Roads, Railroads and Decentralization of Chinese Cities*

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Abstract: We investigate how the configurations of urban railroads and highways have influenced urban form in Chinese cities since 1990. Each radial highway displaces at least 5 percent of central city population to surrounding regions and ring roads displace an additional 20 percent. Each radial railroad displaces 26 percent of central city industrial GDP with ring roads displacing an additional 50 percent. Products with high weight-to-value ratios appear unresponsive to transport changes. However, products with medium and low weight-to-value ratios decentralize in response to radial railroads and ring roads. Historical transportation infrastructure provides identifying variation in more recent measures of infrastructure.

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1. Introduction

Developing countries spend huge sums on transportation infrastructure investments that shape their cities for decades to come. In 2011, 20 percent of World Bank lending was for transportation infrastructure, more than the Bank's lending on social programs. In a modern city, highway and rail investments are central to land use planning and policy, the development of feeder roads and street networks, and the spatial lay-out of utilities. Urban transportation improvements generate direct welfare benefits through reduced commuting and shipping costs. They lead to changes in urban form, including the density of population and production throughout the metropolitan region, which also influence welfare through their effects on urban productivity, social externalities in the residential sector, urban environmental costs and the supply of land available for agricultural production versus urban housing. While mayors and planners worldwide ultimately want to determine the optimal scale, scope, and lay-out of 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 various aspects of urban form.

In the early 1990s, China began to build and upgrade its transportation infrastructure, particularly its highways. From a low level in 1990, investment in transportation infrastructure has grown at approximately 15 percent a year, much of it in cities. This infrastructure investment coincided with other profound changes in the Chinese economy. There was a gradual relaxation of internal migration restrictions and an enormous amount of migration of rural individuals to cities. In addition, as the constraints of central planning on economic activity relaxed, Chinese cities transformed; central cities were torn down and rebuilt, Maoist era residential and industrial buildings almost all disappeared, and industries decentralized into previously agricultural areas. This happened in a context in which economic growth has averaged over 10 percent a year, yielding a GDP per capita today of about $7750 (Penn World Tables). We investigate how the extent and configuration of

Chinese highway and railroad networks contributed to the relative decentralization of population and specific types of economic activity from central cities to suburban and ex-urban areas during this period. Since such decentralization could 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 digitized national road and railroad maps from 1962, 1980, 1990, 1999, 2005 and 2010 with population census information by county from 1982, 1990, 2000, 2010, economic census information by county for 1995 and 2008, and information assembled from city and national urban yearbooks for components of GDP for 1990-2010. We also at times utilize satellite images of lights at night from 1992 to 2010. We focus on urban decentralization between 1990 and 2010.

We find strong evidence that the presence of radial highways and ring roads outside of central cities reduce population density in central cities. Our estimates indicate that each additional radial highway displaced at least 5 percent of central city population to suburban regions and that the existence of some ring road capacity in a city reduced city population by about 20 percent. Since most Chinese central cities experienced rapidly growing population during our study period, highways retarded this centralization. Conditional on the radial and ring configuration of the highway network, total kilometers of neither highways nor railroads influence urban population decentralization. These findings provide econometric evidence in support of the conventional wisdom (e.g. World Bank, 2002) that urban density is reduced by radial and ring road construction.

In their classic work, Meyer, Kain and Wohl (1965) suggests that in mid-20th century America, "[a] circumferential highway, placed in the first band of uninhabited land just beyond the city limits or built-up suburban residential area, provides an almost ideal site for the performance of truck-to-rail transfers…. Large parking lots for storing and moving containers for truck trailers, and rail sidings required to create piggyback or containerized trains are conveniently located there. Manufacturing and other businesses requiring transport inputs can be expected to locate reasonably close to these new transportation facilities" (Meyer et al., 1965, p19). Consistent with this intuition, we find that the location of industrial production responds to the extent of the local *railroad* network and the development of ring roads, but not to radial highways. A marginal radial railroad line displaces about 27% of central city industrial GDP, while the existence of some ring road capacity displaces more than 50% of central city industrial GDP. These are huge effects, but they are consistent with case studies in the literature reviewed below.

The discussion in Meyer et al. also suggests that the way that industries respond to infrastructure may vary among products which have high, medium and low weight-to-value ratios. High weight-to-value products, especially those with large plant capital stocks, may be slow to decentralize and may continue to rely on central rail terminal facilities. Medium and lower weight-to-value products decentralize in response to the availability of railroads on city peripheries, and sometimes the existence of linking ring roads. 'Footloose' production which can be more easily organized around long distance trucking may also respond to highway rays. For example, we find that railroads and ring roads displaced similar percentages of employment in machinery and equipment as in industrial GDP overall. However, highway rays also played a role in promoting decentralization of the more footloose textiles and apparel. That rail rays play such an important role in decentralization of production overall may be enhanced by China's unusually heavy historical reliance on railroads 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 roads. While this share increased over time, even in 2005, it is recorded at less than 15%, well below the US where 30% of freight moves by road.[1]

A number of recent papers investigate the roles of transport infrastructure investments in the allocation of resources across regions. Michaels (2008) and Chandra & Thompson (2000) investigate the effect of U.S. interstate highways on the development of rural U.S. counties. Duranton, Morrow and Turner (2013) examine the effects of the interstate highway system on trade between cities. These papers find that the interstate system had a modest effect on inter-regional trade flows and regional economic activity in the late 20th century U.S. Donaldson (2013) examines the impacts of railroads in late 19th and early 20th century India and finds large effects on trade and welfare. However, for China, Banerjee, Duflo, and Qian (2012) and Faber (2013) find transport investments can harm some rural counties. Each of these papers explicitly addresses 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, and finds large and consistent effects. This literature begins with Baum-Snow (2007), which finds that limited access radial highways caused economically important decentralization in U.S. metropolitan areas. Complementing Baum-Snow's work, Duranton and Turner (2012) find that 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 on the extent of other road networks. Hsu and Zhang (2011) replicate this

[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 US, mostly reflecting a discontinuous jump in the 2008 statistics as a result of changing coverage. See China Statistical Abstract, Table 16-9.

result using Japanese data. All of these papers make use of plausibly exogenous variation in road networks to identify the effects of roads on 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 cities in a developing country. 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. None of these papers addresses the role of transportation investments in the decentralization of industry.

A small literature considers the general process of industrial decentralization. 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 have much higher land and somewhat higher labor costs than suburban and ex-urban locations. 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 (Arzaghi and Henderson, 2008). Standardized manufacturing is typically found on the lower cost urban periphery and in small cities and towns (Kolko, 2000; Swartz, 1992).

In developing countries, the situation is different and corresponds to the 19th and early 20th century U.S. 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, when large centrally planned factories typically dominated central 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 & Puga, 2001), industrial firms decentralize to find lower land and labor costs. Meyer et al. (1965) describe this process in the U.S. from 1940 through the 1960's.

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 substantially on the ability of the transportation network to connect peripheral locations to the rest of the local economy (Lee & Choe, 1990; Lee, 1982; Hansen, 1987; Henderson, Kuncoro & Nasution, 1996). Such transformation of cities may improve efficiency through better use of the rich information environments in central cities, thus promoting local economic growth. This paper is the first to investigate the extent to which different highway and railroad network configurations contribute to this transformation overall and for specific industries, in a context where econometric identification of causal effects is addressed.

In summary, we improve on the existing literature in three important ways. 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,[2] where household incomes are much lower and where cities are much denser than in the United States. We start by confirming that Baum-Snow's analysis of the effect of highway rays on population decentralization in the US holds in a developing country. Second, we examine the effects of ring roads and the competing influences of railroads on population decentralization. This is 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, we examine the relationships between different forms of transportation infrastructure and the spatial distribution of production in specific industries, as industries differentially suburbanize. This is also novel.

[2] 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 rather than 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.)

Our conclusions rely on achieving exogenous variation in the transportation variables of interest. We generate such 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. The Context and Experiment

Table 1 shows the growth of population and economic activity in central cities and residual portions of prefectures. Results in Panel A indicate that population grew much more quickly in central cities than in surrounding regions throughout our study period. Between 1990 and 2010 aggregate population growth was 54% in central cities relative to just 5% in city hinterlands. This is urbanization: the flows of Chinese peasants from primarily own prefecture rural counties into central cities.

Data availability restricts the sample of cities for which we observe GDP in the prefecture remainder. To describe the decentralization of economic activity for our whole sample of cities we rely on `lights at night' data. While lights at night may also reflect residential development, Henderson, Storeygard and Weil (2012) show a strong relationship between lights and GDP. Table 1 Panel B shows that lights grew more quickly in suburban areas, especially in the 1990 to 2000 period, despite the much faster growth rate of population in central cities. For the sample for which data is available, Table 1 Panel C presents industrial sector GDP growth. Suburban industrial GDP grew by 1996% between

1990 and 2010 relative to 886% for central cities. These numbers indicate relative decentralization of manufacturing. Our data also allow us to look at total GDP or the production of services. However, patterns of decentralization for total GDP are driven by industrial GDP, and we worry that the service sector was not measured consistently over time.

Figure 1 depicts 1990-2010 trends in aggregate population and industrial GDP for the same central cities and prefecture remainders as in Table 1. Figure 1a shows that almost all central city populations grew more rapidly than did surrounding prefecture populations throughout our study area of Han China, including in the interior. Figure 1b shows that, unlike population, industrial GDP decentralized rapidly in most of the prefectures for which we have complete data during this period.

On the surface, our research design resembles the investigation in Baum-Snow (2007). Baum-Snow examines the effect on central city populations of the Eisenhower highway system, which was begun in the 1950s. He assumes that before 1950 there were no highways connecting central to suburban areas, so that any the change in highways after 1950 reflected new construction. We make the same `no initial highways' assumption, but note that this assumption is even easier to defend for China. In 1990, Chinese 'highways' near major cities were almost universally one or two lane roads and were often unpaved. Paved highways with more than two lanes were built since 1990.

