Roads, Railroads and Decentralization of Chinese Cities*

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Abstract: We investigate how configurations of urban railroads and highways influenced urban form in Chinese cities since 1990. Each radial highway displaces about 4 percent of central city population to surrounding regions and ring roads displace about an additional 20 percent. Each radial railroad reduces central city industrial GDP by about 20 percent, with ring roads displacing an additional 50 percent. Similar estimates for the locations of manufacturing jobs and residential locations of manufacturing workers is evidence that radial highways decentralize service sector activity, radial railroads decentralize industrial activity and ring roads decentralize both. Historical transportation infrastructure provides identifying variation in more recent measures of infrastructure.

J.E.L.: R4, O2

Keywords: China, Roads, Railroads, Infrastructure

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1. Introduction

Developing countries spend huge sums on transportation infrastructure projects that shape their cities for decades to come. In recent years, about 20 percent of World Bank lending has been devoted to 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 layout of utilities. Urban transportation infrastructure generates direct welfare benefits through reduced commuting and shipping costs, it leads to changes in urban form and it affects urban environmental costs and the supply of land available for agricultural production. While mayors and planners worldwide ultimately want to determine the optimal scale, scope, and layout 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 per year, much of which 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 migration of the rural population to cities. In addition, as central planning constraints 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. During this period, economic growth averaged over 10 percent per year, resulting in GDP per capita of about $8800 in 2010 (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 between 1990 and 2010. Since such decentralization could precipitate infrastructure investments, we rely on exogenous variation in transportation networks predating China's conversion to a modern market based economy to estimate the causal effects of such infrastructure on urban decentralization.

To conduct 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 during 1990-2010. We also use satellite images of lights at night from 1992 to 2010.

We find strong evidence that radial highways and suburban ring roads reduce population density in central cities. Our estimates indicate that each additional radial highway displaced about 4 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. Conditional on the radial and ring configuration of the highway network, neither total kilometers of 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) suggest 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 amount of central city 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 20% of central city industrial GDP, while the existence of some ring road capacity displaces about 50% of central city industrial GDP. These components of the urban transport network generate similar estimated responses of the residential and work locations of manufacturing workers. These are large effects, but they are consistent with case studies in the literature reviewed below. This important role of railroads in shifting the composition of central city output may be explained 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%. This is well below the U.S., where just over 40% of freight moves by road.[1] Importantly, as we discuss further below, we do not have the requisite information to separate out the extent to which the declines in central city industrial output caused by railroads and ring roads reflect decentralization versus shifts in the sectoral composition of prefecture output.

Overall, this paper extends Baum-Snow's (2007) analysis of highways and urban decentralization in the U.S. to a developing country context and introduces consideration of additional transport modes and decentralization of different types of economic activity. Starting around 1950, central cities in the U.S. experienced absolute declines in population, while in China after 1990, central cities saw large absolute and proportionate population

[1]For comparability between Chinese and U.S. data, we report the percentage of ton miles provided by trucks. Since heavy low value goods travel long distances by train, this is less than the share of value travelling by truck (Redding and Turner, 2015). Changes in coverage of Chinese reports somewhat complicate comparisons. Roads' reported percentage of freight (ton km) 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 30%, mostly reflecting a discontinuous jump in the 2008 statistics from the changing coverage. See China Statistical Abstract, Table 16-9 and Statistical Abstract of the USA 2012, Table 1070 (yr 2007).

gains relative to their rural suburbs. Thus, in China rather than radial highways potentially causing absolute decentralization, they retard the high rate of centralization. To our knowledge, only Deng et al. (2008) investigate the effect of roads on the internal development of cities in a developing country context. 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. [2]

A larger literature focuses on the effects of transport investments on economic growth in counties, cities and regions. For example, Qian et al (2012) and Faber (2014) examine whether areas near Chinese trans-national transport infrastructure gain or lose compared to areas further away. Michaels (2008) and Chandra and Thompson (2000) investigate the effects of U.S. interstate highways on the development of rural U.S. counties. Duranton and Turner (2012) find that the extent of urban interstate highways has economically important impacts on the growth rates of population and employment of metropolitan regions. García-López, Holl and Viladecans-Marsal (2013) replicate these results for Spain. Donaldson (2014) finds large impacts of railroads on trade and welfare in late 19th and early 20th century India. Finally, Duranton, Morrow and Turner (2014) examine the effects of the interstate highway system on trade between cities in the U.S., finding that while highways had modest effects on inter-regional trade flows, they do affect city industrial composition. All of these papers make use of plausibly exogenous variation in road networks to identify the effects of roads on outcome variables of interest.

What about urban form and decentralization of industry within cities? Since Marshall (1890), economists have recognized that denser cities provide richer information environments, which in turn improve productivity and increase innovation (Jacobs, 1969; Lucas, 1988). However, central city environments have much higher land and somewhat

[2] In a companion literature, 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 (2014) replicate this result using Japanese data.

higher labor costs than suburban and ex-urban locations. As a result, large central cities in developed market economies typically specialize in business and financial services, which benefit sufficiently from richer information environments to justify these higher factor costs (Arzaghi and Henderson, 2008). In developed countries, standardized manufacturing is typically found on the lower cost urban periphery and in small cities and towns (Kolko, 2000; Swartz, 1992). The situation in developing countries better resembles the U.S. in the late 19th and early 20th centuries when industry was concentrated in central cities, as in Chinese cities circa 1990. Manufacturing facilities in developing countries often start in central cities, perhaps in part because of the externalities involved in the learning and adaptation of technologies from abroad (Duranton, 2007). However, as transferred technologies mature and economic growth proceeds, central city environments become expensive locations for standardized manufacturing and, in a version of the product cycle (Duranton and Puga, 2001), industrial firms decentralize to find lower land and labor costs. Meyer et al. (1965) describe this process in the U.S. from 1940 through the 1960s. Rothenberg (2013) describes this process for Indonesia in the 1990s.

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 and Choe, 1990; Lee, 1982; Hansen, 1987; Henderson, Kuncoro and Nasution, 1996). This paper is the first to investigate the extent to which different highway and railroad network configurations contribute to this transformation using a research design that identifies causal effects.

In summary, we improve on the existing literature in three important ways. First, we are among the first to investigate the effects of transportation infrastructure on urban form in a developing country where automobiles are less prevalent,[3] household incomes are much lower and cities are much denser than in the United States. Second, we 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 within cities. This is also novel.

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 the residual portions of prefectures. Results in the left block 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

[3] In 1990, car production was only 50,000 units. This increased to slightly more than 600,000 units by 2000, but a major portion of these sales was to institutions rather than individuals. By 2010, car sales exceeded 10 million units, mostly to individuals (*zhongguo qiche gongye nianjian* (China Automotive Industry Yearbook), various years). In 2010, about 15 percent of urban commutes were by private automobile.

just 5% in city hinterlands. This is urbanization, the flow of Chinese peasants primarily from rural counties into central cities within prefecture.

Data availability restricts the sample of cities for which we observe GDP in prefecture remainders. Moreover, Table 1 incorporates a number of imputations for these remainders. So, to first 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. The middle block of Table 1 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. In the sample for which data is available or could be imputed, the right block of Table 1 presents industrial sector GDP growth. Suburban industrial GDP grew by 1673% between 1990 and 2010 relative to 873% for central cities. These numbers indicate relative decentralization of manufacturing. Our data also include total GDP. However, observed patterns of decentralization in total GDP are similar to those for industrial GDP and we worry that the service sector component 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 central city populations grew more rapidly than did surrounding prefecture populations throughout our study area, including in the interior. Figure 1b shows that, unlike population, industrial GDP decentralized rapidly in most of the prefectures for which we could construct complete data during this period.

While our research design for recovering effects of transport infrastructure on urban decentralization resembles the investigation in Baum-Snow (2007a), the different Chinese and U.S. contexts make aspects of the analysis distinct. Baum-Snow assumes that before 1950 no highways connected central to suburban areas, so that any change in highways after 1950 reflected new construction. We make the same `no initial highways' assumption, but note that this assumption is easier to defend for China. In 1990, Chinese ‘highways’ near major cities were almost universally one or two lane roads and were often unpaved. Almost all paved highways in China with more than two lanes were built after 1990.

However, the institutional environments of post-war U.S. and post-1990 China are radically different, which provides a second source of identification. In contrast to the U.S., where there are no institutional restrictions on factor mobility, the urban and rural sectors in China as of 1990 were under separate institutional and economic regimes. People had citizenship in either the urban or rural sector (as a birthright based on mother’s registration) and migration between the two sectors was rare and strictly controlled (Chan, 2001; Au and Henderson, 2006). Industry and land in rural counties surrounding central cities were owned by local collectives. 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 (Zhou and Logan, 2007). Except for a few `special economic zones’ created before 1990, housing, factory, and 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 begin in the early 1990s and that 1990 is a census year, it 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 restructured. 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 even for population, this relaxation was what allowed decentralization of population once highways were built. In particular, we will show that existing pre-1990 roads only led to population decentralization after 1990. Therefore, 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 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. Subordinate to provinces are prefectures (*diqu*), most of which have one core city (*shixiaqu*), numerous rural counties (*xian*), and several county cities (*xianji shi*).[4] Core cities are made up of urban districts (*qu*). Core cities are administered as one unit and are the nearest possible Chinese analog to central cities of U.S. metropolitan statistical areas. Each rural county and county city is administered separately under the supervision of its prefecture. Much of our data are reported separately for 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

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

many migrants, especially in the 1990s (Chan 2001, 2005).[5] Thus, our analysis primarily 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 three because their central cities coincide with the full prefecture, precluding any analysis of decentralization,[6] eight 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 objective 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 the allocations of population, employment

[5] Census data do not allow us to distinguish migration between prefectures from migration within prefectures within a province. For the mid-1990s, Chan (2001, Table 4) estimates that 36% of rural migrants remained within their own county and 71% of such migrants remained within their home province. Even if we assume that half of those within province who cross a county boundary also crossed a prefecture boundary, over half of all migration was within prefecture. The share of cross provincial boundary migration increased in the 2000s, and with it, the share of cross prefecture migration probably also increased.

[6] These are Laiwu, Ezhou and Jiayuguan.

and economic activity 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 2005 year units that were designated as urban districts in 1990, or that 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. We call such cities ‘promoted’. For these, central cities consist of the county cities or rural counties first promoted to urban status.[7] In 1990, most of these yet to be promoted central cities were already treated as urban counties in the 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.[8]

3.2 Demographic, GDP and Employment 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 and 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

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

[8] Some boundary definitions between rural counties and urban districts also changed. In these cases, we aggregate relevant adjacent rural counties or county cities with core cities to maintain consistent central city geographic units over time.

sector GDP information comes from national and provincial printed data year books (China Statistics Press, 1992b and 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 in both 1990 and 2010.[9]

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 discussion of grouping of industries into types later in the paper 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, Morrow and Turner (2014). Given that most of these products are internationally traded, such ratios from U.S. sources are likely to apply reasonably closely in China as well.

3.3 Infrastructure

To describe the Chinese road and railroad network, we digitize a series of large scale national transportation maps. 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

[9] 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. We impute 2010 industrial GDP for the central city portions of core cities that expanded geographically between 1990 and 2010 using reported total core city GDP allocated to urban districts with manufacturing employment shares. 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.

than more detailed provincial maps to ensure consistency within each cross-section. To improve consistency across time, when possible, we select maps from the same publisher, drawn using the same projection, the same scale 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.[10] As we discuss in the following section, our analysis ultimately uses infrastructure data only from 1962, 1990, 2005 and 2010.

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. 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 the only two

[10] These routes were plotted and digitized by Tuan Hwee 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.

types of roads indicated on our 2005 map. From the 1999 map, we use the union of the national and high grade highways networks in place and under construction (*gao su*, *gao deng ji gonglu*, *jianzhuzhong gao su, gao dengji gonglu, guo jia ji gonglu).*[11] Finally, our measure of 1962 roads is based on the single highway network (*gong lu*) described in 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 that 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 high grade 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 high grade highway network in Beijing, exactly what one would choose if doing the calculation by eye.[12]

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

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

[12] In practice, we use all 2010 highway rays, not just high grade highways, for the purpose of estimation. Beijing has a total of 11 highway rays in 2010.

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 that lie between 5 and 9 km from the center. In the figure, these are areas bounded by the two black circles. We next identify all intersections of each ray with the road network within the rings. In the case of Beijing there is one each. The northwest quadrant ring road index for the 5 to 9 km ring is the minimum of these two counts of intersections, which is still one each. For the other cities shown, the minimum is zero. To finish our calculation of the ring road index in the 5 to 9 km annulus centered on the CBD, we replicate this calculation for each of the four quadrants and sum the resulting quadrant by quadrant index numbers. Thus, a one unit increment in this index reflects a single 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 9-15 km and 15-25 km from the CBD.[13] In our empirical work, we sum the results of these three calculations and restrict attention to roads that 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.

3.4 Supplemental Data Sources

We use satellite data primarily as a source for lights at night. Table 1 uses images from 1992, 2000, and 2010 (NGDC 1992-2010). 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 top code. Top coding 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

[13] We choose 9, 15 and 25 km so that the minimum angle at which a straight-line highway may intersect both rays in any distance-quadrant segment is the same for all rings.

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.

Table A1 presents summary statistics.

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 considering a static economic model that describes the allocations of population and firms across space within a prefecture, as in Alonso (1964), Muth (1969), Fujita and Ogawa (1982) and Lucas and Rossi-Hansberg (2002). The primary role of this model is to identify important exogenous control variables for the empirical analysis and gain some intuition about the mechanisms through which transport cost reductions may influence the locations of population, employment and output within urban areas.

In the standard land use model, freely mobile residents and firms rent from absentee landlords, so that identical residents have the same welfare and identical firms have the same profits at all locations in equilibrium. Equilibria of these models typically have most people commuting toward the city center to work and the strongest agglomeration spillovers between firms in the center. Higher rents nearer to the city center capitalize both lower time and out-of-pocket cost for commuters and higher agglomeration economies for firms. Agriculture is the alternative use of land at the city edge. Residents and firms thus consume less land nearer the city center, ceteris paribus, and population densities are higher there. Holding the spatial distribution of employment fixed, a reduction in transport costs reduces the relative value of locations nearer to the city center for commuting purposes. Holding the area's population constant, the city land rent and population density gradients thus typically both shift down at the center and rotate so that the city spreads out into the surrounding agricultural area. Such population decentralization as a consequence of lower commuting cost occurs in standard monocentric urban models, 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 (Duranton and Puga, 2015).

Theoretical predictions about the impacts of transportation infrastructure on firm location within regions are less informative. If firms locate near the periphery, they face lower land and labor costs because their workers have shorter commutes and land is less valuable. If firms locate in the center, they are more productive because of agglomeration economies but face higher costs. 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).[14] Moreover, comparative statics with respect to transport costs are inconclusive. As such, we organize our empirical work investigating how the location of economic activity responds to transport infrastructure around hypotheses suggested by Meyer et al. (1965) and described above.

For empirical purposes, we define inner metropolitan regions as 1990 central cities and outer regions as prefecture remainders. We define these regions both because their attributes can be consistently measured over time and because they have natural theoretical analogs.

[14] As is demonstrated in Fujita and Ogawa (1982), high commuting costs imply no commuting and mixed land use, while low commuting costs imply a monocentric city. However, no clear predictions are possible for intermediate commuting costs.

