Roads, Railroads 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: April 14th, 2012

Abstract: This paper investigates how the extent and configuration of recently expanded Chinese highway and railroad networks have influenced urban form in Chinese cities over the past 20 years. This is a period when cities experienced large population inflows and relative losses of industry to urban peripheries. In this context, we find that each radial highway displaces 4 to 5 percent of central city population to surrounding regions and the existence of a ring road displaces an additional 20 percent. While railroads have no effect on the spatial distribution of population in urban areas, each radial railroad displaces 26 percent of industrial GDP from central cities to surrounding regions. We find no effect of radial highways on the spatial distribution of GDP in urban regions, though the existence of a ring road decentralizes large amounts of industrial GDP beyond the amounts decentralized by the existence of railroads. Historical transportation infrastructure provides the identifying exogenous variation in more recent measures of such infrastructure used to measure these treatment effects.

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 Management, Peking University, Beijing China

1. Introduction

In the early 1990s, China embarked on an ambitious initiative to build and upgrade its transportation infrastructure, particularly its highways. From a low level, spending on transportation infrastructure has grown at about 15% a year since 1990 to about $200 billion in 2007. Much of the associated construction has occurred in cities. This period also saw rapid migration of rural populations to cities and economic growth rates averaging over 10 percent a year. We investigate how the extent and configuration of Chinese highway, railroad, and public transit networks affected the decentralization of population and economic activity from central cities during this period. Since such decentralization 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 such infrastructure on urban decentralization.

For our investigation we construct a unique data set describing population, economic activity and infrastructure in a panel of constant-boundary Chinese central cities. These data integrate satellite images of lights at night from 1992 to 2009 with digitized national road and railroad maps from 1962, 1990, 1999, 2005 and 2010. Our data also include census information by county from 1982, 1990, 2000, 2010, and information assembled from city and national urban yearbooks for components of GDP for 1990-2005.

We find strong evidence that the presence of radial highways and suggestive evidence that the presence of ring roads outside of central cities reduce population density in central cities. Our estimates indicate that each additional radial highway displaced at least 4.2 percent of central city population to suburban regions. Since most Chinese central cities experienced rapidly growing population during our study period, such highways retarded centralization. Conditional on the radial and ring configuration of the highway network, total kilometers of roadways in or outside central cities do not affect their population density. We find suggestive evidence that central city buses and trolleys increase population density. Together these findings provide econometric evidence in support of the conventional wisdom (e.g. World Bank, 2002) that urban compactness is reduced by radial and ring road construction and enhanced by public transportation.

We find that the location of industrial production responds to the extent of the local railroad network, but not to highway rays nor to the extent of the highway network. Each additional radial railroad line displaces about 17 percent of central city GDP and 26 percent of central city industrial sector GDP to surrounding regions. Ring roads built outside of central cities displace additional central city production to outlying areas. That railroads, but not radial highways, affect the location of production probably reflects China's unusually heavy historical reliance on railroads and waterways for long haul and even short haul freight (World Bank, 1982). In 1978, less than 5% of freight (in ton kilometers) in China was carried on highways. This share has increased though remained at less than 15% up to 2005, well below the US where 30% of freight moves by road.[1]

Developing countries spend huge sums on transportation infrastructure investments that shape their cities for many decades to come. About 20% of World Bank lending for 2007 was for transportation infrastructure, more than the Bank's lending on social programs. Urban transportation improvements generate direct welfare benefits through reduced commuting and shipping costs. Changes in urban form, in particular urban compactness, can also influence welfare through their effects on urban productivity, urban environmental costs and the amount of land available for agricultural production. While mayors and planners worldwide ultimately want to determine the optimal transportation infrastructure networks for their cities (World Bank, 2002), a necessary precursor to describing optimal transportation networks is a determination of how such infrastructure affects urban form. We investigate precisely this issue.

Since Marshall (1890), economists have recognized that denser cities provide richer information environments, which in turn improve productivity and increase innovation (Jacobs, 1969 and Lucas, 1988). However, central city environments come with much higher land and labor costs. As a result, in developed market economies, large cities typically specialize in business and financial services which benefit sufficiently from richer information environments to justify these higher factor costs. Standardized manufacturing is typically found on the lower cost urban periphery and in small cities and towns (Kolko, 2000; Swartz, 1992). In contrast, manufacturing facilities in developing countries often locate in large cities, perhaps because learning and adaptation are critical to the successful transfer of technology from abroad (Duranton, 2007). This pattern was particularly evident in Chinese cities circa 1990, where large centrally planned factories often completely dominated city landscapes. 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 decentralize to find lower land and labor costs.

Case studies suggest that migration of manufacturing to the urban periphery, growth of rural industry, and the subsequent development of business and financial services in central cities, all depend

[1] Changes in coverage of Chinese reports somewhat complicate comparisons. Estimates suggest that roads' percentage of freight rose to over 15% in the late 1990s before falling to about 12% in 2004. In 2009, however, this percentage is reported to be about the same as in the USA, mostly reflecting a discontinuous jump in the 2008 statistics. See China Statistical Abstract, Table 16-9.

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). This paper is the first to investigate the extent to which different highway and railroad network configurations contribute to this transformation. Such transformation 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.

Beyond the promotion of urban productivity, Chinese policymakers have promoted compact cities for two reasons. First, as elsewhere, they recognize that more compact cities may have lower environmental costs. Second, they worry about food security and hence about urban encroachment on agricultural land. Our results show how transportation networks affect compactness of cities and therefore inform environmental and land use policy.

Chinese cities have struggled to accommodate rapid population growth driven by a mass migration of peasants from the countryside that almost certainly ranks as the largest migration in human history.[2] To limit the inflow, authorities have utilized administrative barriers to migration. Given the rural-urban gap in income, these barriers impose high costs on the rural population. Thus, this study will also contribute to understanding how transportation infrastructure can help cities to accommodate large influxes of rural migrants by providing more decentralized residential options.

We note three important ways that 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 are among the first to investigate the effects of transportation infrastructure on urban form in a developing country where automobiles are less prevalent,[3] household incomes are much lower and cities are much denser than in the United States. 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 highways and railroads is entirely novel. The extant literature focuses on one mode or another, provides little insight into the effects of railroads on urban form and has never considered ring roads. Third, our analysis is among the first to examine the relationships between transportation infrastructure and the spatial distribution of production.

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

[3] 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 chengshi gongye nianjian (China Automotive Industry Yearbook), various years.)

The validity of our conclusions relies on achieving exogenous variation in transportation variables of interest. We generate such exogenous variation by using the configurations of urban transportation infrastructure in 1962 as instruments for more recent transportation infrastructure. The validity of this identification strategy depends crucially on the fact that Chinese roads and railroads served different purposes in 1962 than they do today. In 1962, roads existed primarily to move agricultural goods to local markets, while railroads existed to ship raw materials and manufactures between larger cities and to provincial capitals according to the dictates of national and provincial annual and 5-year plans. Thus, conditional on the control variables enumerated below, we expect 1962 road and railroad measures to affect the organization of population and production in modern, market based, Chinese cities only through their effects on the modern transportation network.

2. Literature and Context

2.1 Literature

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. Banerjee et al. (2012) find that railroads influence the allocation of factors of production across Chinese counties. Puga and Nunn's (2011) 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 transportation infrastructure within cities affects the spatial development of cities. This literature began with Baum-Snow (2007) which finds that limited access radial highways caused economically important decentralization in U.S. metropolitan areas. We estimate a 4-5% decline in Chinese central city population for each radial highway over 20 years, close to Baum-Snow's estimate of 6% for the U.S. Complementing Baum-Snow's work, Duranton and Turner (2012) find that of the extent of urban interstate highways has economically important impacts on the growth rates of population and employment in cities. Holl and Viladecans-Marsal (2011) replicate these results using data describing Spanish cities and highways. Duranton and Turner (2011) 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. Hsu and Zhang (2011) replicate this result using Japanese data. All of these papers rely on exogenous variation to identify the effects of roads on their outcome variables of interest and all investigate wealthy western countries. To our knowledge, only Deng et al. (2008) investigate the effect of roads on the development of Chinese cities. They find that roads are associated with an increase in the spatial diffusion of development in Chinese counties, but do not address the likely reverse causality problem.

A third literature describes changes in the location of industrial production as countries develop. It shows that standardized industrial activity in city centers decentralizes to ex-urban areas to take advantage of lower labor and land costs as development proceeds. At the same time, central city economies become more service oriented. Lee and Choe (1990) examine this process in Seoul, Lee (1982) in Bogota, Hansen (1987) in Sao Paulo, and Henderson, Kuncoro and Nasution (1996) in Jakarta. These case studies assert that transportation infrastructure facilitates decentralization but none of these papers actually measures infrastructure or deals with the possibility of reverse causality.

2.2 Context

Table 1 shows the growth of economic activity and population in central cities and residual portions of prefectures for three samples of prefectures. Because it has more complete geographic coverage than other measures, we use lights at night (Henderson, Storeygard and Weil, 2012) as one measure of economic activity. Panels A and B describe the decentralization of population and lights at night while Panel C describes the decentralization of GDP and just its industrial component. Each panel is broken into central city versus prefecture remainders and shows growth over the indicated time periods. Starting values in 1990 for population and GDP measures are noted.

Table 1 indicates that population grew much more quickly in central cities than in surrounding regions throughout our study period. Panel A shows that between 1990 and 2010 aggregate population growth was 55% in central cities relative to just 5% in city hinterlands, with somewhat more rapid growth in both regions during the 1990s than after 2000. In contrast to population, Table 1 shows that lights increased more quickly in suburban than central city regions. In the full sample of 257 prefectures, lights grew by 102% in central cities and 165% in prefecture remainders between 1990 and 2010.

Table 1 Panel C presents information on total GDP and industrial sector GDP growth by urban region for a smaller common sample of 108 areas for which we have consistent GDP data 1990-2005 disaggregated by sector for both central cities and prefecture remainders. It shows that suburban industrial GDP grew by 794% between 1990 and 2005 relative to 417% in central cities. These numbers indicate a relative decentralization of manufacturing. The shift of services (and agriculture) to the suburbs was less dramatic. Total suburban GDP grew by 605% while central city GDP grew by 530%. Note the GDP numbers reflect China's high rate of economic growth during our study period.

Figure 1 shows that the relative trends in aggregate population and industrial GDP growth in central cities and prefecture remainders seen in Table 1 reflect population centralization and industrial GDP decentralization respectively in most prefectures. Figure 1a depicts population growth rates between 1990 and 2010 for these two geographic units. It shows that almost all central city populations grew more rapidly than did surrounding prefecture populations in every region of China. Figure 1b depicts industrial GDP growth rates between 1990 and 2005 for a smaller sample. It shows that, unlike population, industrial GDP decentralized rapidly in most of the prefectures for which we have complete data during this period.

3. Data

3.1 City and Prefecture Geography

China is split into 34 provinces and provincial level cities, 26 of which are primarily populated by Han Chinese and comprise our study area. Below provinces are prefectures (*diqu*), most of which have one core city (*shiqu*), numerous rural counties (*xian*), and several county cities (*xianji shi*).[4] Core cities are made up of urban districts (*qu*). Core cities are administered as one unit and are the nearest possible Chinese analog to central cities of U.S. metropolitan statistical areas. Each rural county and county city is administered separately under the supervision of its prefecture. Most tabular data that we use is reported separately for the urban districts, county cities and rural counties in our study region.

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 core cities have drawn many migrants, especially in the 1990s (Chan 2001, 2005).[5] Thus, our analysis primarily focuses on two geographic units: constant

[4] Some prefectures consist only of rural units and have no core city.

[5] Census data do not allow us to distinguish migration between prefectures from migration within prefectures within a province. For the mid-1990s, Chan (2001, Table 4) estimates that 36% of rural migrants remained within their own county and 71% of such migrants remained within their home province. Even if we assume that half of those within province who cross a county boundary also crossed a prefecture boundary, over half of all migration

boundary 1990 core cities (”central cities”), and the surrounding prefecture regions from which they draw many migrants.

Our most complete sample is a set of 257 prefectures in primarily Han provinces of China drawn to 2005 boundaries. Of the 286 total prefecture units in this region, we exclude 3 because their central cities coincide with their full prefectures, precluding any analysis of decentralization,[6] 8 because they had fewer than 50,000 inhabitants in 1990 and 18 because they do not include a core city by 2005. Our study area contains about 85% of China's population. Figure 2a illustrates the Han provinces of China, prefecture boundaries, and the boundaries of core cities in 1990. We exclude the less developed non-Han territories in the West because data availability is much poorer in these regions. Since the liberalization of urban economies during the 1990s fostered the operation of urban land markets and moved industry toward a competitive market basis, 1990 is an appropriate starting point for our analysis.

Core cities in 1990 are typically much smaller than prefectures and, as illustrated in Figure 2b for the Beijing area, they often consist of many urban districts. Figure 2b illustrates the spatial extent of 1990 core cities and the rate at which their administrative boundaries changed during our study period. In this figure, 1990 core cities are shaded green while regions shaded yellow are urban districts that were added between 1990 and 2005. 88 of the 257 year 2005 core cities in our sample did not exist as core cities in 1990. That is, in 1990 these 2005-definition prefectures did not contain a single urban district. We call such cities ”promoted” cities. Whereas the extant literature sometimes treats the entire prefecture or county as the statistical city (Deng et al. 2008, Faber 2011), inspection of Figure 2 reveals that neither unit appears to be a defensible geography for cities.

Ours is the first study to develop data for China to analyze population allocation between consistently defined central cities and surrounding prefecture areas. In order to capture decentralization away from urbanized areas in 1990 using consistent geographic units, we maintain year 2005 prefecture boundaries and year 1990 central city boundaries for our entire analysis. We construct constant boundary central cities by describing core cities in 1990 as a collection of 2005-definition counties. For core cities that existed in 1990, our 1990 central cities consist of all year 2005 units that were designated as urban districts in 1990, or which overlap with 1990 counties having this designation. For core cities that came into being after 1990, our central cities consist of the county cities or rural

was within prefecture. The share of cross provincial boundary migration increased in the 2000s, and with it, the share of cross prefectural migration probably also increased.

