is informative about some of the processes generating 1962 infrastructure. A regression of 1962 road rays on various 1990 observables reveals that agricultural population in the prefecture is a good predictor of the number of roads serving the prefectural level city. 1990 city population, prefecture area and being located in the West are also positively associated with the number of 1962 road rays. Conditional on these variables, larger area cities received fewer road rays.

The highway system built after 1990 is designed to serve a modern economy in cities where work and living places are separated and commuting is a major consideration. Given reasonable controls for the propensity of central cities to grow during our study period, it is therefore likely that 1962 transportation networks affect the growth of modern cities only through their affect on the

modern road network. However, it is important to appropriately control for any variables that are correlated with 1962 road rays and may cause changes in urban form.

Chinese inter-city transportation networks up until 1962 consisted largely of railroads, more than two-thirds of which were built before the PRC was established in 1949. Major trunk lines constructed in the early 20^{th} century ran north-south, and helped to link key political and commercial centers. Russian and later Japanese investment financed a major expansion in Manchuria (northeast China), which facilitated the extraction and export of agricultural goods and raw materials, and later helped to linking emerging industrial centers, e.g. Shenyang, Changchun, with China proper. In the Maoist era railway construction decisions were centralized. Much of the investment after 1949 but before 1962 built under Soviet influence extended rail coverage to western China, to connect resource rich regions of the West with manufacturing centers in the East. After 1964 the "Third Front" policy to move military and other strategic production to the Sichuan area resulted in 5 additional strategic rail lines. For our key year, 1962, because most railways had been built in prior decades for long distance shipping of raw materials to fuel industrialization efforts that almost exclusively occurred in cities, manufacturing centers in particular had a lot of railway infrastructure in 1962. Because there was very limited trade between provinces, provincial capitals were the most important trade nodes and therefore received a lot of railways. Indeed, a regression of 1962 rail rays on 1990 observables reveals that while agricultural employment is not a good predictor of railroads, a provincial capital indicator is. As may be expected, other significant predictors of roads also hold for rails except the West region indicator. Overall, rails were constructed to serve the interests of colonial powers, Soviet advisors, and the designs of Chinese Central planners. It is at least plausible that much of the rail network was constructed without regard to its impact on the spatial organization of cities during the decades that followed the market reforms of the late 1980s.

Our analysis in the following section uses road and rail transport variables measured as of different years. In particular, we use road measures as of the year at the end of the sample period and railway measures as of 1990 for the following reasons. As noted above, in 1990 there existed no modern highways whatsoever in China. The highways that were subsequently built often followed the same rights of way as existing roads. Therefore, roads in 1962 have good predictive power for changes in highway road capacity experienced by cities between 1990 and later years. However, most of the railways that existed in 2010 had been built by 1990. Furthermore, our data do not distinguish track quality. Because the few railways that were built since 1990 represented new capacity, the 1962 network is not a good predictor of the change in rail capacity between 1990 and the end of our study

period. Because of this instrument validity problem, we are forced to measure railroads as a level rather than a change. We focus on the 1990 level rather than the level at the end of the sample period because we expect changes in urban form to respond to existing rather than future infrastructure.

Another way of thinking of this is that in 1990, there was still very little freedom of movement of people or employment facilities within prefectures; there was little commuting or separation of living and workplaces; and no type of land market existed. Excepting a few development regions, housing, factory, and even farm location patterns within areas defined as urban were largely unchanged since the 1960s. Only after 1990 with the freeing up of urban land and labor markets was there much opportunity for urban form to change in response to market forces. If the highways that existed in 2010 were in place in 1990, they could not have been used for commuting or to motivate the movement of factories. But once reform was in place, we would see the responses we see in the regressions. Correspondingly, for rails, we are asking the extent to which the level of rail transport infrastructure as of 1990 potentially shaped the changes documented in Table 1. That is, our estimates of the effects on changes in outcomes between 1990 and later periods from the initial level of rail infrastructure come in the context of an environment in which such change was largely not possible prior to 1990. Because of this unique context, we see our analysis of the effects of highway construction between 1990 and later years on changes in urban form as analogous and comparable to our investigation of the effects of railroad levels in 1990.

Table 2 presents first stage results for the four transport network measures we use in our primary analysis. In all cases, we instrument for a recent transport network variable with its analog built from the 1962 network. Evidence in Table 2 indicates that our instruments are individually strong conditional on a standard set of control variables. Therefore, there is useful available variation in the instruments that can be used to help identify effects of transportation networks in later years. Each 1962 road ray predicts 0.37 of a 2010 ray and 0.32 of a 2000 ray. Each 1962 railway ray predicts 0.71 railway rays in 1990. Finally, each 1962 ring road predicts 0.43 of a ring road in 1999. Main coefficients on road infrastructure variables change by less than 0.02 if additional regressors including 1990 prefecture or city proper population, region, land cover and weather variables are added to the regression. The coefficient on 1962 rail rays in column (3) declines from 0.71 to 0.65 with these additional controls.

5. Results

5.1 Effects on population

In investigating the effects of transport infrastructure on population decentralization, we first focus on highway rays as a predictor since this transport measure has been most widely studied in other contexts. We then expand our analysis to other elements of urban transport networks.

Table 3 reports baseline estimates of the empirical relationship between highway rays and 1990 central city population. Table 3 reports first difference OLS regression results - estimates of parameters in Equation (4). In column 1 we use only our 2010 radial road index as an explanatory variable for the change in log central city population between 1990 and 2010. Our 2010 radial road index is a measure of radial highway capacity of which there was none in 1990, and thus can be thought of as a change rather than a level. In column two we include various additional control variables. Columns 3 and 4 report analogous regressions examining changes between 1990 and 2000 using a more complete sample of prefectures.

Regardless of specification, estimated OLS coefficients on the highway rays variable is generally near 0. Adding one radial road to a city is associated with a 1 log point increase in central city population from 1990 to 2000 but a 2 log point decline in central city population between 1990 and 2010. Coefficients on highway rays in Column 2 and Column 4 change by less than 0.003 when additional control variables for region, land cover, location and weather are also included in regressions. However, there are reasons to believe that OLS is likely to be biased. There are many variables correlated with rays that are likely to also generate changes in city population. For example, more robustly growing cities may generate more rapid increases in demand for roads which then may get built to fulfill this demand. This story implies a positive relationship between roads and central city population that is not causal. One potential explanation for the different sign coefficients in Columns 2 and 4 is that cities receiving new highways during the 1990s were the ones growing the quickest, whereas the new highways built after 1999 were of lower priority. It should also be noted, however, that our measure of road rays in 2010 is based on a higher quality of highways than the 1999 measure.

Our choice of control variables in Columns (2) and (4) has two motivations. Controls for prefecture and central city areas and the change in log prefecture population can be motivated by a standard closed city static land use model in which we are interested in measuring the population within

some exogenously defined region, the “central city”.[16]

Column (1) would represent a consistent estimate of the average causal effect of highway rays on central city population, with additional control variables only serving to reduce estimated standard errors.