Define y_{tA} to be population, employment or output in year *t* and administrative unit *A*, either prefecture *P* or central city *C*. We denote a vector of additional observed control variables of what will be time invariant variables by x and a vector of transportation network measures by r. We use Δ_t to denote a first difference, where 1990 is always the base year and *t* is the terminal year. For example, $\Delta_{2010} lny_P$ denotes $lny_{2010P} - lny_{1990P}$.

A straightforward way to characterize the relationship between transportation infrastructure and centralization is with a levels equation of the form

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

Equation (1) follows directly from "closed city" versions of theoretical models described above, though a careful accounting for the endogeneity of $\ln y_{tP}$ will be important in the empirical work. Error term components δ and ε_t represent unobserved constant and time varying prefecture specific variables that influence the outcome. The coefficient of interest, A_1, indicates the portion of central city population, employment or output displaced to prefecture remainders for each additional unit of transportation infrastructure. Consistent with theoretical predictions described above, we expect $A_1 < 0$ for population but have no strong prior for other outcomes.[15]

Equation (1) describes the relationship between infrastructure and a central city outcome holding prefecture scale constant. The following related empirical specification describes the central city *share* of y as a function of infrastructure:

(2) $\ln y_{tC} - \ln y_{tP} = A'_0 + A'_1 r_t + B'_0 x + \delta' + \varepsilon'_t.$

A'_1 captures some combination of the effects of infrastructure on combined prefecture and central city outcomes, whereas A_1 captures the effect of infrastructure on the allocation of the outcome between the central city and prefecture remainder, where the prefecture outcome is held constant in (1). Equation (2) can be decomposed into

[15] Equation (1) posits a static relationship between infrastructure and urban form. To the extent allowed by our data, section 5.2 investigates the dynamics of adjustment to new infrastructure.

(2a) $\ln y_{tC} = A'_{a0} + A'_{a1}r_t + B'_{a0}x + \delta'_a + \varepsilon'_{at}$ and

(2b) $\ln y_{tP} = A'_{b0} + A'_{b1}r_t + B'_{b0}x + \delta'_b + \varepsilon'_{bt}$.

Since y_{tP} is the sum of central city and prefecture remainder outcomes, A'_{a1} captures some combination of the direct effect of infrastructure on the central city outcome and the indirect effect that operates through infrastructure's influence on the prefecture outcome. For example, roads may cause central city population to fall through displacement to prefecture remainders and to rise because they draw in new population to all prefecture locations. Therefore, isolating the decentralization effects of infrastructure requires estimation of (1) rather than (2) or (2a). However, because $\ln y_{tP}$ does not appear on their right hand sides, estimation of (2), (2a) and (2b) presents fewer identification challenges than does estimation of (1). In practice, we show below that since our estimates of A'_{b1} are about 0, estimates of A_1, $A'_1$and A'_{a1} turn out to statistically coincide for all outcomes and transport measures considered.

Some of our analysis also considers the effects of infrastructure on the location of industrial output and employment in particular sectors. For these outcomes, a complete characterization of the effects of infrastructure requires at least four equations, one each for output or employment in each sector in the central city and the prefecture (or its remainder). One logical step would be to express the effect of infrastructure on the allocation of sectoral employment or output between central cities and prefecture remainders using the following equation analogous to (1)

$$\ln y_{ktC} = a_{0k} + a_{1k}r_t + a_{2k}\ln y_{ktP} + b_{0k}x + d_k + e_{kt},$$

in which y_{ktA} as employment or output in sector k at time t in region A. However, this formulation would need to account for the potentially endogenous reallocation of prefecture employment or output across sectors, as in Duranton, Morrow & Turner (2014).

One could simultaneously characterize such sectoral reallocation and decentralization effects in each sector by estimating versions of (2a) and (2b) for each sector. However, absence of prefecture level data on output by sector lead us to focus on estimating more reduced form relationships between infrastructure and central city sector specific outcomes, as in

(1') $\ln y_{ktC} = A_{0k} + A_{1k} r_t + A_{2k} \ln y_{tP} + B_{0k} x + \delta_k + \varepsilon_{kt}$.

Here, A_{1k} compounds the effects of infrastructure on decentralization of sector k with sectoral reallocation of prefecture employment or output. Limited information about prefecture GDP leads us to measure y_{tP} as prefecture population or employment at time t in all empirical work, even if the outcome is central city industrial GDP. [16]

In addition to the probable endogeneity of y_{tP} noted above, there are two problems with using (1) and (1') directly for estimation. First, while the coefficients should describe approximate land use 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. This condition is unlikely to hold. In particular, we are concerned that historically productive or attractive city centers have been allocated more modern highways. In this case, the coefficient on highways at least partly reflects this unobserved attractiveness rather than a causal effect of infrastructure.

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

(3) $\ln y_{1990C} = (A_0 + \Delta A_0) + (A_1 + \Delta A_1) r_{1990} + (A_2 + \Delta A_2) \ln y_{1990P} + (B_0 + \Delta B_0) x + \delta + \varepsilon_{1990}$.

Subtracting (3) from (1) yields

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

[16] Baum-Snow (2014) carries out such an analysis, estimating a full system of industry specific equations for the United States 1960-2000.

First-differencing removes any time invariant unobservables that may be correlated with *r* and drive decentralization.

There is a number of practical difficulties in recovering the coefficients in (4) 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. 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 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. 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 is indicated in Section 2, there was little freedom for central city firms to decentralize to suburban regions even if they wanted to in 1990. Existing roads and railroads could not be used to decentralize. Once economic reforms were in place, cities began to adjust to market equilibria with 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, which only became possible after 1990. Since most intra-city railroads in 2010 had been built by 1990, we recover similar estimates whether we use 1990 or year *t* railroads as our infrastructure measure. [17] 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

[17] Nationally, network length increased by about 20 percent between 1990 and 2010 with some additional double-tracking of 1990 railroad lines. We cannot use the change in railroads as a predictor anyways 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.

to our investigation of the effects of railroad levels in later years. Our primary estimation equation thus becomes

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

There are potentially serious estimation concerns that $r_t,\ \Delta_t \ln y_P\ , and\ \ln y_{1990P}$ in (5) are correlated with the error term. We address each one in turn.

Transportation infrastructure may have been assigned to cities in a way that was correlated with unobserved factors driving decentralization. To resolve this problem, we rely on instrumental variables, which generate pseudo-randomization of the infrastructure treatments. Conditional on appropriate controls, we require instruments that predict endogenous variables but are otherwise uncorrelated with the error term in our structural equation. Similar to Baum-Snow (2007a), Duranton and Turner (2011, 2012), Garcia-Lopez, Holl and Viladecans-Marsal (2013) and Hsu and Zhang (2014), we use information about year 1962 networks as instruments for r_t. We lay out conditions for validity of this class of instruments in Section 4.2.

We pursue three parallel strategies to handle the potential endogenity of prefecture population growth. First, we calculate bounds on A_1 by estimating (5) including and excluding the change in prefecture population as a control. It is straightforward to show that the true value of A_1 is bounded by the estimates that arise from estimating (5) including and excluding $\Delta_t \ln y_P$ respectively. The logic of this bounding argument is seen in the following simplified environment. Suppose that the underlying structural equation for central city population is $\Delta_t \ln y_C = \alpha_0 + \alpha_1 r_t + \alpha_2 \Delta_t \ln y_P + u$, where r_t is instrumented with r^{62}, which is uncorrelated with u. The IV estimate of α_1 excluding $\Delta_t \ln y_P$ from the regression equals $\alpha_1 + \alpha_2 Cov(r^{62}, \Delta_t \ln y_P)\ / Cov(r_t, r^{62})$. This expression reflects the possibility that infrastructure promotes prefecture population growth, which includes some central city population growth as well. The IV estimate of α_1 including $\Delta_t \ln y_P$ in the regression equal $\alpha_1 - \frac{Cov(r^{62}, \Delta_t \ln y_P) Cov(\Delta_t \ln y_P, u)}{D}, D > 0 \; and \; Cov(\Delta_t \ln y_P, u) > 0$. Therefore, regardless of the sign of $Cov(r^{62}, \Delta_t \ln y_P)$, these are bounds on the true value of α_1.

Our second, and primary, strategy is to use a migration shock instrument for prefecture population growth, following Bartik (1991) and Card (2001). The idea is to use historical migration pathways as a predictor of more recent migration. We construct this instrument by interacting the fraction of out-migrants from each province going to each prefecture between 1985 and 1990 with the total number of out-migrants from each province between 1995 and 2000. This measure is a good predictor of 1990-2010 prefecture population growth.[18] The identification assumption for validity of this instrument is that 1985-1990 internal migration flows are uncorrelated with unobservables (like productivity shocks) driving changes in central city population between 1990 and 2010. Especially because the instrument is based on data from the pre-market reform period, this assumption seems plausible. Our analysis relies primarily on this instrumental variables approach, as it both allows for a strict interpretation of the infrastructure coefficient as only capturing decentralization, while avoiding the need to report both bounds on each coefficient of interest. Since 1962 infrastructure does not predict 1990-2010 prefecture population or employment growth, we demonstrate below that all three exercises yield statistically identical coefficients on infrastructure measures. As a result, conclusions about the consistency of estimates of coefficients of interest do not rely on the validity of the Card instrument.

Third, we estimate a differenced version of (2), which does not include prefecture population as an explanatory variable. Here as noted above we are combining effects of transport investment on decentralization and on prefecture growth.

[18] We have no information about migrant origins or migration flows in any other time period. We also tried using an industry shift-share type instrument for prefecture population growth, as in Bartik (1991), but it was insufficiently strong.

There is the remaining issue of the potential endogeneity of $\ln y_{1990P}$ in (5), which may arise from the mechanical correlation between the outcome and $\ln y_{1990P}$. We handle this issue by controlling for $\ln y_{1982P}$ instead, as a proxy. In the *x* controls, correspondingly, we also use 1982 rather than 1990 variables to reduce the potential that they are correlated with later shocks affecting $\Delta_t \ln y_C$.

In sum, our main regression specification includes three components. First, we include and instrument for the potentially endogenous transportation infrastructure measures at time *t*. Second, we include and instrument for prefecture population growth. Third, as we discuss further below, we include control variables potentially correlated with instruments and outcomes. These are historical levels of prefecture population, central city and prefecture land areas, an indicator of whether the city is one of 4 provincial level cities or 26 provincial capitals, historical educational attainment levels and historical specialization in manufacturing. 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 that influence outcomes of interest. Therefore, though it is likely that unobserved variables affect population and industrial GDP location patterns, the IV estimator prevents any resulting bias to estimates of A_1.

We note that the effects of infrastructure on decentralization probably vary with certain city characteristics such as land use planning policy, housing supply elasticity, the availability of alternatives to auto travel and local variation in hukou policies. That is, we expect there to be heterogeneous treatment effects. For the named items, we have no measures for any large sample of cities. Moreover, while we attempt to recover heterogeneous treatment effects in other dimensions, we simply do not have the statistical power to do so precisely. Given this, the IV results presented below should be viewed as local average treatment effects (Angrist and Imbens, 1994). The fact that historical infrastructure is a strong predictor of modern infrastructure for various subsets of the sample, as we establish in the following subsection, suggests that the treatment effects we estimate represent averages over a broad set of prefectures.

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. Valid 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. We find that 1962 road network 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 rights of way were already established and the local street networks already fed into these roads.[19]

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 possible. Because little commuting occurred in 1962, the road network outside of central cities served primarily to connect 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

[19] 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 are also concerned 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.

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 remains 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.[20] Since 1982 is the earliest year for which there is county level census data, we include 1982 share of prefecture employment in

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

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. Because of concerns about introducing lagged dependent variables, we only control for analogous 1982 central city outcomes in robustness checks.

More than two-thirds of 1962 railroads had been 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 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 Columns 1-4 show representative first stage results for the three 2010 transportation network measures we emphasize and one for 1999, which will be relevant for our consideration of dynamics. Table 2 reveals that the instruments are individually strong conditional on the standard set of control variables used throughout our analysis, and that each modern transport measure is predicted by its 1962 counterpart. Each 1962 road ray predicts about 0.35 of both 1999 and 2010 highway rays conditional on base specification controls and instruments for the other infrastructure measures and prefecture population growth. Because the coefficient on 1962 radial roads is statistically identical in each of these regressions, this instrument does not predict changes in roads between 1999 and 2010, keeping in mind that these 1999 and 2010 roads measures are not directly comparable. These facts mean that we cannot empirically isolate effects of radial highways built between 1999 and 2010. Each 1962 railroad ray predicts 0.37 railroad rays in 2010. Finally, the existence of ring road capacity in 1962 increases the probability of such capacity in 2010 by 0.52.

For completeness, Table 3 Column 4 presents a representative first stage regression for prefecture population growth. We see that historical infrastructure measures do not predict prefecture population growth while the Card instrument does.

In order to determine which local average treatment effects (Angrist and Imbens, 1994) IV regression results presented below recover, it is instructive to know which types of cities' 1962 transport networks provide identifying variation in the first stage. Relevant 1962 transport network coefficients are statistically significant at the 5 percent level with the correct sign for 8 of the 12 1990 central city population tercile/transport network measure pairs. Similarly, such measures work for 6 of the 8 East vs Center/West region by transport measure pairs.[21] Given that our instruments have good predictive power in much of the sample, we conclude that our treatment effect estimates apply broadly to Chinese cities.

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[21] 1962 highway rays coefficients are insignificant at the 5 percent level for medium sized and Eastern cities when 2010 rays is the outcome, and small cities when 1999 rays is the outcome (with marginal

5. Results for Population Decentralization

5.1 Basic Results

Table 3 reports baseline OLS estimates of the empirical relationship between highway rays and 1990-2010 central city population decentralization. The 2010 radial road index is the only explanatory variable in Column 1. Column 2 adds a base set of controls and Column 3, our preferred specification, adds 1982 prefecture controls. While we expect the true causal relationship to be negative, OLS coefficients of highway rays are near zero. Consistent with our priors, results in Columns 4 and 5 show that growing and decentralizing prefectures received more highways between 1990 and 2010.

The first three columns of Table 4 report IV estimates of Equation (5), with the 1962 road ray index instrumenting for 2010 radial highways in each column. Column 1 includes a non-instrumented control for prefecture population growth while Column 3 has no such control. These two columns define the bounds on A_1 in Equation 5 as discussed in Section 4.1. In Column 2, our primary specification, we instrument for prefecture population growth in addition to 2010 radial highways, to obtain an unbiased estimate of A_1. Column 4 has the change in log prefecture population as the dependent variable and Column 5 has the change in log central city population share as the dependent variable. All five regressions include the same set of controls as Table 3 Column 3.[22]

The regressions in Table 4 show that each radial highway decentralizes about 4% of central city population. Indeed, all three procedures discussed in Section 4.1 to account for the potential endogeneity of prefecture population growth yield this conclusion. As seen in Column 4, the reason is that there is essentially no effect of highways on prefecture

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insignificance for Eastern cities). The 1962 railroad rays coefficient for medium sized cities is insignificant when 2010 railroad rays is the outcome. The 1962 ring capacity indicator is insignificant for large cities and non-Eastern cities when 2010 ring capacity is the outcome.