[6] These are Laiwu, Ezhou and Jiayuguan.

counties first promoted to urban status.[7] Of the promoted cities in our sample, 18 experienced boundary changes between 1990 and 2005, while 52 sampled incumbent cities experienced boundary changes. By carefully tracking these changes, we are able to follow these same constant boundary central cities and prefectures through the four cross-sections covered by our data, 1990, 2000, 2005 and 2010.[8]

3.2 Satellite Data

We use satellite data primarily as a source for lights at night. Henderson, Storeygard and Weil (2012) show that lights at night are a good proxy for GDP at the national level. As is hinted at in Table 1, lights and GDP are also strongly correlated at the Chinese prefecture level. We rely on six separate lights at night images of China (NGDC 1992-2009). These images are for 1992, 2000, 2005, and 2009, with two sets of data for 2000 and 2005. Lights at night data are first processed so that their projection and grid cells align with the 1 km square cells in 1992 landcover data described below. For each cell, these data report an intensity of nighttime lights ranging from 0 to 63. The codes 0-62 indicate intensity, while 63 is a topcode. Topcoding is rare in China, although it is common in cities of western countries.

We first use the 1992 lights at night data to identify the central business district (CBD) in each 1990 central city. To accomplish this, we select the brightest cell in each central city. If there is not a single brightest cell, we break ties with the sum of light in successively larger rings surrounding each brightest cell. Figure 3a 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 CBDs. As the figure demonstrates, our algorithm identifies points that look like the most central point of the 1992 lights data. In Figure 3b we show lights at night for the same area in 2009. In spite of the fact that light increases enormously over the intervening 17 years, 1992 city centers are still clearly brightest in 2009 as well. In Figure 5 we see that these points also tend be centrally located in the central cities' road networks. Our 1992 CBDs are also almost always within a few kilometers of an old walled city. If they are not, it is usually because the old walled city is at one sub-center while our calculated CBD is at another.

---

[7] In most cases, just one unit was promoted, though in a few instances neighboring county cities were promoted together and combined into one core city.

[8] In addition to core cities adding adjacent rural counties, there are cases in which boundaries of rural counties and urban districts at core city borders themselves change. When these boundaries change, we aggregate relevant adjacent rural counties or county cities with core cities to maintain consistent central city geographic units over time.

We use 1992 land cover data (USGS 1992) to calculate the 1992 share of land in agriculture in each prefecture and central city. This is based on about 21 land cover classification codes that include urban and various agricultural uses.[9] We also calculate total lights contained in each prefecture and in each central city drawn to 1990 boundaries in each sampled year.

3.3 Demographic and GDP Data

We construct demographic data for 1990 definition central cities and 2005 definition prefectures using the 1982, 1990, 2000 and 2010 Chinese censuses of population. In 1982 we use data based on a 1% sample (NBS, 1982 Population Census). In 1990, we primarily use data aggregated to the prefecture level city, rural county or county city level based on a 100% count (China Statistics Press, 1992a). For 2000 and 2010, our census data are the 100% counts at the urban district, county city and rural county levels (China Statistics Press, 2002 & http://www.luqyu.cn, 2012). In 2010, data is available for only 210 of the 257 prefectures in our sample.

Most prefecture level cities, some large county cities, and some prefectures report GDP back to 1990. Because less complete GDP information is available at the prefecture than central city level, we make little use of prefecture level GDP data. 1990 GDP and industrial sector GDP information comes from national and provincial printed data year books (China Statistics Press, 1992b & 1992c). Some cities included in these yearbooks were county level cities at the time, not yet promoted to core cities. In 2005 we use GDP information from the University of Michigan's Online China Data Archive. These data describe rural counties, county cities and core cities according to contemporaneous definitions. We supplement these data with prefecture yearbooks for urban district level data for 23 cities for GDP and 18 cities for industrial sector GDP. Because we do not have a comprehensive source for GDP information disaggregated below the core city level, when studying effects of transportation infrastructure on output growth in 1990 central cities we exclude many cities whose administrative boundaries expanded over time. This restriction plus the lack of data availability for some central cities in 1990 leaves us with a sample of 205 for which we observe GDP and 187 where we observe industrial

[9] These data are classified according to the USGS Land Use/Land Cover System Legend (Modified Level 2). Pixels classified 1 are `Urban and Built-Up Land'. Pixels classified 2-6 are respectively: `Dryland Cropland and Pasture', `Irrigated Cropland and Pasture', `Mixed Dryland/Irrigated Cropland and Pasture', `Cropland/Grassland Mosaic', `Cropland/Woodland Mosaic'. We define any pixel classified in one of these five classes as agricultural.

sector GDP. For this reason, our use of lights at night as an alternative GDP measure is valuable as it presents no sample selection difficulties.[10]

3.4 Infrastructure

To describe the Chinese road and railroad network, we digitize a series of large scale national transportation 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 each cross-section. To have consistency across time, we select maps from the same publisher, drawn using the same projection and with similar legends. However, the physical characteristics of recorded highways change over time. For example, 1990 and 1962 highways are typically two-lane free access roads, some of which are not all-weather or even paved.

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 from SinoMaps Press (1982); 1962 from SinoMaps Press (1962), and 1924 by Jiarong Su (1924). We also use a map of mid 18th century post roads. This map describes the imperial postal relay system, which connected the capital (Beijing) to provincial capitals.[11] Figure 4a presents an image of Beijing taken from our 2005 map. Figure 4b shows the resulting electronic map of the 2005 railroad and national highway network. As we discuss in the following section, we only end up using infrastructure information from 1962, 1999, 2005 and 2010 in our analysis.

Using these digital maps, we calculate radial and ring highway and railroad capacity measures and the total length of each transportation network within each prefecture and 1990 definition central city. For highways in 2010, we use the union of the high-grade highway (*gao dengji gonglu*) and national highway (*guo dao*) networks indicated on our 2010 road map. We exclude a third lower quality indicated road class from our analysis. For 2005, we use the union of the `highgrade highway and highgrade highway under construction' (*gao deng ji gonglu* and *Wei cheng gao deng ji gonglu*) network

[10] Because boundary changes resulted in some rural counties being counted as part of central cities, 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. Full GDP and industrial GDP samples include many central cities for which we do not observe information on surrounding prefectures.

[11] 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 Emperor of the Qing Dynasty and ruled 1722-1735.

and `highway and highway under construction' (*gonglu* and *wei cheng gonglu*) network. These are the only two types of roads indicated on our 2005 map. For 1999, we use the union of the `express, high grade highway and express, high grade highway under construction' (*gao su*, *gao dengji gonglu* and *jianzhuzhong gao su*, *gao dengji gonglu*) network and the `national highway' (*guo jia ji gonglu*) network, the only two road types indicated on our 1999 map.[12] Finally, our measure of 1962 roads is based on the single highway network (*Gong lu*) described on our 1962 road map. While all specified roads from 1999 forward capture major highways, the unavoidable inconsistencies of maps between 2010 and earlier years render our road measures not directly comparable over time. Most maps only have one railroad classification.

To calculate our radial road index, we first draw rings of radius 5km and 10km around the CBD of each central city. We then count the number of times a particular transportation network crosses each of these 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 city center. Figure 5a illustrates this algorithm. In this figure, the green area is the Beijing central city, the locations of CBDs are given by dots, the 2010 highway network is represented by red lines and the two relevant rings around each CBD are in black. Figure 5a indicates that our radial road index value is 6 for the 2010 highway network in Beijing, exactly 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 to measure the capacity of a particular network to move traffic in a circle around the CBD. We proceed quadrant by quadrant. Figure 5b illustrates the calculation of our ring road index for the 2010 national road network for the northwest quadrant of Beijing and two nearby cities. For each city, we begin by drawing two rays from the CBD, one to the west and the other to the northwest. We next restrict attention to intersections which lie between 5 and 9 km 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 the case of Beijing there is one each. The northwest quadrant ring road index for the 5 to 9 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 to 9 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

[12] Attempts to use only the top road category rather than the top two for constructing road capacity measures in 1999, 2005 and 2010 yield too few roads to provide sufficient identifying variation across locations.

road traveling about 45 degrees around the center while remaining between 5 and 9 km from the center. We replicate this calculation for roads that lie between 9 and 15 km from the CBD and 15-25 km from the CBD. These distances of 9, 15 and 25 are chosen so that to be counted as a ring road, the minimum angle a straight-line highway may intersect both rays in any distance-quadrant segment is the same for all rings. In our empirical work, we sum the results of these three calculations and restrict attention to roads which lie outside the central city. Because few cities had circumferential road infrastructure in 2010, we use an indicator of the existence of any ring road segment outside the central city as our primary ring road measure.

3.5 Supplemental Data Sources and Summary Statistics

We calculate the range in elevation and an index of the roughness of topography in each core city and prefecture using a digital elevation map with 90m sq. resolution.[13] We calculate the distance from each CBD to the nearest point on the Chinese coastline using our map of Chinese administrative districts. We calculate our radial transportation index for navigable waterways.[14] We construct annual average temperature and total precipitation using data from 194 Chinese weather stations over the period 1971 to 2000. Each 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 road and railroad 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

[13] Our digital elevation map is the Global Digital Elevation Model based on NASA/NGA Shuttle Radar Topography Mission (SRTM) data sets from the U.S. Geological Survey's EROS Data Center. The resolution is 3 arc seconds (90 meters). Let v be the elevation of the subject pixel and s_1 to s_8 the elevations for the eight adjacent pixels. For each v in a given jurisdiction we calculate $g(v) = \sqrt{\sum_{i=1}^{8}(v - x_i)^2}$. Our roughness index is the mean of $g(v)$ 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 was developed in Riley et al. (1999). This index provides an intuitive measure of roughness and is particularly simple to calculate with GIS software.

[14] To describe Chinese rivers we rely on "Rivers of China", created by National Fundamental GIS of China, June 2008 and available for download from http://nfgis.nsdi.gov.cn/ or http://gist.fas.harvard.edu/CEGRP/. This map contains four data layers; `largest rivers in China', `secondary rivers in China', `tributary rivers in China' and `secondary tributary rivers in China'. Our measure of navigable rivers is based on the union of all four networks.

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

within a prefecture as in Alonso (1964), Mills (1967) and Muth (1969). In such a model, we take prefecture economic activity as given and investigate transportation's role in determining its allocation between the central city and suburban regions whose characteristics are described in our data. Define y_{tA} to be the outcome variable of interest: population or a measure of economic activity. The year t takes the values 1990, 2000, 2005 or 2010. A indexes the administrative unit, either prefecture P or central city C. We denote a vector of additional control variables by x. Our data describe the road and railroad networks in each of several years. Let r denote a vector of transportation network measures. We will often be interested in first differences of our variables. 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, $\Delta_{2000} \ln y_P$ denotes $\ln y_{2000P} - \ln y_{1990P}$, the 1990 to 2000 change in $\ln y$ measured at the prefecture level.

A simple way to estimate the effect of transportation infrastructure on urban form is with a levels equation such as,

(1) $$\ln y_{tC} = A_0 + A_1 r_t + A_2 \ln y_{tP} + B_0 x_t + \delta + \varepsilon_t .$$

Equation (1) predicts central city population or economic activity as a function of the infrastructure variables of interest r_t, total prefecture population or economic activity $\ln y_{tP}$, and additional factors x_t that may influence $\ln y_{tC}$ and be correlated with r. Error term components δ and ε_t represent unobserved constant and time varying prefecture specific variables that influence central city population or economic activity. Inclusion of the control $\ln y_{tP}$ is central to our analysis. With this control included, the coefficient of interest, A_1, indicates the fraction of central city population or economic activity displaced to prefecture remainders for each additional unit of transportation infrastructure. Without this control, the coefficient of interest would reflect both decentralization and the amount of prefecture population growth caused by r_t that ends up in central cities. We expect $A_1 < 0$. To describe an Alonso-Mills-Muth equilibrium, controls in x_{1990} include central city land area and a measure of land productivity in agriculture, which proxies for the cost to the city of obtaining rural land.

There are two problems with using (1) directly for estimation. First, while the coefficients in (1) should describe approximate Alonso-Mills-Muth equilibria in Chinese cities in 2010, the 1990 planning process is probably better described by a larger set of variables, with the overlapping variables having different coefficients. Second, a necessary condition for an estimate of A_1 to be a casual effect of infrastructure is that our infrastructure variables be conditionally uncorrelated with the two error terms. That is, $Cov(r, \delta + \varepsilon \mid .) = 0$. This condition is unlikely to hold. In particular, we are concerned that historically productive or attractive city centers have been allocated more modern highways. In this case, the coefficient on highways at least partly reflects this unobserved attractiveness rather than a causal effect of infrastructure. We also worry that the allocation of railroads is not random either.

As a response to these issues, we first specify an equation with different coefficients and additional variables, q, for 1990 and then first difference to examine growth in $\ln y_{tC}$ between 1990 and a later year. For 1990, the resulting equation is

(2) $\ln y_{1990C} = (A_0 + \Delta A_0) + (A_1 + \Delta A_1) r_{1990} + (A_2 + \Delta A_2) y_{1990P} + (B_0 + \Delta B_0) x_{1990} + C_0 q_{1990} + \delta + \varepsilon_{1990}.$

Subtracting (2) from (1) yields

(3) $\Delta_t \ln y_C = \Delta A_0 + A_1 \Delta_t r + \Delta A_1 r_{1990} + A_2 \Delta_t \ln y_P + \Delta A_2 \ln y_{1990P} + B_0 \Delta_t x + \Delta B_0 x_{1990} - C_0 q_{1990} + \Delta_t \varepsilon.$

By taking first differences, we remove time invariant aspects of the error term. This means that an estimate of A_1 in Equation 3, for example, represents a causal effect of infrastructure on the spatial distribution of y if the infrastructure measure is conditionally uncorrelated with the remaining error term. This condition is arguably weaker than the corresponding condition for the levels equation, though it remains unlikely.