More careful consideration reveals two important differences between our research context and that in Baum-Snow (2007). First, starting around 1950, central cities in the U.S. experienced absolute declines in population, while in China after 1990, central cities saw large absolute population gains and proportional gains relative to their suburbs. Thus, radial highways in the US caused decentralization, while in China during our study period we find that radial highways slowed the rate of centralization.

Second, the institutional environment of the post-war U.S. and in post-1990 China is radically different. In contrast to the U.S., where there are no institutional restrictions on mobility, the urban and rural sectors were under separate institutional and economic regimes in China in 1990. People had citizenship in either the urban or rural sector (as a birth right based on mother's registration) and migration between the two sectors was rare and strictly controlled (Chan, 2001; Au & Henderson, 2006). The U.S. and Chinese economic systems were also entirely different. While private property rights were the norm in the U.S., in China industry and land in the rural counties surrounding central cities were owned by the local collective. In cities, industry and land were owned by the state (Naughton, 2006). Chinese institutions around 1990 did not provide a formal mechanism for individual urban residents or firms to acquire land rights in the rural sector and move out from the central city.

These institutional barriers to the mobility of labor and capital mean that any roads and railroads in place in 1990 could neither be used for commuting, nor could they influence factory relocation from central cities to potential suburbs, a point made by Zhou and Logan (2007). Except for 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 land and labor market reforms, could urban form change in response to market forces. Given that urban reforms start in the early 1990s and that 1990 is a decennial census year, 1990 is a natural base period for our analysis.

That our study period includes this change in economic regime is critical for considering the role of railroads in shaping changes in urban form. The rail system was extensive in 1990 and changes since then have been modest. Thus, a rail analog of our `no initial roads' assumption is not defensible. However, industry could decentralize only after the change in economic regime that occurs early in our study period, when a market for land developed and the state sector privatized. Thus, our investigation considers the effect on industrial decentralization of having a more extensive rail network, once economic reforms allow this decentralization to occur. Indeed, we demonstrate that relaxing these institutional constraints did influence population location patterns. In particular, we will show that pre-1990 roads only led to population decentralization after 1990. Therefore, it is logical that pre-1990 railroads could not have led to changes in the locations of production facilities either.

Of course the locations of railroads and highways were not randomized, and a key aspect of our estimation strategy must be to achieve pseudo-randomization. We postpone our detailed discussion of how we achieve such pseudo-randomization to Section 4.

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 (*shixiaqu*), numerous rural counties (*xian*), and several county cities (*xianji shi*).[3] 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. Much of our data are reported separately for the urban districts, county cities and rural counties.

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).[4] Thus, our analysis primarily

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

[4] 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

focuses on two geographic units: constant 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, as illustrated in Figure 1a. 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,[5] 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. We exclude the less developed non-Han territories in the West because data availability is much poorer in these regions.

Core cities are typically much smaller than prefectures and they sometimes consist of many urban districts. Figure 2 illustrates the spatial extent of 1990 core cities for the Beijing area and the changes in their administrative boundaries during our study period. 1990 core cities are shaded green while urban districts added between 1990 and 2010 are shaded yellow. Whereas the extant literature sometimes treats the entire prefecture as the statistical city (e.g., Deng et al. 2008), inspection of Figure 2 reveals that this is not a defensible geography for cities.

The first step in our analysis, and an important contribution of this project, is to develop a defensible geography of cities. Since our object is to study the decentralization of population and economic activity, we define `central city' and `hinterland' pairs. Ours is the first study to develop data for China to analyze population allocation between consistently defined central cities and surrounding prefecture areas. 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

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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 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.

[5] These are Laiwu, Ezhou and Jiayuguan.

were designated as urban districts in 1990, or which overlap with 1990 counties having this designation. However 88 of the 257 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'. For these, central cities consist of the county cities or rural counties first promoted to urban status.[6] In 1990, most of these yet to be promoted central cities were already treated as urban counties for data purposes in relevant Chinese statistical yearbooks, indicating the intention to promote. Of the promoted cities in our sample, 18 experienced boundary changes between 1990 and 2010, while 52 sampled incumbent cities experienced boundary changes. By carefully tracking these changes, we are able to follow constant boundary central cities and prefectures through the four cross-sections covered by our data, 1990, 2000, 2005 and 2010.[7]

3.2 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).

Most prefecture level cities and some large county cities report GDP back to 1990. Less complete GDP information is available at the prefecture level. 1990 GDP and industrial sector GDP information comes from national and provincial printed data year books (China

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[6] 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.

[7] 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.

Statistics Press, 1992b & 1992c). In 2010 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. Because we do not have a comprehensive source for GDP information disaggregated below the core city level in 1990 and there are a few missing observations in the 2010 data, we have a sample of 241 out of 257 cities for which we observe industrial sector GDP.[8]

3.3 Detailed Industrial Employment Data

We use the first and second national economic censuses of China from 1995 and 2008 for detailed industrial employment data by central city and prefecture remainder. We aggregate establishment level information into data on the number of workers by location and industry type. Our grouping of industries into types is based on weight to value ratios of output in each narrow industry category, except for high tech, for which we use the Chinese definition. We take weight to value ratios for other manufactures from the U.S., following Duranton et al. (2013). Given that most of these products are traded internationally, such ratios from U.S. sources are likely to apply reasonably closely in China as well.

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 and railroad maps. We rely on national maps rather than more detailed provincial maps to ensure consistency within each cross-section. To improve consistency across time, we select maps from the same publisher when

[8] Because boundary changes resulted in some rural counties being counted as part of central cities, we also need measures of GDP by sector for these rural counties in 1990. In these few cases, we impute GDP by subtracting observed urban GDP from provincial GDP by sector and using value added by sector to allocate the remainder across rural counties. For the portion of our analysis that involves GDP, we omit central cities in which over half of the population lived in a region for which we would have had to impute GDP.

possible, 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, many 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.[9] As we discuss in the following section, we only end up using infrastructure information from 1962, 1990, 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 high-grade highways (*gao dengji gonglu*), national highways (*guo dao*), and general highways (*yi ban gonglu*) indicated on our 2010 road map. Using Google Earth, for a sample of randomly selected points in 20 cities, we find general highways average 3.7 lanes, versus 4.3 lanes for high-grade highways. However general and national highways were usually not limited access. In a robustness check, we use the union of the high-grade highway and high-grade highway under construction (*gao deng ji gonglu* and *Wei cheng gao deng ji gonglu*) plus highway and highway under construction (*gonglu* and *wei cheng gonglu*) for the 2005 network. These are

[9] 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.

the only two types of roads indicated on our 2005 map.[10] Finally, our measure of 1962 roads is based on the single highway network (*Gong lu*) described on our 1962 road map. While all of the roads we study from 1999 forward are highways, the unavoidable inconsistencies between 2010 maps and earlier years mean that our highway measures are not directly comparable over time. Most maps only have one railroad classification.

To calculate our radial road (or rail) index, we first draw rings of radius 5km and 10km around the central business district (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 3a 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 3a 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 3b 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

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

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 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 use satellite data primarily as a source for lights at night. For Table 1, we used lights at night images of China (NGDC 1992-2010) from 1992, 2000, and 2010. For each cell, these data report an intensity of night time 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 also use the 1992 lights at night data to identify the CBD location 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. The left part of Figure 4 illustrates lights information and 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. The right part of Figure 4 shows 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. 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. We calculate the distance from each CBD to the nearest point on the Chinese coastline using our map of Chinese administrative districts.

4. Empirical Strategy

4.1 Econometric Model

Our goal is to determine how the configuration and extent of urban road and railroad networks affect the levels of population and industrial activity within constant boundary central cities, while holding total prefecture population or industrial activity constant. We begin by conceptualizing a static economic model that describes the allocation of population across space within a prefecture as in Alonso (1964) and Muth (1969). In this classic model, most people commute to the city center to work; land nearer the city center is more valuable because it has lower time and out-of-pocket cost of commuting to the city center. Agriculture is the alternative use of land at the city edge. With a rental market where agents are freely mobile (so identical agents have the same welfare in equilibrium), the advantage of locations nearer to the center is reflected in higher land rents and agents thus consume less land nearer the city center, ceteris paribus. Less land per person means higher population density, so as we move away from the city center, land rents and population densities decline. A reduction in the unit cost of commuting because of better highways lowers the relative value of locations nearer to the city center. Holding the area's population constant, the city land rent and population density gradients both shift down at the center and rotate anti-clockwise so that the city spreads out into the surrounding agricultural area. Such population decentralization as a consequence of lower commuting cost occurs in standard urban models, starting from Alonso (1964) and going through many books and papers to Fujita (1989), in both simple models and those that allow for heterogeneity of consumers and various other extensions.

Theoretical predictions about the impact of transportation infrastructure on the location of firms within cities are less informative. If firms locate at the edge of a city they face lower land and labor costs because their workers have shorter commutes and these firms use less valuable land. If firms locate in the center of the city they are more productive because of agglomeration economies including information spillovers. The equilibrium location pattern of firms that results from this tradeoff is often complicated and sensitive to model assumptions and parameter values (Fujita and Ogawa, 1982). Although one can simulate the effects of changes in transportation networks on patterns of firm location, there is no clear implication for intermediate transportation costs.[11] As such, we organize our empirical work around hypotheses suggested by Meyer et al. (1965).

For analyzing data, we define inner regions as 1990 central cities and outer regions as prefecture remainders. Define y_{tA} to be the outcome variable of interest: population or a measure of economic activity in year t and administrative unit A, 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. We use the symbol Δ_t to denote a first difference, where 1990 is always 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.

[11] As is demonstrated in Fujita & Ogawa (1982), very high commuting costs imply no commuting and very low commuting costs imply a monocentric city but no clear comparative static exists among intermediate commuting costs.