[22] Online Appendix Figure A1 plots residuals from an OLS regression with the specification of Table 3 Column 3 excluding radial highways against first stage residuals. It thus provides information about the identity of cities that provide identifying variation. Figures A2-A4 repeat this exercise for other outcomes and predictors discussed below.

population growth. Therefore, the bounds reported in Columns 1 and 3 are fairly tight at -0.041 and -0.048, with the IV estimate of -0.042 in Column 2 in between. The shares specification in Column 5 produces a coefficient of -0.041. The shares coefficient can be derived by comparing coefficients in Columns 3 and 4. That is, it partly reflects the result in Column 4 that highways cause a small insignificant decline in prefecture population. We note that coefficients in Columns 1, 3 and 5 are significant at the 6 percent level. As we show in Tables 6 and 8 below, excluding cities in the far West, where pro-market institutional reforms allowing decentralization have been implemented more slowly, or controlling for other aspects of urban transport networks that have their own effects on decentralization improves this estimate's precision.

Coefficients on non-transportation related covariates are also of interest. In Column 2, a 1% increase in prefecture 1990-2010 population growth leads to a 0.81% increase in 1990-2010 central city growth holding 1982 prefecture population constant. A persistent 1% increase in 1982 prefecture population, however, is associated with just a 0.11% increase in 1990-2010 central city population growth. The growth elasticity is higher than related estimates in Baum-Snow (2007a) 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. Population in provincial capital central cities grew more quickly, which may reflect political influence. The 1982 control for prefecture education is not significant, nor is 1982 manufacturing share. Coefficients on control variables are similar for OLS results in Table 3 (unreported).

Consistent with evidence in Baum-Snow (2007a) and Duranton and Turner (2012) for the U.S., differences between OLS and IV highway rays coefficients suggest that our 2010 radial roads index is 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. While more rapidly growing Chinese cities received more highway infrastructure, the decentralization that occurred because of this infrastructure is more than offset by the growth that precipitated construction of this infrastructure. As a result, the use of pseudo-random variation from the 1962 network is essential to recovering the true causal effects of these transportation improvements on the spatial organization of Chinese cities.

5.2 Validity and robustness

The validity of the no initial highways assumption employed so far rests on the claims that 1990 roads were not highways and that pre-reform urban China did not permit market responses to cross-city differences in transportation networks. An implication is that cities did not decentralize in response to old roads during the pre-reform period. To address this hypothesis, we investigate the impact of 1980 road rays and the highly correlated 1990 rays on decentralization during the 1982 to 1990 pre-urban reform period.[23]

Table 5 presents estimates similar to those in Table 4 but for the 1982-1990 period. Specifications in Columns 1 and 2 approximately correspond to that in Table 4 Column 1. In Table 5, Columns 3 and 4 are identical to 1 and 2 except they omit the control for change in prefecture population, corresponding to Table 4 Column 3. As in Table 4, coefficients in Columns 1-2 and 3-4 thus bound true coefficients.[24] Implied effects of 1980 or 1990 road rays on 1982-1990 decentralization are positive and not distinguishable from zero. This is evidence that roads only started to cause decentralization after the urban market reforms of the early 1990s. Columns 5 and 6 of Table 5 correspond to Table 4 Column 4 and report effects of radial roads on prefecture population growth. Like the 1990-2010 period, we see that radial roads do not have a measurable effect on 1982-1990 prefecture population growth. As with Table 4, differencing rays coefficients between Columns 3 and 5 or 4 and 6

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[23] Since 1980 and 1990 roads are more comparable than are 1990 and 2010 highways, the case for using levels in these regressions is driven entirely by statistical considerations. Our instrument predicts 1980 and 1990 roads but not their difference.

[24] We cannot instrument for 1982-1990 change in prefecture population. Thus, Table 5 does not provide regressions corresponding to Table 4 Column 2.

allows for recovery of the radial roads coefficient that would result from estimating a differenced version of the shares equation (2). Resulting roads coefficients are small and insignificant.

Table 6 presents robustness checks of our preferred specification in Column 2 of Table 4. Column 1 includes 1990 road rays as an additional (un-instrumented) control to investigate the validity of the `no initial highways' assumption. Not only does this approximate the exact first difference specification in Equation (4), 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. This result supports our focus on estimating Equation (5) rather than (4).[25]

In Column 2 we control for distance to the coast. This leaves the coefficient of road rays nearly unchanged. Columns 3 and 4 add controls for 1982 central city characteristics with different functional representations. We refrain from including such controls in our prime specifications to avoid introducing variables constructed using lags of 1990 central city population, which is part of the dependent variable. However, we also think it important to attempt to control for all variables that may affect central city growth and are potentially correlated with our instruments in robustness checks. Column 3 controls for 1982 fraction of residents with secondary school education and fraction of employment in manufacturing in the central city. Column 4 controls for the share of prefecture population, those with secondary school education and total manufacturing employment in the central city. The highway rays coefficient is reasonably stable across these specifications.

[25] An alternative to controlling for 1990 roads is to estimate the effect of the 1990-2010 difference in measured roads, despite the vastly differing qualities in the two years. The first stage for this regression is very weak but it also yields a roads coefficient that is much larger in absolute value than our primary estimate in Table 4 column 2.

Results in Columns 5-7 allow us to 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 land use models do not suggest that differential effects should exist per se. More specifically, in Columns 5 and 6 we restrict attention to the 78 cities in our sample with 1990 population over 1 million. Because the Card instrument does not have good power in this smaller sample, we present specifications excluding and including the prefecture growth control uninstrumented. Resulting bounds on the highway rays coefficient are tight and do not suggest that large cities respond to radial highways differently than do small cities.

Finally in Column 7, we drop the 49 cities in the West of China. The West is significantly less developed than the rest of the country and has lagged in introducing urban sector land and input market reforms. Here, we see an increase in the point estimate of the effect of radial rays about equal to one standard error. This suggests that cities in the more developed and less constrained regions of China decentralize more in response to radial roads than Western cities.

5.3 Dynamics

Our data allow for a limited investigation of the rate at which decentralization occurs in response to changes in the road network. In the first two columns of Table 7 we estimate the effect on 1990-2010 population decentralization of radial roads in place by 2005 and 1999. Coefficients on the two highway measures are similar to those in Table 4 at about -0.04. As noted in Section 4.2, this occurs because the 1962 radial roads variable predicts 1999 radial highways but does not predict post-1999 highway growth. Importantly, this suggests a refinement in the way we interpret our results. Since our first stage predicts radial roads built in 1999, regardless of the nominal year of the endogenous radial road variable, our second stage results must also describe the effect of radial roads built by 1999, also regardless of the nominal year of the endogenous radial road variable.

Column 3 of Table 7 shows the effect on 1990-2000 decentralization of radial roads in place by 1999 while Column 4 shows their effect on 2000-2010 decentralization. Other details of the regressions are analogous to our preferred specification in Table 4 Column 2, except for Column 4 in which we are not able to instrument for prefecture population growth. Estimated decentralization responses are -0.023 and -0.018 over the 1990-2000 and 2000-2010 periods respectively, adding up to the full 1990-2010 decentralization response reported in Column 2. This suggests that about half of the total 1990-2010 decentralization caused by radial highways built 1990-1999 occurred by 1999 and half occurred between 2000 and 2010.[26]

5.4 Railroads and Ring Roads

We now investigate the population decentralization effects of other elements of urban transport networks. The results will show that correlations between this other infrastructure and highway rays in both 1962 and recent years are not driving the results in Table 4. Moreover, inclusion of these other forms of investment tends to sharpen radial highway ray results, and in one case has an independent impact. Table 8 Column 1 shows that adding total highway kilometers in the prefecture remainder to our preferred specification from Table 4 Column 2 yields a positive insignificant coefficient. The magnitude and significance of the coefficient on highway rays increases relative to Table 4. Using total kilometers for the whole prefecture (not reported) yields the same result. Both indicate that it is highway rays specifically, not kilometers of the network, which affect decentralization. Columns 2 and 3 explore the effect of railroad rays on population decentralization. The estimated effect of railroad rays is zero and its inclusion leaves the highway rays coefficient unchanged. If

[26] Subtracting 1990-2000 growth from 2010-2000 growth effectively yields a rate of change specification. Consistent with the results just reported, estimating the rate of change on the same covariates yields a coefficient of about 0 on 1999 radial highways.

we substitute kilometers of the rail system for rail rays, the result is no different (not reported).

Understanding the effects of ring roads on urban form is important for policymakers. To date there has been almost no investigation of such effects because of econometric identification difficulties. China is one of the very few contexts for which exogenous variation in the number of ring roads across cities is available, although there are some limitations. In particular, few roads in 1962 look like ring roads. Even in 2010 only 29 percent of cities in our sample 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 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 of 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.

Columns 4 and 5 of Table 8 present estimated effects of ring road capacity. Ring roads on their own (Column 4) or combined with highway rays (Column 5) have large significant effects on decentralization. Conditional on highway rays, ring road capacity reduces central city populations by about 20%, although the joint F on the first stage (4.1) is low. Because of low power in the first stage, we cannot identify an additional separate interaction effect between rays and rings. We also note that rings roads and rays are often thought of as substitutes in designing urban transport networks, which may be why controlling for ring roads increases the highway ray effect in Column 5. [27]

Our estimates of the effects of highway rays on population decentralization are in line with existing evidence from the United States. The estimates of the effects of railroads and

[27] Figure A2 indicates the cities providing identifying variation for the ring road results in Table 8 Column 4.

ring roads are novel. 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 the post-WWII U.S., any relocation of people from central cities to suburbs is relatively modest.

6. Production Decentralization

We now consider the relationships between transportation infrastructure and the decentralization of production. We begin by examining the effects of different transportation networks on the 1990-2010 growth of central city industrial GDP per prefecture person. 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. We then square these results with the population results reported in Section 5. Finally, we comment on the determinants of employment decentralization for industries that 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, 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, with increased use of trucking, industry was no longer tied to central city rail terminals, freeing it to move to suburban areas where ring roads connected plants to intercity railroads or highways. Moreover, the large tracts of land required for continuous process production in manufacturing cost less in the suburbs than in city centers.

6.1 Central City Industrial GDP

Table 9 Panel A reports IV estimates of the effects of highway rays, railroad rays, total railroad length, and ring road capacity on 1990-2010 central city industrial production, holding prefecture population constant. To see the degree of bias in OLS estimates, Panel B shows the corresponding OLS coefficients on the transportation measures examined in each column. We use the same set of control variables as for our analysis of population decentralization. Consistent with our discussion in Section 4.1, estimates in Table 9, while indicating decentralization, may also reflect shifts in prefecture sector composition.

Results in Table 9 Panel A Columns 1, 3 and 6 reveal that highway rays have insignificant estimated effects on central city industrial GDP, regardless of which other elements of the urban transportation network are considered simultaneously. In contrast, results in Column 2 show the central role of radial railroads for facilitating central cities' loss of industry. Each radial railroad causes a 21% 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, with the rail rays coefficient almost unchanged and an insignificant effect for kilometers. The same result ensues if we instead control for total kilometers of rails in the entire prefecture, rather than just the remainder.

Table 9 Columns 5-7 report estimates of the effect of ring roads alone, and combined with highway rays and rail rays respectively. Whichever other infrastructure is considered, ring roads have a large effect. The existence of some ring road capacity causes at least a 43% 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 large. Results in Table 9 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 9 Panel B appear to be positively biased. For example, the OLS rail rays and ring roads coefficients in Column 7 are -0.041 and -0.145 respectively, compared to the IV estimates of -0.236 and -0.710. As with highways and population, this positive bias reflects the assignment of railroads and ring roads to central cities with more rapid GDP growth.

From our discussion in Section 4.2 of the processes by which 1962 roads and railroads were assigned, the crucial control variables in Table 9 are different from those in our analysis of population decentralization in Table 4. Instead of 1982 prefecture population, the provincial capital indicator and 1982 prefecture manufacturing employment share are controls that contribute most to the difference between the uncontrolled IV coefficient on railroad rays of -0.34 in Column 9 and the primary specification estimate of -0.24 in Column 2. Coefficients on control variables in Table 9 also differ somewhat from those in Table 4, with the control for 1982 education share now having significant coefficients in many specifications and signs of the area coefficients reversing. Central city industrial GDP growth is lower in prefectures with higher education and a greater share working in manufacturing in 1982. State owned enterprises were more prominent in such prefectures, potentially explaining this result. [28]

Results in Table 9 indicate that radial railroads and ring roads caused some combination of industrial GDP decentralization and reallocation of production toward other sectors. Data limitations preclude further investigation of the extent to which the second mechanism is important.

6.2 Decentralization of Residents and Jobs

Results in Tables 4 and 9 reveal that while roads matter for the location of people, in China railroads matter for the location of industrial production. Because production requires

[28] Generalized share regressions in which log prefecture population is put into the dependent variable produce results that are very similar to those in Table 9.

workers, these differing roles of highways and railroads may seem mutually inconsistent. However, results in Table 10 indicate that our estimated effects of radial highways and railroads are in fact consistent. Specifically, Table 10 shows that radial railroads caused similar declines in the number of central city residents employed in manufacturing as in industrial GDP and manufacturing employment. Each pair of regressions reported in Table 10 is identical except for the prefecture growth control. Odd columns use population and even columns use employment. Not surprisingly, our population based Card instrument predicts employment less well than population in the first stage.

Results in Columns 1 and 2 confirm the role of radial highways in the decentralization of population and also that radial railroads did not contribute to population decentralization. Columns 3 and 4 examine the effects of transport on the decentralization of the residential locations of workers. Estimated effects of infrastructure on residential location are almost the same as for population. However, results in Columns 5 and 6 reveal that, contrary to what we observe for all workers, radial railroads caused a dramatic decline in central city residents working in manufacturing. In particular, each radial railroad is estimated to cause about 35 percent of central city residents working in manufacturing to move to the prefecture remainder or switch sectors, with no significant effect of radial highways. Results in Columns 7 and 8 indicate that each radial railroad caused about 25 percent of central city manufacturing jobs to depart, with no effect for highways. This estimate is very close to the radial railroads coefficient of -0.24 reported in Table 9 for the effect on central city industrial GDP.

Without reliable data on the location of non-manufacturing production, it is difficult to gain a complete picture of how highways and railroads have affected the full spatial distribution of population and residents in China. However, taken together, we can infer quite a bit from our results. The population decentralization promoted by highways could either reflect more intensive commuting from prefecture remainders to central cities or the decentralization of non-manufacturing jobs. While there is little systematic data about commuting mode choice for China, all the evidence that we do have points to the latter explanation. Based on various sources, it seems that by 2010 the fraction commuting by private automobile could not have been greater than 20% in any city.[29] Therefore, if those working in non-manufacturing industries have similar commuting patterns as manufacturing workers, highways promote decentralization of service jobs and workers while railroads promote decentralization of manufacturing jobs and workers, and potentially some sectoral shift in prefecture economic activity. The fact that railroads do not affect the allocation of total working population between cities and suburbs means that railroads likely promote central city shifts toward the service sector. Ring roads decentralize all types of activities.

In Table 11, we further investigate effects of infrastructure on central city manufacturing employment. Columns 1-4 show effects on the 1990-2010 growth in the number of central city residents working in manufacturing and Columns 5-8 show effects on the 1995-2008 growth in the number of central city manufacturing jobs. The results show that highway and railroad ray coefficients for these outcomes in Table 10 persist when infrastructure variables enter individually. Though highway rays have no effect on central city industry, each railroad ray is estimated to cause about a 30 percent decline in residents working in manufacturing and a 25 percent decline in manufacturing jobs. Results in Column 4 indicate that some ring road capacity additionally reduces the number central city residents working in manufacturing by 62%. However, results in Column 8 give weaker evidence that ring road capacity reduces the number of central city manufacturing jobs. The relevant coefficient is large and negative, but not statistically significant.