There are a number of practical difficulties in recovering the coefficients in Equation (3) using our data. First, while our 1990, 1999, 2005 and 2010 measures of roads are nominally the same, there is little resemblance between a highway in 2010 and a `national road' visible on our 1990 map. In particular, 1990 highways near major cities were almost universally one or two lane roads and were often unpaved. If such a 1990 road is recorded as a highway in 2010, it was either substantially widened and improved during our study period or it was an entirely new highway built alongside the old road. We believe that treating the 1990 highway stock as zero allows us to more accurately measure the change in highways over our study period. Therefore, our measures of changes to the road network are actually levels at t, as in Baum-Snow (2007).

In contrast, railroad network quality changed less during our study period. Most intra-city railroads in 2010 had been built by 1990. Nationwide network length increased by about 20 percent between 1990 and 2010 while double-tracking increased from 24% to 46%. Unfortunately, our data do not distinguish track quality and maps in various years do not necessarily record the same minor branch lines. Because differences in measured railroad infrastructure over our study period are likely to incorporate a lot of measurement error, we get very similar estimates whether we use 1990 or year t railroads as our infrastructure measure. We cannot use the change in railroads as a predictor as we have no strong instruments for it.

As with highways, we include only the level of railroads at time t to recover their causal effects. That is, we assume that 1990 railroads have no effect on outcomes, or more formally that $A_1 + \Delta A_1 = 0$. Our reasoning is as follows. In 1990, there was little freedom of movement of people or employment facilities within prefectures; there was little commuting or separation of living and workplaces, and no land market existed. Excepting a few special economic zones created before 1990, housing, factory, and even farm location patterns within areas defined as urban were largely unchanged from the 1960s. Only after 1990, with the advent of urban land and labor markets, was there much opportunity for urban form to change in response to market forces. The highways and railroads in place in 1990 could not be used for commuting or influence factory relocation within urban areas (Zhou and Logan, 2007).

Once economic reforms were in place, cities began to adjust to Alonso-Mills-Muth equilibria. Correspondingly, our analysis of the effects of railroads examines the extent to which the level of railroad infrastructure shaped the changes documented in Table 1. That is, our estimates of railroads' effects on changes in outcomes between 1990 and later periods occur in an environment in which change in response to railroads was not possible prior to 1990, even though much of the 2010 stock existed in 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 is comparable to our investigation of the effects of railroad levels in later years.

In summary, there are two reasons why our primary specification uses year t highways as the road measure when the dependent variable is a first difference from 1990: there were no highways in 1990 and urban spatial structure could not respond to whatever transportation infrastructure that did exist in 1990. Together with our inability to instrument for changes in infrastructure, this second reason also justifies using year t railroads as our primary railroad predictor. Our resulting base regression specification is:

(4) $$\Delta_t \ln y_C = \Delta A_0 + A_1 r_t + A_2 \Delta_t \ln y_P + \Delta A_2 \ln y_{1990P} + B_0 \Delta_t x + \Delta B_0 x_{1990} - C_0 q_{1990} + \Delta_t \varepsilon.$$

We remain concerned that r_t is endogenous in Equation (4), i.e., that transportation infrastructure was not randomly assigned to cities. To resolve this problem, we rely on instrumental variables estimation, which achieves the desired pseudo-randomization. In particular, we require instrumental variables z which satisfy

(5) $Cov(z, r_t \mid x_{1990}, q_{1990}, \Delta_t x, \Delta_t \ln y_P, \ln y_{1990P}) \neq 0$ and $Cov(z, \Delta_t \varepsilon \mid x_{1990}, q_{1990}, \Delta_t x, \Delta_t \ln y_P, \ln y_{1990P}) = 0$.

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. As in Baum-Snow (2007), Duranton & Turner (2011, 2012), Adelheid & Viladecans-Marsal (2011) and Hsu & Zhang (2011), we use historical network data as instruments for r_t.

Our resulting base regression specification includes four components: potentially endogenous transportation infrastructure measures at time t (for which we instrument), prefecture level growth in and the 1990 level of the dependent variable, growth in and base year levels of exogenous Alonso-Mills-Muth variables and additional base year variables that influenced the 1990 planning allocation and may be correlated with instruments. To maintain a consistent specification throughout our analysis of both population and components of GDP, we always control for growth in both prefecture population and lights.[16] We use lights because GDP is not observed for most prefectures in 1990. Alonso-Mills-Muth type models also justify controlling for the growth in prefecture income, which can be proxied by lights growth, and growth in population. Such models also justify including 1990 ln central city area and a measure of agricultural land productivity.[17] Inclusion of ln prefecture area captures any restrictions on the size of the suburban region.

We include ln 1990 agricultural *hukou* population outside of the central city and a provincial capital indicator as additional controls in our base specification. There are three motivations for inclusion of ln 1990 agricultural *hukou* population outside of the central city. First, when combined with prefecture and central city areas, it proxies for agricultural land productivity. Second, because it has a high correlation, 0.81, with total 1990 prefecture population, it stands in for $\ln y_{1990P}$ in population regressions.[18] Third, migration restrictions across prefectures mean that a large share of rural migrants to central cities have come from surrounding hinterlands (Chan, 2001 and 2005 and Au and Henderson, 2006). Therefore, it controls for population supply to central cities. The provincial capital indicator is included because provincial capitals were favored manufacturing centers in the planning era. Additional controls discussed in Section 5 are included as robustness checks.

We emphasize that for IV regressions to return consistent estimates of A_1, we need only control for variables that are correlated with instruments and influence outcomes of interest. Therefore, though it is likely that we omit some relevant unobserved variables from both x and q, the IV estimator nullifies any resulting bias to A_1. As the following subsection explains in detail, the only controls crucial to establishing the validity of IV estimates are the agricultural *hukou* population outside

[16] In Section 7 we address the possibility that these two controls are endogenous.
[17] Since these two variables are constant over time, we only control for their 1990 levels.
[18] Including both variables in our regressions yields large standard errors on both coefficients.

of the central city (when examining the effects of highways) and the provincial capital indicator (when examining the effects of railroads).

4.2 Instrument Validity

We rely 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 influence on the location and configuration of the modern transportation network, conditional on control variables. More formally, instruments cannot be correlated with unobserved variables that themselves influence highways and the post-1990 evolution of central city economies.

We have historical transportation 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 central city and prefecture. We find that the 1962 road measures are good predictors of their modern counterparts but that the earlier networks are not. Many urban highways built after 1990 followed the 1962 roads as a cost saving measure, since right of ways were already established and the local street networks already fed into these roads. Thus measures of the 1962 road network are good predictors of changes in highway road capacity experienced by cities between 1990 and later years. While some modern networks clearly follow routes laid out by the 1700 and 1924 networks, these networks are not sufficiently extensive to predict the modern networks in a statistical sense. We use 1962 measures as instruments because of the concern that 1982 measures post-date the initial rural sector market reforms in 1978 and thus may be influenced by the prospect of a future market economy.

Determining the set of appropriate control variables requires understanding the processes by which the 1962 transportation networks were established and how these processes could relate to modern forces affecting urban form. One of the hallmarks of Sino-Soviet planning was to minimize commuting. Much of the housing stock was nationalized during the 1950s and urban residents lived near their work locations. Because little commuting occurred in 1962, the road transportation network was oriented almost entirely toward the movement of goods. Moreover, because the little long-distance trade within the country 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).

The highway system built after 1990 is designed to serve a modern economy in cities where places of work and residence are separated and commuting is common. It is therefore likely that 1962 road networks affect the growth of modern cities only through their effects on the modern road network. However, it is important to control for any variables that are correlated with 1962 measures and cause changes in urban form or growth. For example, since the strength of local agricultural ties between central cities and surrounding regions could influence outcomes today, it is in principle important to control for agricultural activity in 1990 or 1982. Indeed, 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 highway rays serving the core city. Thus, prefecture agricultural population is an important control in estimation as it is correlated with highway instruments and it may directly predict population and GDP allocation between cities and prefecture remainders, at least in 1990.

Chinese inter-city transportation networks prior to 1962 consisted largely of railroads, more than two-thirds of which were built before the People's Republic of China was established in 1949. Major trunk lines constructed in the early 20th 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) to facilitate the extraction and export of agricultural goods and raw materials and later helped to link emerging industrial centers (e.g. Shenyang and Changchun) with China proper. In the Maoist era, railroad construction decisions were centralized. Between 1949 and 1962 much of the railroad investment was subject to Soviet influence and served to connect resource rich regions of the West with manufacturing centers in the East. After 1964 the "Third Front" policy moved military and other strategic production to the Sichuan area, resulting in five additional strategic railroad lines. Because there was little trade between provinces, provincial capitals were the most important trade nodes and therefore received a lot of railroads. Indeed, a regression of 1962 railroad rays on 1990 observables reveals that while agricultural employment is not a good predictor of railroads, a provincial capital indicator is. Given the variety of actors and motives behind the construction of the pre-1962 railroad network it is plausible that much of the railroad network was constructed without regard to its impact on the internal organization of cities during the decades that followed the market reforms of the early 1990s. However, this conclusion is conditional on a provincial capital indicator, as this indicator is both correlated with railroad instruments and is likely to influence the 1990 allocation of resources between core cities and prefecture remainders.

Table 2 presents representative first stage results for the four transportation network measures we emphasize in the paper. We instrument for each recent transportation network variable with its analog from the 1962 network. Table 2 indicates that our instruments are individually strong conditional on the standard set of control variables used throughout our analysis. Each 1962 road ray predicts 0.37 of a 2010 ray and 0.32 of a 2000 ray conditional on base specification controls and instruments for the other infrastructure measures. Each 1962 railroad ray predicts 0.50 railroad rays in 2005. Finally, each 1962 ring road predicts 0.44 of a ring road in 1999. Coefficients on road and railroad infrastructure variables change little when we add region, land cover and weather variables to these regressions.

5. Main Results

In this section, we first examine the effects of various types of highway and railroad infrastructure on population decentralization. We then examine infrastructure's effects on the decentralization of GDP, particularly its manufacturing component.

5.1 Effects on Population

Table 3 reports baseline OLS estimates of the empirical relationship between highway rays and central city population decentralization, as specified in Equation (4). Columns 1 and 2 examine 1990-2010 changes whiles Columns 3 and 4 examine 1990-2000 changes using a more complete sample. Columns 1 and 3 include the 2010 radial road index as the only explanatory variable while Columns 2 and 4 add our base set of controls.

Regardless of specification, estimated OLS coefficients on highway rays are either near 0 or positive, while we expect the true causal relationship to be negative. For example, faster growing cities may have faster increases in their demand for roads, which governments may fulfill. This suggests a positive relationship between roads and central city population that is not causal. While the sign on the highways coefficient turns negative in subsequent IV analysis, signs on the control variables remain remarkably stable across estimators. We delay a discussion of these control variable coefficients until after our discussion of the main IV results for highway rays.

Table 4 reports IV estimates of coefficients in Equation (4). All regressions in Table 4 use the road ray index for 1962 roads as an instrument for more recent measures of highway rays. Columns 1-3 examine effects of 2010 highways on the change in ln central city population between 1990 and 2010 for our sample of 210 prefectures, while columns 4-6 examine the 1990-2000 period using the complete sample of 257 prefectures. In addition to our base set of controls, in columns 3 and 6 we control for various geography and weather variables to better account for variation in agricultural productivity, housing supply elasticities and other exogenous features that might be correlated with 1962 transportation infrastructure and population decentralization.

While OLS estimates of the effects of highway rays on decentralization are zero or positive, Table 4 column 1 with no controls shows an (insignificant) 3% reduction looking between 1990 and 2010. The addition in column 2 of our base set of controls yields an estimated significant highway ray coefficient of -0.046. Inclusion of additional weather and geography controls, none of which are significant, reduce this estimate in absolute value to a marginally significant -0.038. Columns 3-5 show results for decentralization for the larger sample available between 1990 and 2000. For this sample, estimates indicate that each highway ray significantly displaces 4.7 percent of central city population to prefecture remainders with basic controls and 4.2 percent with additional controls, some of which are now significant. These results persist in a regression with only the 1990 agricultural population and prefecture population growth as controls. This sparser specification yields rays coefficients of -0.044 in the smaller sample and -0.039 in the larger sample, both highly significant.

The estimates in columns 2-3 and 5-6 for the different time periods are very similar. However, they are not strictly comparable for two reasons. First, we impose a lower standard for what constitutes a highway in 1999 than in 2010. Second, there is more heterogeneity in the amount of time cities in the 2010 sample were treated with highways than in the 2000 sample. Restricting the 1990-2000 sample to only include the prefectures in the 2010 sample yields a larger rays coefficient of -0.059 with a standard error of 0.020.

Because 1990 agricultural *hukou* population in the periphery is the only control variable significantly correlated with the highway rays instrument, inclusion of this one control variable alone generates rays coefficients that are statistically indistinguishable from those in Columns 2 and 4 at -0.091 (se=0.040) and -0.042 (se=-.019) respectively. Therefore, we view the inclusion of additional controls in our base specification as serving mainly to reduce the variance of the error term, and consequently provide us with more precise estimated causal effects of highway infrastructure. We note that while controlling for prefecture level population and lights growth does matter for interpretation of transportation coefficients, in practice our preferred estimates are not sensitive to the inclusion of these controls. In Section 7 we address potential endogeneity concerns with these variables and further discuss such interpretation issues.