A central result from the Alonso-Muth model is that population moves away from the city center as a result of improvements in the transportation network. A straightforward way to characterize the effect of transportation infrastructure on urban form is thus with a levels equation of the form

(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 portion 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 $A_1 < 0$, consistent with an Alonso-Muth equilibrium. Controls in x_{1990} include central city land area.

There are two problems with using (1) directly for estimation. First, while the coefficients in (1) should describe approximate Alonso-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 causal effect of infrastructure is that our infrastructure variables be conditionally uncorrelated with the two error terms. That is, $Cov(r, \delta + \varepsilon \,|\, .) = 0$. 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 of 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 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) $\ln y_{1990C} = (A_0 + \Delta A_0) + (A_1 + \Delta A_1) r_{1990} + (A_2 + \Delta A_2) y_{1990P} + (B_0 + \Delta B_0) x_{1990} + \delta + \varepsilon_{1990}.$

Subtracting (2) from (1) yields

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

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.

There are a number of practical difficulties in recovering the coefficients in Equation (3) using our data. First, while our 1990 and 2010 highway measures 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. As we discuss above, treating the 1990 highway stock as zero allows us to more accurately measure the change in highways over our study period. We will evaluate the validity of the zero initial stock assumption below.

We use the same empirical specification to estimate the degree of production decentralization in response to highways and railroads. However, most intra-city railroads in

2010 had been built by 1990.[12] Consequently, we recover 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 because we have no strong instruments for it, nor do we consider it to be the relevant measure given our discussion in Section 2.2.

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 $A_1 + \Delta A_1 = 0$. As indicated in Section 2.2, there was little freedom for central cities firms to decentralize to suburban regions even if they wanted to in 1990. Existing roads and rails could not be used to decentralize. Once economic reforms were in place, cities began to adjust to market equilibria with production decentralization. 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 became possible after 1990. Because of the unique context, we see our analysis of the effects of highway construction between 1990 and later years on changes in urban form as comparable to our investigation of the effects of railroad levels in later years.

In summary, given this reasoning, our base regression specification becomes:

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

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 that satisfy:

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

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-

[12] Nationally, network length increased by about 20 percent between 1990 and 2010 with some additional double-tracking of 1990 railroad lines.

Snow (2007), Duranton & Turner (2011, 2012), Holl & Viladecans-Marsal (2011) and Hsu & Zhang (2011), we use information about historical networks as instruments for r_t.

Our base regression specification includes four components: potentially endogenous transportation infrastructure measures at time t (for which we instrument); prefecture level growth and the 1990 level of the dependent variable; base year levels of exogenous Alonso-Muth variables, in particular central city and prefecture land areas; and a control for whether the city is one of the 4 provincial level cities or 26 provincial capitals in our data set for reasons discussed below. A key problem is that prefecture growth in the dependent variable is surely endogenous: unobserved factors that influence central city growth also mechanically influence prefecture level growth while transportation investments also are expected to influence prefecture growth. We do have a Card (2001) type instrument for prefecture population growth which we consider in robustness checks, but it has limited strength that is independent of instruments for the variety of transportation experiments we want to conduct. Therefore, our primary strategy is to omit 1990-2010 prefecture growth variables, and instead to control for historical factors which set the stage for post-1990 prefecture growth and could also have influenced historical road allocations (our instrument). These are the 1982 prefecture population, the share of manufacturing in total prefecture employment in 1982, and the fraction of the prefecture population in 1982 with high school or more. The last variable is a typical determinant of growth in the city growth literature dating from Lucas (1988) and applied initially in Glaeser, Scheinkmann and Shleifer, 1995). Note that by controlling for both 1982 and 1990 prefecture population we effectively control for pre-1990 prefecture growth.

We maintain a consistent specification throughout our analysis of both population and industrial GDP growth in the central city as we do not have measures of prefecture level industrial GDP in 1990 or 1982. For our analysis of industrial employment growth by sector, we examine 1995-2008 changes. Here, while we maintain the same controls as for other outcomes, we add base period prefecture employment in the relevant sector.

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 unobserved variables that help determine population and industrial GDP growth, the IV estimator nullifies any resulting bias to A_1. The following subsection discusses the controls that seem key to establishing the validity of IV estimates.

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. 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 1980 measures post-date the initial rural sector market reforms in 1978 and thus may be influenced by the prospect of a future market economy.

Selecting the set of appropriate control variables requires an understanding of 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. With the strict institutional separation of the urban and rural sectors, there was no suburbanization of the urban population. Because little commuting occurred in 1962, to the extent the road network was used outside of central cities, it was oriented to connecting rural counties to the nation. Lyons (1985, p. 312) states: "At least through the 1960s most roads in China (except perhaps those of military importance) were simple dirt roads built at the direction of county and commune authorities. According to Chinese reports of the early 1960s, most such roads were not fit for motor traffic and half of the entire network was impassable on rainy days." Lyons also notes that average truck speeds were below 30 km/hr due to poor road quality. Because all long-haul and most short-haul movement of the goods produced in cities was by rail, roads were built as part of the early 1960s effort to facilitate short distance transport of goods in the rural sector. Indeed, the People's Daily reported on June 11, 1963 that "The present effort at building roads aims at opening up commercial routes to the villages to facilitate the transport of locally produced goods as part of the policy of priority given to agriculture. Better roads are being built by provincial governments, but most of them are being built at local initiative. They are rarely fit for motor traffic; on the better roads horses and ox-carts may travel; on others hand-carts….can be pushed or pulled by man" (Lippit, 1966 p. 115). It seems that the vintage 1962 road network generally consisted of unimproved roads connecting rural farming regions to nearby cities. But this period of construction established right of ways, giving us a solid first stage.

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 form of modern cities, but 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 in 1962 could influence outcomes today as well as 1962 roads, it is in principle important to control for either relative agricultural activity or its effective converse, relative industrial activity, in prefectures prior to 1990.[13] Since 1982 is the earliest year for which there is county level census data, we include 1982 prefecture share of employment in manufacturing as a control. 1982 controls for prefecture population and education are also important as they are correlated with highway and rail instruments and may directly predict subsequent changes in population and GDP allocation between cities and prefecture remainders.

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 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

[13] The service sector prior to 1990 is anemic and ill-defined.

strategic railroad lines. Because there was little trade between provinces, provincial capitals were the most important trade nodes and therefore received main rail lines. Indeed, a regression of 1962 railroad rays on 1990 observables reveals that a provincial capital indicator is an important predictor, as it is for 1962 road rays as well. 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 may influence the allocation of resources between core cities and prefecture remainders.

Table 2 presents representative first stage results for the three 2010 transportation network measures we emphasize and one for 2005. In our IV estimations, we instrument for each recent transportation network variable with its analog from the 1962 network. Here we show regressions in which all 1962 measures are in each first stage. This illustrates the strength of the instruments and reveals that each 2010 measure is predicted by its 1962 analog only. Table 2 reveals that our instruments are individually strong conditional on the standard set of control variables used throughout our analysis. Each 1962 road ray predicts 0.34 of a 2010 highway ray and 0.36 of a 2005 ray conditional on base specification controls and instruments for the other infrastructure measures. Each 1962 railroad ray predicts 0.37 railroad rays in 2010. Finally, the existence of any roads that could be seen as ring roads in 1962 increases the probability of having a ring road in 2010 by 0.53.

5. Results for Population Decentralization

In this section, we examine the effects of various types of highway and railroad infrastructure on population decentralization. Our results are novel in two ways. First, we look at the effects of the transportation network on population decentralization in a developing country context in the midst of rapid national urbanization. Second, we look beyond radial highways to examine the effects of railroads and ring roads.

5.1 Basic Results

Table 3 reports baseline OLS estimates of the empirical relationship between highway rays and 1990-2010 central city population decentralization, as specified in Equation (4). Analogous regressions for 1990-2000 decentralization yield very similar results. The 2010 radial road index is the only explanatory variable in column 1. Column 2 adds control set A, which includes variables from 1990. Column 3 additionally adds 1982 controls. Our preferred specification includes the full set of controls in column 3, which label control set B. Table 4 will report coefficients on these controls.

Regardless of specification, in Table 3 estimated OLS coefficients of highway rays are near 0 when we expect the true causal relationship to be negative. While highways coefficient changes as expected in subsequent IV analysis, signs on the control variables remain remarkably stable across estimators.

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 and the columns follow the format of Table 3. With no controls the IV coefficient is close to zero, as seen in column 1. With set A of 1990 controls for the basic determinants of urban form, the IV coefficient becomes a significant -0.055 (column 2). With set B of controls in column 3, the road rays coefficient becomes even more negative at -0.071 and remains significant. The added covariates in column 3 control for both determinants of prefecture growth beyond 1990 and for factors which may have influenced the 1962 allocation of road rays.

Controls for prefecture scale and pre-1990 growth are the most critical. Controlling only for 1990 prefecture population yields a highway rays IV coefficient of -0.051. More populous prefectures both had more roads in 1962 (which predicts more highway construction 1990-2010) and experienced more rapid post-1990 central city population growth. Adding 1982 prefecture population, which additionally accounts for pre-1990 growth, raises this coefficient to -0.064, near its final level. We view the inclusion of additional controls as serving mainly to reduce the variance of the error term, consequently providing more precisely estimated causal effects of highway infrastructure.

Estimated coefficients on non-transportation related covariates are of interest. The interpretation of the combined 1982 and 1990 prefecture population controls is that a 1% increase in prefecture population growth from 1982 to 1990 is associated with a 0.58 to 0.71 percent increase in central city growth 1990-2010. The net coefficient indicates that a central city in a prefecture that was 1% larger in both 1982 and 1990 experiences 0.13% more rapid growth 1990-2010. The growth elasticity is higher compared to related estimates in Baum-Snow (2007) for U.S. metro areas, reflecting the rapid urbanization of the Chinese economy during our study period. Conditional on other controls, more spacious central cities grew more slowly. In an Alonso-Muth framework, the further out one draws the central city radius, the less is the population loss with a reduction in commuting costs. Population in provincial capital central cities grew a bit more quickly, which may reflect political influence. The 1982 control for prefecture education has no significant effect after controlling for 1982-1990 prefecture population growth, nor does 1982 manufacturing share.