Meyer et al. (1965) suggest more detailed patterns for the exodus of industry from central cities in the U.S. in the 1950s and 1960s. They surmised that large plant heavy

[29] Zhou et al. (2013) report on a survey of 1000 people in Guangzhou, in which 75% bicycle or walk, 15% take buses and 10% use private automobiles to get to work. Car ownership rates reported in various city yearbooks confirm an upper bound on private automobile commuting of about 20%.

industry would be slower to leave central cities and would, for a while, continue to rely on central city rail infrastructure. However, intermediate weight footloose production would move to city fringes, where ring roads facilitate the trucking of goods to suburban rail sidings. 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 inter-regional highways, with ring roads providing suburban connections to these rays. The 1995 and 2008 Economic Censuses allow us to investigate how infrastructure influences the prevalence of central city employment in five industry groups characterized by weight to value ratios of their output shipments.[30]

Results in Table A2 show that radial railroads promote reductions of employment in all types of industry in central cities. Production of heavy goods responds the least to railroads whereas production of light weight goods such as textiles, apparel, leather and high tech responds the most. Radial highways play no role for heavy and medium weight goods production, but each radial highway is estimated to reduce central city employment in most lighter weight industries by 20-25 percent. However, a horse race between rail and highway rays, both of which seem to have strong effects for lighter weight goods on their own, has no statistical power. Ring road effects are large in most industries, but only significant for high tech. High tech is the poster-child for the Meyer et al. hypothesis on the role of ring roads.

7. 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. Both radial highways and ring roads lead to substantial population

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[30] Ideally, we would also like to know about intensity of land use by these different industries, since land costs may be a key factor in the decentralization decision. Unfortunately, we know of no data on land intensity in specific industries. The 1995 industrial census was taken 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. We use Duranton, Morrow and Turner's (2014) table relating weight to value for shipments of goods by U.S. industries.

decentralization out of central cities. Radial railroads and ring roads both promote the decentralization of industrial production and its workforce.

While it is well beyond the scope of this analysis to precisely quantify the welfare consequences of new urban transport infrastructure, our results generally point to associated welfare gains. Given our result that infrastructure does not lead to prefecture population gains, which makes sense given China's hukou migration restrictions, we can analyze the welfare consequences of transport infrastructure in the context of a closed city environment.

Holding the relative locations of households and firms fixed, the following broad mechanisms for welfare gains are potentially important. New infrastructure makes more space accessible for urban use. The associated positive supply shift in the amount of urban space reduces the cost of space, allowing people and firms to consume more space through standard substitution effects. The decline in living costs comes both through cheaper housing and lower commuting costs per unit distance. Cheaper space also increases firms' allocations of space per worker, thereby increasing wages. The real wage thus increases, thereby improving residents' welfare. Given the rapid increases in urban land values that occurred in Chinese cities during our study period, it is evident that other forces have counteracted the effects of highways and ring roads. The important element for our analysis is that these other forces are held constant, or are orthogonal to the amount of new infrastructure allocated to prefectures.

Holding firm productivity and factor ratios constant, the welfare gain associated with each new highway is the sum of resulting reductions in commuting and housing costs. Individuals who do not commute take the welfare gain entirely in the form of housing cost declines whereas individuals with the longest commutes, who pay agricultural rents at the fringe, take the welfare gain entirely in the form of commuting cost reductions. Given our result that each highway causes per-capita space consumption to rise by 4 percent in the central city and assuming a circular metropolitan area, we can calculate the implied reduction in commute distance for residents who do not use the highway. Model simulations in Baum-Snow (2007b) in which highways are twice as fast as other roads yield impacts on central city population that are two to three times as large as our estimates of -0.04 in this paper, with associated commuting distance reductions for those not using the new highway of 1-2 percent depending on parameter values and utility functional form. Therefore, in this context the longest commute distance for those not using a highway decreases by 0.5-0.7 percent per highway, which amounts to a decrease in commuting cost of the same amount in percentage terms. Given that the average city received 3.8 radial highways and 0.3 ring roads, this puts the total welfare gain only due to commuting cost and rent reductions at about 2-4 percent of income for all infrastructure built. This result makes sense given that no more than 20 percent of Chinese urban commuters drive to work.

Reorganization of the metropolitan area may also drive productivity and welfare gains. With railroads facilitating the movement of industrial production out of central cities, this space is freed up for less land intensive activities that benefit more from agglomeration spillovers. This spatial reorganization can be reflected in higher average productivity, which feeds through to higher wages and consumer welfare. A full quantification of the size of these forces is an important area for future research. We hope that estimates in this paper can be a useful input into such calculations.

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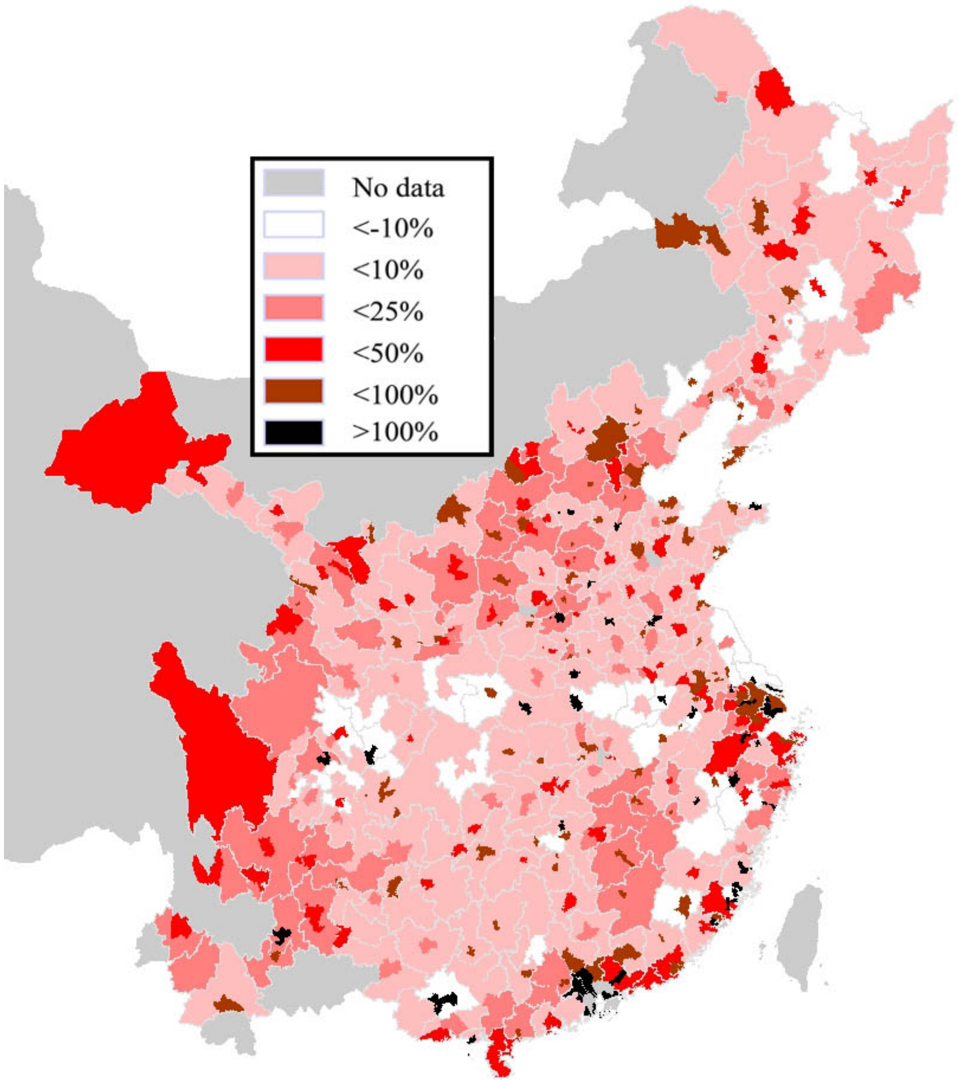


Figure 1a: Population growth by location, 1990-2010
See the notes to Table 1 for a description of the sample.

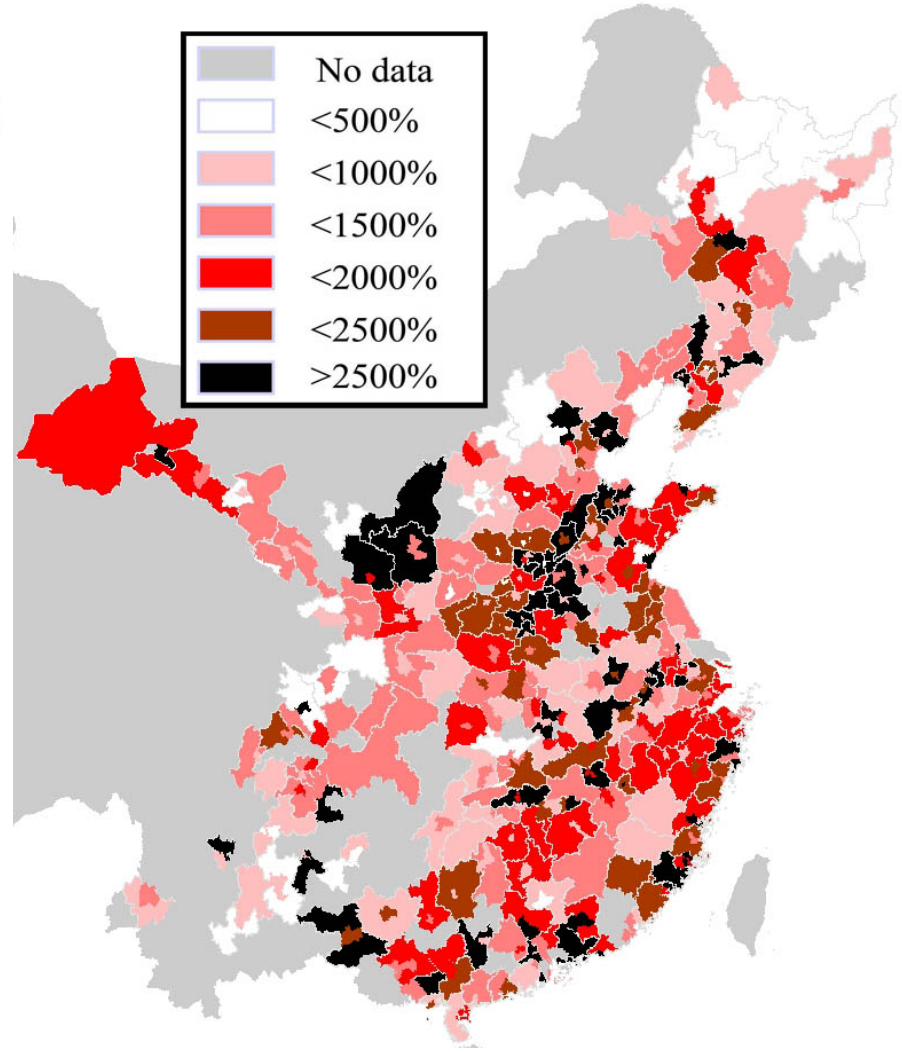


Figure 1b: Industrial sector GDP growth by location, 1990-2010
See the notes to Table 1 for a description of the sample and an explanation of how we construct industrial GDP.

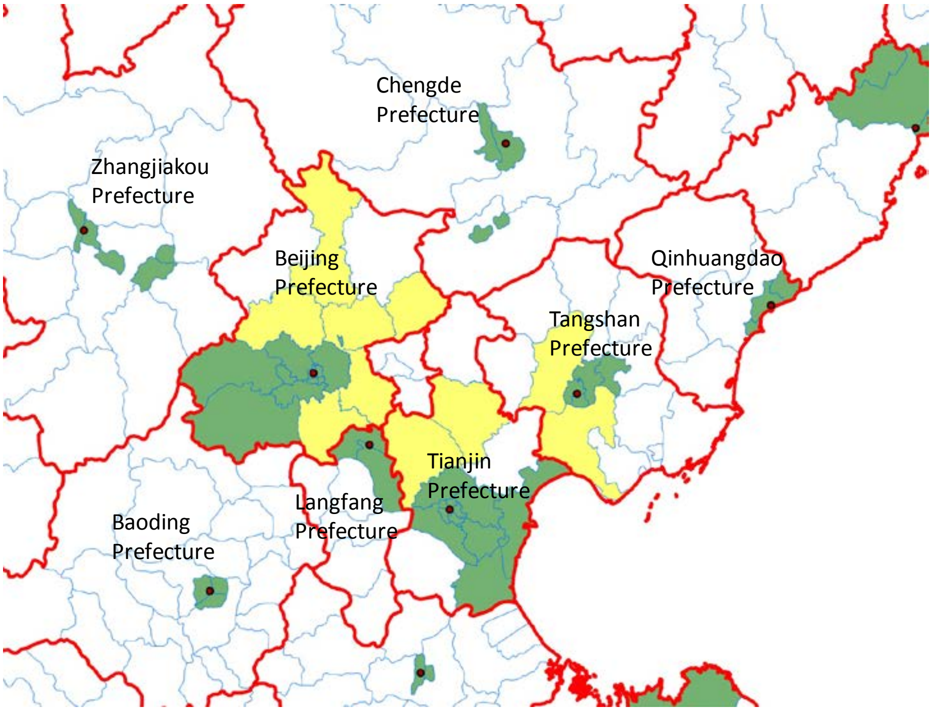


Figure 2: Beijing area political geography Red lines indicate 2005 definition prefecture boundaries and light blue lines indicate county/urban district boundaries. Green shaded regions are 1990 central cities and yellow shaded regions are central city expansions 1990-2010.