Though not our focus, estimated coefficients on non-transportation related regressors are also of interest. Prefectures with larger 1990 agricultural populations had faster growing central cities, with estimated elasticities between 0.053 and 0.076. These estimates likely reflect both the greater supply of migrants in more agriculturally productive prefectures and the higher opportunity cost of suburban land. Central cities of prefectures with more rapidly growing populations also grew more quickly, with estimated elasticites between 0.75 and 0.91. These are more than double the elasticities that Baum-Snow (2007) finds for U.S. metro areas, reflecting the rapid urbanization of the Chinese economy during our study period.[19] Conditional on other controls, less spacious central cities in more populous prefectures grew more quickly. This may reflect convergence in city size or that central cities of larger prefectures had fewer nearby cities competing for migrants. While the change in lights is intended to control for changes in income, the sign of the coefficient on income is theoretically ambiguous since higher income means greater demand for suburban space but also a greater value of commuting time. Population in provincial capital central cities also grew a bit more quickly. Significant geographic and climate features in Column 5 include a positive estimated effect of precipitation and a negative effect of central city elevation range. Higher precipitation may cause land to be more productive in agriculture. Elevation range may reduce central city housing supply elasticity (Saiz, 2010), which in turn impedes population growth.

Consistent with evidence for the U.S. in Baum-Snow (2007) and Duranton and Turner (2012), differences between OLS and IV highway rays coefficients suggest that our 1999 and 2010 radial roads indices are endogenous. In particular, while more roads were built in central cities with more rapidly growing populations relative to their surrounding prefectures, these roads were themselves causing population to decentralize. This indicates that, while more rapidly growing Chinese cities received more transportation infrastructure of various types, the decentralization that occurred because of this infrastructure is swamped by the growth that precipitated construction of this infrastructure in the first place. As a result, the use of pseudo-random variation from the 1962 network is essential to understanding the true causal effects of these transportation improvements on the spatial organization of Chinese cities.

While we do not have sufficiently detailed migration data to determine how many suburban residents came from central cities versus from more outlying hinterlands, we can provide some indirect evidence that highways retarded centralization of suburban residents. 51 of the cities in our sample expanded their jurisdictions beyond our definition of their central cities after 1990. The resulting

[19] Our control for the change in prefecture population is meant to account for potential changes in demand for living in the region overall. However, because prefectures are often much larger than their urban region, it is conceivable that there were differential shifts in demand for living in the more urbanized portion of the prefecture relative to the prefecture overall. Our attempts to econometrically isolate effects of transportation on the allocation of population between more urbanized suburbs and more distant rural hinterlands are inconclusive.

conversion of rural counties to urban use resulted in dramatically less agricultural activity and much more opportunity to increase population density in these suburban regions than in unconverted rural counties adjacent to 1990 central cities. If we drop the 51 cities whose legal central cities expanded, highway rays coefficients for both 1990-2010 and 1990-2000 drop by 25-29% but remain statistically significant. This suggests that indeed a good portion of our results are driven by retarding rural in-migration from immediate outlying areas.[20]

A number of additional robustness checks confirm that highway rays cause population decentralization. Dropping the 10 largest cities modestly increases the absolute value of the highway ray coefficient in both columns 2 and 5. Replacing the 1990 agricultural *hukou* population with total prefecture population in 1990 leaves highway ray coefficients unchanged.

Table 5 reports estimated effects on population decentralization of total prefecture highway network length, highway network length outside of central cities and railroad rays. Our goal is to examine both the causal links from such additional infrastructure to population decentralization and confirm that correlations between other infrastructure and highway rays in 1962 and recent years are not driving the results in Table 4. Table 5 presents IV regressions using our base specification, but adds one different transportation measure in each column. Columns 1-3 examine effects on central city population growth 1990-2010 while Columns 4-6 examine the 1990-2000 period with larger samples. Excluded from this analysis are ring roads, which we analyze separately in Section 6.

Coefficients on highway rays, reported in the top two rows of Table 5, are all well within the standard error bands of estimates reported in Table 4. Each of the additional transportation measures we analyze has an insignificant positive coefficient, although this may partly reflect weak first stages. We find similar results for additional railroad network measures. For example, the coefficient on ln total prefecture km of railroads in a regression like that in Column 3 is 0.03 with a standard error of 0.14. These results rule out the possibility that these other types of infrastructure were driving results in Table 4. We also find no evidence that these alternative infrastructure measures themselves affect population decentralization. We conclude that whatever the mass of highways and railroads in a central city, it is the radial highway system that is relevant for population decentralization.

While our estimates are in line with existing evidence from the United States, the underlying mechanism in China is clearly somewhat different. Because of the rapid increases in Chinese urban populations during our study period, highways contributed to population decentralization both by

[20] Of course sample selection difficulties lead us to treat this result with caution. Conversions predominantly took place in rapidly growing cities where suburban demand increases were large enough to overcome usually strong local opposition and regulation by the central government.

retarding the degree to which rural people living near central cities moved to these cities and by inducing rural migrants from further away to settle in these suburbanizing areas. Unlike the post-WWII United States, movement of people from central cities to suburbs is likely to have been quite modest.

5.2 Effects on Output

We now examine the roles of transportation infrastructure in shaping the decentralization of production from central cities, with a focus on industrial GDP. Table 6 reports IV estimates of the effects of highway rays, railroad rays and total prefecture railroad length on the decentralization of production activity between 1990 and 2005. Results in columns 1-3 are for the industrial component of GDP, those in columns 4-6 are for all GDP and those in columns 7-9 are for lights at nights. As we explain in Section 3.3, central city industrial GDP data are available for 187 of the 257 central cities in our full sample, and total GDP for an additional 18 cities. We use lights at night to obtain output results for the full sample while recognizing that these data are difficult to interpret, which makes lights and GDP results difficult to compare. To be consistent with our analysis of population decentralization, Table 6 uses the same base set of controls as in Tables 4 and 5. Prefecture lights and population growth are now intended to jointly control for prefecture GDP growth, which we directly observe for an unsatisfactorily small subset of prefectures.

Whether examining industrial GDP, GDP, or lights, results in Columns 1, 4 and 7 show that highway rays have no significant effect on the decentralization of central city economic activity. A similar statement applies to highway network length, whether in the prefecture overall or just outside of central cities. However, each railroad ray is estimated to displace 26 percent of central city industrial GDP and 17 percent of central city GDP to prefecture remainders. This larger effect on industrial GDP is evidence that the industrial sector is primarily driving the estimated effects on total GDP. These railroad effects are very strong. Similar strong results hold for prefecture railroad network length. Unfortunately, we do not have the statistical power to jointly estimate the effects of these two railroad network measures in one regression.[21] Results for lights at night in columns 8 and 9 are consistent with those for the other two GDP measures but somewhat weaker.[22]

[21] In regressions with both railroad network measures, both have large negative but insignificant coefficients and the overall first stage F-statistic is under 2. The inability to distinguish the effects of these two variables is unsurprising since most railroads emanate as spokes from central cities.

[22] We also examine the effects of transport infrastructure on the decentralization of service sector GDP. These results follow the sign patterns for total GDP but are statistically weaker. Analyzing the Chinese service sector is difficult because it is poorly measured in 1990, its business and financial component is tiny, and we cannot distinguish traded from non-traded services in the data.

Significant coefficients on railroad infrastructure in Table 6 are remarkably stable across specifications. For example, the -0.26 coefficient for industrial GDP in Column 2 is exactly the same without any covariates included and changes to -0.23 with inclusion of the complete set of geographic and weather controls used in Table 4 Columns 3 and 5, all of which are insignificant. These same conclusions hold true for coefficients on prefecture railroad network length and for total GDP as an outcome. As in our analysis of population decentralization, OLS estimates appear to be positively biased. Table 6 Column 2, estimated with OLS, yields a significant coefficient of just -0.063. As with highways and population, this positive bias comes from the assignment of railroads to central cities with more rapid GDP growth.[23]

With a few exceptions, coefficients on control variables are in line with those in Table 4. 1990 rural agricultural population predicts more rapid central city output growth and central city output growth is strongly correlated with prefecture population growth, holding this base year agricultural population constant. When output is measured by lights, prefecture lights growth is associated with stronger central city growth in lights instead. Contrary to our analysis of population, coefficients on central city area are near 0 or positive while those on prefecture area are negative. in regressions with railroad transportation measures, we find no significant effects on output from being a provincial capital.

We conjecture that railroads are so critical to Chinese industrial decentralization because they dominate trucking as the primary intercity shipping mode. More radial railroads facilitate the migration of manufacturing activity out of central cities while maintaining access to the national railroad network via sidings and ring road connections. Industrial decentralization is likely a desired reorganization of urban production activities since cheaper land and rural labor is well-suited for the land intensive low skilled manufacturing sector. At the same time, CBD land can be repurposed toward services which are less space intensive and typically benefit more from local agglomeration spillovers.

Results in Tables 4 and 6 reveal that while roads matter for the location of people, in China railroads matter for the location of production. Because production requires workers, these differing roles of highways and railroads may seem mutually inconsistent. However, the nature of commuting and ex-provincial migrant location patterns in Chinese urban regions indicate that a sufficient suburban labor pool exists to work in decentralizing factories. While there is no systematic national commuting

[23] Contrary to our findings for population, we find no evidence that treatment effects are stronger in central cities with expanding jurisdictions. This is evidence that urban/rural status of counties had little influence on where industrial plants could locate.

data for China, there is select information for a few individual cities. Garske et al. (2011) show that in Shenzhen and Huangshan about 10 percent of commutes are over 20 km. Ma and Fan (1994) report that in 1984 15 percent of the daytime population of 6 Jiangsu county capitals were commuters, a number which has no doubt grown considerably since then. Therefore, there is a reservoir of suburban commuting labor available to work decentralized jobs while enjoying shorter commutes. In addition, since most jobs in industry are low skilled, and industry accounts for most of the apparent employment decentralization, the migrant labor pool is an especially important source of its workers. The 2000 census and 2005 population survey indicate that the less skilled migrants from other provinces are more likely to live in prefecture remainders relative to central cities than migrants from within a central city's province. In 2000, 42 percent of out of province migrants lived in prefecture remainders while 32 percent of in-province migrants did. This suggests that a migrant labor pool existed at the urban peripheries to work in newly decentralized jobs. Because of migrants' difficulty in accessing central city housing markets, it is likely that many migrants could not have moved to central cities even if they had wanted to.

6. Effects of Other Transportation Measures

In this section we examine the effects of ring roads, public transportation and waterways on the decentralization of economic activity. As far as we know, these are the first estimates of the causal effects of ring roads and waterways on urban form anywhere in the literature.

6.1 Ring Roads and Network Design

Understanding the effects on urban form of ring roads and how they interact with other elements of the urban transportation network is important information for policymakers engaged in the planning of such networks. To date there has been almost no investigation of the effects of ring roads because of econometric identification difficulties. China is one of the very few contexts in which exogenous variation in the number of ring roads received across cities is available, though limited. Scant ring infrastructure in 1962 forces us to focus only on estimating the effects of having any ring road capacity at all. We do not have sufficient statistical power to estimate causal effects of anything beyond this blunt measure. The 35, 56 and 57 cities with some ring road capacity in our most complete sample had average values of 1.3, 1.3 and 1.4 of our index of ring road capacity for 1999, 2005 and 2010 respectively.

Table 7 reports IV regressions showing the effects of any amount of ring road capacity on the decentralization of population, industrial GDP and GDP. These regressions include other transportation measures with significant effects in tables 4 and 6, and our base set of control variables. Each regression in Table 7 except one shows that the existence of a ring road has a large significant negative effect on central city economic activity. The effects of ring roads are in addition to persistent separate effects of highway rays on population 1990-2000 and of railroad rays on the natural logs of industrial and total GDP 1990-2005.[24] Estimated ring road indicator coefficients are -0.20 for population change 1990-2000, -0.80 for industrial GDP and -0.46 for GDP, reported in columns 2, 4 and 6 respectively.[25] Estimated effects of ring roads on industrial GDP and GDP decentralization are not sensitive to the other transportation measure included. Coefficients on highway rays in Column 2 and railroad rays in Columns 4 and 6 are statistically indistinguishable from those reported in Tables 4 and 6 without inclusion of the ring road measure. That is, our data allow us to separately identify the effects of ring and radial network characteristics on the decentralization of population and production. Results in columns 3 and 5 reveal similar coefficients on ring roads as those in Columns 4 and 6 and negative but insignificant coefficients on highway rays for industrial GDP and GDP decentralization respectively. While our estimate for 1990-2010 population change in Column 1 is not significant, it suffers from a weak first stage F-statistic of 4.66.

Our estimates indicate that ring roads cause a huge amount of decentralization, particularly of industrial production. We note, however, that only about 5 percent of cities in our sample had ring road capacity in 1962. Because there were so few ring roads in 1962, we emphasize that these treatment effects are more local than those found in the rest of our analysis and only necessarily hold for larger cities, which had variation in 1962 ring road capacity.

6.2 Public Transportation and Waterways

Our final exercise investigates the effects of public transit and waterways. A large literature investigates the consequences of public transit, mostly using travel demand modeling. However, transit's effects on urban decentralization has received less attention, particularly in a developing country context. Because finding strategies to identify the effects of public transit on cities is difficult, existing knowledge of such effects is limited. Therefore, while one can imagine objections to our method, results reported in this

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

[25] We did experiment with other measures of ring road capacity and results are similar in magnitude but statistically weak; first stage F statistics are much smaller.

sub-section improve our understanding of the role of public transit in shaping urban form. There exists even less analysis of the effects of navigable waterways on urban form.

We examine the effects of the number of buses and trolleys in 2005 on measures of urban decentralization. Because such data are only reported at the core city level of geography, we cannot account for city boundary changes and use reported 2005 numbers without modification. Results reported in Column 1 of Table 8 indicate an elasticity of 0.028 between the number of buses and trolleys in 2005 and central city population growth 1990-2010. In this regression, we instrument only for the number of 2010 highway rays. This supports the notion that public transportation contributes to urban compactness, counteracting road infrastructure that pushes the population to suburbanize.