In Column 4 we additionally control for region, resulting in a change in the coefficient of interest from -0.63 to -0.042. To understand why this coefficient decreases in absolute value, it is useful to examine estimated IV relationships between highway rays and central city population for the West and the remainder of China separately. A regression analogous to Column (4) but in which West is interacted with the treatment yields a coefficient of 0.064 (se=0.037) for the West region and -0.070 (0.024) for the remainder of the country. The estimate in Column 4 reflects a weighted average of these two very different effects. Leaving out the region indicator variables allows for identification to come from comparisons of cities across regions, which is more global. Given the small sample size of 182, and the fact that inclusion of region does not matter for the full sample over the 1990-2000 period (because of a large standard error on within-West results), we choose to exclude region from our base specification.

Columns 5 and 6 examine the 1990-2000 time period using the same smaller sample of 182 prefectures. These estimates are a bit higher than over the longer time period, potentially indicating that highways built first had greater effects on central city population than subsequent highways. Columns 7 and 8 use the broader sample of 264 prefectures for the same regressions, yielding somewhat smaller estimates of -0.047 using our preferred specification and -0.041 using a saturated specification. Both of these estimates are highly statistically significant. Because of the relatively high standard errors on estimates using the more constrained sample, the coefficient on rays in Column 5 is not statistically distinguishable from that in Column 7, nor are the coefficients in columns 6 and 8 distinguishable from each other.

Consistent with evidence for the U.S. in Baum-Snow (2007) and Duranton and Turner (2011b), differences between OLS and IV results suggest that our 1999 radial roads index is endogenous. In particular, while more roads were built in cities with more rapidly growing populations (relative to their surrounding prefectures), these roads were themselves causing this population to decentralize. While we do not discuss OLS estimates for other transport measures or outcomes, all significant IV estimates discussed below are in all cases negative and of larger magnitudes than analogous OLS estimates. This indicates that while more rapidly growing Chinese cities, however growth is measured, received more transport infrastructure of various types, the decentralization that occurred because of this infrastructure is swamped by the growth that led to much of this infrastructure being built in the first

place. That is, the use of pseudo-random variation from the 1962 network is absolutely essential to understand the true causal effects of these transport improvements on the spatial organization of economic activity within cities.

We now examine the effects of other types of transport infrastructure on central city population growth. Excluded from the list are ring roads which we analyze separately later and do have strong effects. Beyond the possibility that other transport measures may be important in addition to radial highways, we wish to evaluate whether other transport measures that are potentially correlated with radial highways (both in 1962 and today) drive the estimates reported in Table 4. Table 5 presents IV regressions using our base specification with the addition of one different additional transport measure beyond radial highway rays in each column. Because of weak instruments difficulties, we could not credibly include more than two transport measures at once in a single regression.

Coefficients on highway rays reported on the top two rows of Table 5 are all well within the standard error bands of estimates reported in Table 4. Furthermore, none of the other transport measures included have significant coefficients. Conditional on the number of radial highways, neither the length of the highway system, the number of radial railways nor the length of the railway system have significant effects on central city population. Whatever is the mass of roads and rails in the city, it is the radial system that is relevant to decentralization.

5.2 Effects on Output

Table 6 investigates the importance of road and rail infrastructure on the decentralization of other measures of economic activity between 1990 and 2005. Columns 1-3 examine GDP, columns 4-6 examine the industrial component of GDP only and columns 7-9 examine lights at nights. Sample sizes differ across outcomes because of limited data availability of the two GDP measures, with the lights at night representing output for the same complete sample used for the final columns of Tables 2, 3 and 4. In these regressions, we use the same set of controls as in Table 4 Column 7 with the addition of the change in log lights at night between 1992 and 2005 at the prefecture level. This variable is intended to capture the overall growth rate of output in the prefecture. We use this lights measure rather than GDP at the prefecture level or the change in prefecture population because we have very thin prefecture level data on GDP in 1990 and no reliable population data for 2005.

Whether examining GDP, industrial output or lights, results in Columns 1, 4 and 7 show that roads had essentially 0 estimated effects on central city economic activity. However, we find that each railway ray is estimated to displace 13 percent of central city GDP, 20 percent of central city industrial

output, and 3 percent of central city lights to prefecture remainders.[18] This importance for railways is also evident when they are measured as km in the prefecture instead. Attempts to jointly estimate effects of rail rays and rail km yields negative estimated coefficients on both variables with high standard errors. These two variables are too highly correlated for the data to allow us to separately identify different effects for each. Conceptually, as cities grew economically at a rapid pace between 1990 and 2005, if that growth occurred in a city with a denser radial rail network that presented more opportunity for production to decentralize to the ex-urban ring where land and labor where cheaper and still have access to rail sidings essential for shipping of goods.

One important lesson from comparing Tables 4 and 6 is that while roads matter for the location of people, railways matter for the location of goods production. The fact that the estimated effect of rail rays on industrial sector GDP is 54 percent higher than for GDP overall is evidence that the industrial sector is primarily driving the estimated effects on GDP. Indeed, industrial GDP represents about 50% of total GDP nationally.

5.3 Ring Roads and Network Design

We now further look into the impacts of different transport network configurations. In particular, we examine how ring roads potentially interact with other elements of the urban transportation system to generate decentralization.

Table 7 reports regressions using our base specification and other transport variables with significant estimated effects from Tables 3-5 plus a ring road measure. Our measure of ring roads is a simple 0/1 dummy variable indicating if the city had a ring road at the end of the sample period. Columns 1-3 examine population decentralization, Columns 4-6 examine GDP decentralization and Columns 7-9 examine industrial sector GDP decentralization.

Each regression in Table 7 except one shows large significant estimated negative effects of the existence of a ring road on central city economic activity. The change in population between 1990 and 2010 outcome, shown in Column 1, is the exception. These significant effects of ring roads come in addition to persistent separate effects of highway rays on population 1990-2000 and railway rays on log GDP and industrial GDP 1990-2005.[19] Each ring road is estimated to cause central city population to be 24 percent lower, central city GDP to be 0.57 log points lower, and industrial GDP to be an enormous 1.00 log points lower. One caveat is that somewhat weak first stages mean that reported standard

[18] Using the smaller sample of 186 prefectures for which we have valid industrial sector GDP data, the estimated effect of each railway ray on GDP is -0.12 rather than -0.13.

[19] We do not have sufficient variation in the data to additionally estimate coefficients on interaction terms between ring road and other transport measures.

errors are likely understated. Greater estimated effects for GDP than population fits with the classic story of U.S. urban development in which highways facilitated the decentralization of manufacturing to urban peripheries with low shipping costs at highway interchanges.