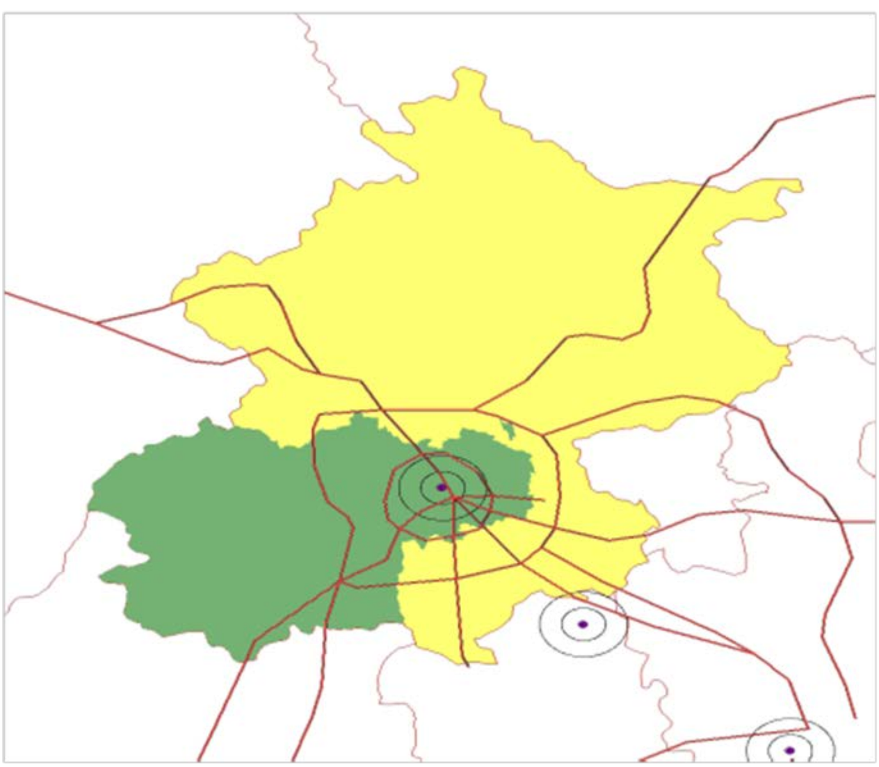


Figure 3a: Construction of our radial road index for Beijing

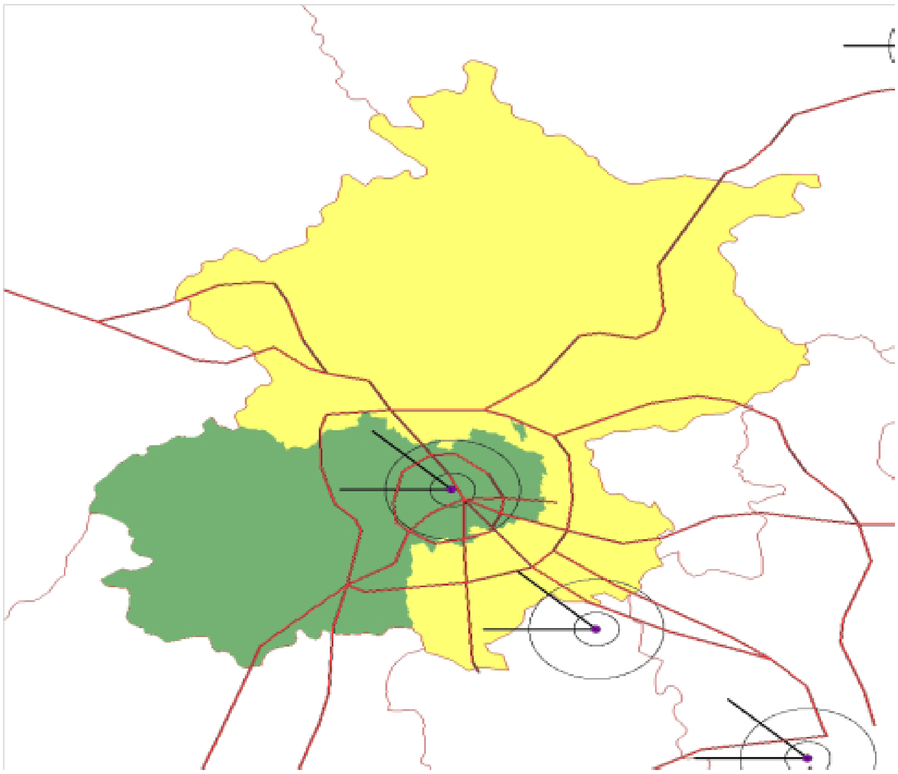
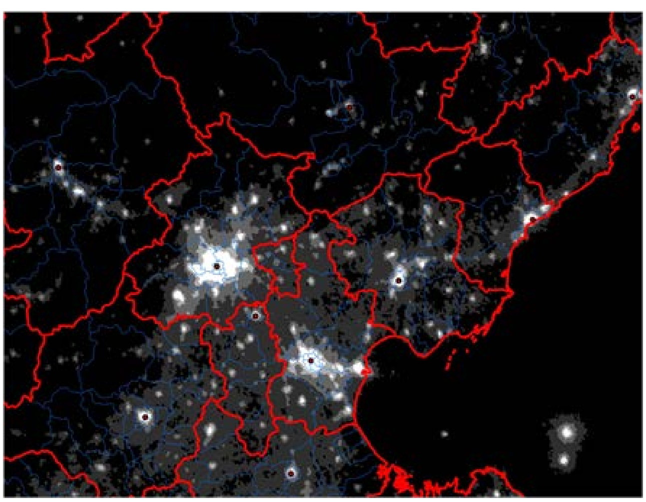


Figure 3b: Construction of our ring road index for Beijing.



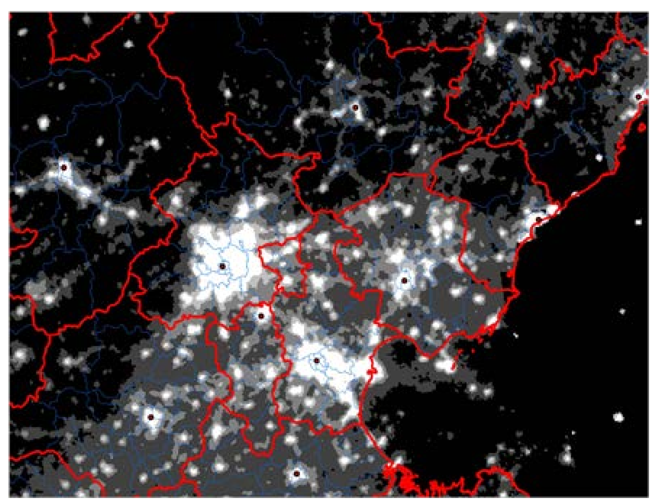


Figure 4. Lights at night for Beijing area The left figure is for 1992 and the right figure is for 2009.

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

	Population Growth (257 Prefectures)		Lights Growth (257 Prefectures)		Real Industrial GDP Growth (189 Prefectures)	
	Central City	Prefecture Remainder	Central City	Prefecture Remainder	Central City	Prefecture Remainder
Mean in 1990	955,683	2,953,557			9.28	6.56
1990-2000	25%	4%	52%	94%	158%	343%
2000-2010	23%	1%	33%	36%	277%	300%
1990-2010	54%	5%	102%	165%	873%	1673%

Notes: The 257 prefectures used to build the 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 overlap in prefecture level information about GDP and its components across years. Of these 189, information for 93 prefecture remainders incorporate substantial imputed information for 1990. Industrial GDP is deflated with provincial deflators and is in 100 million RMB.

Table 2: First Stage Regressions

	2010 Radial Highways (1)	1999 Radial Highways (2)	2010 Radial Railroads (3)	2010 Ring Highway Indicator (4)	Δln(Prefecture Pop) 1990-2010 (5)
1962 radial roads	0.361***	0.350***	0.0211	-0.0234	-0.00462
	(0.0860)	(0.0801)	(0.0345)	(0.0228)	(0.00594)
1962 radial railroads	0.177	0.166*	0.373***	0.00517	0.00453
	(0.107)	(0.0924)	(0.0528)	(0.0326)	(0.00851)
1962 ring road indicator	-0.617	-1.082***	-0.232	0.522***	-0.0237
	(0.427)	(0.302)	(0.305)	(0.146)	(0.0322)
ln(central city area)	0.125	-0.0527	-0.0135	-0.181***	-0.0265**
	(0.123)	(0.123)	(0.0937)	(0.0288)	(0.0126)
ln(prefecture area)	0.0419	0.239	-0.0551	0.0294	-0.0431
	(0.205)	(0.178)	(0.167)	(0.0454)	(0.0266)
provincial capital indicator	1.369**	1.239**	0.198	0.0910	0.162***
	(0.507)	(0.492)	(0.237)	(0.115)	(0.0293)
ln(prefecture population, 1982)	0.703***	0.302*	0.435***	0.0747	-0.0818***
	(0.190)	(0.150)	(0.133)	(0.0605)	(0.0287)
fraction high school or more	4.523	1.846	4.586**	-0.203	-0.188
in prefecture, 1982	(2.671)	(3.227)	(2.191)	(0.913)	(0.377)
share employed in manufacturing	-4.416**	-1.513	-1.403**	0.360	0.0833
in prefecture, 1982	(2.079)	(1.997)	(0.661)	(0.374)	(0.175)
Card migration instrument	2.08e-06*	2.05e-06***	-1.01e-06	-2.36e-07	7.61e-07**
	(1.10e-06)	(6.92e-07)	(7.09e-07)	(1.40e-07)	(3.02e-07)
constant	-9.114***	-4.596**	-4.783**	0.196	1.890***
	(2.762)	(2.080)	(2.043)	(0.895)	(0.564)
Observations	257	257	257	257	257
R-squared	0.330	0.340	0.252	0.242	0.500

Notes: Each column shows coefficients from a separate OLS regression of the variable listed at top on the variables listed at left. The final covariate is the instrument for 1990-2010 prefecture population growth constructed using 1985-1990 migration pathways, as is explained in the text. 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 Population Outcomes

	Δ ln(CC Pop) 1990-2010			Δ ln(Pref Pop)	Δ ln(CC Share)
	(1)	(2)	(3)	(4)	(5)
2010 radial highways	0.0097	-0.0105*	-0.0114**	0.0135*	-0.0125**
	(0.0088)	(0.0058)	(0.0050)	(0.0078)	(0.0054)
Δ ln(Pref Pop) 1990-2010		0.8841***	0.9212***		
		(0.0614)	(0.0641)		
Base controls	No	Yes	Yes	Yes	Yes
Additional 1982 controls	No	No	Yes	Yes	Yes
Observations	257	257	257	257	257
R-squared	0.004	0.480	0.490	0.319	0.263

Notes: Each column shows coefficients from a separate OLS regression of the variable listed at top on the number of radial highways in 2010 and the indicated set of control variables. Base controls include ln(central city area), ln(prefecture area) and ln(prefecture population, 1982). Additional controls are fraction high school or more in prefecture, 1982 and share employed in manufacturing in prefecture, 1982. Standard errors in parentheses are clustered by province.

Table 4: IV Estimates of Effects of Highway Rays on Population Outcomes

	Δ ln(CC Pop) 1990-2010			Δ ln(Pref Pop)	Δ ln(CC Share)
	(1)	(2)	(3)	(4)	(5)
2010 radial highways	-0.0413*	-0.0423*	-0.0477	-0.0067	-0.0410*
	(0.0220)	(0.0223)	(0.0309)	(0.0198)	(0.0221)
ln(central city area)	-0.1153***	-0.1178***	-0.1311***	-0.0164	-0.1148***
	(0.0184)	(0.0191)	(0.0232)	(0.0153)	(0.0182)
ln(prefecture area)	0.0607***	0.0508***	-0.0016	-0.0645*	0.0629***
	(0.0175)	(0.0178)	(0.0354)	(0.0330)	(0.0173)
provincial capital indicator	0.1409*	0.1751**	0.3566***	0.2234***	0.1332*
	(0.0725)	(0.0724)	(0.0847)	(0.0492)	(0.0757)
ln(prefecture population, 1982)	0.1177***	0.1101***	0.0694	-0.0500	0.1195***
	(0.0318)	(0.0365)	(0.0562)	(0.0484)	(0.0311)
fraction high school or more	-0.4455	-0.3790	-0.0261	0.4343	-0.4605
in prefecture, 1982	(0.3296)	(0.3415)	(0.4987)	(0.4019)	(0.3244)
share employed in manufacturing	-0.3288	-0.2845	-0.0496	0.2891	-0.3388
in prefecture, 1982	(0.2235)	(0.2544)	(0.3677)	(0.2099)	(0.2138)
Δ ln(Pref Pop) 1990-2010	0.9654***	0.8124***			
	(0.0673)	(0.1389)			
constant	-0.9859**	-0.7535	0.4805	1.5189	-1.0384**
	(0.4611)	(0.5667)	(0.8968)	(0.9307)	(0.4470)
Instrument for Δln(Pref Pop)	No	Yes	N/A	N/A	N/A
Observations	257	257	257	257	257
First stage F	23.4	13.1	19.7	19.7	19.7

Notes: Each column shows coefficients from a separate IV regression of the variable listed at top on the number of radial highways in 2010 and the set of indicated additional controls. First stage results for 2010 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 parentheses are clustered by province.

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

	Δ ln(CC Pop) 1982-1990				Δ ln(Pref Pop) 1982-1990	
	(1)	(2)	(3)	(4)	(5)	(6)
radial roads in 1980	0.0321		0.0570		0.0172	
	(0.0249)		(0.0349)		(0.0119)	
radial roads in 1990		0.0494		0.0890		0.0268
		(0.0388)		(0.0552)		(0.0188)
ln(central city area)	-0.0278	-0.0243	-0.0144	-0.0078	0.0092	0.0112
	(0.0268)	(0.0309)	(0.0354)	(0.0422)	(0.0117)	(0.0132)
ln(prefecture area)	0.0705**	0.0619	-0.0189	-0.0373	-0.0615**	-0.0671**
	(0.0334)	(0.0379)	(0.0470)	(0.0554)	(0.0261)	(0.0282)
provincial capital indicator	-0.0949	-0.1257	-0.0984	-0.1542	-0.0024	-0.0192
	(0.0695)	(0.0857)	(0.1063)	(0.1322)	(0.0308)	(0.0402)
fraction high school or more in prefecture, 1982	0.9476*	0.7941	2.0976***	1.8579***	0.7910***	0.7188***
	(0.5495)	(0.5781)	(0.7229)	(0.6934)	(0.2877)	(0.2600)
share employed in manufacturing in prefecture, 1982	0.1075	0.2288	-0.4076	-0.2055	-0.3543***	-0.2935***
	(0.3160)	(0.3212)	(0.3043)	(0.3147)	(0.0739)	(0.0857)
Δ ln(Pref Pop) 1982-1990	1.4539***	1.4800***				
	(0.2496)	(0.2331)				
constant	-0.6533**	-0.6584**	0.1409	0.1574	0.5462**	0.5512**
	(0.3130)	(0.3278)	(0.3801)	(0.4373)	(0.2210)	(0.2328)
Observations	257	257	257	257	257	257
First stage F	60.4	16.7	58.9	17.6	58.9	17.6

Notes: Each column shows coefficients from a separate IV regression of the variable listed at top on the number of radial highways in 1980 or 1990 and the set of indicated additional controls. Counterparts measured as of 1962 instrument for radial highways in 1980 and 1990. Standard errors in parerentheses are clustered by province.