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 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.

So far our analysis has not considered potential effects of the 1990 stocks of roads on subsequent decentralization. For roads, the validity of the no initial highways assumption employed so far rests on two factors. First 1990 roads were not highways. Second pre-reform urban China did not permit market responses to cross-city differences in transportation networks. We now provide econometric evidence that pre-reform decentralization was not a response to more 1980 or 1990 road rays.

Specifically, we investigate the impact of 1980 road rays or the closely correlated 1990 rays (single or at most 2 lane roads) on central city population growth from 1982 to 1990, the pre-urban reform period. Table 5 presents estimates analogous to those in column 3 of Tables 3 and 4, except that we omit the 1990 prefecture population variable. The IV coefficient of the rays variable for 1980 in column 1 is positive but only significant at the 10% level. The coefficient of the 1990 rays variable is even higher but again only significant at the 10% level. Prior to the urban reforms, road rays did not contribute to population decentralization, consistent with our notion that the institutional environment in 1990 precluded decentralization regardless of transportation costs. We could speculate about why roads could have positive effects in the pre-urban reform period given the institutions and reform environment of the time, but a proper analysis is beyond the scope of this paper.

Table 6 presents robustness checks for the results in column 3 in Table 4. Column 1 includes 1990 road rays as an additional (un-instrumented) control to investigate the validity of the `no initial highways' assumption implied by our estimating equation, Equation (4). Not only does this approximate the exact first difference specification in Equation 3, but it also addresses the possibility that some 1990 roads may persist and affect decentralization. The technical problem with adding the 1990 control is that 1962 and 1990 rays are strongly correlated so that the first stage F-statistic for column 1 is low. However, results in column 1 are consistent with 1990 road rays not contributing to decentralization while 2010 highway rays do. Thus, the `no initial highways' assumption finds indirect support in column 1 of Table 6. This, in turn, supports our focus on estimates of Equation (4) rather than Equation (3).

In column 2 we account for the potential concern that the 1982 controls do not adequately hold constant 1990-2010 prefecture population growth, as required by the Alonso-Muth model. As such, we add 1990-2010 prefecture population growth directly to the specification in Table 4 column 3. Following Card (2001), we instrument for this variable with predicted 1995-2000 immigration flows from other provinces. To construct these predicted flows, we first calculate the share of migrants 1985-1990 from each province going to every prefecture outside the province using the 1990 census. Using the 2000 census, we calculate 1995-2000 migration outflows from each province, interact them with these 1985-1990 shares and aggregate over all provinces.[14]

Given that 1985-1990 migration is limited and we only predict migration over one-quarter of our sample period, a somewhat weak first stage ensues. However, the joint F-statistic on both the Card and 1962 rays instruments in column 2 is still a reasonable 9.4. Not surprisingly, coefficients on the 1990 and 1982 population controls now become insignificant, with the 1990-2010 population growth elasticity estimated to be 0.72. The resulting rays coefficient of -0.045 is smaller than in our primary specification, but lies within its standard error band.

In column 3, we use highway rays lagged to 2005, including a few under construction at that time to allow for adjustment time in the response. The coefficient of -0.068 is very close to that in Table 4.

[14] While we would ideally use predicted migration flows out of each province for the entire 1990-2010 period, the only period after 1990 for which reliable migration information is available to us is 1995-2000.

In columns 4 and 5, we evaluate whether effects of highways are heterogeneous in two dimensions. First we ask if highways cause more decentralization in larger cities, under the notion that small cities lack measured ‘suburbs’ to which people can decentralize. This is mostly a measurement issue, as the Alonso-Muth model does not suggest that differential effects should exist per se. In column 4 we drop the smallest 25% of central cities as of 1990. The coefficient of highway rays drops modestly in absolute value and remains within its Table 4 confidence interval. This does not support the story that relative effects are weaker in smaller cities or that we are measuring smaller cities as of 1990 too bluntly. Similarly, dropping the very largest cities slightly strengthens estimated effects.

In column 5, we drop the cities in the West region. The West is significantly less developed than the rest of the country and has arguably lagged in introducing urban sector land and output market reforms. Dropping these 49 cities noticeably strengthens the decentralization coefficient from -0.071 to -0.100.

5.2 Railroads and Ring Roads

Besides highway rays, do other transportation infrastructure types or network measures causally affect population decentralization? In addition to answering this question, we also want to confirm that correlations between other infrastructure and road rays in both 1962 and recent years are not driving the results in Table 4. Table 7 explores these issues. Column 1 shows that adding total kilometers in the prefecture remainder to our base specification in column 3 of Table 4 yields a positive insignificant coefficient, while the magnitude and significance of that on highway rays is unchanged from Table 4. Using total kilometers for the whole prefecture yields the same result. It is highway rays specifically, not kilometers of the network which drive decentralization.

Columns 2 and 3 explore the effect of railroad rays on population decentralization. The effect of railroad rays is estimated to be zero and its inclusion leaves the highway rays coefficient unchanged. If we substitute kilometers of the rail system for rail rays, the result is no different.

Understanding the effects on urban form of ring roads and how they interact with other elements of the urban transportation network is important for policymakers. 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 plausibly available, although there are some limitations. In particular, few roads in 1962 look like ring roads. Even in 2010 only 28 percent of cities have some ring road capacity, with an average index value of 1.5, meaning that they serve about 38 percent of the circumference of the city. In 1962 only 5.1 percent of our cities register any ring road capacity with a maximum of 1 for our index of rings. Given this, we must restrict our ring road capacity measure to simply be an indicator as to whether a city has any ring road capacity in a given year. Because of the small amount of ring capacity in 1962, the IV results to follow must be viewed with some caution, although the results are strong.

Table 7 columns 3 and 4 present estimated effects of ring road capacity. Ring roads on their own (column 3) or combined with highway rays (column 4) have large significant effects on decentralization. Conditional on highway rays, ring road capacity reduces central city populations by 30%, although the joint F on the first stage (5.8) is low. We cannot additionally identify a separate interaction effect between rays and rings. We also investigate whether ring roads effects are greater in larger cities. Dropping the 25% of smallest cities in 1990 raises the absolute value of the coefficient modestly (to -0.38), but the F-statistic for the first stage falls to 3.7.

Our estimates of the effect of highway rays on population decentralization are in line with existing evidence from the United States. The estimates of the effects of railroads and ring roads are novel. Moreover, our evidence is in a developing country context where the underlying mechanisms are somewhat different. Because of the rapid increases in Chinese urban populations during our study period, highways contributed to population decentralization both by 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. In contrast to post-WWII United States, any movement of people from central cities to suburbs is modest.

6. Decentralization of Industrial Production

We now consider the relationship between transportation infrastructure and the decentralization of production. We begin by examining the effects of different transportation networks on the growth of central city industrial GDP 1990-2010 and its implied decentralization. We then turn to the 1995 and 2008 industrial censuses to confirm that the same patterns hold for central city growth of total industrial employment. Finally, we investigate the determinants of employment decentralization for industries which tend to have high, medium and low weight to value ratios.

As we note in section 4.1, formal theoretical models of cities do not provide robust predictions about the relationship between transportation costs and the location of production activities. However, Meyer et al. (1965) examine the role of transportation infrastructure in reshaping U.S. cities during the late 1950s. As is the case for China in the latter part of our study period, this was a time of rapid highway construction and increasing reliance on trucking for long-haul freight. During this time period, U.S. central cities were beginning to de-industrialize and to focus on services, while industry migrated to new suburban or ex-urban areas. One reason for this shift was that industry was no longer tied to central city rail terminals with increased use of trucking, freeing it up to move to suburban areas with ring roads connecting plants to intercity railroads or highways. Moreover, the large tracts of land required for continuous process production in manufacturing were much lower cost in the suburbs than in city centers.

Meyer et al. (1965) suggest a pattern for the exodus of industry from central cities in the US in the 1950s and 1960s. Large plant heavy industry would be slower to leave central cities and would for a while continue to rely on central city rail infrastructure. However, more intermediate weight footloose production would move to city fringes, where ring roads facilitate the trucking of goods to suburban rail sidings. More light weight products could start to rely more on trucking for long-haul moves. If so, radial highways would provide quick exit from metropolitan areas to connecting or continuation interstate highways, with ring roads providing suburban connections to these rays. Our employment data by sector allows us to test these hypotheses explicitly in China.

6.1 Decentralization of Industrial GDP

Table 8a reports IV estimates of the effects of highway rays, railroad rays and total railroad length and ring road capacity on the decentralization of production activity between 1990 and 2010. To see the degree of bias in OLS estimates, Table 8b shows the corresponding OLS coefficients on the transportation measures examined in each column. We use the same set B of control variables, as for our analysis of population decentralization. We note that we cannot control for 1990 prefecture industrial GDP and instead must rely on 1982 covariates, including the share of employment in manufacturing, to control for the initial amount of industry in the prefecture. 1982 and 1990 covariates control for prefecture growth potential after 1990.

Results in Table 8a columns 1, 3 and 6 reveal that highway rays have insignificant estimated effects on industrial GDP decentralization, regardless of the other elements of the urban transportation network that are considered simultaneously.

In contrast, results in column 2 show the central role of radial railroads for facilitating the decentralization of industry. Each radial railroad causes a 26% decline in the growth of central city industrial GDP. Column 4 reports a ‘horse race’ between rail rays and total kilometers of the rail network in the prefecture remainder. Rail rays win. Adding the kilometers of the rail network leaves the rail rays coefficient little changed and results in an insignificant effect for kilometers. The same result occurs if we instead control for total kilometers of rails in the entire prefecture, rather than just the remainder. Adding ring roads has little effect on the rail rays coefficient. Indeed, the rail rays coefficient is very stable across columns.