5.4 Public transport

We were able to collect data for 2005 and 2008 on the number of buses and trolleys in use in central cities in 2005. We have no way to convert this to data just for the 1990 city proper in each prefecture, which has been the area on which we have focused, so there are measurement issues with the variable. Since this is an endogenous variable there was also the issue of how to instrument for it. We use the employee base in the transport service sector in the 1990 city proper, as a political commitment from the pre-urban-reform era. Despite the obvious limitations of the exercise, it seems worthwhile to look at this key measure of commitment to public transport. Results are in Table 8, looking at decentralization of population for 1990-2010 as a function of road rays in 2010 and the log of the number of buses and trolleys in 2008. The IV results suggests that an elasticity of .05 for the effect of buses and trolleys on central city populations. This supports the notion that public transport contributes to urban compactness, counteracting road infrastructure that pushes the population to suburbanize.

6. Conclusions

References

Angrist, Joshua & Guido Imbens, Identification and Estimation of Local Average Treatment Effects, *Econometrica*, 1994, 62(2):467-475

Au, C.C. and J.V. Henderson, How Migration Restrictions Limit Agglomeration and Productivity in China, *Journal of Economic Development*, 2006, 80, 350-388.

Au, C.C. and J.V. Henderson, Are Chinese Cities Too Small, *Review of Economic Studies*, 2006, 73, 549-576.

Baum-Snow, Nathaniel. 2007. Did highways cause suburbanization? *Quarterly Journal of Economics* 122(2):775–805.

Chan, Kam Wing. (2005) " Migration and Small Town Development: Some Notes" , World Bank workshop, Beijing, June.

Chandra, Amitabh and Eric Thompson. 2000. Does public infrastructure affect economic activity? Evidence from the rural interstate highway system. *Regional Science and Urban Economics* 30(4):457–490.

Cheung, Kin Tai, Wen-Tai Hsu and Hongliang Zhang 2011. The Fundamental Law of Highway Congestion: Evidence from Japanese Expressways, Processed Chinese University of Hong Kong.

China Center for Automotive and Technical Research, Zhongguo chiche gungye nianjian (China Automotive Industry Yearbook), Beijing: Beijing Hualian Publishing Company, miscellaneous years.

Donaldson, David. 2010. Railroads of the Raj: Estimating the Impact of Transportation Infrastructure. manuscript.

Duranton G. and D Puga. 2001. "Nursery Cities: Urban Diversity, Process Innovation, and the Life Cycle of Products, " *American Economic Review,* 91, 1454-1477

Duranton, Gilles, Peter M. Morrow, and Matthew A. Turner. 2011. Roads and trade: Evidence from US cities. Processed, University of Toronto.

Duranton, Gilles and Matthew A. Turner. 2011a. The fundamental law of road congestion: Evidence from US cities. *American Economic Review* 101(forthcoming).

Duranton, Gilles and Matthew A. Turner. 2011b. Urban growth and transportation. Processed, University of Toronto.

Deng, Xiangzheng, Jikun Huang, Scott Rozelle and Emi Uchida (2008). Growth, population and industrialization, and urban land expansion of China, *Journal of Urban Economics* 63: 96–115.

Faber, Benjamin, 2009. Integration and the Periphery: The Unintended Effects of New Highways in a Developing Country, Processed LSE

Fernald, John G. 1999. Roads to prosperity? Assessing the link between public capital and productivity. *American Economic Review* 89(3):619–638.

Heckman, James J., Sergio Urzua and Edward J. Vytlacil. 2006. Understanding Instrumental Variables in Models With Essential Heterogeneity. *Review of Economics and Statistics* 88(3):389-432.

Hanson E.R. 1987. "Industrial Location choice in Sao Paulo" *Regional Science and Urban Economics*, 17, 89-108.

Henderson J.V. A. Kuncoro, and D, Nasution. 1996 "The Dynamics of Jabotabek Development," *Bulletin of Indonesian Economic Studies*

Henderson, J. V., Adam Storeygard and David Weil, 2011 "Measuring Economic Growth from Outer Space", *American Economic Review*, forthcoming

Jacobs, J. 1969. *The Economy of Cities*, Random House: Toronto

Kahn, M.E. 2006. *Green Cities*, Brookings Institute; Washington

Kolko J 2000. *Essays on information technology, Cities and Location Choice,* PhD thesis Harvard University

Lee, K.S. 1982. “A model of itra-industry employment location: an application to Bogota Columbia” *Journal of Urban Economics*, 12, 263-279

Lee K.S. and S.-C. Choe, 1990 “Changing location patterns of industries and urban decentralization policies in Korea”. In: J. K. Kwon, Editor, *Korean Economic Development*, Greenwood, New York.
Lucas, R.E. 1988. “On the mechanics of economic development,” *Journal of Monetary Economics*, 22, 3-42

Lucas R.E and E. Rossi-Hansberg. 2004. “On the Internal structure of cities,” *Econometrica,* 70, 1445-1476

Lyons, 1985. Transportation in Chinese Development, 1952-1982. *Journal of Developing Areas* 19(2):305-328.

Marshall, A. 1890 *Principles of Economic,* MacMillan: London

Michaels, Guy. 2008. The effect of trade on the demand for skill Evidence from the Interstate Highway System. *Review of Economics and Statistics* 90(4):683–701.

National Geophysical Data Center, 4 DMSP-OLS Nighttime Lights Time Series, 1992-2005.

Planet Map Press , *Map of the Peoples Republic of China*, scale 1:6000000, as of Jan 1999, publication March 1999, Peoples Liberation Army, Factory 1206, distributed by Xinhua bookstore.

Riley, Shawn J., Stephen D. DeGloria, and Robert Elliot, “A Terrain Ruggedness Index that Quantifies Topographic Heterogeneity,” *Intermountain Journal of Sciences,* (1999), 23–27.

SinoMaps press, Map of the Peoples Republic of China, scale 1:4000000, as of 1980, publication date October 1982, Shanxi, Zhong guo di zhi tu zhi yin chang.

SinoMaps press, *Map of the Peoples Republic of China*, scale 1:4000000, as of August 1990, publication date August 1990, Hebei, Zhong guo di zhi tu zhi yin chang

SinoMaps press, *Map of the Peoples Republic of China*, scale 1:4500000, as of March 2005, published June 2006, Peoples Liberation Army, Factory 1206, distributed by Xinhua bookstore.

SinoMaps press, *Map of the Peoples Republic of China*, scale 1:4500000, as of Jan 2010, published Jan 2010, Peoples Liberation Army, Factory 1206, distributed by Xinhua bookstore.

Swartz, A 1992 “Corporate service linkages in large metropolitan areas,” *Urban Affairs Quarterly*, 28, 276-296

United States Geological Survey, Global Land Cover Characterization, Eurasia version2, 1992.

World Bank. 2002. *Cities on the Move* , World Bank Publications

Zhu, J. 2004. “From Land Use Right to Land Development Right.” *Urban Studies,* 1249-1269.

