Transportation and the Decentralization of Chinese Cities*

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Abstract: It is widely believed that transportation infrastructure has important impacts on the development of cities. Specifically, we expect that improvements to urban infrastructure generate welfare benefits by reducing commuting and shipping costs, that they affect driving behavior, that they affect the physical layout of cities and that they affect the organization of activities within cities. Until recently, however, there has been little systematic evidence with which to evaluate claims about the effects of transportation infrastructure on the development of cities and regions. In this paper, we describe the evolution of Chinese transportation infrastructure and how it relates to the evolution of location patterns of population and production in Chinese cities and surrounding regions. Using empirical evidence from our work with Loren Brandt, Vernon Henderson and Qinghua Zhang on the causal effects of various types of transportation infrastructure on the decentralization of Chinese cities, we evaluate the efficacy of various urban transport infrastructure policies for China. Finally, we put our results in context of the existing literature on the effects of infrastructure on productivity and the allocation of resources across locations.

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1. Introduction

Over the past two decades China has made huge investments in highways and railroads. Between 1990 and 2010, an average Chinese prefecture saw its railroad network length increase from 142 km to 210 km. More dramatically, in 1990 there were no limited access highways in China. By the end of 2010, there were about 220km of limited access highways in an average prefecture. China is not alone. All over the world, developing countries are making enormous investments in transportation infrastructure. The importance of infrastructure has been recognized by aid agencies. In 2007, approximately 20% of the World Bank's lending was for the construction and maintenance of transportation infrastructure in poor countries.

It is widely believed that transportation infrastructure has important impacts on the development of cities. Specifically, we expect that improvements to urban transport infrastructure change location incentives for people and firms and influence the amount of driving and mode choice conditional on residential and firm location. Such infrastructure improvements may ultimately generate welfare benefits by reducing commuting and shipping costs. Moreover, they may affect the physical layout of cities and that the organization of activities within cities. Until recently, however, there has been little empirical investigation of these phenomena, especially in a developing country context. Little systematic evidence exists with which to evaluate claims about the effects of transportation infrastructure on the development of cities or regions.

This paper has four goals. The first is to describe the evolution of location patterns of Chinese transportation infrastructure, population and production and how it is allocated between cities and their surrounding regions. The second is to describe our work with Loren Brandt, Vernon Henderson and Qinghua Zhang (Baum-Snow et al. 2012, henceforth BBHTZ) on the effects of transportation infrastructure on the spatial distribution of population and production in Chinese urban areas. The third is to use these estimates to evaluate the extent to which the expansion in urban transport infrastructure in Chinese cities since 1990 has accommodated the population and GDP growth of these cities, and indirectly improved welfare, especially of the migrant population. Finally, we provide some projections for the effects of various additional urban transport infrastructure construction plans and put our estimates in the context of the existing literature on the effects of infrastructure on urban and regional development. In sum, we describe the state of infrastructure and cities in China, and summarize what is known about the ways that infrastructure affects the development of cities in China and how we can use this knowledge to improve urban transportation policy in urban areas in developing economies.

The decentralization of cities is of particular interest for several reasons. First, the expansion of cities has immediate implications for land use, travel behavior and the availability of agricultural land. Secondly, the decentralization of cities appears to be an important part of the process of economic development. Early in the industrial revolution, Western cities tended to be dense and highly centralized: workers typically travelled under their own power to centrally located factories. With the advent of the internal combustion engine, manufacturing moved to urban peripheries where land was cheaper, allowing less land intensive business services to occupy central business districts. In Western countries, incomes have increased many times over since the beginning of the industrial revolution and while our understanding of this growth process is incomplete, it is now widely accepted that much of the innovation responsible for this growth happens in the densest parts of cities. See Rosenthal & Strange (2004) for a review of the empirical evidence on local spillovers. More specifically, there is evidence that large cities whose centers are occupied by diverse, mostly white collar industries, are engines of economic growth. Thus, our interest in the role of infrastructure in the decentralization of cities is justified by the importance of the effects that centralization has on land use and travel demand, but also by the likely importance of decentralization in the evolution of cities from places organized around manufacturing into places organized around innovation.