Columns 5-7 report estimates of the effect of ring roads alone, combined with highway rays, and combined with rail rays respectively. Whatever other infrastructure is considered, ring roads have a large effect. The existence of some ring road capacity causes more than a 50% decline in industrial GDP growth in the central city, though the standard error is large. While the first stage F-statistic is less than 6 when ring road capacity is included with either highway or rail rays, the coefficient on ring capacity remains at about -0.5. Results in Table 8 indicate that railroad rays and ring roads play important roles in industrial decentralization, much as Meyer et al. (1965) suggest.

As with our analysis of population decentralization above, OLS estimates in Table 8b appear to be positively biased. For example, the OLS rail rays and ring roads coefficients in column 7 are -0.048 and -0.145 respectively, compared with IV estimates of -0.265 and -0.650. As with highways and population, this positive bias comes from the assignment of railroads and ring roads to central cities with more rapid GDP growth.

Coefficients on control variables in Table 8 differ somewhat from those in Table 4, with 1982 controls for education and manufacturing share now having significant coefficients in many specifications. However, the inclusion of controls does not influence the results as much; the IV coefficient of railroad rays with no controls is -0.34, versus -0.26 in the most saturated specification. Central city industrial GDP growth is lower in prefectures with higher education in 1982, consistent with the possibility that service sector development is positively influenced by the local human capital stock. A greater share of manufacturing in 1982 leads to lower central city industrial GDP growth.

Results in Tables 4 and 8 reveal that while roads matter for the location of people, in China railroads matter for the location of industrial 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 indicates that a sufficient suburban labor pool exists to work in decentralizing factories. While there is no systematic national commuting data for China, 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 15 percent of the daytime population of 6 Jiangsu county capitals were commuters in 1984, a number which has no doubt grown considerably since. This suggests that 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.

6.2 Decentralization of Industrial Employment by Sector

The 1995 and 2008 Economic Censuses allow us to investigate the decentralization of industrial employment for various specific industry groups.[15] Consistent with the discussion above, we construct five industry groups. The first two of these are `heavy weight' and `medium weight' industries.

[15] We note that the 1995 census is the first economic census and occurred at a time when industry was dominated by the state. State owned firms often carried non-active workers on their payrolls and smaller cities had very limited employment in certain industries.

To construct these two industry groups, we rely on the table relating weight to value for shipments of goods by U.S. industries from Duranton and Turner (2013) and our matching of SIC codes to the more limited set of NAICS codes for which the weight-to-value data are available. We drop a few non-manufacturing and miscellaneous categories. Our heavy weight group is industries with weight to value ratios equal to or greater than 0.8 and includes primary metals, food, non-metallic minerals, wood products, coal, chemicals and the like. Our medium weight group has weight-to-value ratios of 0.22 to 0.35 (with nothing between 0.35 and 0.81) and includes industries like fabricated metals, plastics, furniture, and printing.

For lighter weight industries, for which we expect highways to play a greater role, we divide industries into three groups. First are apparel and textiles, which have proven footloose in other contexts. Second is the lightest weight category, 'high tech'. As defined by the Chinese, this consists of communications equipment, computers and instruments. The final light weight category is non-high tech non-electrical and electrical machinery. We consider this group of industries separately because the items themselves tend to be heavy and bulky, even if of high value.

Table 9 reports analogous regressions to those in Table 8, but only reports the coefficients on the infrastructure variables and own industry employment in 1995. Table 9a starts with overall industry employment and shows similar results as those for industrial GDP in Table 8. Highway rays have no effect on decentralization. Each railroad ray leads to decentralization of about 28 percent of central city overall industrial employment, which is almost identical to the estimate of -0.26 for industrial GDP reported in Table 8. Ring road capacity for overall industry has a large negative coefficient but is not statistically significant.

Hereafter we only report the highway rays effect on its own for the one case in which highways alone influence employment location. For more specific industry groups, we typically show results for railroad rays alone, combined with ring roads, and finally ring roads combined with highway rays.

Results in Table 9a columns 5-7 reveal that the location of heavy industry does not respond to new transportation infrastructure. Consistent with Meyer et al. (1965), such industry still in place in 1995 may have been slower to move. In contrast, medium weight-to-value ratio industries (columns 8-10) exhibit strong decentralization in response to railroad rays (coefficient of -0.24) but their ring road coefficient, while large, is insignificant.

It is for the lighter weight industries in Table 9b that highways play a larger role. In all cases, railroad rays have strong significant decentralization effects of -0.27 to -0.68 depending on outcome and specification. For non-high tech machinery, that is absolutely heavy and bulky, there are no highway ray effects and ring road effects are insignificant. For high tech, rail ray and ring road effects are large and significant. Each extra rail ray leads to 67% decline in central city high tech employment and ring road capacity leads to a 200% decline. High tech is the poster-child for the Meyer et al. hypothesis.

For apparel and textiles, highway rays lead strongly to decentralization. However, a horse race between rail and highway rays, both of which seem to have strong effects on their own, has no statistical power. While ring road capacity has a very large negative coefficient it is not significant. Clearly we are pushing the data here as each first stage F-statistic when ring roads are included is less than 6.

We also examine whether these detailed industry effects differed for cities in the West, which may have been slower to reform, or are stronger if we drop the 25% smallest cities. Results for these reduced samples are less precise coefficients of interest with similar magnitudes.

8. Conclusions

Transportation infrastructure networks have profound and long-lasting impacts on urban form and the compactness of cities. We find that this common assessment applies to a large developing country. For population, we find that both radial highways and ring roads lead to substantial decentralization out of central cities. For production, we find that in general radial railroads and ring roads both enhance industrial decentralization. However, the magnitudes of these estimates depend on the class of manufacturing goods. The location of employment in industries producing high weight to value products does not significantly respond to any type of urban transportation infrastructure that we investigate. Medium weight to value employment responds to radial railroads and possibly to ring roads as well. The locations of all low weight to value industries respond to radial railroads and possibly ring roads, but only textiles, apparel and leather also respond to radial highway locations.

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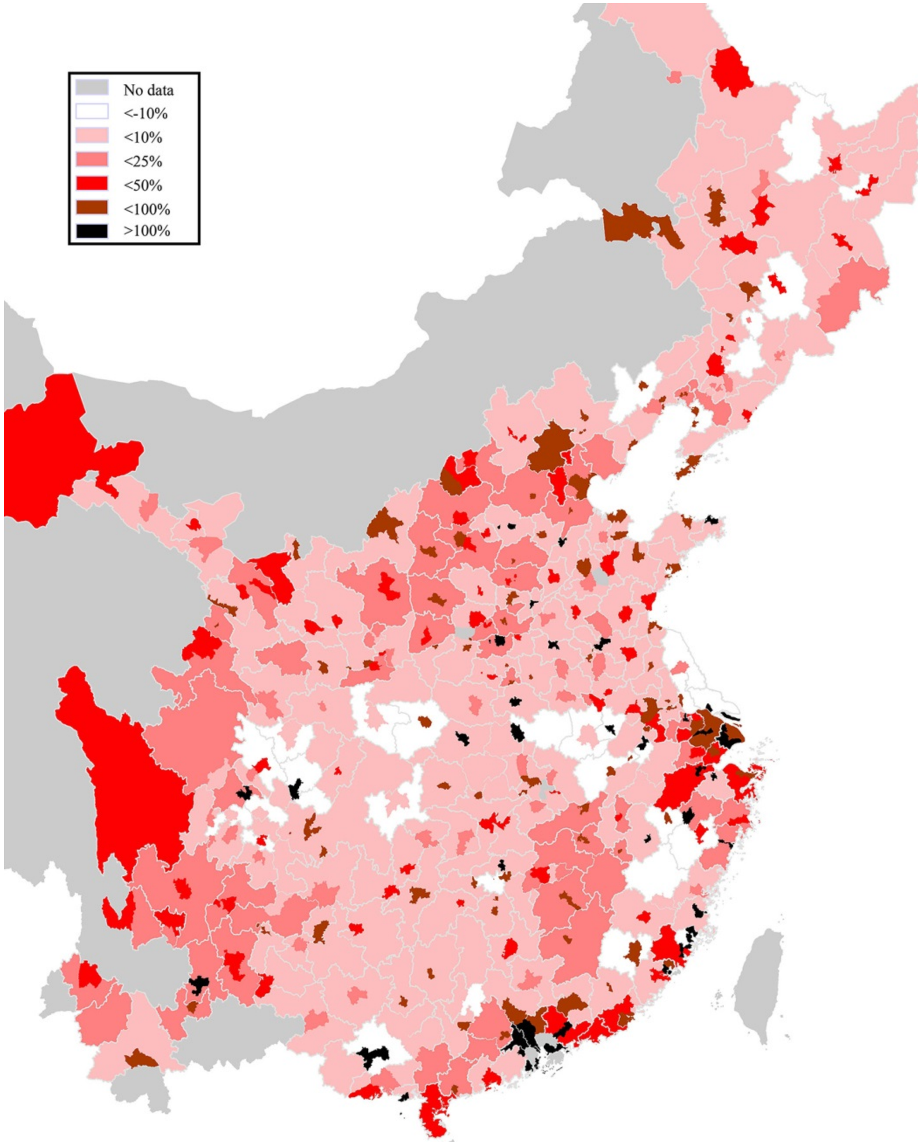