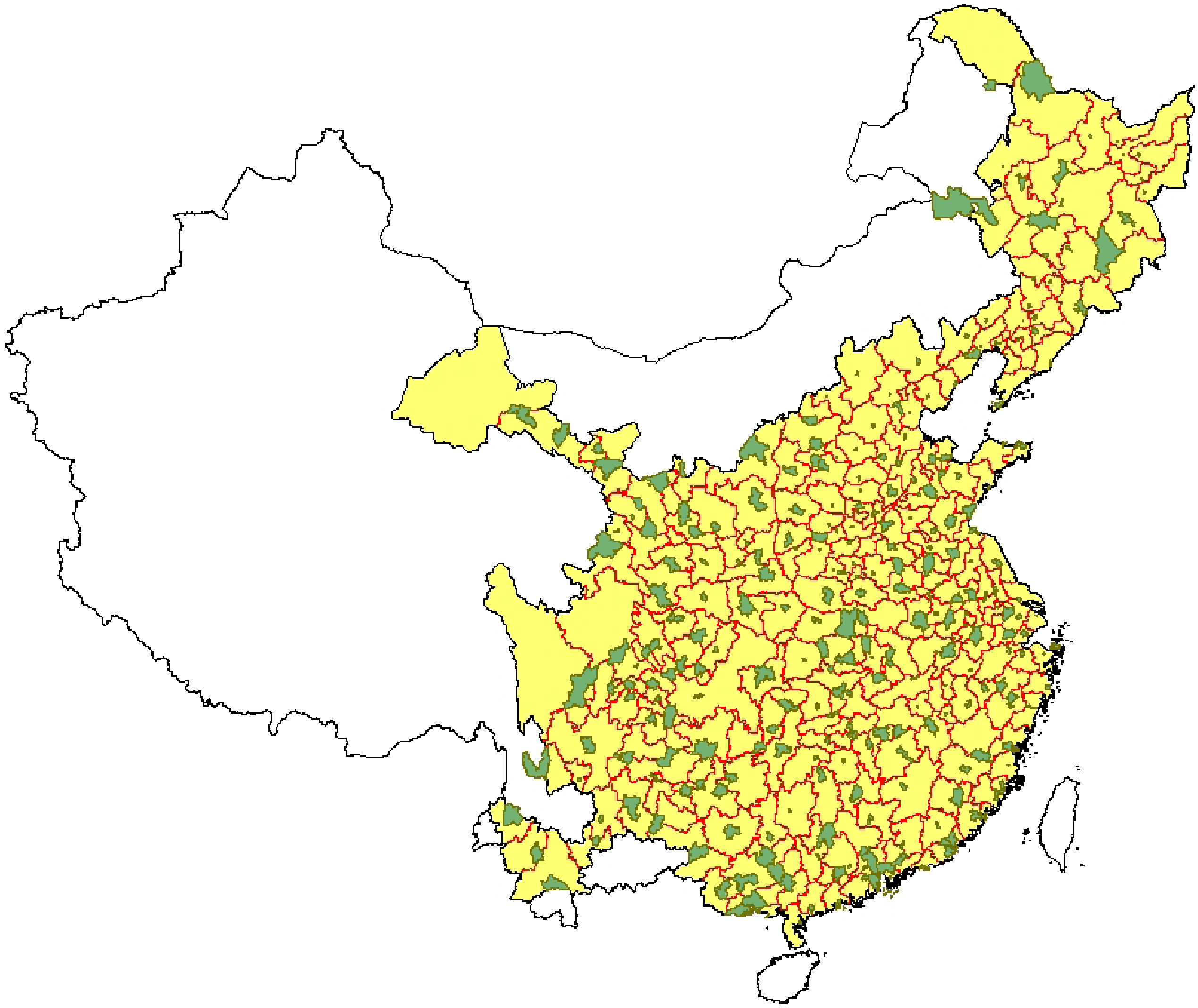

Figure 1a: Study area. The yellow area includes the prefectures included in our study. Red lines indicate prefecture boundaries. Green indicates the extent of constant boundary 1990 prefectural cities.

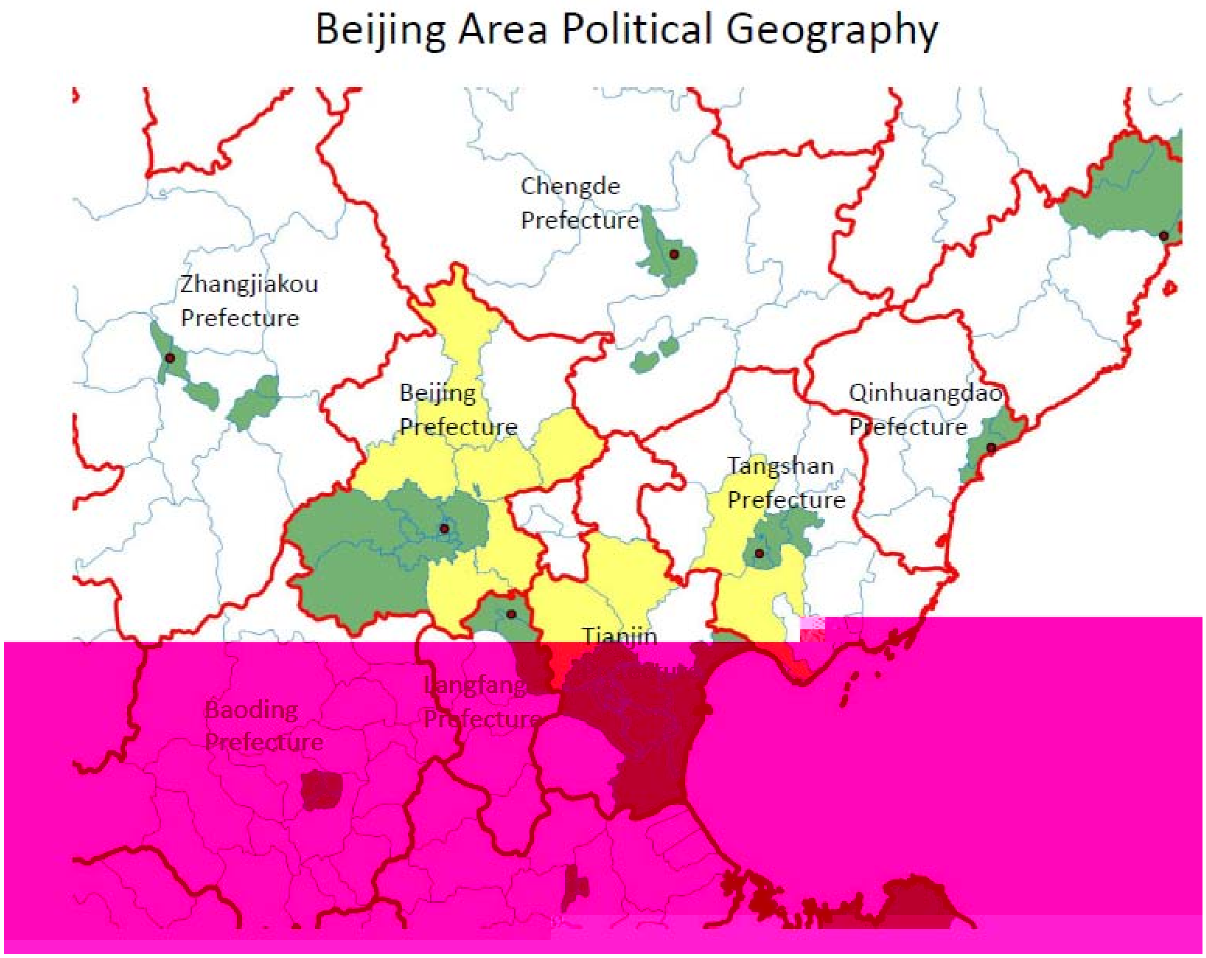

Figure 1b: Beijing and surrounding prefectures. Counties and prefectures are drawn based on 2005 boundaries for each. The green counties make up the 1990 city prefecture city, the central city. The yellow counties are counties converted to urban districts after 1990. The dots are the city centers, the locations of which are discussed later.