Beyond these motivations that apply quite generally, understanding the effects of transportation infrastructure on the decentralization of Chinese cities in particular is of interest for three reasons. First, over the past 20 years between one and two hundred million Chinese have migrated from the countryside to cities, one of the largest human migrations in history. This has naturally led to very high population densities in Chinese cities and is probably partly to blame for the current restrictions on internal migration. These restrictions, known as `hukou', restrict access to schools and health care for rural migrants and limit rural dwellers' ability to access urban housing markets and work in urban labor markets. To the extent that transportation infrastructure facilitates the decentralization of cities, it may also reduce crowding and makes Chinese cities more open to rural migrants, generating welfare improvements for these migrants. Second, Chinese cities have a history of having centrally planned allocation of land to housing and production facilities. One legacy of the planning economy is some cities whose centers are still dominated by large manufacturing establishments. An important feature of the process of urban growth and development is the decentralization of manufacturing to urban peripheries to be replaced by younger more dynamic industries that are less land intensive and benefit more from local productivity spillovers and the availability of a broader range of inputs and ideas. If infrastructure can help Chinese cities to overcome this legacy of planning and become centers of innovation, then it is important to learn what elements of the transport network are most effective at facilitating industrial decentralization. Third, Chinese policy makers are particularly interested in food security. To the extent that transportation infrastructure causes conversion of agricultural land to urban use, such transport expansions also potentially negatively influence food production.

2. Background and Some Basic Facts

Our study area consists of the 26 provinces that make up Eastern China. Chinese provinces are comprised of prefectures which are in turn made up of three types of county; rural counties (*xian*), county towns (*xianji shi*), and urban districts (*qu*). There are 282 prefectures in our study area and about 2500 counties. Each prefecture contains at most one core city. Core cities are administrative units and consist of all of the urban districts within the prefecture. The extent of our study area is indicated by the green area in figure 2. Prefectures are indicated by the red boundaries in figure 5 and the extent of core cities is indicated by the tan regions in figure 2.

We are primarily interested in two geographic units, the prefecture and the core city drawn to constant 1990 boundaries. One goal of this paper is to review evidence on the extent to which transportation infrastructure contributes to decentralization of Chinese cities. More precisely, we evaluate the extent to which transportation infrastructure influences changes in the share of prefectural economic activity and population within 1990 prefectural city boundaries between 1990 and 2010.

2.1 Transportation Infrastructure in China: Data and Basic Facts

To construct data describing Chinese road and railroad infrastructure, we digitize large scale national Chinese road maps. That is, we measure highways and railroads as lines on maps. We rely on national maps rather than more detailed provincial maps in order to ensure consistency of measurement across locations. For example, a red line describes the same class of road in two provinces if both provinces are on the same map. Figure 1 illustrates the way our data is constructed for Beijing for 2010. In all, we construct digital maps for the following networks: limited access highways in 1995, 2000, 2005 and 2010; railroads in 1924, 1962, 1980, 1990, 1999, 2005 and 2010; smaller highways in 1962, 1980, 1990, 1999, 2005 and 2010. We also construct data on Chinese river networks. Detailed bibliographical information is available in BBHTZ.

Figure 2 shows the development of the Chinese network of limited access highways. There were no limited access highways in China in 1990. The construction of this network began in the early

1990s and in the top left panel of Figure 2 we see that a few segments had been constructed by 1995, most of them near Beijing and Shanghai. The top right panel of Figure 2 shows the highway network in 1999. By this time, routes connecting Hong Kong to both Beijing and Shanghai are complete, with fragments scattered broadly throughout the country. The bottom left panel of Figure 2 shows the road network in 2005, just five years later. In this figure we see that the network is well developed along the coast, but that the coastal network is not well connected to the central part of the country. The bottom right panel of Figure 2 shows the limited access highway network in 2010. In this panel we see that the highway network in the central part of the country is now connected to the coastal network. We also see that by 2010 the large majority of core prefecture cities, indicated by the tan regions, have been connected to the network.