Table 6: Robustness Checks for Table 4

	Δ ln(CC Pop) 1990-2010						
					cities over 1 million		drop West
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
2010 radial highways	-0.0814*	-0.0376*	-0.0323*	-0.0362*	-0.0408	-0.0397	-0.0595**
	(0.0460)	(0.0223)	(0.0185)	(0.0198)	(0.0253)	(0.0351)	(0.0237)
1990 radial roads	0.0502						
	(0.0335)						
ln(central city area)	-0.1082***	-0.1223***	-0.0269	-0.0661***	-0.0713*	-0.0676	-0.1119***
	(0.0225)	(0.0205)	(0.0271)	(0.0240)	(0.0370)	(0.0483)	(0.0214)
ln(prefecture area)	0.0502***	0.0699***	0.0152	0.0146	0.1100***	-0.0189	0.0720***
	(0.0156)	(0.0198)	(0.0276)	(0.0273)	(0.0300)	(0.0669)	(0.0266)
provincial capital or level city indicator	0.1753**	0.2130***	0.1853***	0.2277***	0.2351***	0.4239***	0.2459***
	(0.0811)	(0.0673)	(0.0459)	(0.0595)	(0.0845)	(0.1046)	(0.0742)
ln(prefecture population, 1982)	0.1190***	0.0911**	0.0483	0.0615	0.0154	0.0681	0.1131***
	(0.0423)	(0.0415)	(0.0367)	(0.0397)	(0.0406)	(0.0833)	(0.0426)
fraction high school or more in prefecture, 1982	-0.2746	-0.4540	-1.9857***	-0.2692	-0.6574**	0.5680	-0.8924*
	(0.3581)	(0.2913)	(0.5619)	(0.3093)	(0.3231)	(0.6275)	(0.4625)
share employed in manufacturing in prefecture, 1982	-0.2870	-0.3646	-1.1955***	-0.1501	-0.5652**	-0.1277	-0.4473*
	(0.2611)	(0.2525)	(0.3972)	(0.2333)	(0.2447)	(0.4411)	(0.2441)
ln(distance to coast)		-0.0235**	-0.0314***	-0.0249***			
		(0.0094)	(0.0086)	(0.0096)			
fraction high school or more in central city, 1982			1.1285***				
			(0.4199)				
share employed in manufacturing in central city, 1982			0.6712***				
			(0.2360)				
fraction of prefecture high school or more in central city, 1982				0.1504			
				(0.2808)			
fraction of prefecture manufacturing employment in central city, 1982				0.0547			
				(0.1097)			
fraction of prefecture population in central city, 1982				-0.6316**			
				(0.2522)			
Δ ln(Pref Pop) 1990-2010	0.8976***	0.7474***	0.7609***	0.7368***	[s]1.3298***		0.9121***
	(0.1869)	(0.1590)	(0.1118)	(0.1503)	(0.1548)		(0.1609)
constant	-0.9690	-0.4888	-0.0830	0.1085	-0.3213	-0.0070	-0.8956
	(0.6972)	(0.6443)	(0.5404)	(0.5881)	(0.6042)	(1.0239)	(0.6834)
Observations	257	257	257	257	78	78	208
First stage F	2.99	12.8	13.3	10.7	20.7	14.5	11.5

Notes: Each column shows coefficients from a separate IV regression of the change in log central city population on the number of radial highways in 2010 and the set of indicated controls. First stage results for radial highways and Δln(Pref Pop) 1990-2010 are in Table 2. Standard errors in parentheses are clustered by province. [s]Δln(Pref Pop) 1990-2010 is not instrumented in Column 5.

Table 7: Time Pattern of Responses to Highway Treatments

	Δ ln(CC Pop)			
	1990-2010		1990-2000	2000-2010
	(1)	(2)	(3)	(4)
radial highways in year t	-0.0420*	-0.0436**	-0.0229	-0.0181*
	(0.0216)	(0.0191)	(0.0167)	(0.0107)
year t	2005	1999	1999	1999
First Stage F	13.8	12.8	9.14	25.7

Notes: Entries show coefficients from IV regressions of the central city population growth rate during the indicated period on radial highways measured as of the indicated year using analogous specifications to that in Table 4 Column 2. All regressions except for that in Column 4 incorporate instrumented Δln(Pref Pop), as is explained in the text.

Table 8: Population Decentralization and Other Transportation Network Variables

	Δln(CC Pop) 1990-2010				
	(1)	(2)	(3)	(4)	(5)
2010 radial highways	-0.0448**		-0.0412*		-0.0587**
	(0.0228)		(0.0246)		(0.0259)
ln(highway kms in prefecture	0.0885				
remainder, 2010)	(0.0797)				
2010 radial railroads		-0.0317	-0.0105		
		(0.0387)	(0.0485)		
2010 ring road indicator				-0.1873**	-0.2520**
				(0.0916)	(0.1111)
ln(central city area)	-0.0966***	-0.1267***	-0.1188***	-0.1620***	-0.1662***
	(0.0225)	(0.0195)	(0.0205)	(0.0295)	(0.0336)
ln(prefecture area)	-0.0335	0.0352	0.0495**	0.0388	0.0566**
	(0.0848)	(0.0269)	(0.0194)	(0.0283)	(0.0249)
provincial capital indicator	0.1864**	0.1379*	0.1798**	0.1393**	0.2233***
	(0.0733)	(0.0719)	(0.0766)	(0.0574)	(0.0738)
ln(prefecture population, 1982)	0.0784	0.0779***	0.1140***	0.0699**	0.1387***
	(0.0549)	(0.0273)	(0.0304)	(0.0349)	(0.0443)
fraction high school or more	-0.4185	-0.3004	-0.3062	-0.4779	-0.2465
in prefecture, 1982	(0.3489)	(0.5417)	(0.5070)	(0.4516)	(0.4257)
share employed in manufacturing	-0.2652	-0.1188	-0.2881	-0.0415	-0.2884
in prefecture, 1982	(0.2717)	(0.2306)	(0.2465)	(0.2486)	(0.2904)
Δ ln(Pref Pop) 1990-2010	0.7555***	0.6511***	0.7975***	0.6228***	0.7752***
	(0.1801)	(0.1493)	(0.1657)	(0.1479)	(0.1733)
constant	-0.1754	-0.1728	-0.7846	0.1749	-0.7697
	(0.9525)	(0.4945)	(0.5151)	(0.5207)	(0.5826)
Observations	257	257	257	257	257
First stage F	8.81	21.5	7.02	7.13	4.05

Notes: Road and rail network measures in 1962 instrument for these measures in 2010. Δln(Pref Pop) 1990-2010 is instrumented with predicted migration flows. Standard errors in parentheses are clustered by province.

Table 9. Effects of Transport on Industrial Sector GDP, 1990-2010

Panel A: IV Results

	Δln(Central City Industrial GDP) 1990-2010							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
2010 radial highways	0.0277		0.0514			-0.0103		
	(0.0528)		(0.0635)			(0.0709)		
2010 radial railroads		-0.2388**	-0.2676**	-0.1867**			-0.2364**	-0.3375***
		(0.0971)	(0.1177)	(0.0941)			(0.1130)	(0.0738)
ln(railroad kms in prefecture				-0.1174				
remainder, 2010)				(0.1101)				
2010 ring road indicator					-0.5624**	-0.5738*	-0.7102**	
					(0.2787)	(0.3220)	(0.3351)	
ln(central city area)	0.0846	0.0715	0.0613	0.0271	-0.0260	-0.0268	-0.0736	
	(0.0597)	(0.0608)	(0.0665)	(0.0577)	(0.0518)	(0.0529)	(0.0634)	
ln(prefecture area)	-0.2357**	-0.2494**	-0.2677**	-0.1271	-0.2299**	-0.2268**	-0.2524***	
	(0.1084)	(0.0981)	(0.1081)	(0.1654)	(0.0988)	(0.1016)	(0.0976)	
provincial capital indicator	0.1885	0.3646*	0.3096	0.3700*	0.2798	0.2952	0.4298*	
	(0.1615)	(0.2010)	(0.2123)	(0.1949)	(0.1864)	(0.1861)	(0.2385)	
ln(prefecture population, 1982)	-0.0158	0.1203	0.0785	0.1250	0.0425	0.0541	0.1558	
	(0.1012)	(0.1158)	(0.1092)	(0.1196)	(0.0904)	(0.1161)	(0.1226)	
fraction high school or more	-3.6602**	-1.6142	-1.5647	-1.2734	-3.2130*	-3.1689*	-1.1949	
in prefecture, 1982	(1.5401)	(1.6733)	(1.6212)	(1.6517)	(1.7882)	(1.8777)	(1.9857)	
share employed in manufacturing	-1.0124	-1.3549*	-1.1373	-1.4133**	-1.0416	-1.0882*	-1.2245*	
in prefecture, 1982	(0.6603)	(0.7061)	(0.7173)	(0.6703)	(0.6676)	(0.5614)	(0.6846)	
Δ ln(Pref Pop) 1990-2010	-0.7585*	-0.9617	-1.1525	-0.9942	-0.8840*	-0.8570*	-1.2235	
	(0.4606)	(0.6491)	(0.7139)	(0.6198)	(0.5331)	(0.4837)	(0.7736)	
constant	5.5634***	4.1251**	4.8470**	3.6507*	5.6586***	5.5016***	4.8267**	3.8227***
	(1.5405)	(1.8353)	(1.9399)	(1.9873)	(1.4638)	(1.7195)	(2.0582)	(0.1413)
Observations	241	241	241	241	241	241	241	241
First stage F	10.9	24.3	5.69	5.63	6.67	4.24	3.90	79.2

Panel B: OLS Coefficients on Transport Measures

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
2010 radial highways	-0.0131		-0.0098			-0.0170		
	(0.0164)		(0.0154)			(0.0173)		
2010 radial railroads		-0.0388	-0.0369	-0.0367			-0.0413	-0.0722**
		(0.0373)	(0.0364)	(0.0385)			(0.0363)	(0.0318)
ln(railroad kms in prefecture				-0.0106				
remainder, 2010)				(0.0333)				
2010 ring road indicator					-0.1388	-0.1468	-0.1445	
					(0.0857)	(0.0884)	(0.0859)	

Notes: In Panel A, road and rail network measures in 1962 instrument for these measures in 2010 while predicted migration flows instrument for Δln(Pref Pop) 1990-2010. Standard errors in parentheses are clustered by province.

Table 10: Population Versus Employment Decentralization

	Δln(CC Pop) 1990-2010		Δln(CC Working Residents) 1990-2010		Δln(CC Residents Working in Manuf.) 1990-2010		Δln(CC Manufacturing Employment) 1995-2008	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
2010 radial highways	-0.0412*	-0.0562**	-0.0438	-0.0620*	0.0087	-0.0086	-0.0008	-0.0063
	(0.0246)	(0.0277)	(0.0351)	(0.0319)	(0.1113)	(0.1102)	(0.0920)	(0.0950)
2010 radial railroads	-0.0105	-0.0047	-0.0475	-0.0404	-0.3499**	-0.3431**	-0.2784**	-0.2762**
	(0.0485)	(0.0551)	(0.0541)	(0.0568)	(0.1623)	(0.1632)	(0.1288)	(0.1294)
ln(central city area)	-0.1188***	-0.1178***	-0.0483**	-0.0472*	0.1933***	0.1944***	0.1207**	0.1211**
	(0.0205)	(0.0249)	(0.0218)	(0.0253)	(0.0653)	(0.0633)	(0.0500)	(0.0497)
ln(prefecture area)	0.0495**	0.0209	0.0472*	0.0124	-0.3591***	-0.3925***	-0.2889***	0.2995***
	(0.0194)	(0.0204)	(0.0252)	(0.0205)	(0.0880)	(0.0827)	(0.0886)	(0.0810)
provincial capital indicator	0.1798**	0.2693***	0.1329	0.2417***	-0.1535	-0.0493	-0.0377	-0.0048
	(0.0766)	(0.0677)	(0.0936)	(0.0776)	(0.1808)	(0.1771)	(0.1756)	(0.1664)
ln(prefecture population, 1982)	0.1140***	0.1324***	0.1399***	0.1623***	0.5769***	0.5983***	0.3137***	0.3205***
	(0.0304)	(0.0370)	(0.0354)	(0.0362)	(0.1217)	(0.1319)	(0.0953)	(0.1029)
fraction high school or more	-0.3062	0.0626	-1.0917	-0.6429	-4.5088**	-4.0790*	-1.1524	-1.0169
in prefecture, 1982	(0.5070)	(0.4889)	(0.7411)	(0.6174)	(2.1664)	(2.1964)	(1.7197)	(1.6874)
share employed in manufacturing	-0.2881	-0.4811*	-0.2644	-0.4993	-0.5180	-0.7430	0.1401	0.0692
in prefecture, 1982	(0.2465)	(0.2832)	(0.3455)	(0.3283)	(0.9950)	(1.0203)	(0.8528)	(0.8806)
Δ ln(Pref Pop) 1990-2010	0.7975***		0.9705***		0.9294		0.2931	
	(0.1657)		(0.1798)		(0.5857)		(0.5052)	
Δ ln(Pref Emp) 1990-2010		0.7784***		0.9473***		0.9072*		0.2861
		(0.1954)		(0.2008)		(0.5359)		(0.4837)
Constant	-0.7846	-0.7177	-1.6781***	-1.5967***	-5.7078***	-5.6299***	-1.8988	-1.8742
	(0.5151)	(0.6132)	(0.5278)	(0.5674)	(1.8444)	(1.7850)	(1.6025)	(1.5686)
Observations	257	257	257	257	257	257	257	257
First stage F	7.02	4.02	7.02	4.02	7.02	4.02	7.02	4.02

Notes: Each column presents results of IV regressions of the variables listed at top on the variables listed at left. Dependent variables in Columns 1-6 are about central city residents, constructed using 1990 and 2010 census data. The dependent variable in Columns 7-8 is about central city jobs, constructed using the 1995 and 2008 Industrial Censuses. In Columns 1, 3, 5, and 7, the predicted change in prefecture population using migration flows instruments for the actual change. In Columns 2, 4, 6 and 8, the same instrument instead enters for 1990-2010 prefecture employment growth.

Table 11. Infrastructure and Central City Manufacturing Employment

	Δln(Central City Residents Working in Manufacturing) 1990-2010				Δln(Total Central City Manufacturing Employment) 1995-2008			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
2010 radial highways	-0.0266		-0.0841		-0.0289		-0.0424	
	(0.0835)		(0.0952)		(0.0806)		(0.0866)	
2010 radial railroads		-0.3454***		-0.3367**		-0.2788***		-0.2760***
		(0.1222)		(0.1377)		(0.0986)		(0.0943)
2010 ring road indicator			-0.8850***	-0.9774***			-0.2073	-0.3123
			(0.3217)	(0.3476)			(0.2785)	(0.2930)
ln(central city area)	0.2254***	0.1950***	0.0557	-0.0014	0.1463***	0.1206**	0.1065*	0.0578
	(0.0527)	(0.0617)	(0.0698)	(0.0809)	(0.0396)	(0.0552)	(0.0594)	(0.0665)
ln(prefecture area)	-0.3163***	-0.3561***	-0.2958***	-0.3516***	-0.2549***	-0.2892***	-0.2501***	-0.2878***
	(0.1050)	(0.0827)	(0.1008)	(0.0847)	(0.0941)	(0.0725)	(0.0931)	(0.0721)
provincial capital indicator	-0.3094*	-0.1446	-0.1403	-0.0463	-0.1617	-0.0386	-0.1221	-0.0071
	(0.1619)	(0.1661)	(0.1964)	(0.2094)	(0.1428)	(0.1766)	(0.1425)	(0.1819)
ln(prefecture population, 1982)	0.4446***	0.5845***	0.5452***	0.6197***	0.2085**	0.3130***	0.2321*	0.3242***
	(0.1349)	(0.1058)	(0.1370)	(0.1085)	(0.1057)	(0.0836)	(0.1186)	(0.0821)
fraction high school or more	-6.9379***	-4.5100**	-6.4726***	-4.2894**	-3.0850**	-1.1523	-2.9760**	-1.0818
in prefecture, 1982	(2.1226)	(2.1652)	(2.1791)	(2.1715)	(1.3290)	(1.7140)	(1.3301)	(1.7086)
share employed in manufacturing	-0.4001	-0.5540	-0.4137	-0.2754	0.2339	0.1435	0.2307	0.2325
in prefecture, 1982	(0.9855)	(0.9518)	(0.9364)	(0.9188)	(0.8660)	(1.0017)	(0.8624)	(1.0100)
Δ ln(Pref Pop) 1990-2010	1.4265***	0.9605*	1.2957***	0.6369	0.6885**	0.2902	0.6579*	0.1868
	(0.3343)	(0.4962)	(0.3700)	(0.6606)	(0.3481)	(0.4621)	(0.3586)	(0.5124)
Constant	-4.6681***	-5.8376***	-4.7252***	-4.7633***	-1.0716	-1.8865	-1.0850	-1.5433
	(1.5810)	(1.4507)	(1.5114)	(1.7437)	(1.4971)	(1.2395)	(1.5221)	(1.2173)
Observations	257	257	257	257	257	257	257	257
First stage F	13.1	21.5	4.05	4.26	13.1	21.5	4.05	4.26

Notes: Each column is a separate IV regressions analogous to those in Table 10.