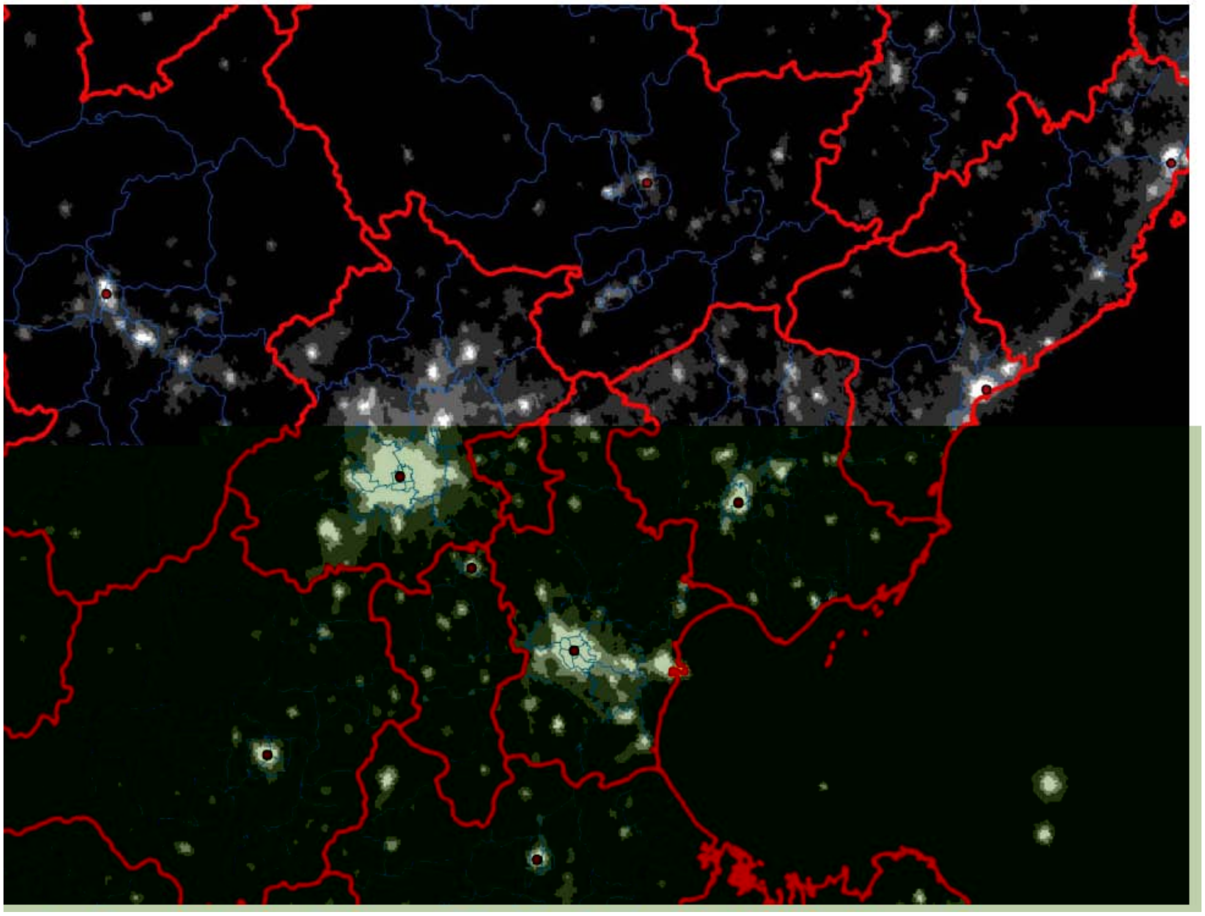

Figure 2a. Boundaries, lights and CBDs in 1992. For the map in Figure 1b, we show lights at nights in 1992 with white to grey shading showing three intensity bands. Red dots circled in black indicate the location of the city center.