We recognize that if high growth cities get assigned more buses and trolleys, our estimated coefficient is biased upwards. We attempt to use the number of employees in the transportation, posts and communication services sector in 1990 to instrument for buses and trolleys. Because these are primarily government jobs, transportation service employment is politically difficult to reduce even as demand conditions for transit may have changed over time. Consequently, the first stage is strong. Doubling the number of prefecture transportation service sector employees in 1990 caused 73 percent more buses and trolleys to be in service in the central city in 2005, conditional on other exogenous variables. However, it is not strong enough to yield a statistically significant coefficient in the second stage. While the coefficient on buses and trolleys increases to 0.039 with instrumenting, the standard error increases to 0.044.[26]

Our investigation of the effects of navigable rivers and canals uses the analogous rays measure to those used for highways and railroads. While we have no instruments for these natural features, they are sufficiently difficult to alter that we can plausibly analyze their effects using OLS only. Unfortunately, we cannot distinguish waterways' quality or capacity. Navigable waterways are an important shipping conduit for raw materials like coal and agricultural products, though less so for manufactures. About 75% of the cities in our sample have waterway rays. Columns 2 and 3 of Table 8 show that waterway rays had small and insignificant effects on industrial GDP and total GDP. Similarly small and insignificant effects are found for kilometers of prefecture waterways and when population decentralization is instead used as an outcome. These results are consistent with waterways' role in shipping non-manufactured goods.

[26] As a placebo exercise, we also evaluate whether buses and trolleys predict GDP growth. As expected, the buses and trolleys coefficient using this alternative outcome instead in a regression analogous to that in Column 1 of Table 8 is -0.01 and not significant.

7. Robustness

We now show that our main results, reported in Tables 4 and 6, are robust to various concerns. First we address the potential endogeneity of prefecture population and lights growth as control variables. We then show that transportation infrastructure built after 1990 cannot predict patterns of urban change prior to 1990. Finally, we investigate regional heterogeneity in estimated treatment effects.

7.1 Accounting for Potentially Endogenous Prefecture Growth

Here we address the concern that transportation infrastructure may induce overall urban area population and economic growth (Duranton and Turner, 2012). This implies that the prefecture population and light growth covariates in Tables 4-8 may be endogenous, which in turn affects the validity of our coefficients on transportation infrastructure measures. While we present results below in which we instrument for prefecture population growth, we note that removing the two prefecture growth covariates from regressions in Tables 4-8 does not affect the sign or significance of transportation coefficients. For example, the estimate in Table 4 Column 2 rises slightly to -0.075 while that in Table 4 Column 4 falls slightly to -0.040, and both coefficients remain statistically significant. Coefficients on railroad rays in Table 6 Columns 2 and 5 both change by less than 0.01 after excluding these controls.

If prefecture population growth is omitted from the regression, there are good reasons to believe that the estimated transportation coefficient is positively biased. If transportation infrastructure causes prefecture population growth, the transportation coefficient in this more parsimonious specification incorporates both the impact of transportation on the allocation of population between cities and suburbs and on the level of prefecture population response. Since some new arrivals drawn by better transportation infrastructure settle in the city, this coefficient understates the magnitude of the negative effect on central city population, holding prefecture population constant.

However, if unobservables or measurement error partly drive variation in central city population, then these factors also drive variation in prefecture population growth, introducing an endogeneity problem with this variable. Assuming a positive correlation between transportation infrastructure and prefecture population growth, this will result in a transportation coefficient that is negatively biased.[27] Because we can bound the transportation coefficient by comparing results with and

[27] The econometrics of these biases is seen in the following simplified environment. Suppose that the underlying structural equation for central city population is $\ln y_C = \alpha_0 + \alpha_1 r + \alpha_2 \ln y_P + u$, $\ln y_P = \ln(e^{\ln y_C} + e^{\ln y_S})$

without the inclusion of prefecture population growth in the regression, we have indirect evidence that both sources of bias are small.

Despite our confidence that we have tight bounds on coefficients of interest, we also proceed with an IV strategy for prefecture population growth. While migration patterns give us some hope of instrumenting for prefecture population growth, there is little we can do to instrument for prefecture lights growth. Because coefficients on lights growth are mostly not significant, we focus on instrumenting for population growth and exclude lights from our regressions.

Because cities primarily draw migrants from nearby prefectures (Zhang, 2011), they compete with nearby cities for these migrants. Base year urban and rural *hukou* populations in nearby prefectures thus plausibly negatively influence a central city's population growth through a competition effect and positively influence its population growth through a stock effect. There is no reason to believe that these two variables should be directly related to urban form, making them plausible instruments for population growth in our context. In particular, we use as instruments the natural logs of aggregate rural and urban population counts across prefectures with any part of their boundaries within 300 kilometers of a given central city in 1982. While the competition effect is significant with an estimated elasticity of -0.06 in the most complete sample, the stock effect is never significant. For this reason, we only use the competition instrument in examining robustness to endogeneity of prefecture population growth.[28]

Table 9 Panel A reports coefficients and standard errors on highway or railroad rays in regressions analogous to those in Table 4 Columns 2 and 4 and Table 6 Columns 2 and 5 except that we exclude prefecture lights growth and instrument for prefecture population growth. First stages are

---

where y_S is population of the prefecture remainder. Transport infrastructrue r is instrumented with r^{62}, which is uncorrelated with u. The IV estimate of α_1 excluding $\ln y_P$ from the regression equation equals $\alpha_1 + \alpha_2 \frac{Cov(r^{62}, \ln y_P)}{Cov(r, r^{62})}$ while the IV estimate of α_1 including $\ln y_P$ in the regression equation equals $\alpha_1 - \frac{Cov(r^{62}, \ln y_P) Cov(\ln y_P, u)}{D > 0}$.

[28] We note that migration across prefectures and provinces in China is strongly restricted, with formal restrictions (essentially "visa" requirements) before the early 2000s and informal restrictions including denial of local public services to ex-prefectural migrants thereafter (Au and Henderson, 2006a and 2006b). Thus we do not expect strong migration responses to changing prefecture economic conditions. Indeed, attempts to use Bartik style industry shift-shares to predict population growth yields a weak first stage. We also experimented with using the ratio of women age 10- 24 to the population in 1990 as a fertility control for natural population growth in the prefecture in the face of the one child policy and an indicator for being one of the special cities that had received FDI by 1990 as instruments. Neither has sufficient first stage explanatory power to be valid.

sufficiently weak in the 1990-2010 population and the GDP regressions such that the revised coefficients are not informative. However, coefficients hardly change in the other two regressions. In Column 2 we see that the highway ray coefficient drops slightly to -0.042 (from -0.048) while Column 3 shows no change in the railroad rays coefficient for industrial GDP at -0.025. We conclude that endogenous prefecture population growth introduces at most a small bias to our coefficients of interest.

7.2 Placebo Regressions

We run "placebo" regressions in which our expected estimated effects of transportation infrastructure are zero to evaluate the validity of our identification strategy. In particular, we run regressions analogous to those in Table 4 Columns 2 and 4 but using population changes between 1982 and 1990 instead of after 1990. If our identification strategy is working correctly, highways built between 1990 and 1999 or 2010 should have no effects on changes in the spatial distribution of the population in urban areas prior to 1990. Because we do not observe lights at night before 1992, we omit this regressor in our analysis. Geography changes rendering it impossible to build outcomes for some 1990 spatial units using 1982 boundaries reduce our sample by 20 prefectures for this analysis.

Table 9 Panel B presents the results of this placebo exercise. It shows that highway rays in 2010 or 1999 predict essentially zero decentralization between 1982 and 1990, as they should. In particular, our point estimates are -0.017 and -0.012 respectively with large standard errors. These point estimates are considerably smaller than those in Table 4. These results suggest that our 1962 instruments are not correlated with unobservables that drive population decentralization, conditional on base control variables. We cannot carry out a similar exercise for GDP as it is not observed before 1990.

7.3 Heterogeneous Effects

We recognize that our estimates of causal effects of transportation infrastructure on decentralization may mask heterogeneity across different types of cities. For example, because decentralization primarily took the form of displacing some city growth to more peripheral regions, one might expect transportation to have a larger effect in more rapidly growing regions. We evaluate the extent to which regional differences are important for our results by estimating versions of our key regressions in which we interact transportation measures with region. After some experimentation, we find that we can break up China into at most two regions, the East and the remainder of the country, without losing first stage power.

Table 9 Panel C shows the results of this exercise. It shows that for population decentralization, estimates are not significantly different in the middle and western part of the country. However, we do find some evidence that the effect of railroad rays on industrial GDP decentralization is weaker in this region. While the effect of an average railroad ray is -0.45 in the East, this effect is 0.30 larger in the Middle and West at -0.15. The difference in East and Middle/West railroad ray effects is significant at the 10 percent level. It may be the case that market pressures of rising central city land and labor costs were not as severe in these cities, which have grown less quickly, and thus industry responded less dramatically to available decentralization opportunities.

8. Conclusions

Transportation infrastructure networks have profound and long-lasting impacts on urban form and the compactness of cities. In this study we find that this common assessment applies to a large developing country where there is yet to be widespread usage of automobiles for commuting and trucks for intercity movement of goods. For population decentralization within cities, we find that both radial highways and ring roads lead to substantial decentralization, while increased bus supplies contribute to compactness. For production, we find that more radial railroads enhance industrial decentralization as do ring roads, with the latter presumably proving links to suburban intermodal railroad connections.

References

Alonso, W., 1964. Location and Land Use, Cambridge: Harvard University Press.

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

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

Banerjee, A., E. Duflo and N. Qian, 2012. On the Road: Transportation Infrastructure and Economic Development, NBER Working Paper 17897.

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

Burchfield, M., H.G. Overman, D. Puga, and M.A. Turner, 2006. Causes of Sprawl: A Portrait from Space, *Quarterly Journal of Economics,* 121:2, 587-633.

Chan, K. W., 2001. Recent Migration in China: Patterns, Trends, and Policies, *Asian Perspectives*, 25:4, 127-155.

Chan, K. W., 2005. Migration and Small Town Development: Some Notes, World Bank Workshop, Beijing.

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

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

China Statistics Press, 1992a. 1990 Provincial Census Books.

China Statistics Press, 1992b. 1990 China Urban Statistical Yearbooks.

China Statistics Press, 1992c. 1990 Provincial Statistical Yearbooks.

China Statistics Press , 2002. 2000 Census County Statistics.

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

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

Duranton, G., 2007. Urban evolutions: the fast, the slow, and the still, *American Economic Review*, 97, 197-221.

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, G., P. M. Morrow, and M. A. Turner, 2011. Roads and trade: Evidence from US cities, manuscript.

Duranton, G. and M. A. Turner, 2011. The fundamental law of road congestion: Evidence from US cities. *American Economic Review,* 101:6, 2616-2652.

Duranton, G. and M. A. Turner, 2012. Urban growth and transportation, *Review of Economic Studies*, forthcoming.

Garske, T., H. Yu, Z. Peng, M. Ye, H. Zhou, X. Cheng, J. Wu and N. Ferguson, 2011. Travel Patterns in China. *PLoS ONE,* 6:2, e16364.

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., A. Storeygard and D. Weil, 2012. Measuring Economic Growth from Outer Space, *American Economic Review*, forthcoming.

Holl, Adelheid and Elisabet Viladecans-Marsal, 2011. Infrastructure and Cities: The Impact of New Highways on Urban Growth, Universitat de Barcelona-Institut d'Economia de Barcelona Working Paper.

Hsu, W-T and H. Zhang, 2011. The Fundamental Law of Highway Congestion: Evidence from Japanese Expressways, Chinese University of Hong Kong Working Paper.

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

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

Lee, K.S., 1982. A model of intra-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.

Lianxinwang Web Site, 2012. Compendium of reports from local statistics bureaus, http://www.luqyu.cn/index.asp.

Lucas, R.E., 1988. On the mechanics of economic development, *Journal of Monetary Economics*, 22, 3-42.

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

Ma, L. J.C. and M. Fan, 1994. Urbanisation from below: The growth of towns in Jiangsu, China, *Urban Studies*, 31:10, 1625-1645.

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

Michaels, G., 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.

Muth, Richard F., 1969. Cities and Housing, Chicago: University of Chicago Press.

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, published in March 1999, Peoples Liberation Army, Factory 1206, distributed by Xinhua bookstore.

Puga, D. and N. Nunn, 2011. Ruggedness: The blessing of bad geography in Africa, *Review of Economics and Statistics*, forthcoming.

Riley, S. J., S. D. DeGloria, and R. Elliot, 1999. A Terrain Ruggedness Index that Quantifies Topographic Heterogeneity, *Intermountain Journal of Sciences, 5:* 23–27.

Saiz, A., 2010. The Geographic Determinants of Housing Supply, *Quarterly Journal of Economics*, 125, 1253-1296.

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.

Su, J., *National Transportation Map*. Scale 1:6000000, as of 1924, Peking University's Modern Style Zhonghua Map Press, publication date August 1924, distributed by Peking University Press.

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

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

World Bank, 1982. *China – Socialist economic development* (Vol. 7 of 9): Annex F: The transport sector.

Zhang, J., 2011. Measuring the income-distance trade-off for rural-urban migrants in China, http://www.clarku.edu/faculty/facultybio.cfm?id=637.

Zhou Y and J. R. Logan, 2007. Growth on the Edge: The New Chinese Metropolis Pp. 140-160 in John R. Logan (editor), *Urban China in Transition*. London: Blackwell Publishers.

Table 1: Growth in Aggregate Lights, Population and GDP by Location, 1990-2010

	City Proper		Prefecture Remainder	
Panel A: 2010 Sample of 210 Prefectures				
	Lights	Population	Lights	Population
(Mean in 1990)		(982,333)		(2,995,989)
1990-2000	54%	27%	99%	4%
2000-2010	33%	22%	37%	1%
1990-2010	105%	55%	172%	5%
Panel B: 2000 Sample of 257 Prefectures				
	Lights	Population	Lights	Population
(Mean in 1990)		(955,683)		(2,953,557)
1990-2000	52%	25%	94%	4%
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
(Mean in 1990)	(20.5)	(12.3)	(17.5)	(7.0)
1990-2000	183%	138%	309%	366%
2000-2005	122%	117%	72%	92%
1990-2005	530%	417%	605%	794%

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 GDP regressions in Tables 6-9 because this table excludes prefectures without valid GDP data in 1990 while Tables 6-9 only use central city GDP information. All GDP numbers are deflated using provincial deflators.