Figure 1a: Population growth by location, 1990-2010

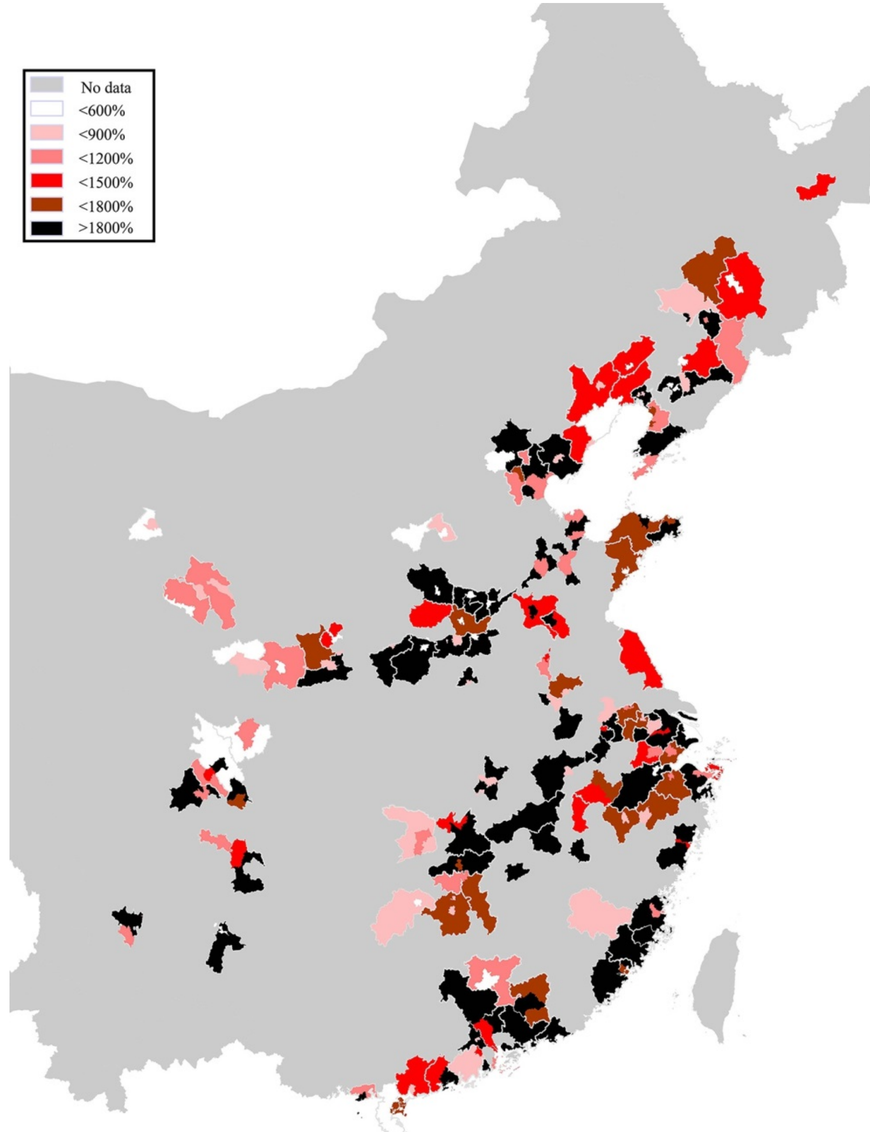

Figure 1b: Industrial sector GDP growth by location, 1990-2010

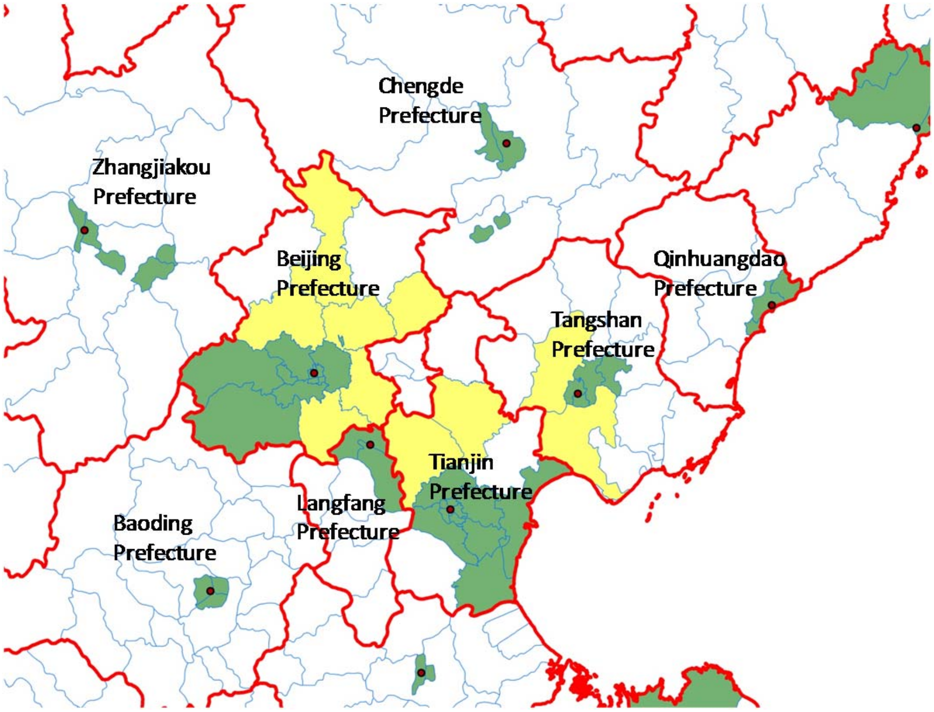

Figure 2: Beijing area political geography. Red lines indicate 2005 definition prefecture boundaries and light blue lines indicate county/urban district boundaries. Green shaded regions are 1990 central cities and yellow shaded regions are central city expansions 1990-2010.

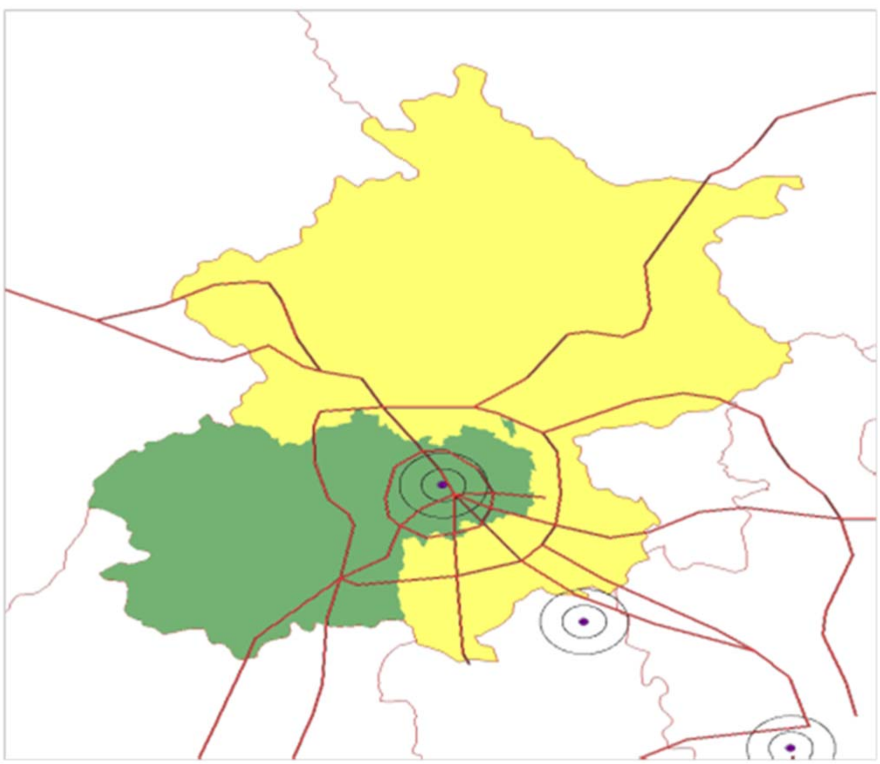

Figure 3a: Construction of our radial road index for Beijing

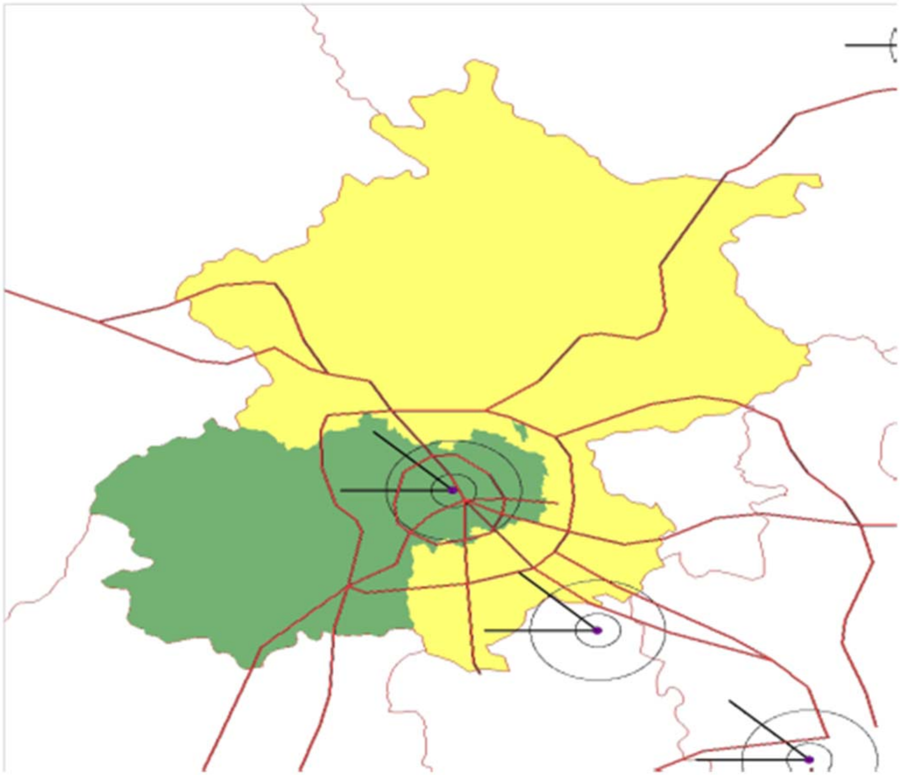

Figure 3b: Construction of our ring road index for Beijing.