Table A1: Summary Statistics

	Mean	Stdev	Min	Max
Panel A: Transport Measures and Instruments				
2010 radial highways	3.81	2.03	0	12
1999 radial highways	2.89	1.74	0	8
ln(highway kms in prefecture remainder, 2010)	6.17	0.81	0.40	8.20
2010 ring road indicator	0.29	0.45	0	1
2010 radial railroads	1.85	1.26	0	6
ln(railroad kms in prefecture remainder, 2010)	4.55	1.42	0	6.71
1962 radial highways	2.04	1.38	0	6
ln(roads kms in prefecture remainder, 1962)	5.33	1.01	0.00	7.33
1962 ring road indicator	0.05	0.22	0	1
1962 railroad rays	1.16	1.25	0	5
ln(railroad kms in prefecture remainder, 1962)	2.83	2.17	0	6
Card migration instrument	0.07	0.13	0	1.18
Panel B: Dependent Variables				
Δln(central city population, 1990-2010)	0.41	0.31	-0.25	1.75
Δln(prefecture population, 1990-2010)	0.14	0.20	-0.25	1.83
Δln(central city industrial GDP, 1990-2010)	3.19	0.61	1.15	5.30
Δln(central city employed residents, 1990-2010)	0.23	0.33	-0.38	1.66
Δln(central city residents working in manuf., 1990-2010)	-0.19	0.75	-2.46	1.87
Δln(central city manufacturing employment, 1995-2008)	0.33	0.59	-0.89	3.21
Panel C: Control Variables				
ln(central city area)	7.11	0.95	4.63	9.91
ln(prefecture area)	9.32	0.74	6.94	12.03
provincial capital indicator	0.10	0.30	0.00	1.00
ln(prefecture population, 1982)	14.86	0.66	12.65	17.11
fraction high school or more in prefecture, 1982	0.12	0.04	0.02	0.29
share employed in manufacturing, 1982	0.12	0.09	0.01	0.46
ln(km to coast)	5.24	1.88	-5.38	7.38
fraction of pref. high school or more in central city, 1982	0.37	0.21	0.05	1.00
fraction of pref. manufacturing emp in central city, 1982	0.50	0.22	0.09	1.00
fraction of pref. population in central city, 1982	0.27	0.19	0.02	1.00

Notes: Statistics are for the primary sample of 257 prefectures except for the growth in central city industrial GDP, which we only observe for 241 cities.

Table A2. Change in Central City Manufacturing Employment by Industrial Sector, 1995-2008

Panel A: High and Medium Weight to Value Ratio Industries

	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)
2010 radial highways		-0.0150			0.0654	
		(0.0743)			(0.0989)	
2010 radial railroads	-0.1355*		-0.1342*	-0.2479**		-0.2442**
	(0.0733)		(0.0713)	(0.1231)		(0.1194)
2010 ring road indicator		-0.0866	-0.1439			-0.4136
		(0.3181)	(0.3200)			(0.4189)
Observations	257	257	257	257	257	257
First stage F	21.5	4.05	4.26	21.5	4.05	4.26

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	-0.2341*		-0.2959**			-0.2175			-0.0325	
	(0.1291)		(0.1366)			(0.3360)			(0.1116)	
2010 radial railroads		-0.4649**		-0.4571**	-0.6545***		-0.6358**	-0.2360**		-0.2332**
		(0.1885)		(0.2018)	(0.2220)		(0.2872)	(0.1019)		(0.1059)
2010 ring road indicator			-0.9503	-0.8753		-2.0085*	-2.1182*		-0.2328	-0.3251
			(0.6415)	(0.5683)		(1.0631)	(1.1235)		(0.3184)	(0.2937)
Observations	257	257	257	257	257	257	257	257	257	257
First stage F	13.1	21.5	4.05	4.26	21.5	4.05	4.26	21.5	4.05	4.26

Notes: Outcomes are the change in log central city employment in the indicated industries, 1995-2008. Transport variables are instrumented by their 1962 counterparts. Each regression includes the same control variables as in Table 4 Column 2, in which change in prefecture population 1990-2010 is instrumented using its predicted counterpart from historical migration flows. Standard errors in parentheses are clustered by province.

Online Appendix

Table 6A: Population Shares Regressions

	Δ ln(CC Pop Share) 1990-2010					
					>1 mill.	drop West
	(1)	(2)	(3)	(4)	(5)	(6)
2010 radial highways	-0.0786	-0.0376*	-0.0347*	-0.0382**	-0.0405	-0.0588**
	(0.0484)	(0.0216)	(0.0182)	(0.0191)	(0.0269)	(0.0233)
1990 radial roads	0.0475					
	(0.0361)					
ln(central city area)	-0.1069***	-0.1171***	-0.0205	-0.0633***	-0.0704*	-0.1110***
	(0.0212)	(0.0192)	(0.0277)	(0.0244)	(0.0386)	(0.0209)
ln(prefecture area)	0.0571***	0.0788***	0.0219	0.0238	0.0780**	0.0815***
	(0.0170)	(0.0189)	(0.0246)	(0.0230)	(0.0387)	(0.0219)
provincial capital or level	0.1514*	0.1491**	0.1350**	0.1780***	0.2820***	0.2285***
city indicator	(0.0894)	(0.0721)	(0.0542)	(0.0678)	(0.0941)	(0.0781)
ln(prefecture population, 1982)	0.1239***	0.1087***	0.0662**	0.0805***	0.0285	0.1141***
	(0.0349)	(0.0332)	(0.0320)	(0.0309)	(0.0514)	(0.0408)
fraction high school or more	-0.3269	-0.5308*	-1.7436***	-0.3985	-0.3535	-0.9452**
in prefecture, 1982	(0.3775)	(0.3075)	(0.6673)	(0.2909)	(0.3308)	(0.4068)
share employed in manufacturing	-0.3178	-0.4061*	-1.3844***	-0.1697	-0.4567*	-0.4664**
in prefecture, 1982	(0.2207)	(0.2118)	(0.4068)	(0.2070)	(0.2419)	(0.2150)
ln(distance to coast)		-0.0160*	-0.0238***	-0.0162*		
		(0.0088)	(0.0082)	(0.0090)		
fraction high school or more			0.8535*			
in central city, 1982			(0.4681)			
share employed in manufacturing			0.7837***			
in central city, 1982			(0.2681)			
fraction of prefecture high school				-0.0022		
or more in central city, 1982				(0.2913)		
fraction of prefecture manufacturing				0.1126		
employment in central city, 1982				(0.1234)		
fraction of prefecture population				-0.5167**		
in central city, 1982				(0.2381)		
constant	-1.1198**	-0.9253*	-0.5040	-0.3343	-0.2433	-1.0113*
	(0.5035)	(0.4931)	(0.4723)	(0.4192)	(0.6702)	(0.5535)
Observations	257	257	257	257	78	208
First stage F	5.06	18.8	20.0	17.1	14.5	13.1

Notes: Each column shows coefficients from a separate IV regression of the change in log share of prefecture population in the central city 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. Standard errors in parentheses are clustered by province.

Table 8A: Population Decentralization and Other Transportation Network Variables - Share Specification

	Δln(CC Pop Share) 1990-2010				
	(1)	(2)	(3)	(4)	(5)
2010 radial highways	-0.0432*		-0.0393		-0.0561**
	(0.0223)		(0.0247)		(0.0257)
ln(highway kms in prefecture remainder, 2010)	0.0875				
	(0.0802)				
2010 radial railroads		-0.0387	-0.0156		
		(0.0399)	(0.0504)		
2010 ring road indicator				-0.1642*	-0.2350**
				(0.0889)	(0.1118)
ln(central city area)	-0.0928***	-0.1211***	-0.1158***	-0.1510***	-0.1592***
	(0.0235)	(0.0182)	(0.0188)	(0.0291)	(0.0328)
ln(prefecture area)	-0.0168	0.0578**	0.0624***	0.0628**	0.0706***
	(0.0782)	(0.0239)	(0.0181)	(0.0256)	(0.0246)
provincial capital indicator	0.1318*	0.0668	0.1352*	0.0592	0.1704**
	(0.0730)	(0.0563)	(0.0757)	(0.0457)	(0.0788)
ln(prefecture population, 1982)	0.0910*	0.1015***	0.1265***	0.0898**	0.1479***
	(0.0470)	(0.0294)	(0.0260)	(0.0370)	(0.0404)
fraction high school or more in prefecture, 1982	-0.5240	-0.3931	-0.3615	-0.6331	-0.3520
	(0.3427)	(0.4612)	(0.4436)	(0.3889)	(0.3950)
share employed in manufacturing in prefecture, 1982	-0.3359	-0.2359	-0.3505*	-0.1636	-0.3524
	(0.2188)	(0.1784)	(0.1952)	(0.2074)	(0.2512)
constant	-0.5522	-0.7771*	-1.1186***	-0.4414	-1.1063**
	(0.7578)	(0.4624)	(0.3986)	(0.5002)	(0.4718)
Observations	257	257	257	257	257
First stage F	9.74	49.4	6.81	13.3	6.26

Notes: Road and rail network measures in 1962 instrument for these measures in 2010. Standard errors in parentheses are clustered by province.

Table 9A: Effects of Transport on Decentralization of Generalized Industrial Sector GDP Share, 1990-2010

	Δln(Central City Industrial GDP/Pref Pop) 1990-2010							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
2010 radial highways	0.0413		0.0752			0.0150		
	(0.0605)		(0.0854)			(0.0760)		
2010 radial railroads		-0.2898***	-0.3391**	-0.2828**			-0.2933**	-0.4037***
		(0.1050)	(0.1329)	(0.1138)			(0.1160)	(0.0859)
ln(railroad kms in prefecture				-0.0160				
remainder, 2010)				(0.1128)				
2010 ring road indicator					-0.4248	-0.4053	-0.5774	
					(0.2791)	(0.3321)	(0.3829)	
ln(central city area)	0.1049*	0.0929*	0.0812	0.0869	0.0249	0.0270	-0.0227	
	(0.0593)	(0.0539)	(0.0601)	(0.0603)	(0.0577)	(0.0622)	(0.0695)	
ln(prefecture area)	-0.1091	-0.1072	-0.1136	-0.0902	-0.0961	-0.0978	-0.0942	
	(0.0864)	(0.0838)	(0.0909)	(0.1674)	(0.0840)	(0.0866)	(0.0864)	
provincial capital indicator	-0.2059	-0.0282	-0.1645	-0.0283	-0.1155	-0.1462	-0.0178	
	(0.1970)	(0.1973)	(0.2525)	(0.1972)	(0.1973)	(0.2021)	(0.2128)	
ln(prefecture population, 1982)	0.0649	0.2501*	0.2074	0.2510*	0.1324	0.1175	0.2930*	
	(0.1207)	(0.1338)	(0.1364)	(0.1349)	(0.1133)	(0.1408)	(0.1498)	
fraction high school or more	-4.5035***	-2.0919	-2.0876	-2.0467	-4.1070**	-4.1900**	-1.8029	
in prefecture, 1982	(1.5272)	(1.7882)	(1.7148)	(1.7549)	(1.6148)	(1.7481)	(2.0051)	
share employed in manufacturing	-1.3899**	-1.8967***	-1.6554***	-1.9058***	-1.5164***	-1.4584***	-1.8494***	
in prefecture, 1982	(0.5473)	(0.4409)	(0.5822)	(0.4499)	(0.4379)	(0.4738)	(0.4244)	
constant	2.9167	0.6899	1.2571	0.6177	2.6031	2.7683	0.8876	3.8004***
	(1.9744)	(2.2377)	(2.3798)	(2.4100)	(1.9294)	(2.1849)	(2.4830)	(0.1595)
Observations	241	241	241	241	241	241	241	241
First stage F	16.8	47.7	5.55	7.95	12.5	6.58	5.31	79.2

Table 10A: Shares Version of Table 10

	Δln(CC Pop Share) 1990-2010		Δln(CC Working Res Share) 1990-2010		Δln(CC Res Work in Manuf Share) 1990-2010		Δln(CC Man Emp Share) 1995-2008	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
2010 radial highways	-0.0393	-0.0583**	-0.0435	-0.0625**	0.0094	-0.0095	0.0059	-0.0131
	(0.0247)	(0.0264)	(0.0362)	(0.0301)	(0.1143)	(0.1064)	(0.0902)	(0.0847)
2010 radial railroads	-0.0156	-0.0088	-0.0482	-0.0414	-0.3517**	-0.3449**	-0.2964**	-0.2895**
	(0.0504)	(0.0585)	(0.0570)	(0.0595)	(0.1687)	(0.1675)	(0.1327)	(0.1304)
ln(central city area)	-0.1158***	-0.1142***	-0.0479**	-0.0463*	0.1944***	0.1959***	0.1311***	0.1327***
	(0.0188)	(0.0239)	(0.0210)	(0.0239)	(0.0624)	(0.0599)	(0.0502)	(0.0488)
ln(prefecture area)	0.0624***	0.0272	0.0491**	0.0139	-0.3546***	-0.3898***	-0.2439***	-0.2791***
	(0.0181)	(0.0224)	(0.0191)	(0.0192)	(0.0767)	(0.0797)	(0.0679)	(0.0687)
provincial capital indicator	0.1352*	0.2447***	0.1264	0.2359***	-0.1691	-0.0596	-0.1934	-0.0838
	(0.0757)	(0.0685)	(0.1021)	(0.0824)	(0.2057)	(0.1974)	(0.1776)	(0.1731)
ln(prefecture population, 1982)	0.1265***	0.1516***	0.1417***	0.1669***	0.5812***	0.6063***	0.3572***	0.3823***
	(0.0260)	(0.0337)	(0.0314)	(0.0306)	(0.1068)	(0.1110)	(0.0799)	(0.0845)
fraction high school or more	-0.3615	0.1055	-1.0997	-0.6327	-4.5281**	-4.0611*	-1.3457	-0.8786
in prefecture, 1982	(0.4436)	(0.4955)	(0.7043)	(0.6308)	(2.1631)	(2.1664)	(1.5391)	(1.4729)
share employed in manufacturing	-0.3505*	-0.6060***	-0.2735	-0.5289**	-0.5398	-0.7953	-0.0778	-0.3332
in prefecture, 1982	(0.1952)	(0.1954)	(0.3288)	(0.2637)	(0.9124)	(0.8585)	(0.7065)	(0.6713)
Constant	-1.1186***	-1.0732*	-1.7266***	-1.6812***	-5.8242***	-5.7787***	-3.0648***	-3.0193***
	(0.3986)	(0.5837)	(0.3656)	(0.4403)	(1.2404)	(1.2399)	(1.0940)	(1.1680)
Pop or Emp Denominator	Pop	Emp	Pop	Emp	Pop	Emp	Pop	Emp
Observations	257	257	257	257	257	257	257	257
First stage F	6.81	6.81	6.81	6.81	6.81	6.81	6.81	6.81

Notes: Each column presents results of IV regressions of the variables listed at top on the variables listed at left. Numerators of dependent variables (logged) in Columns 1-6 are about central city residents, constructed using 1990 and 2010 census data. Numerators of dependent variable in Columns 7-8 is about central city jobs, constructed using the 1995 and 2008 Industrial Censuses. In Columns 1, 3, 5, and 7, prefecture population is used in denominators of dependent variables. In Columns 2, 4, 6 and 8, prefecture employment is used in denominators of dependent variables.