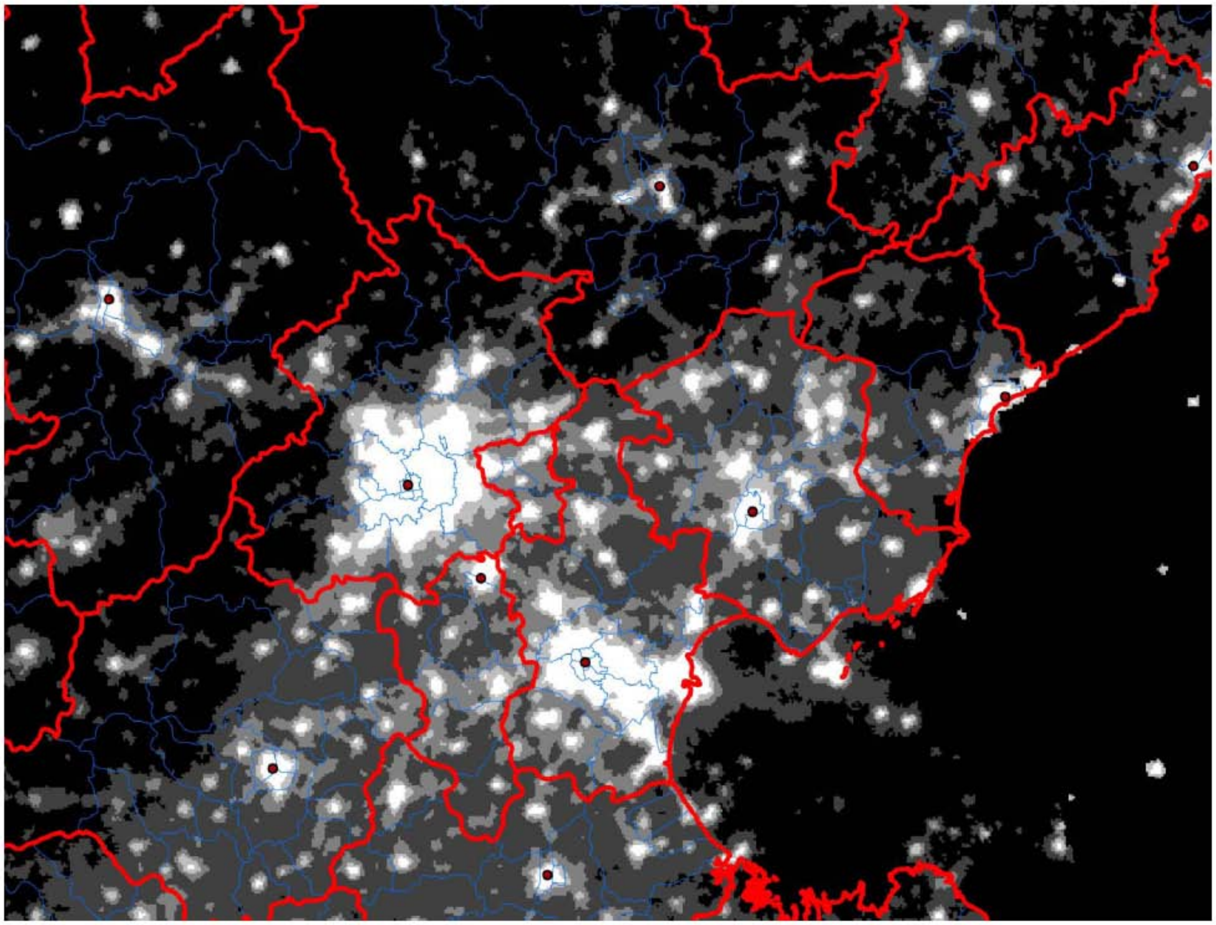

Figure 2b. Lights in 2009

Figure 3: Geocoding maps. The right panel shows and image of Beijing taken from our 2010 national map of China, with area outside of Beijing shaded dark. The right panel shows the resulting digital map. Green indicates the extent of the province of Beijing, tan the extent of the 1990 central city, hatched lines the 2005 railroad line, and solid lines the 2005 national road network with 2 grades of highways (black versus color).

Figure 4: Illustration of radial and ring road index algorithms for 2010 roads. The panels illustrate the calculation of our radial and ring road indices for the Beijing region. Roads are in red. The calculations are detailed in the text.

Table 1: Growth in Lights and Population, 1990-2010

	City Proper		Prefecture Remainder	
Panel A: 2010 Sample of 182 Prefectures				
	Lights	Population	Lights	Population
1990-2000	56%	29%	101%	6%
2000-2010	32%	21%	37%	-1%
1990-2010	106%	56%	174%	5%
Panel B: 2000 Sample of 264 Prefectures				
	Lights	Population	Lights	Population
1990-2000	52%	27%	95%	6%
2000-2010	33%	NA	36%	NA
1990-2010	102%	NA	165%	NA
Panel C: Sample of 108 Prefectures With GDP Data				
	GDP	Industrial GDP	GDP	Industrial GDP
1990-2000	187%	141%	297%	351%
2000-2005	119%	113%	73%	94%
1990-2005	527%	413%	588%	773%

Notes: The sample in Panel A is used for all regressions examining central city population changes between 1990 and 2010 in subsequent tables. The sample in Panel B is used for regressions examining population changes between 1990 and 2000. The sample in Panel C is smaller than that used for regressions in Tables 6 and 7 involving GDP because for this table only we exclude prefectures without valid GDP data in 1990. All GDP numbers are deflated using provincial deflators.

Table 2: First Stage Regressions

	2010 Hwy Rays (1)	1999 Hwy Rays (2)	1990 Rail Rays (3)	1999 Hwy Rings (4)
Highway Rays in 1962	0.37***	0.32***	0.072	-0.0049
	(0.083)	(0.080)	(0.047)	(0.016)
Railway Rays in 1962	0.30**	0.15*	0.71***	0.0070
	(0.14)	(0.081)	(0.071)	(0.019)
Highway Rings in 1962	-0.28	-0.56	-0.17	0.43***
	(0.94)	(0.36)	(0.20)	(0.13)
Log Central City Area	0.12	0.17	0.12	-0.056**
	(0.17)	(0.11)	(0.089)	(0.025)
Log Prefecture Area	0.071	0.22	-0.13	-0.034
	(0.23)	(0.14)	(0.16)	(0.044)
Log(1990 Rural Agricultural	0.21	0.38***	0.082	0.0065
Employment)	(0.20)	(0.13)	(0.14)	(0.027)
Δ log(Prefecture Population)	0.38	1.60***	-0.37	0.16
	(0.62)	(0.46)	(0.48)	(0.13)
Provincial Capital Indicator	2.27***	1.40***	0.050	0.10
	(0.45)	(0.43)	(0.21)	(0.090)
Constant	-3.08	-6.86***	-0.28	0.70
	(2.97)	(2.13)	(1.97)	(0.45)
Observations	182	264	264	264
R-squared	0.32	0.28	0.45	0.16

Notes: Each column shows coefficients from a separate OLS regression of the variable listed at top on the variables listed at left. Standard errors are clustered by province.

Table 3: Relationships Between Highway Rays and Central City Populations

	Δ ln(CC Pop), 1990-2010		Δ ln(CC Pop), 1990-2000	
	(1)	(2)	(3)	(4)
Highway Rays in 2010	0.0078	-0.020**		
	(0.014)	(0.0093)		
Highway Rays in 1999			0.020***	0.0099
			(0.0071)	(0.0072)
Log Central City Area		-0.13***		-0.054***
		(0.020)		(0.016)
Log Prefecture Area		0.050*		0.019
		(0.029)		(0.015)
Log(1990 Rural Agricultural Employment)		0.063*		0.045***
		(0.032)		(0.016)
Δ log(Prefecture Population)		0.82***		0.78***
		(0.10)		(0.084)
Provincial Capital Indicator		0.15**		0.0065
		(0.065)		(0.026)
Constant	0.37***	-0.34	0.18***	-0.32
	(0.066)	(0.34)	(0.028)	(0.22)
Observations	182	182	264	264
R-squared	0.00	0.55	0.03	0.36

Notes: Each column shows coefficients from a separate OLS regression of the variable listed at top on the variables listed at left. Standard errors are clustered by province. Estimated coefficients on highway rays change by less than 0.003 when controls for region and geography are additionally included.