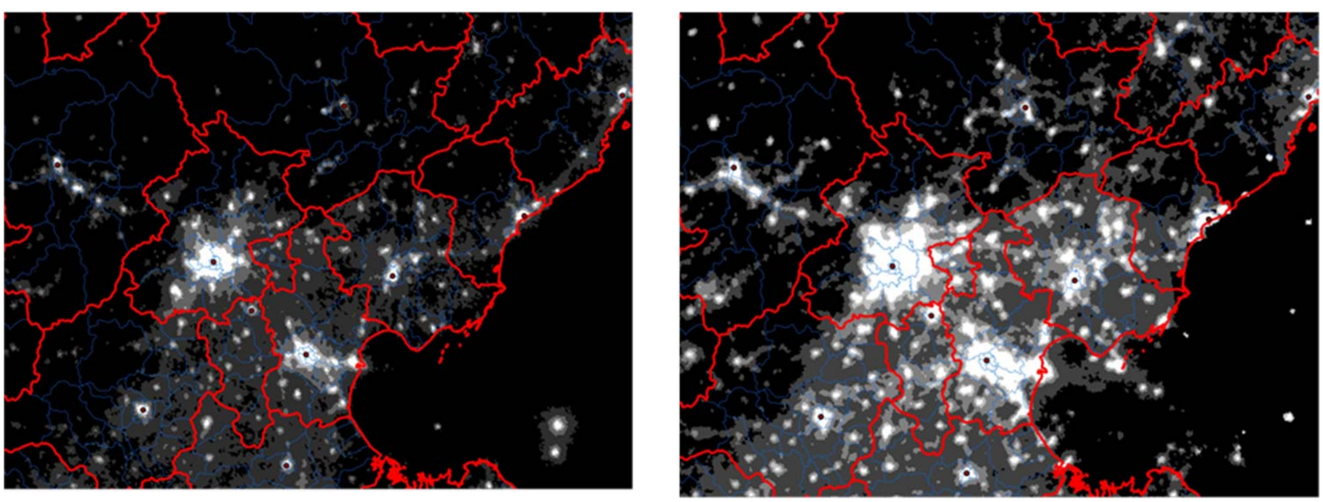

Figure 4. Lights at night for Beijing area. The left figure is for 1992 and the right figure is for 2009.

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

	Population Growth (257 Prefectures)		Lights Growth (257 Prefectures)		Real Industrial GDP Growth (96 Prefectures)	
	Central City	Prefecture Remainder	Central City	Prefecture Remainder	Central City	Prefecture Remainder
Mean in 1990	982,333	2,995,989			1204	646
1990-2000	27%	4%	52%	94%	148%	439%
2000-2010	22%	1%	33%	36%	291%	289%
1990-2010	55%	5%	102%	165%	886%	1996%

Notes: The 257 prefectures used to build numbers in the first four columns is our primary sample. We do not include 1990 means for lights because levels of lights are difficult to interpret. The smaller sample for the final 2 columns is because of limited prefecture level information about GDP and its components in 1990. Industrial GDP is deflated with provincial deflators.

Table 2: First Stage Regressions

	2010 Radial Highways (1)	2005 Radial Highways (2)	2010 Radial Railroads (3)	2010 Ring Highway Indicator (4)
1962 radial roads	0.3436***	0.3630***	0.0171	-0.0254
	(0.090)	(0.085)	(0.036)	(0.024)
1962 radial railroads	0.1783	0.0763	0.3684***	0.0037
	(0.106)	(0.084)	(0.052)	(0.032)
1962 ring road indicator	-0.5915	-0.6109	-0.2174	0.5279***
	(0.429)	(0.380)	(0.302)	(0.144)
ln(central city area, 1990)	0.1574	0.0987	-0.0244	-0.1834***
	(0.123)	(0.117)	(0.088)	(0.030)
ln(prefecture area, 2005)	0.0427	0.213	-0.022	0.04
	(0.206)	(0.196)	(0.173)	(0.045)
provincial capital or level	1.3764**	0.9642**	0.1247	0.0686
city indicator	(0.505)	(0.443)	(0.240)	(0.111)
ln(prefecture population, 1990)	1.8336**	1.3182**	0.1594	0.1247
	(0.679)	(0.615)	(0.362)	(0.240)
ln(prefecture population, 1982)	-0.9518	-0.7587	0.2563	-0.0492
	(0.594)	(0.589)	(0.342)	(0.224)
fraction high school or more	5.2057*	1.6917	3.8334*	-0.4161
in prefecture, 1982	(2.659)	(2.984)	(2.116)	(0.874)
share employed in manufacturing	-3.2888	-3.2202*	-1.6236**	0.3332
in prefecture, 1982	(2.120)	(1.761)	(0.627)	(0.357)
constant	-12.2732***	-8.5047**	-4.6844*	0.1037
	(3.335)	(3.277)	(2.321)	(0.994)
Observations	257	257	257	257
R-squared	0.3251	0.2736	0.2436	0.2394

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		
	(1)	(2)	(3)
2010 radial highways	0.0097	-0.0019	-0.0042
	(0.0088)	(0.0077)	(0.0073)
control set A	No	No	Yes
control set B	No	Yes	Yes
Observations	257	257	257
R-squared	0.0041	0.2444	0.2757

Notes: Each column shows coefficients from a separate OLS regression of the change in central city population on the number of radial highways in 2010 and the set of indicated additional controls. See Table 4 for a list of the variables in each control set. Standard errors in parentheses are clustered by province.

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

	Δ ln(CC Pop), 1990-2010		
	(1)	(2)	(3)
2010 radial highways	-0.0067	-0.0554**	-0.0710**
	(0.0186)	(0.0263)	(0.0331)
ln(central city area, 1990)		-0.1250***	-0.1250***
		(0.0248)	(0.0240)
ln(prefecture area, 2005)		-0.006	0.021
		(0.0355)	(0.0299)
provincial capital or level		0.3384***	0.3472***
city indicator		(0.0545)	(0.0911)
ln(prefecture population, 1990)		0.1061**	0.7145***
		(0.0510)	(0.2412)
ln(prefecture population, 1982)			-0.5822***
			(0.2181)
fraction high school or more			-0.1638
in prefecture, 1982			(0.4557)
share employed in manufacturing			0.0744
in prefecture, 1982			(0.3915)
constant	0.4349***	-0.0598	-0.7103
	(0.0971)	(0.8467)	(0.7669)
Observations	257	257	257
First stage F	36.2	21.8	17.2

Notes: Each column shows coefficients from a separate IV regression of the change in central city population on the number of radial highways in 2010 and the set of indicated additional controls. First stage results are in Table 2. Standard errors in rentheses are clustered by province. *** p<0.01, ** p<0.05, * p<0.1

Table 5: IV Estimates of Effects of Roads on Pre-Reform Population Growth

	Δ ln(CC Pop), 1982-1990	
	(1)	(2)
radial roads in 1980	0.0687*	
	(0.0388)	
radial roads in 1990		0.1132*
		(0.0641)
ln(central city area, 1990)	-0.0265	-0.024
	(0.0357)	(0.0422)
ln(prefecture area, 2005)	0.0085	-0.0008
	(0.0380)	(0.0437)
provincial capital or level	-0.0661	-0.1126
city indicator	(0.0820)	(0.1041)
ln(prefecture population, 1982)	-0.0636	-0.0992
	(0.0650)	(0.0795)
fraction high school or more	1.8268***	1.3646***
in prefecture, 1982	(0.5442)	(0.5103)
share employed in manufacturing	-0.3095	-0.0079
in prefecture, 1982	(0.3200)	(0.3512)
constant	0.9065	1.3693
	(1.0219)	(1.2247)
Observations	257	257
First stage F	54.8	16.0

Notes: Each column shows coefficients from a separate IV regression of the change in central city population 1982-1990 on the number of radial highways in 1980 or 1990 and the set of indicated additional controls. Standard errors in parerentheses are clustered by province. *** p<0.01, ** p<0.05, * p<0.1

Table 6: Robustness Checks for Table 4

	Δ ln(CC Pop), 1990-2010				
				drop 25% smalles	drop West
	(1)	(2)	(3)	(4)	(5)
2010 radial highways	-0.1688*	-0.0448*		-0.0583*	-0.1040**
	(0.1022)	(0.0251)		(0.0341)	(0.0483)
1990 radial roads	0.1169				
	(0.0781)				
2005 radial highways			-0.0684**		
			(0.0303)		
ln(central city area, 1990)	-0.1044***	-0.1189***	-0.1288***	-0.1327***	-0.1165***
	(0.0354)	(0.0197)	(0.0225)	(0.0259)	(0.0280)
ln(prefecture area, 2005)	0.0121	0.0466***	0.0326	0.0037	0.0062
	(0.0300)	(0.0177)	(0.0307)	(0.0379)	(0.0354)
provincial capital or level	0.3895***	0.1952**	0.3124***	0.3553***	0.4458***
city indicator	(0.1342)	(0.0811)	(0.0763)	(0.0949)	(0.1132)
ln(prefecture population, 1990)	0.8800**	0.0579	0.6717***	0.7226***	0.7600***
	(0.3619)	(0.2612)	(0.2282)	(0.2624)	(0.2793)
ln(prefecture population, 1982)	-0.7222**	0.0526	-0.5667***	-0.6031***	-0.5734**
	(0.3166)	(0.2494)	(0.2089)	(0.2314)	(0.2443)
fraction high school or more	0.1334	-0.3492	-0.4844	-0.2361	-0.4416
in prefecture, 1982	(0.5636)	(0.3425)	(0.5089)	(0.4453)	(0.6479)
share employed in manufacturing	0.1554	-0.2466	0.0769	0.331	-0.1542
in prefecture, 1982	(0.4539)	(0.2970)	(0.3760)	(0.3926)	(0.4184)
change in ln prefecture population,		0.7182***			
1990-2010		(0.2518)			
constant	-1.1879	-0.7078	-0.3799	-0.4264	-1.257
	(1.2082)	(0.5748)	(0.6698)	(0.9266)	(1.1327)
Observations	257	257	257	193	208
First stage F	3.6	9.4	20.6	12.1	11.2