Table 2: First Stage Regressions

	2010 Hwy Rays (1)	1999 Hwy Rays (2)	2005 Rail Rays (3)	1999 Hwy Rings (4)
highway rays in 1962	0.37***	0.32***	0.022	-0.0043
	(0.080)	(0.079)	(0.082)	(0.018)
railroad rays in 1962	0.24*	0.17**	0.50***	0.0045
	(0.13)	(0.078)	(0.057)	(0.023)
highway rings in 1962	0.55	-0.56	0.013	0.44***
	(1.04)	(0.37)	(0.26)	(0.12)
ln(central city area)	0.039	0.16	0.069	-0.073***
	(0.16)	(0.11)	(0.12)	(0.023)
ln(prefecture area)	0.25	0.23	-0.13	-0.030
	(0.20)	(0.14)	(0.16)	(0.043)
ln(1990 agric. *hukou* pop	0.0098	0.36**	0.19	0.0059
outside central city)	(0.14)	(0.14)	(0.12)	(0.020)
ln(1992 prefecture lights)	0.44***	-0.042	0.030	-0.0087
	(0.15)	(0.13)	(0.17)	(0.032)
Δ ln(prefecture population)	-0.18			
1990-2010	(0.60)			
Δ ln(prefecture population)		1.76***	-1.55***	0.15
1990-2000		(0.48)	(0.41)	(0.13)
Δ ln(prefecture lights)	-0.15	0.020	-0.46	0.044
1992-20xx	(0.53)	(0.32)	(0.36)	(0.061)
provincial capital indicator	1.91***	1.44***	0.096	0.13
	(0.42)	(0.46)	(0.24)	(0.096)
constant	-5.06*	-6.30***	-0.62	0.86*
	(2.49)	(2.14)	(1.79)	(0.49)
Observations	210	257	205	257
R-squared	0.31	0.29	0.29	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 in parentheses are clustered by province. *** p<0.01, ** p<0.05, * p<0.1

Table 3: OLS 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	0.014	-0.011		
	(0.011)	(0.0073)		
highway rays in 1999			0.022***	0.011
			(0.0076)	(0.0073)
ln(central city area)		-0.12***		-0.063***
		(0.021)		(0.016)
ln(prefecture area)		0.031		0.016
		(0.030)		(0.014)
ln(1990 agric. *hukou* pop		0.070**		0.035*
outside central city)		(0.029)		(0.018)
ln(1992 prefecture lights)		0.021		0.016
		(0.026)		(0.012)
Δ ln(prefecture population)		0.79***		0.80***
1990-20xx[a]		(0.11)		(0.085)
Δ ln(prefecture lights)		0.090*		0.072**
1992-20xx		(0.046)		(0.034)
provincial capital indicator		0.087		0.0017
		(0.059)		(0.032)
constant	0.36***	-0.43	0.17***	-0.28
	(0.058)	(0.38)	(0.031)	(0.24)
Observations	210	210	257	257
R-squared	0.01	0.56	0.03	0.39

Notes: Each column shows coefficients from a separate OLS regression of the variable listed at top on the variables listed at left. Standard errors in parentheses are clustered by province. *** p<0.01, ** p<0.05, * p<0.1

[a]Growth is from 1990 to 2010 in Columns (1) and (2) and to 1999 in the remaining columns.

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)
highway rays in 2010	-0.030	-0.046**	-0.038*			
	(0.030)	(0.022)	(0.022)			
highway rays in 1999				-0.0053	-0.047***	-0.042***
				(0.015)	(0.014)	(0.013)
ln(central city area)		-0.12***	-0.13***		-0.054***	-0.052***
		(0.020)	(0.020)		(0.016)	(0.016)
ln(prefecture area)		0.043	0.058*		0.032***	0.055***
		(0.027)	(0.034)		(0.011)	(0.012)
ln(1990 agric. *hukou* pop		0.076***	0.064*		0.065***	0.053***
outside central city)		(0.028)	(0.035)		(0.020)	(0.018)
ln(1992 prefecture lights)		0.036	0.037		0.013	0.0053
		(0.027)	(0.030)		(0.016)	(0.019)
Δ ln(prefecture population)		0.79***	0.75***		0.91***	0.91***
1990-20xx[a]		(0.088)	(0.092)		(0.095)	(0.098)
Δ ln(prefecture lights)		0.083*	0.076		0.073*	0.050
1992-20xx		(0.045)	(0.053)		(0.038)	(0.039)
provincial capital indicator		0.16**	0.16**		0.097**	0.097**
		(0.081)	(0.076)		(0.042)	(0.039)
ln(precipitation)			0.029			0.029**
			(0.039)			(0.014)
central city elevation range			8.1e-06			-0.000038**
			(0.000023)			(0.000016)
prefecture elevation range			1.3e-07			8.9e-06
			(0.000011)			(8.7e-06)
ln(distance to coast)			-0.0086			-0.0084
			(0.014)			(0.0057)
constant	0.49***	-0.66*	-0.77**	0.25***	-0.76**	-0.87***
	(0.11)	(0.35)	(0.37)	(0.055)	(0.30)	(0.31)
Observations	210	210	210	257	257	257
First stage F	30.3	23.2	26.3	23.8	17.0	15.2

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 2. Columns (1)-(3) use the sample of cities for which we have data on population in 2010 while Columns (4)-(5) use the more complete sample of prefecture level cities in our study region. Standard errors in parentheses are clustered by province. *** p<0.01, ** p<0.05, * p<0.1

[a]Growth is from 1990 to 2010 in Columns (1) through (3) and to 1999 instead in the remaining columns.

Table 5: IV Estimates of Additional Transport Infrastructure Effects 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 or 1999	-0.054**	-0.052**	-0.052**	-0.047***	-0.047***	-0.047***
	(0.025)	(0.023)	(0.024)	(0.015)	(0.017)	(0.018)
ln(km of highways in prefecture)	0.045			-0.0034		
in 2010 or 1999	(0.17)			(0.085)		
ln(km of highways in prefecture		0.027			0.040	
outside of CC) in 2010 or 1999		(0.071)			(0.067)	
railroad rays in 2010 or 1999			0.039			0.0013
			(0.048)			(0.024)
ln(central city area)	-0.12***	-0.11***	-0.12***	-0.054***	-0.046**	-0.054***
	(0.019)	(0.025)	(0.024)	(0.016)	(0.019)	(0.016)
ln(prefecture area)	0.021	0.020	0.045	0.034	-0.0075	0.032***
	(0.11)	(0.074)	(0.028)	(0.065)	(0.069)	(0.011)
ln(1990 agric. *hukou* pop	0.071	0.076**	0.071***	0.065***	0.062***	0.065***
outside central city)	(0.047)	(0.035)	(0.024)	(0.021)	(0.022)	(0.020)
ln(1992 prefecture lights)	0.022	0.025	0.030	0.014	0.0094	0.013
	(0.031)	(0.023)	(0.025)	(0.018)	(0.017)	(0.018)
Δ ln(prefecture population)	0.79***	0.79***	0.82***	0.91***	0.86***	0.92***
1990-20xx[a]	(0.093)	(0.095)	(0.087)	(0.10)	(0.11)	(0.100)
Δ ln(prefecture lights)	0.077*	0.077*	0.100*	0.075*	0.065	0.074
1992-20xx	(0.044)	(0.045)	(0.058)	(0.041)	(0.040)	(0.048)
provincial capital indicator	0.17**	0.17**	0.15*	0.098**	0.098**	0.096**
	(0.083)	(0.079)	(0.079)	(0.043)	(0.045)	(0.041)
constant	-0.51	-0.55	-0.64**	-0.76*	-0.59	-0.75**
	(0.79)	(0.57)	(0.31)	(0.42)	(0.50)	(0.30)
Observations	209	205	210	255	253	257
First stage F	6.15	11.0	8.19	6.99	8.07	6.51

Notes: Elements of the 1962 road and rail infrastructure instrument for indicated elements of road and rail infrastructure from 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. Standard errors in parentheses are clustered by province. *** p<0.01, ** p<0.05, * p<0.1

[a]Growth is from 1990 to 2010 in Columns (1) through (3) and to 1999 instead in the remaining columns.

Table 6: IV Estimates of Transport Infrastructure Effects on the Decentralization of Production

	∆ln(Ind Sect GDP)			∆ln(GDP)			∆ln(Lights)		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
highway rays in 2005	-0.028			0.0049			0.015		
	(0.083)			(0.048)			(0.029)		
railroad rays in 2005		-0.26**			-0.17***			-0.044*	
		(0.11)			(0.064)			(0.026)	
ln(2005 km of railroads in			-0.82***			-0.54***			-0.22*
prefecture)			(0.24)			(0.15)			(0.12)
ln(central city area)	0.12*	0.11*	0.11	0.015	0.015	-0.0011	0.071***	0.076***	0.072***
	(0.066)	(0.068)	(0.065)	(0.047)	(0.048)	(0.047)	(0.024)	(0.023)	(0.023)
ln(prefecture area)	-0.29**	-0.31***	0.22	-0.20**	-0.20***	0.17	-0.090*	-0.087**	0.040
	(0.13)	(0.11)	(0.17)	(0.077)	(0.070)	(0.11)	(0.048)	(0.042)	(0.088)
ln(1990 agric. *hukou* pop	0.28***	0.31***	0.29***	0.13**	0.17***	0.16***	-0.00041	0.024	0.030
outside central city)	(0.11)	(0.11)	(0.11)	(0.056)	(0.063)	(0.063)	(0.042)	(0.036)	(0.038)
ln(1992 prefecture lights)	-0.010	0.054	0.15	0.072	0.090	0.15*	0.020	0.020	0.063
	(0.13)	(0.11)	(0.14)	(0.076)	(0.063)	(0.082)	(0.040)	(0.032)	(0.041)
∆ ln(prefecture population)	1.67**	1.37**	0.80	0.51**	0.31	-0.0054	-0.053	-0.088	-0.33*
1990-20xx[a]	(0.82)	(0.69)	(0.64)	(0.24)	(0.20)	(0.23)	(0.17)	(0.14)	(0.17)
∆ ln(prefecture lights)	0.31	0.14	0.046	0.30**	0.17	0.081	0.93***	0.89***	0.81***
1992-20xx	(0.22)	(0.28)	(0.24)	(0.15)	(0.17)	(0.16)	(0.080)	(0.079)	(0.085)
provincial capital indicator	-0.40**	-0.31	-0.22	-0.057	0.036	0.12	-0.11*	-0.066	-0.033
	(0.19)	(0.21)	(0.19)	(0.097)	(0.13)	(0.13)	(0.065)	(0.051)	(0.052)
constant	-0.63	-0.86	-2.56	0.68	0.37	-0.75	0.076	-0.19	-0.76
	(1.67)	(1.64)	(2.09)	(0.95)	(1.06)	(1.26)	(0.38)	(0.30)	(0.49)
Observations	187	187	184	205	205	202	257	257	248
First stage F	16.7	48.3	16.4	16.9	76.4	25.8	35.8	90.1	20.9

Notes: Infrastructure measures from 1962 instrument for those in 2005. Sample sizes are larger than in Table 1 Panel C because we observe more GDP data for existing or soon to be promoted prefecture level cities in 1990 than we do GDP data for full 2005 definition prefectures. Standard errors in parentheses are clustered by province. *** p<0.01, ** p<0.05, * p<0.1

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

	∆ln(CC Pop)		∆ln(CC Ind. GDP)		∆ln(CC GDP)	
	1990-2010	1990-2000	1990-2005		1990-2005	
	(1)	(2)	(3)	(4)	(5)	(6)
highway rays at time t	-0.038	-0.054***	-0.089		-0.073	
	(0.024)	(0.019)	(0.12)		(0.10)	
railroad rays at time t				-0.28**		-0.18***
				(0.11)		(0.071)
highway ring outside CC	0.055	-0.20**	-0.76*	-0.80***	-0.54*	-0.46**
indicator at time t	(0.099)	(0.086)	(0.42)	(0.28)	(0.31)	(0.22)
ln(central city area)	-0.11***	-0.072***	0.029	-0.00036	-0.041	-0.050
	(0.024)	(0.018)	(0.075)	(0.067)	(0.046)	(0.043)
ln(prefecture area)	0.038	0.030**	-0.27**	-0.32***	-0.19**	-0.21***
	(0.025)	(0.013)	(0.14)	(0.10)	(0.084)	(0.064)
ln(1990 agric. *hukou* pop	0.073***	0.067***	0.36***	0.35***	0.21**	0.19***
outside central city)	(0.026)	(0.024)	(0.10)	(0.089)	(0.098)	(0.064)
ln(1992 prefecture lights)	0.034	0.011	-0.036	0.059	0.047	0.097*
	(0.026)	(0.016)	(0.11)	(0.093)	(0.072)	(0.054)
∆ ln(prefecture population)	0.79***	0.95***	2.26***	1.77***	0.69*	0.28
1990-20xx[a]	(0.087)	(0.11)	(0.86)	(0.66)	(0.36)	(0.21)
∆ ln(prefecture lights)	0.092**	0.079**	0.25	0.094	0.25	0.15
1992-20xx	(0.039)	(0.038)	(0.23)	(0.30)	(0.16)	(0.18)
provincial capital indicator	0.14	0.13**	-0.38*	-0.34	0.046	0.057
	(0.088)	(0.053)	(0.22)	(0.25)	(0.14)	(0.14)
constant	-0.65*	-0.58*	-0.72	-0.40	0.46	0.73
	(0.36)	(0.35)	(1.68)	(1.54)	(1.21)	(0.95)
Observations	210	257	187	187	205	205
First stage F	4.66	8.61	9.20	9.92	5.01	5.63

Notes: Year t as indicated in variable names at left is the end year of the dependent variable listed at the top of each column. Road and rail network measures in 1962 instrument for these measures in later years. Standard errors in parentheses are clustered by province. *** p<0.01, ** p<0.05, * p<0.1