Figure 3 presents corresponding maps of the Chinese rail network. The top left panel shows the rail network in 1990. This network is concentrated in the northeast, and while almost all core cities in this region are connected to the network, cities in the South and West are much less likely to be connected. The top right panel of Figure 3 shows the rail network in 1999. While the network is clearly more extensive than in 1990, the rate of growth is nowhere near as fast as for the highway network. The 1999 network is denser everywhere, but many core cities in the South and West are still not on the network, while many spur lines serve the regions around cities in the Northeast. The lower left panel of Figure 3 shows the Chinese rail network in 2005. The 2005 network is more extensive than the 1999 network, but just as changes to the 1999 allowed major northeastern cities to interact with smaller cities nearby, so do new rail lines built between 1999 and 2005. The bottom right panel of Figure 3 shows the rail network in 2010. The main change from 2005 is the addition of East-West line to connect the rail network in the central part of the country to the coastal network.

A few comments about these maps are in order. First, the rail and highway networks are obviously different. The rail network is more extensive and grows more slowly. Moreover, in addition to connecting major cities to each other, the rail network was designed to connect major cities to the smaller cities that surround them. The highway network, on the other hand, is more specialized in connecting major cities to each other. Second, China relies heavily on railroads for long haul and even short haul freight (World Bank, 1982). In 1978, perhaps 3% of freight (in ton-distance units) in China was carried on highways. By 2004 this number had risen to almost 15%, still much less than in the USA. We will ultimately find that highways and rails have different effects on the decentralization of cities. Highways affect the locations of people within urban areas, while railroads affect the locations of manufacturing. These different effects may reflect the intrinsic comparative advantages of railroads and highways for moving goods and people. Alternatively, they may also reflect the fact that the road and rail networks were laid out to serve different purposes. While the data in BBHTZ do not allow for distinguishing between the two possibilities, the second alternative seems consistent with an inspection of the way the networks are laid out.

To proceed with our investigation of how transportation infrastructure affects the decentralization of Chinese cities, we need to have measures that quantify the road and rail networks in each core city and its surrounding region. To do this, we construct three variables for each network. The first is simply the length of each network in kilometers in each prefecture and in each 1990 core city. The second and third are radial and ring road indexes. The radial road index describes the ability of a network to carry traffic radially in an out of the central business district, while the ring index measures the ability of a network to carry traffic in a circle around the central business district.

The top panel of Figure 4 illustrates how we construct our radial road index. To begin, we draw two circles around the central business district of each core city, one with radius 5km and one with radius 10km. We then count the number of times a transportation network intersects each ring. The smaller of these two numbers is our measure of radial road capacity in the 5-10km donut surrounding the CBD. In the top panel of Figure 4 we illustrate this process for the 2010 highway network surrounding Beijing. This network intersects the smaller ring six times and the larger ring eight times. In this case, our radial road index takes the value six, which is exactly what one would choose if doing the calculation by eye. We conduct a similar process for each city using rings of radius 10km and 25 km in order to count radial road capacity in a larger donut surrounding each city. Our measure of radial road capacity for each transportation network is the sum of the index values for smaller and larger donuts.

Calculating our ring road index is somewhat more involved. We proceed quadrant by quadrant. For the northwest quadrant, as illustrated in the bottom panel of Figure 4, we begin by drawing two rays out from the CBD, one to the west and one to the northwest. We then restrict attention to the portion of each ray that lies between 9 and 15 km from the CBD and count the number of times that the transportation network intersects each ray. The ring road capacity of the network in the northwest quadrant between 9km and 15km is the smaller of these two counts of intersections. For the example illustrated in the lower panel of Figure 4, we count one ring road in the northwest quadrant. We repeat this procedure for each of the four quadrants and for roads that lie between 15 and 25km from the CBD. To construct our ring road capacity index, we sum over all quadrants and the small and large donut. We are also able to restrict attention to prefectural ring roads which lie outside the boundaries of 1990 core city boundaries. The construction of this measure of peripheral ring road capacity is the same as is described above, but considers only roads outside the boundaries of the 1990 core city. As we discuss below, these peripheral ring roads appear to have been most important in shaping Chinese cities since 1990.