Table 4: IV Estimates of Effects of Highway Rays on Central City Population

	Δ ln(CC Pop), 1990-2010				Δ ln(CC Pop), 1990-2000			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Highway Rays in 2010	-0.067*	-0.071***	-0.063***	-0.042*				
	(0.038)	(0.023)	(0.021)	(0.023)				
Highway Rays in 1999					-0.079***	-0.063**	-0.047***	-0.041**
					(0.027)	(0.025)	(0.016)	(0.016)
Log Central City Area		-0.13***	-0.13***	-0.12***	-0.057***	-0.059***	-0.044***	-0.045***
		(0.019)	(0.020)	(0.022)	(0.022)	(0.019)	(0.017)	(0.016)
Log Prefecture Area		0.056**	0.087***	0.068**	0.048**	0.076***	0.035**	0.061***
		(0.027)	(0.031)	(0.029)	(0.022)	(0.021)	(0.014)	(0.012)
Log(1990 Rural Agricultural		0.085***	0.061*	0.068*	0.091***	0.061**	0.075***	0.055***
Employment)		(0.031)	(0.036)	(0.035)	(0.030)	(0.030)	(0.019)	(0.018)
Δ log(Prefecture Population)		0.84***	0.79***	0.79***	0.97***	0.91***	0.88***	0.85***
		(0.072)	(0.077)	(0.085)	(0.13)	(0.12)	(0.098)	(0.094)
provincial capital indicator		0.28***	0.28***	0.23***	0.14**	0.13**	0.099***	0.097***
		(0.090)	(0.084)	(0.085)	(0.062)	(0.052)	(0.035)	(0.034)
middle region indicator				0.077		0.014		0.033
				(0.073)		(0.037)		(0.030)
west region indicator				-0.055		-0.015		0.033
				(0.082)		(0.044)		(0.036)
log(precipitation)			0.034	0.013		0.036		0.051***
			(0.033)	(0.036)		(0.023)		(0.015)
central city elevation range			-0.000029	4.1e-07		-0.000032*		-0.000039**
			(0.000025)	(0.000024)		(0.000017)		(0.000015)
prefecture elevation range			9.5e-06	0.000023**		0.000011		0.000010*
			(9.3e-06)	(0.000011)		(7.0e-06)		(6.3e-06)
log(distance to coast)			-0.017	-0.024		-0.014		-0.014
			(0.013)	(0.017)		(0.012)		(0.0086)
Constant	0.59***	-0.41	-0.47	-0.37	-1.00**	-1.01**	-0.82***	-1.06***
	(0.13)	(0.37)	(0.38)	(0.43)	(0.44)	(0.45)	(0.29)	(0.30)
Observations	182	182	182	182	182	182	264	264
R-squared	-0.22	0.48	0.52	0.58	0.14	0.31	0.17	0.24
First stage F	29.4	20.7	28.3	22.1	11.1	8.93	15.2	14.0

Notes: Each column is a separate IV regression of the variable listed at top on the variables listed at left. The number of road rays in 1962 instruments for the two transport variables considered. First stage results are in Table A1. Columns (1)-(4) use the sample of cities for which we have data on population in 2010 while Columns (5)-(8) use the more complete sample of prefecture level cities in our study region.

Table 5: IV Estimates of Additional Transport Infrastructure on Central City Population

	Δ ln(CC Pop), 1990-2010				Δ ln(CC Pop), 1990-2000	
	(1)	(2)	(3)	(4)	(5)	(6)
Highway Rays in 2010	-0.090**	-0.078***	-0.071***	-0.073***		
	(0.042)	(0.026)	(0.024)	(0.022)		
log(2010 km of highways in prefecture)	0.18					
	(0.21)					
log(2010 km of highways in prefecture outside of CC)		0.058				
		(0.071)				
log(km of railroad in prefecture outside central city)				-0.0097		
				(0.016)		
Highway Rays in 1999					-0.047***	-0.047***
					(0.016)	(0.017)
log(1999 km of highways in prefecture)					-0.0027	
					(0.080)	
Railroad Rays in 1990			-0.0012			-0.00076
			(0.034)			(0.017)
Log Central City Area	-0.11***	-0.10***	-0.13***	-0.13***	-0.044***	-0.044***
	(0.029)	(0.037)	(0.020)	(0.022)	(0.017)	(0.017)
Log Prefecture Area	-0.035	0.012	0.056**	0.069*	0.037	0.035**
	(0.12)	(0.068)	(0.027)	(0.037)	(0.065)	(0.014)
Log(1990 Rural Agricultural Employment)	0.041	0.061	0.085***	0.084***	0.076***	0.076***
	(0.059)	(0.039)	(0.028)	(0.033)	(0.021)	(0.018)
Δ log(Prefecture Population)	0.78***	0.82***	0.84***	0.84***	0.88***	0.88***
	(0.098)	(0.084)	(0.072)	(0.070)	(0.097)	(0.097)
provincial capital indicator	0.24**	0.27***	0.29***	0.30***	0.099**	0.099***
	(0.10)	(0.10)	(0.095)	(0.093)	(0.040)	(0.035)
Constant	0.010	-0.12	-0.41	-0.44	-0.83**	-0.82***
	(0.65)	(0.47)	(0.35)	(0.35)	(0.40)	(0.29)
Observations	181	179	182	182	262	264
R-squared	0.43	0.47	0.48	0.48	0.17	0.17
First stage F	4.24	10.3	9.29	11.2	6.35	7.74

Notes: Elements of the 1962 road and rail infrastructure instrument for indicated elements of road and rail infrastructure frim 1999 and 2010. Some regressions have fewer observations than are in the full sample because of dropped cities with 0 km of road or rail.

Table 6: IV Estimates of Transport Infrastructure on Output and Lights

VARIABLES	Δln(GDP)			Δln(Ind Outpt)			Δln(Lights)		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Highway Rays in 2005	-0.0068			-0.037			0.0072		
	(0.047)			(0.082)			(0.026)		
Railway Rays in 1990		-0.13***			-0.20**			-0.032*	
		(0.047)			(0.083)			(0.019)	
log(1990 km of railways in			-0.084***			-0.12***			-0.036***
prefecture)			(0.025)			(0.032)			(0.012)
Log Central City Area	0.025	0.029	0.0094	0.14*	0.15*	0.12*	0.070***	0.076***	0.070***
	(0.050)	(0.051)	(0.049)	(0.073)	(0.078)	(0.070)	(0.025)	(0.024)	(0.022)
Log Prefecture Area	-0.19**	-0.19***	-0.10	-0.30**	-0.31***	-0.19*	-0.085*	-0.082**	-0.047
	(0.076)	(0.071)	(0.080)	(0.13)	(0.11)	(0.11)	(0.043)	(0.039)	(0.043)
Log(1990 Rural Agricultural	0.18***	0.20***	0.14***	0.30***	0.32***	0.24***	0.0080	0.021	0.0061
Employment)	(0.058)	(0.056)	(0.054)	(0.11)	(0.098)	(0.090)	(0.032)	(0.030)	(0.032)
Δ log(Prefecture Lights)	0.21*	0.069	0.061	0.33*	0.089	0.12	0.91***	0.87***	0.83***
	(0.12)	(0.14)	(0.13)	(0.18)	(0.21)	(0.19)	(0.053)	(0.062)	(0.063)
Δ log(Prefecture Population)	0.74***	0.75***	0.76***	1.91***	1.82***	1.95***	-0.078	-0.071	-0.075
	(0.22)	(0.22)	(0.22)	(0.66)	(0.64)	(0.64)	(0.11)	(0.099)	(0.11)
provincial capital indicator	-0.0036	0.079	0.074	-0.42***	-0.29	-0.34**	-0.080*	-0.051	-0.029
	(0.072)	(0.099)	(0.092)	(0.15)	(0.17)	(0.14)	(0.041)	(0.042)	(0.038)
Constant	0.71	0.54	0.86	-0.98	-0.95	-0.47	0.14	-0.0069	0.038
	(0.87)	(0.97)	(0.85)	(1.64)	(1.55)	(1.35)	(0.41)	(0.31)	(0.33)
Observations	203	203	203	186	186	186	264	264	264
R-squared	0.19	0.17	0.18	0.20	0.16	0.20	0.69	0.70	0.71
First stage F	19.0	61.8	35.4	18.7	57.4	37.3	43.5	91.7	60.5