Table 8. Effects of Public Transport and Waterways

	∆ln(CC Pop) 1990-2010 (1)	∆ln(CC Ind. GDP) 1990-2005 (3)	∆ln(CC GDP) 1990-2005 (4)
highway rays in 2010	-0.039*		
	(0.022)		
ln(central city buses & trolleys	0.028*		
in 2005)	(0.016)		
railroad rays in 2005		-0.26**	-0.16**
		(0.11)	(0.066)
river & canal rays		0.011	0.020
		(0.023)	(0.015)
ln(central city area)	-0.12***	0.11*	0.017
	(0.019)	(0.068)	(0.047)
ln(prefecture area)	0.046	-0.31***	-0.20***
	(0.028)	(0.11)	(0.071)
ln(1990 agric. *hukou* pop	0.067**	0.30***	0.16**
outside central city)	(0.029)	(0.11)	(0.068)
ln(1992 prefecture lights)	0.021	0.057	0.096
	(0.031)	(0.11)	(0.064)
∆ ln(prefecture population)	0.76***	1.37**	0.33*
1990-20xx[a]	(0.090)	(0.69)	(0.19)
∆ ln(prefecture lights)	0.095**	0.14	0.17
1992-20xx	(0.041)	(0.28)	(0.17)
provincial capital indicator	0.10	-0.33	0.00033
	(0.083)	(0.21)	(0.12)
constant	-0.61	-0.85	0.39
	(0.38)	(1.64)	(1.04)
N	208	187	205
First stage F	28.0	44.2	67.0

Notes: Standard errors in parentheses are clustered by province. *** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table 9: Robustness

	Δln(CC Pop) 1990-2010 (1)	Δln(CC Pop) 1990-2000 (2)	Δln(CC Ind GDP) 1990-2005 (3)	Δln(CC GDP) 1990-2005 (4)
Panel A: Instrumenting for Prefecture Population Growth				
highway rays in 2010 or 1999	-0.033	-0.042***		
	(0.034)	(0.015)		
railroad rays in 2005			-0.25***	-0.14**
			(0.094)	(0.057)
N	210	257	187	205
First stage F	2.49	8.63	8.01	2.65
Panel B: Placebo Regressions Using Outcomes 1982-1990				
highway rays in 2010	-0.017			
	(0.04)			
highway rays in 1999		-0.012		
		(0.028)		
N	237	237		
First stage F	7.28	12.6		
Panel C: Heterogeneous Effects by Region				
highway rays in 2010 or 1999	-0.060*	-0.049***		
	(0.032)	(0.015)		
highway rays X Middle or West	0.026	0.0042		
	(0.039)	(0.024)		
railroad rays in 2005			-0.45***	-0.22***
			(0.12)	(0.086)
railroad rays X Middle or West			0.30*	0.095
			(0.17)	(0.11)
N	210	257	187	205
First stage F	11.5	9.22	12.8	17.9

Notes: All regressions in Panel A also include the same non-transport control variables as in Table 4 Column 2 or 4, or Table 6 Column 2 or 5 except prefecture lights levels and growth. Regressions in Panel A use the aggregate central city population within 300 km of each central city as an instrument for prefecture population growth. Regressions in Panel B use ln 1982-1990 central city population growth as the outcome and control for the same variables as in Table 4 Column 2 except prefecture lights levels and growth, prefecture population growth and 1990 prefecture agricultural population. Instead, ln 1982-1990 prefecture population growth and ln 1982 prefecture population are included as controls. Regressions in Panel C use the same specifications as in Table 4 Column 2 or 4, or Table 6 Column 2 or 5 but also include a middle/west region dummy variable. As in Tables 4 and 6, 1962 transport infrastructure instruments for transport infrastructure variables in all regressions.

Table A1: Summary Statistics

	Sample of 210 1990-2010				Sample of 257 1990-2000			
	Mean	Stdev	Min	Max	Mean	Stdev	Min	Max
Panel A: Transport Measures and Instruments								
Highway Rays at End of Period	2.97	2.02	0	11	2.84	1.69	0	8
log(km of highways in prefecture)	5.86	0.72	3	7.63	5.96	0.69	1.60	7.93
Ring road indicator at End of Period	0.22	0.41	0	1	0.14	0.34	0	1
Railroad Rays at End of Period	1.78	1.23	0	5	1.64	1.39	0	6
log(km of railroad in pref outside cc)	4.72	1.05	-2	6.71	4.70	0.83	2	6.35
1962 Highway Rays	1.94	1.24	0	6	1.87	1.26	0	6
1962 log (km of highways in pref)	5.55	0.87	0.00	7.42	5.58	0.85	0.00	7.42
1962 Ring Road Indicator	0.03	0.18	0	1	0.05	0.23	0	1
1962 Railroad Rays	1.01	1.18	0	4	1.08	1.16	0	4
1962 log(km of highways in pref)	2.70	2.19	0	6.36	2.83	2.17	0	6.36
Panel B: Dependent Variables								
Δlog(Central city population)	0.40	0.30	-0.25	1.42	0.23	0.21	-0.08	1.48
Δlog(Central city GDP)	1.83	0.45	0.47	3.00	1.81	0.44	0.47	3.00
Δlog(Central city industrial GDP)	1.75	0.65	-0.84	3.86	1.74	0.65	-0.84	3.86
Δlog(central city lights)	0.63	0.41	-0.26	2.58	0.60	0.41	-0.26	2.58
Panel C: Control Variables								
Log Central City Area	7.15	0.95	4.63	9.88	7.10	0.95	4.63	9.91
Log Prefecture Area	9.31	0.75	6.95	12.03	9.31	0.74	6.95	12.03
Log(1990 Agric Hukou Pop Outside CC)	14.50	0.85	12.03	16.96	14.50	0.83	12.03	16.96
Log(1992 Prefecture Lights)	9.61	0.94	6.88	11.97	9.64	0.93	6.88	11.97
Δlog(Prefecture Population)	0.14	0.21	-0.17	1.83	0.09	0.12	-0.10	1.44
provincial capital indicator	0.11	0.32	0	1	0.10	0.30	0	1
log(precipitation)	6.84	0.52	4.47	7.80	6.81	0.52	4.47	7.80
central city elevation range	827	646	15	4129	794	614	15	4129
prefecture elevation range	1598	1334	34	8837	1575	1362	26	8837
log(distance to coast)	5.32	1.86	-5.38	7.43	5.25	1.84	-5.38	7.43
middle/west region indicator	0.61	0.49	0	1	0.58	0.50	0	1

Notes: The two GDP outcome measures reported in Panel B are for the 1990-2005 time period on both sides of the table and reflect fewer observations than for other reported variables. For Δlog(Central city GDP) there are 185 observations in the restricted sample and 229 observations in the broader sample. For Δlog(Central city industrial GDP) there are 165 and 207 observations in each respective sample. Δlog(Central city lights) is reported for the 1992 to 2005 period.

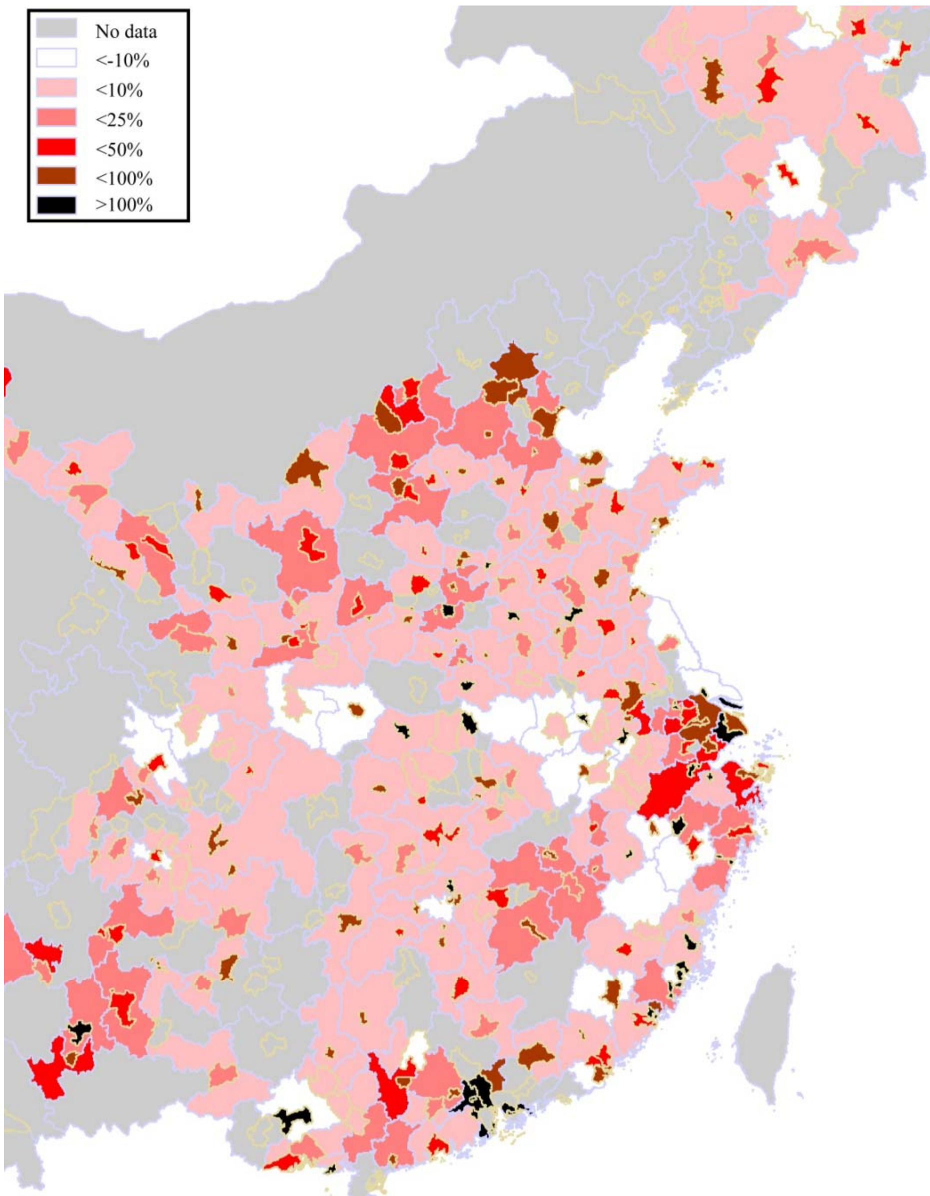

Figure 1a: Population growth by location, 1990-2010.

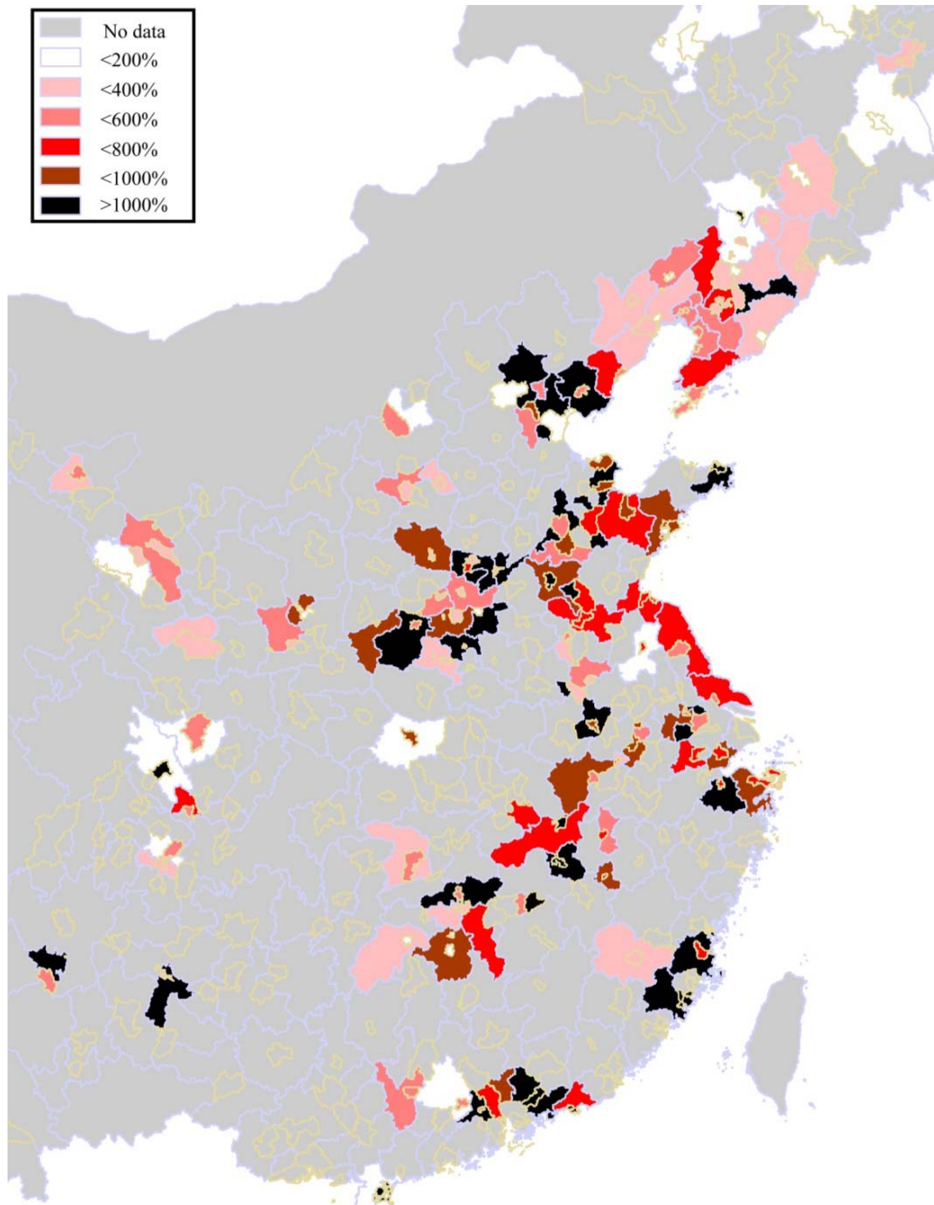

Figure 1b: Industrial sector GDP growth by location, 1990-2005.