Notes: Each column shows coefficients from a separate IV regression of the change in central city population on the number of radial highways in 2010 and the set of indicated additional controls. First stage results for radial highways are in Table 2. Column 2 has an additional first stage in which change in prefecture population, 1990-2010 is instrumented with predicted migration flows as is explained in the text. Standard errors in rentheses are clustered by province. *** p<0.01, ** p<0.05, * p<0.1

Table 7: Population Decentralization and Other Transportation Network Variables

	Δln(CC Pop) 1990-2010				
	(1)	(2)	(3)	(4)	(5)
2010 radial highways	-0.0712**		-0.0726*		-0.0925**
	(0.0334)		(0.0388)		(0.0385)
ln(highway kms in prefecture remainder, 2010)	0.0972				
	(0.0937)				
2010 radial railroads		-0.0255	0.0149		
		(0.0461)	(0.0681)		
2010 ring road indicator				-0.1987**	-0.3034**
				(0.0958)	(0.1339)
ln(central city area, 1990)	-0.1013***	-0.1346***	-0.1240***	-0.1720***	-0.1819***
	(0.0288)	(0.0229)	(0.0261)	(0.0314)	(0.0390)
ln(prefecture area, 2005)	-0.0696	0.0082	0.0214	0.0137	0.033
	(0.0930)	(0.0318)	(0.0312)	(0.0333)	(0.0330)
provincial capital or level city indicator	0.3466***	0.2315***	0.3454***	0.2298***	0.3941***
	(0.0872)	(0.0668)	(0.0918)	(0.0564)	(0.1005)
ln(prefecture population, 1990)	0.6477***	0.5415**	0.7129***	0.5371***	0.7781***
	(0.2470)	(0.2178)	(0.2401)	(0.1969)	(0.2199)
ln(prefecture population, 1982)	-0.5529***	-0.4732**	-0.5875***	-0.4713**	-0.6033***
	(0.2089)	(0.1999)	(0.2149)	(0.1903)	(0.2048)
fraction high school or more in prefecture, 1982	-0.2213	-0.2708	-0.2577	-0.4136	-0.0358
	(0.4604)	(0.7252)	(0.7466)	(0.5596)	(0.5034)
share employed in manufacturing in prefecture, 1982	0.0658	0.2492	0.0851	0.3112	0.0686
	(0.3931)	(0.3340)	(0.3916)	(0.3348)	(0.4269)
constant	-0.0591	0.2297	-0.631	0.5024	-0.9053
	(1.1600)	(0.4996)	(0.6429)	(0.5299)	(0.7233)
Observations	257	257	257	257	257
First stage F	8.4	50.2	5.6	13.4	5.8

Notes: Road and rail network measures in 1962 instrument for these measures in 2010. Standard errors in parentheses are clustered by province. *** p<0.01, ** p<0.05, * p<0.1

Table 8. Effects of Transport on Decentralization of Industrial Sector GDP, 1990-2010

Panel A: IV Results

	Δln(CC Pop) 1990-2010							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
2010 radial highways	0.0485		0.0808			0.0123		
	(0.0576)		(0.0798)			(0.0764)		
2010 radial railroads		-0.2611***	-0.3120**	-0.2347**			-0.2654**	-0.3375***
		(0.0969)	(0.1251)	(0.1020)			(0.1123)	(0.0738)
ln(highway kms in prefecture remainder, 2010)				-0.0603				
				(0.1105)				
2010 ring road indicator					-0.5146*	-0.5005	-0.6497*	
					(0.2781)	(0.3211)	(0.3535)	
ln(central city area, 1990)	0.09	0.0812	0.068	0.0586	-0.0065	-0.0053	-0.0487	
	(0.0581)	(0.0567)	(0.0645)	(0.0582)	(0.0484)	(0.0525)	(0.0620)	
ln(prefecture area, 2005)	-0.1952**	-0.1874**	-0.2003**	-0.1237	-0.1754*	-0.1777*	-0.1722*	
	(0.0958)	(0.0770)	(0.0824)	(0.1588)	(0.0902)	(0.0947)	(0.0776)	
provincial capital or level city indicator	0.021	0.1904	0.0583	0.1908	0.1167	0.0939	0.2005	
	(0.1812)	(0.2014)	(0.2264)	(0.2017)	(0.2007)	(0.1893)	(0.2211)	
ln(prefecture population, 1990)	-0.4226	-0.2522	-0.4501	-0.2646	-0.2855	-0.3174	-0.2352	
	(0.4098)	(0.3464)	(0.3829)	(0.3564)	(0.4560)	(0.5019)	(0.4471)	
ln(prefecture population, 1982)	0.4025	0.4197	0.5589*	0.4347	0.3542	0.372	0.4524	
	(0.3779)	(0.3137)	(0.3395)	(0.3227)	(0.4425)	(0.4585)	(0.4112)	
fraction high school or more in prefecture, 1982	-3.9218***	-1.7631	-1.6916	-1.5881	-3.5057**	-3.5596**	-1.4424	
	(1.4996)	(1.6711)	(1.5738)	(1.6308)	(1.6699)	(1.7488)	(1.9096)	
share employed in manufacturing in prefecture, 1982	-1.2564**	-1.6998***	-1.5025**	-1.7385***	-1.3577**	-1.3204***	-1.6400***	
	(0.6014)	(0.5158)	(0.5946)	(0.5054)	(0.5400)	(0.5030)	(0.4640)	
constant	5.1544***	2.7885	3.6699*	2.533	4.6092***	4.7877**	2.9839	3.883***
	(1.6043)	(1.8736)	(2.0398)	(2.0552)	(1.5899)	(1.9931)	(2.2121)	(0.1413)
Observations	241	241	241	241	241	241	241	241
First stage F	14.4	48.1	4.4	7.9	12.5	5.9	5.3	79.2

Panel B: OLS Coefficients on Transport Measures

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
2010 radial highways	-0.0091		-0.0058			-0.0133		
	(0.0158)		(0.0151)			(0.0164)		
2010 radial railroads		-0.0382	-0.0371	-0.0357			-0.0722	
		(0.0366)	(0.0360)	(0.0376)			(0.0738)	
ln(highway kms in prefecture remainder, 2010)				-0.0125				
				(0.0343)				
2010 ring road indicator					-0.1390	-0.1455		
					(0.0864)	(0.0876)		

Notes: Road and rail network measures in 1962 instrument for these measures in 2010. Standard errors in parentheses are clustered by province. *** p<0.01, ** p<0.05, * p<0.1

Table 9. Employment Decentralization by Industrial Sector, 1995-2008

Panel A: High and Medium Weight to Value Ratio Industries

	All Industry				Heavy weight (food, wood & paper, chemicals, non-metallic, primary metals: SIC13-16,20,22,25-28,31-33)			Medium weight (fab. metals, furniture, plastics, rubber, printing: SIC 21, 23, 24, 29, 30, 34)		
Weight to Value Ratio					0.51 to 0.80			0.22 to 0.35		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
2010 radial highways	-0.0500		-0.0666			-0.0148			0.0518	
	(0.0924)		(0.0999)			(0.0772)			(0.1179)	
2010 radial railroads		-0.2820***		-0.2815***	-0.0792		-0.0793	-0.2446*		-0.2440**
		(0.1087)		(0.1037)	(0.0844)		(0.0836)	(0.1260)		(0.1208)
2010 ring road indicator			-0.2339	-0.3036		-0.0516	-0.0721		-0.2288	-0.3983
			(0.2895)	(0.2937)		(0.2751)	(0.2805)		(0.4171)	(0.4144)
ln(prefecture employment in the same industry, 1995)	-0.0869	0.0193	-0.0843	0.0198	-0.2948***	-0.3233***	-0.2937***	0.0993	0.0998	0.0854
	(0.0784)	(0.0791)	(0.0792)	(0.0832)	(0.0910)	(0.0865)	(0.0900)	(0.1406)	(0.1215)	(0.1344)
Observations	257	257	257	257	257	257	257	257	257	257
First stage F	17.1	42.6	5.7	5.5	36.1	5.8	5.5	51.1	5.9	6.1

Panel B: Low Weight to Value Ratio Industries

	Textiles, apparel, leather (SIC 17-19)				High tech (SIC 368, 376, 40, 411, 412, 414, 419)			Elec. & non-elec. machinery & equip (non-high tech) [SIC 35-39 (exc. 368, 376), 413, 415]		
Weight to Value Ratio	0.06 to 0.25				0.01			0.12-0.13		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
2010 radial highways	-0.2882*		-0.3584**			-0.1745			-0.0619	
	(0.1569)		(0.1718)			(0.4086)			(0.1280)	
2010 radial railroads		-0.4566**		-0.4591**	-0.6768***		-0.6726**	-0.2661**		-0.2669**
		(0.1818)		(0.1973)	(0.2591)		(0.3054)	(0.1152)		(0.1152)
2010 ring road indicator			-0.9973	-0.8373		-1.9585*	-2.0646**		-0.2735	-0.3194
			(0.6751)	(0.5563)		(1.0323)	(1.0211)		(0.3399)	(0.3128)
ln(prefecture employment in the same industry, 1995)	0.1717	0.0709	0.1366	0.0355	-0.2457***	-0.2569***	-0.2597***	0.1731*	0.1505**	0.1795**
	(0.1760)	(0.1893)	(0.1851)	(0.1948)	(0.0767)	(0.0861)	(0.0817)	(0.0957)	(0.0698)	(0.0899)
Observations	257	257	257	257	257	257	257	257	257	257
First stage F	17.4	48.9	5.9	5.8	49.9	5.9	5.9	44.2	6.1	5.8

Notes: Road and rail network measures in 1962 instrument for these measures in 2010. Standard errors in parentheses are clustered by province. *** p<0.01, ** p<0.05, * p<0.1