Notes:

Table 7: Effects of Ring Roads and Network Variables on Decentralization

VARIABLES	Δln(CC Pop)			Δln(GDP)			Δln(Ind Outpt)		
	1990-2010	1990-2000		1990-2005			1990-2005		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Highway Rays	-0.072**	-0.057***		-0.10			-0.13		
	(0.032)	(0.021)		(0.10)			(0.13)		
Highway Rings	-0.0042	-0.24**	-0.14**	-0.64*	-0.56*	-0.57**	-0.94**	-0.79*	-1.00***
	(0.14)	(0.11)	(0.072)	(0.36)	(0.32)	(0.28)	(0.44)	(0.40)	(0.32)
Railway Rays in 1990						-0.17**			-0.25*
						(0.078)			(0.13)
Log Central City Area	-0.13***	-0.061***	-0.063***	-0.047	-0.061	-0.067	0.010	0.011	-0.028
	(0.020)	(0.018)	(0.017)	(0.058)	(0.064)	(0.051)	(0.093)	(0.091)	(0.080)
Log Prefecture Area	0.056**	0.030*	0.018	-0.18**	-0.21***	-0.21***	-0.29**	-0.33***	-0.34***
	(0.026)	(0.018)	(0.016)	(0.080)	(0.065)	(0.061)	(0.13)	(0.11)	(0.095)
Log(1990 Rural Agricultural	0.086**	0.079***	0.049***	0.25***	0.19***	0.23***	0.39***	0.31***	0.38***
Employment)	(0.039)	(0.023)	(0.018)	(0.092)	(0.048)	(0.057)	(0.11)	(0.078)	(0.082)
Δ log(Prefecture Lights)				0.16	0.17	0.023	0.26	0.26	0.010
				(0.14)	(0.15)	(0.17)	(0.19)	(0.20)	(0.26)
Δ log(Prefecture Population)	0.84***	0.93***	0.81***	0.88**	0.73***	0.51*	2.52***	2.32***	2.27***
	(0.073)	(0.11)	(0.081)	(0.35)	(0.26)	(0.30)	(0.81)	(0.71)	(0.81)
provincial capital indicator	0.29**	0.14***	0.037	0.10	0.0081	0.11	-0.40*	-0.50**	-0.36
	(0.12)	(0.049)	(0.027)	(0.13)	(0.10)	(0.13)	(0.22)	(0.19)	(0.25)
Constant	-0.41	-0.67**	-0.26	0.49	1.43***	1.33*	-1.10	0.031	-0.0022
	(0.39)	(0.34)	(0.25)	(1.15)	(0.47)	(0.70)	(1.63)	(1.22)	(1.43)
Observations	182	264	264	203	203	203	186	186	186
R-squared	0.48	0.05	0.32	-0.15	-0.05	-0.14	-0.03	0.05	-0.15
First stage F	3.76	7.61	11.1	3.54	8.54	4.38	4.87	11.8	6.63

Notes: Highway rays and rings are measured as of 2010 for the regressions in Columns (1)-(3) and as of 2005 for the remaining regressions. Road and rail network measures in 1962 instrument for these measures in later years.

Table 8. Effects of Public Transport

VARIABLES	Δln(CC Pop) 1990-2010	
	OLS	IV
	(1)	(2)
Highway rays in 2010	-0.0167**	-0.0562***
	(0.01)	(0.02)
Log buses & trolleys 2008 in 2005 central city	0.0321**	0.0497*
	(0.02)	(0.03)
Log Central City Area	-0.127***	-0.117***
	(0.02)	(0.02)
Log Prefecture Area	0.0618**	0.0732**
	(0.03)	(0.03)
Log(1990 Rural Agricultural Employment)	0.0575**	0.0748**
	(0.02)	(0.04)
Δ log(Prefecture Population)	0.808***	0.837***
	(0.15)	(0.13)
N	182	182
R^2	0.56	0.51
First stage F		15.35

Table A1: Summary Statistics

	Sample of 182 1990-2010				Sample of 264 1990-2000			
	Mean	Stdev	Min	Max	Mean	Stdev	Min	Max
Panel A: Transport Measures and Instruments								
Highway Rays at End of Period	2.91	2.06	0	11	2.84	1.68	0	8
log(km of highways in prefecture)	5.84	0.83	0.00	7.63	5.98	0.68	1.60	7.93
Ring road indicator	0.20	0.40	0	1	0.13	0.34	0	1
Railway Rays in 1990	1.45	1.26	0	4	1.42	1.24	0	5
log(km of railroad in pref outside cc)	3.42	2.08	0.00	6.31	3.59	2.04	0.00	6.35
1962 Highway Rays	1.95	1.25	0	6	1.85	1.27	0	6
1962 log (km of highways in pref)	5.58	0.79	1.92	7.42	5.61	0.77	1.92	7.42
1962 ring road indicator	0.04	0.19	0	1	0.05	0.22	0	1
1962 railway rays	0.94	1.15	0	4	1.06	1.16	0	4
1962 log(km of highways in pref)	2.61	2.20	0.00	6.36	2.80	2.17	0.00	6.36
Panel B: Dependent Variables								
D log(Central city population)	0.40	0.33	-0.79	1.42	0.40	0.33	-0.79	1.42
D log(Central city GDP)	1.81	0.47	0.47	2.89	1.79	0.45	0.47	3.00
D log(Central city industrial GDP)	1.70	0.67	-0.84	3.31	1.71	0.67	-0.84	3.86
D log(central city lights)	0.65	0.43	-0.22	2.58	0.62	0.42	-0.26	2.58
Panel C: Control Variables								
Log Central City Area	7.17	0.95	4.63	9.88	7.14	0.95	4.63	9.91
Log Prefecture Area	9.30	0.76	6.95	12.03	9.34	0.74	6.95	12.03
Log(1990 Rural Agricultural Emp)	14.54	0.84	12.06	16.96	14.49	0.82	12.03	16.96
Δ log(Prefecture Population)	0.74	0.37	-0.12	2.23	0.70	0.38	-0.19	2.23
Δ log(lights at night)	0.14	0.23	-0.31	1.83	0.10	0.12	-0.11	1.42
provincial capital indicator	0.12	0.33	0	1	0.09	0.29	0	1
middle region indicator	0.36	0.48	0	1	0.38	0.49	0	1
west region indicator	0.24	0.43	0	1	0.21	0.41	0	1
log(precipitation)	6.85	0.52	4.47	7.80	6.80	0.53	4.47	7.80
central city elevation range	858	695	15	4129	822	633	15	4129
prefecture elevation range	1652	1595	34	8837	1665	1551	26	8837
log(distance to coast)	5.28	1.91	-5.38	7.43	5.29	1.83	-5.38	7.43