Table 1 uses our three city level statistics of total kilometers, radial roads and ring roads, to describe the evolution of transportation infrastructure in prefectures and their core cities. Panel A describes the rail network. In 1962 an average prefecture had about 93km of rail, of which about 30km was in the core city. The rail network grew steadily between 1962 and 2005, at which point an average prefecture contained about 207 km of rail, about 47km of which was in the core city. There is little change in the network between 2005 and 2010. In all, the top panel of Table 1 bears out what we see in Figure 2. That is, the rail network increased steadily over the 1990 to 2005 period, with much of the expansion devoted to rail lines that connect core cities to satellite cities just outside their administrative boundaries.

Table 1 Panel A also describes the configuration of the rail network in an average prefecture. In 1962 an average core city had one radial rail line and about half of all core cities had no rail lines. By 1990, the first year illustrated in Figure 2, the average core city had about 1.5 radial rail lines and only one-third of core cities had zero. By 2005, radial railroads in core cities increase only marginally. An average core city in 2005 had about 1.8 radial rail lines and the share of core cities without radial rail lines declined to about one quarter

The final four rows of Table 1 Panel A describe ring rail capacity. In 1990 an average prefecture had 0.14 units of ring rail capacity. Recalling the way the ring capacity measure is constructed, this means that an average prefectural city in 1990 has a rail line which travelled about 13 degrees around its perimeter. With this said, only about 13% of core cities have ring rail capacity at all. Thus, Table 1 tells us the almost all of the cities with ring rail capacity had exactly one unit, i.e., a rail line travelling about 90 degrees around their CBD. Suburban ring rail capacity is even scarcer. In 1990 an average core city has two one hundredths of a unit of peripheral ring rail capacity and only about five core cities have any peripheral ring rails at all. As for other measures of the extent of the rail network, ring rail capacity increases gradually until 2005. Between 2005 and 2010 ring rail capacity actually drops. This appears to reflect measurement error. Our rail maps are hand drawn so the location of any given rail line will move slightly from year to year. Since our ring road algorithm is sensitive to such small changes, we can observe year to year variation in the ring index even when, as is the case for 2005 and 2010, the underlying network is little changed.

Data reported in Table 1 Panel B is analogous to that in Panel A except it describes the evolution of China's limited access highway network. Prior to 1995, there are no limited access highways. By 1999 an average prefecture had about 47 km of limited access highway and of these, about 13km lay in the prefecture's core city. Unlike the rail network, which appears mostly complete in 2005, the highway network continues to grow through 2010. By 2010 an average prefecture contains 222 km of limited access highways, of which 54 km are in the 1990 core city. As for railroads, the share of highways in prefectures' core cities falls slightly over time. The amount of radial road capacity increases from 0.31 per city in 1999 to about 1 in 2010 and the share of cities with at least one radial road increases from 0.13 to about one half. Unlike for the rail network, there is substantial ring road capacity by 2010. An average core city has more than three times as much ring road capacity as ring rail capacity in 2010, while almost half of all core cities have some ring road capacity. If we restrict attention to peripheral roads, the contrast with rail is even more dramatic.

In sum, Table 1 tracks the evolution of road and rail networks in China over the past 50 years. Broadly, this table confirms the impressions formed by inspection of Figures 2 and 3. The rail network has grown rapidly over this period and was largely completed by 2005, but the limited access highway network has grown much faster than the rail network and this growth continues to the end of our sample. More subtly, the rail network is relatively more specialized in radial capacity and the highway network is relatively more specialized in ring capacity. If people or goods move radially in China they are more likely to travel by rail. If they move around city centers, they are more likely to travel by highway.