Figure 2a: Study area. Light gray indicates prefectures included in our study. Black lines indicate 2005 prefecture boundaries. Dark gray indicates the extent of constant boundary 1990 central cities.

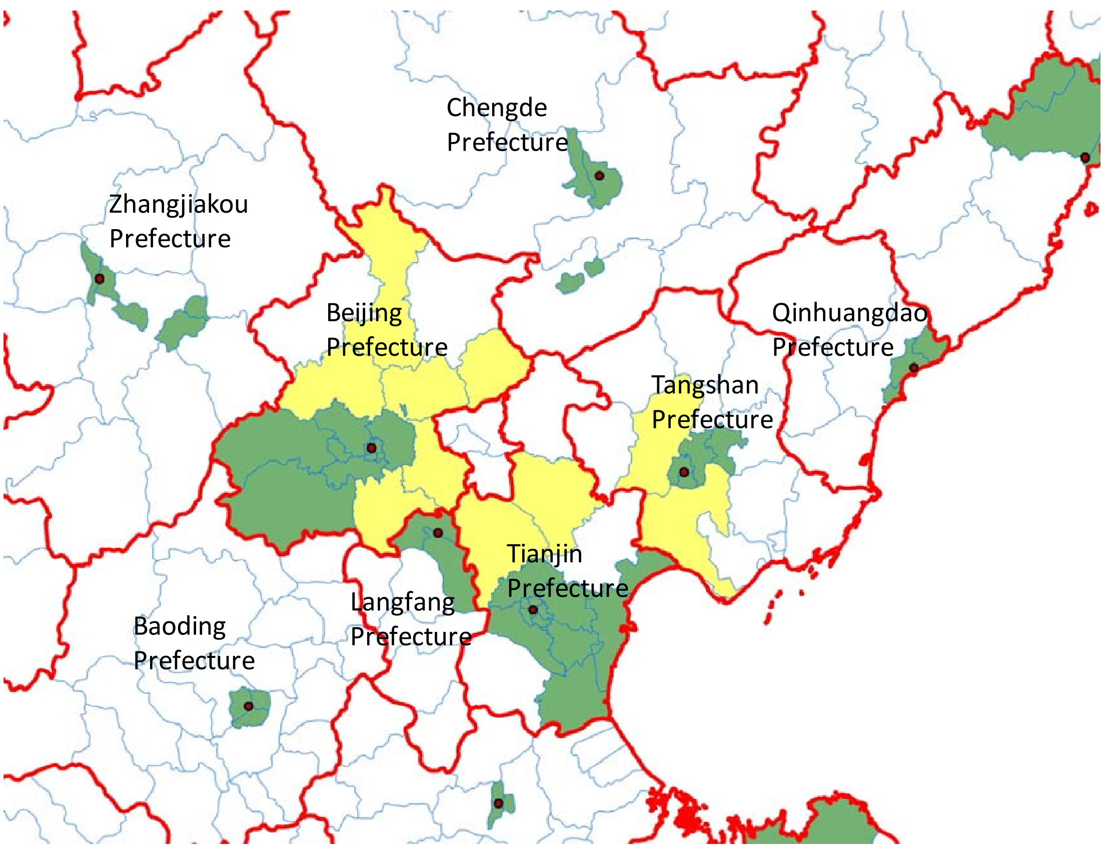

Figure 2b: Beijing area political geography. Red lines indicate 2005 definition prefecture boundaries and light blue lines indicate county/urban district boundaries. Green shaded regions are 1990 central cities and yellow shaded regions are central city expansions 1990-2005.

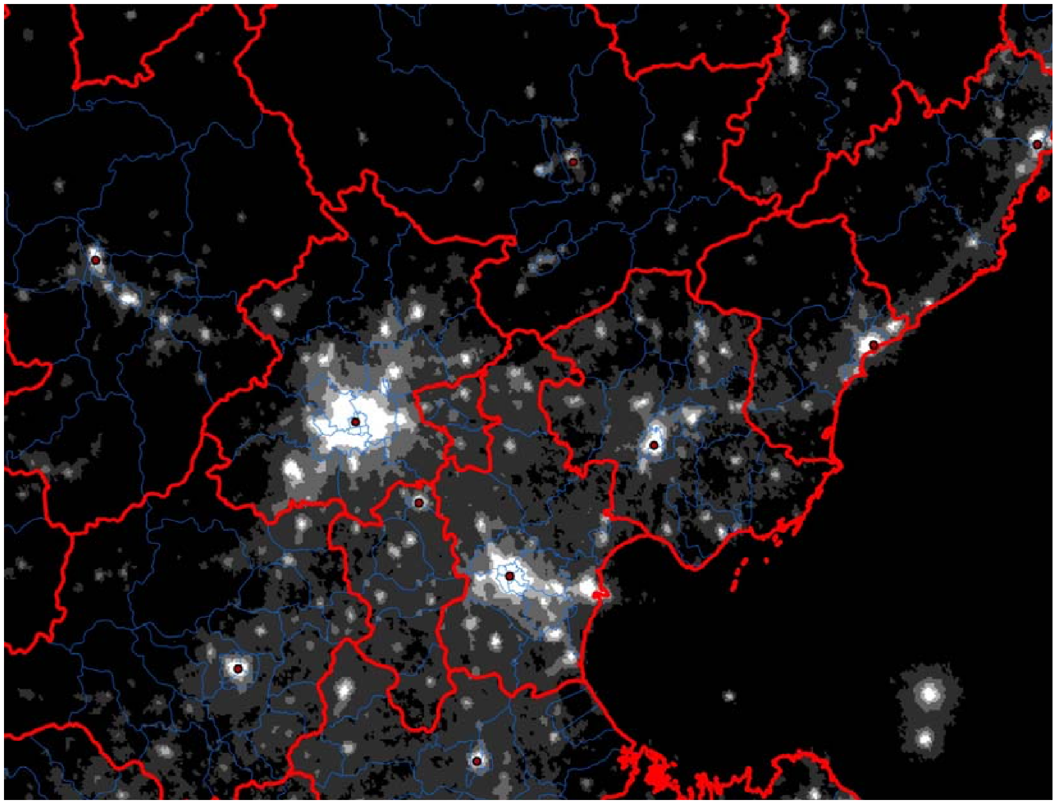

Figure 3a: Lights at night in 1992 for the Beijing area.

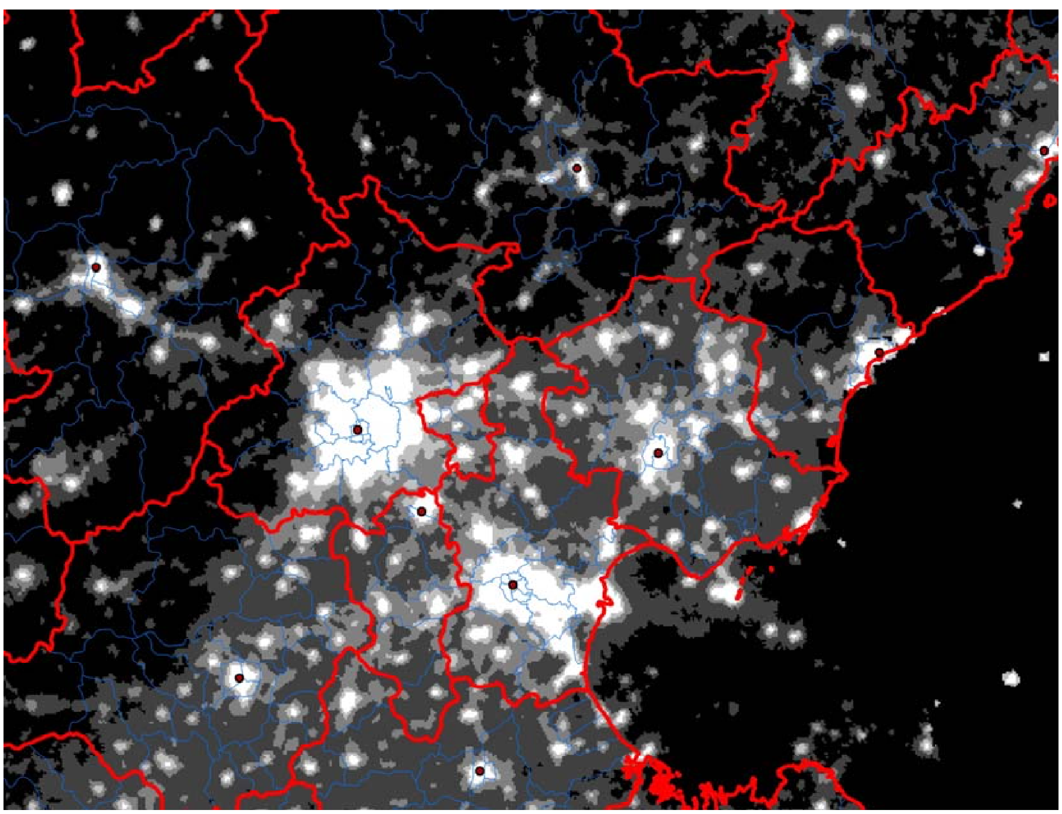

Figure 3b: Lights at night in 2009 in the Beijing area.

Figure 4a: Beijing area from the 2005 printed national China map.

Figure 4b: Digital map of the Beijing area. Green indicates the extent of the Beijing province & prefecture, tan the extent of the 1990 central city, hatched lines 2005 railroads, and solid lines 2005 national roads.

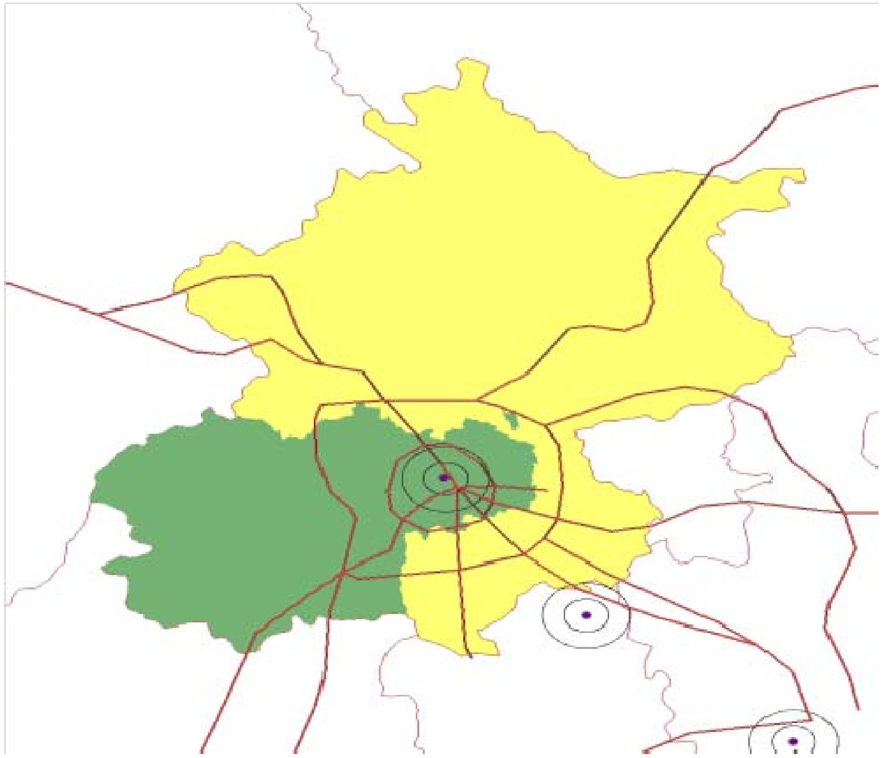

Figure 5a: Construction of our radial road index for Beijing.

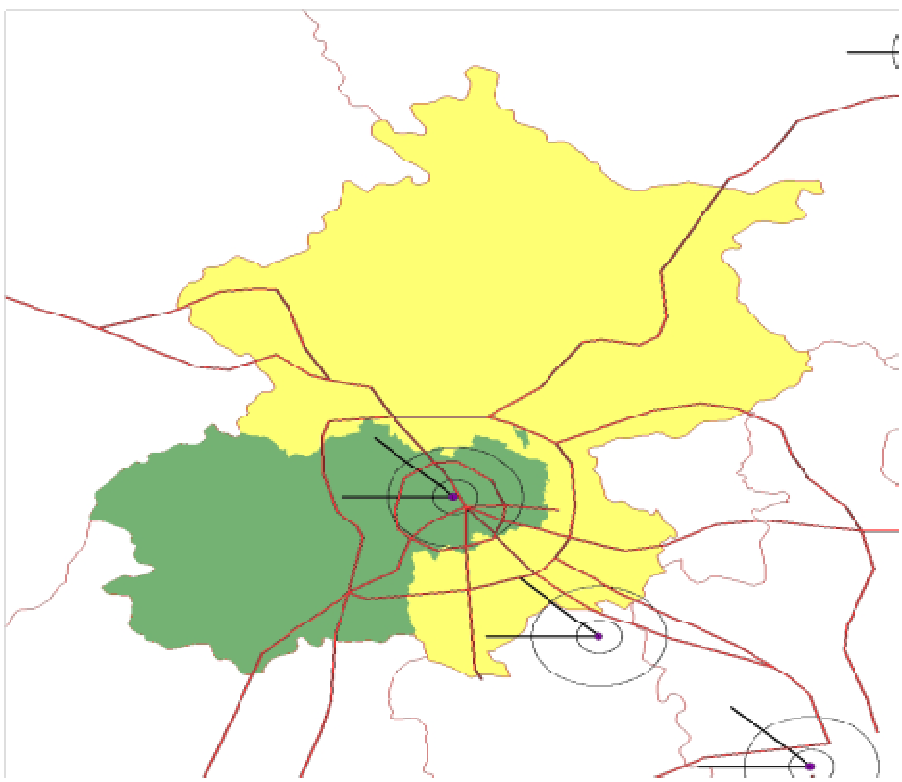

Figure 5b: Construction of our ring road index for Beijing.