Table 9B: Robustness Checks for Table 9

	(1)	(2)	(3)	(4)	(5)
2010 radial railroads	-0.2948***	-0.2676***	-0.1745**	-0.2622***	-0.1852**
	(0.0941)	(0.0845)	(0.0744)	(0.0999)	(0.0920)
2010 ring road indicator				-0.5860**	-0.4225
				(0.2945)	(0.3076)
ln(central city area)	0.0426	0.0799	0.0813	-0.0093	0.0168
	(0.0677)	(0.0803)	(0.0706)	(0.0839)	(0.0751)
ln(prefecture area)	-0.1886*	-0.2571**	-0.1618	-0.2769***	-0.1910*
	(0.1080)	(0.1020)	(0.1000)	(0.1029)	(0.0999)
provincial capital indicator	0.3253	0.2882	0.4415**	0.3404	0.4550**
	(0.2188)	(0.2008)	(0.2065)	(0.2187)	(0.2213)
ln(prefecture population, 1982)		0.1337	0.0134	0.1494	0.0436
		(0.1094)	(0.1081)	(0.1137)	(0.1212)
fraction high school or more		-7.3562***	-8.2012***	-6.7830***	-7.6553***
in prefecture, 1982		(1.7997)	(1.3625)	(2.1354)	(1.7149)
share employed in manufacturing		0.9680	0.3643	0.5222	0.1377
in prefecture, 1982		(1.1450)	(0.9293)	(1.2896)	(0.9969)
fraction high school or more		5.5154***	5.5849***	5.2006***	5.3471***
in central city, 1982		(1.6101)	(1.1614)	(1.7290)	(1.2695)
share employed in manufacturing		-1.7912***	-1.6800***	-1.3485*	-1.3783**
in central city, 1982		(0.6930)	(0.5606)	(0.7247)	(0.6188)
ln(distance to coast)			-0.1120***		-0.0944***
			(0.0290)		(0.0351)
Δln(Pref Pop) 1990-2010	-1.3865*	-1.1750*	-1.3162**	-1.3488*	-1.4193**
	(0.7820)	(0.6406)	(0.5653)	(0.7304)	(0.6361)
constant	5.3684***	3.9431**	5.3815***	4.6361**	5.6553***
	(1.2472)	(1.8047)	(1.8455)	(1.9429)	(1.9322)
Observations	241	241	241	241	241
First stage F	35.8	23.7	26.9	5.23	3.81

Notes: Regressions are analogous to those in Table 9. Transport measures are instrumented with 1962 counterparts and Dln(Pref Pop) 1990-2010 is instrumented with the Card migration instrument.

Table 11B: Robustness Checks for Table 11

	Δln(CC Manufacturing Employment) 1995-2008			
	(1)	(2)	(3)	(4)
2010 radial railroads	-0.2166**	-0.2573***	-0.2905***	-0.2145**
	(0.0860)	(0.0980)	(0.0906)	(0.0933)
2010 ring road indicator	-0.3782	-0.4126	-0.3119	-0.1589
	(0.3064)	(0.3174)	(0.2680)	(0.2898)
ln(central city area)		-0.0233	0.0104	0.0314
		(0.0849)	(0.0820)	(0.0718)
ln(prefecture area)		-0.1575**	-0.2612***	-0.1783*
		(0.0621)	(0.0836)	(0.0955)
provincial capital indicator		0.1694	-0.0306	0.0688
		(0.1798)	(0.1830)	(0.1769)
ln(prefecture population, 1982)			0.3495***	0.2562***
			(0.0720)	(0.0915)
fraction high school or more			-3.6100	-4.5950**
in prefecture, 1982			(2.5865)	(2.2841)
share employed in manufacturing			2.0489	1.7938
in prefecture, 1982			(1.8111)	(1.6288)
fraction high school or more			2.5204	2.6816
in central city, 1982			(1.7852)	(1.6761)
share employed in manufacturing			-1.4110	-1.4872*
in central city, 1982			(0.8759)	(0.8550)
ln(distance to coast)				-0.0863**
				(0.0375)
Δln(Pref Pop) 1990-2010		0.2569	0.0418	-0.0156
		(0.3304)	(0.5802)	(0.4780)
Constant	0.8428***	2.5092***	-1.7705	-0.9050
	(0.2161)	(0.8117)	(1.2168)	(1.1718)
Observations	257	257	257	257
First stage F	10.9	5.02	5.65	4.01

Notes: Regressions are analogous to those in columns 7-8 of Table 10 and columns 5-8 of Table 11.

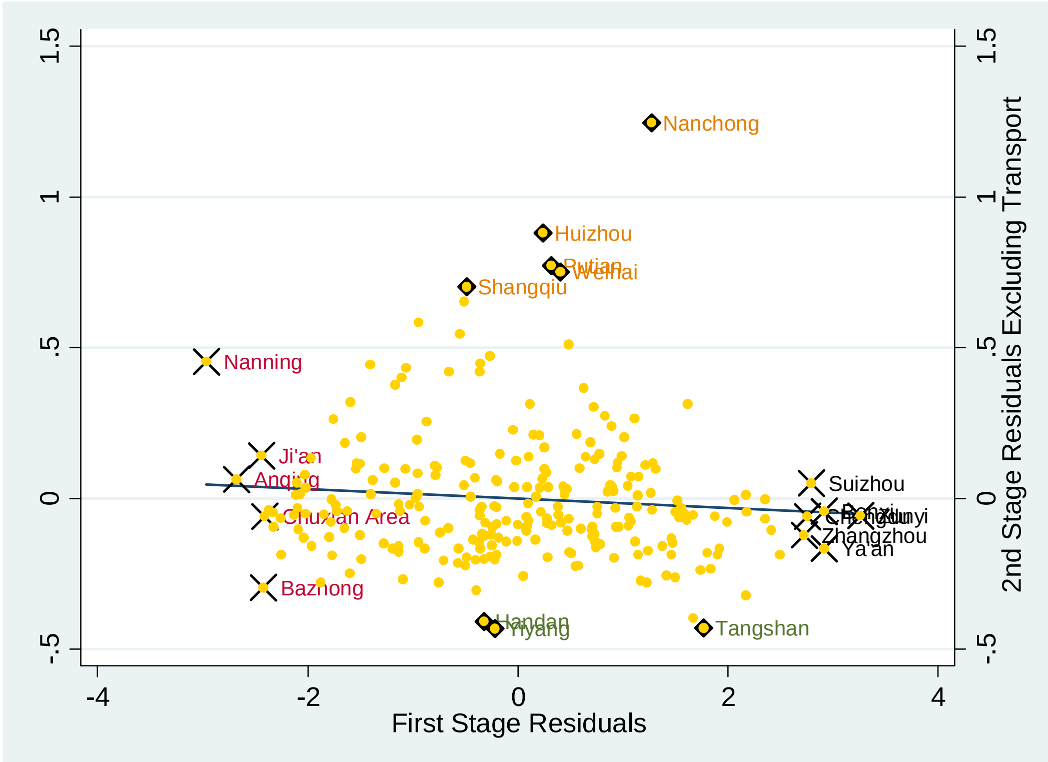


Figure A1: Residuals from Table 3 Column 2 excluding radial highways plotted against first stage residuals

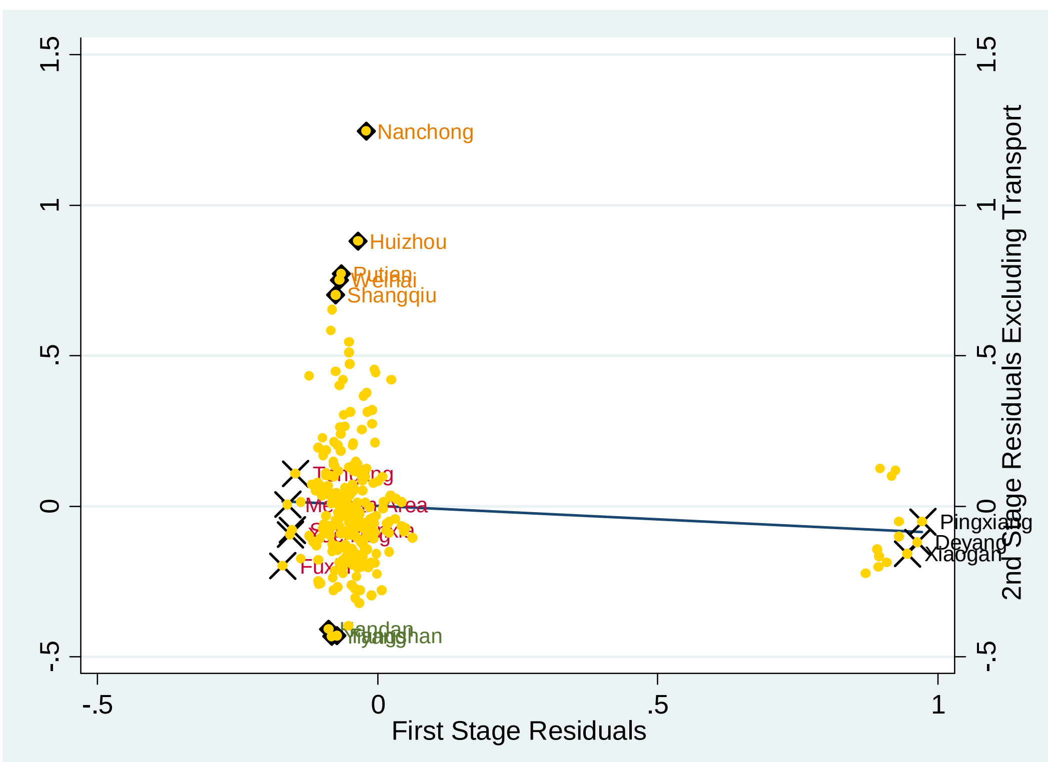


Figure A2: Residuals from Table 8 Column 4 excluding ring roads plotted against first stage residuals

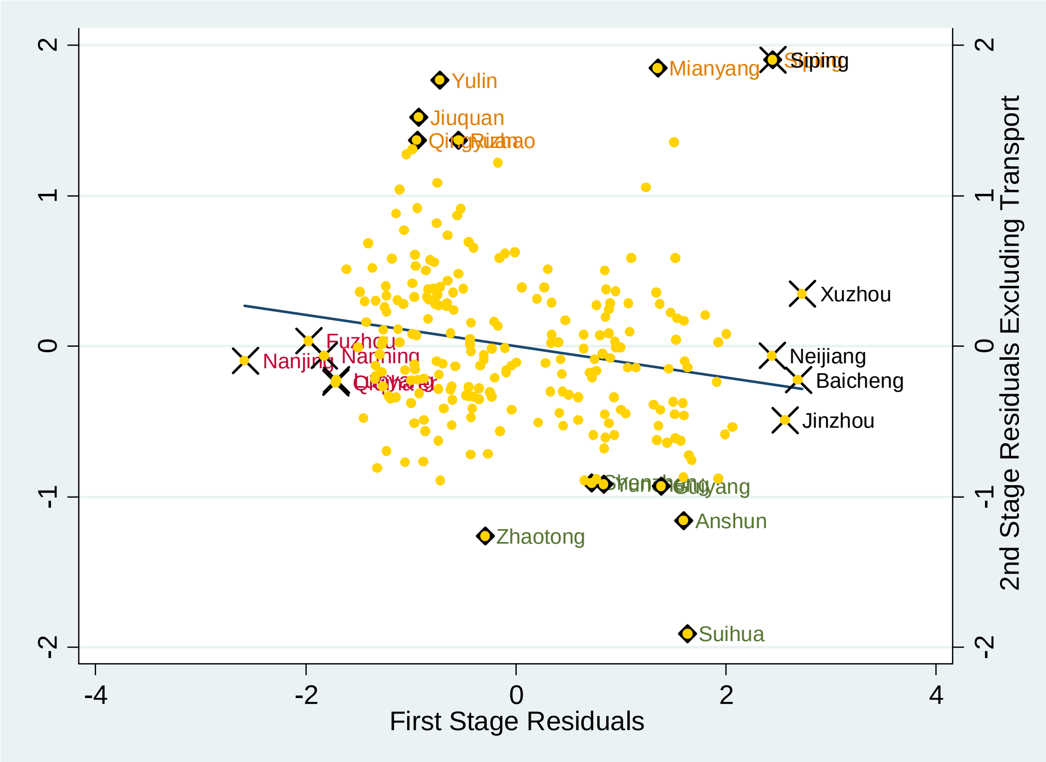


Figure A3: Residuals from Table 9 Column 2 excluding radial railroads plotted against first stage residuals

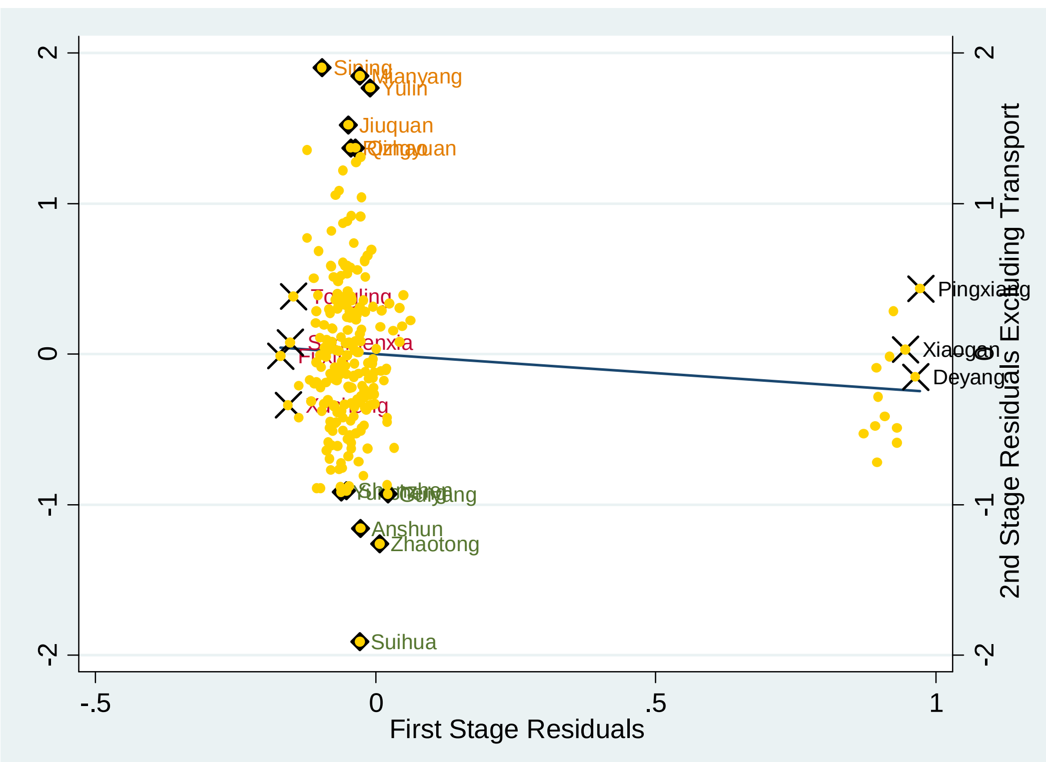


Figure A4: Residuals from Table 9 Column 5 excluding ring roads plotted against first stage residuals