2.2 Population and Production in China: Data and Basic facts

We have two primary measures of production: lights at night satellite images and explicit measures of prefecture and core city GDP from various Chinese censuses and yearbooks. We have one measure of population taken from various Chinese censuses and yearbooks. We begin by discussing the lights at night data before turning to GDP and population data.

We rely on six separate lights at night images of China (NGDC 1992-2009). These images are for 1992, 2000, 2005, and 2009, with two sets of data for 2000 and 2005. For each cell in a regular 1 km grid covering our study area, these data report an intensity of nighttime lights ranging from 0-63. The codes 0-62 indicate intensity, while 63 is a topcode. Topcoding is rare in China, although it is common in developed countries. Henderson, Storeygard and Weil (2012) show that lights at night are a good proxy for GDP at the national level. As we discuss below, lights and GDP are also strongly correlated at the Chinese prefecture level. While lights at night are clearly related to production, they are surely also related to other human activities, including those occuring in residences, which may not be directly related to production. Thus, while lights at night give us a very detailed picture of where activity occurs that is much more detailed than is available from administrative data, some caution in interpreting these images is required.

Figure 5 presents lights at night images for our study area for 1992, 1999, 2005 and 2009. In these images, lighter shades indicate higher nighttime intensity of light and red indicates prefecture boundaries. These figures show that lights are concentrated in the northeastern part of the country, in much the same area as the early railroad network is concentrated. Over time, lights expand to the whole country, but light in the region between Beijing and Shanghai expands most rapidly while the West grows less dramatically. While the major cities such as Beijing, Shanghai and Hong Kong clearly grow over our study period, growth is not confined to these cities. Small cities all over the country grow rapidly as well.

Panel A of Table 2 quantifies this growth in lights. The first row of this table reports the total amount of light in our study area, with 1992 normalized to one. Consistent with inspection of the images in Figure 5, we see steady, rapid increase in the total amount of light in the China, with almost 2.5 times as much light in 2010 as in 1992. The second row of panel A in Table 2 reports the share of all lights that lie in 1990 core cities. We see a gradual decrease in the share of lights in core cities, from 38% in 1990 to 32% in 2010. Thus, as with the road and rail networks, lights increase faster outside the 1990 boundaries of core cities than inside.

The third row of Panel A of Table 2 confirms this finding with an alternative geographic unit. In this row, we calculate the share of total prefectural light that lies within 5km of the CBD of the 1990 core city. On average this 5km disk is much smaller than an average core city: it contains less than 1/4 as much light as an average core city. The share of light in these disks declines over time, from 11% in 1992 to 6% In 2010. Thus, not only does development favor the suburbs over the 1990 city, but development favors the edges of the 1990 cities over their centers.

We now turn our attention to direct GDP measures. For 1990, we use GDP and industrial sector GDP information from various national and provincial printed data year books (China Statistics Press, 1992b & 1992c). In 2005 we use output information from the University of Michigan's Online China Data Archive at the rural county, county city or core prefecture city levels according to contemporaneous definitions. We supplement these data with prefecture level printed yearbooks. We note that GDP data is not available for all of our 1990 core cities in all years. As a consequence our initial analysis of GDP is based on a sample of 108 prefectures. More detail about data construction is available in BBHTZ.

The top panel of Figure 6 describes our GDP data. This figure shows the percent change in GDP between 1990 and 2005 for constant boundary 1990 core cities and for the residual portion of each prefecture. Gray signifies missing data. For cities and prefectures, rates of GDP growth are assigned to one of six categories, less than 200%, less than 400%, less than 600%, less than 800%, less than 1000% and at least 1000%, each of which is color coded. Light yellow indicates less than 200% growth and the three successively darker shades of orange indicate the next three bins. Red is less than 1000% growth and brown is the top category, at least 1000% growth. While our GDP map is clearly fragmentary, as expected, it shows that development has been faster along the coasts, both in prefectural cities and in the surrounding prefectures. Close inspection does not suggest a pattern of either decentralization or centralization. In many cases, central cities appear to grow more quickly than the surrounding prefecture, and conversely.

We also separately observe the industrial component of GDP. Panels B of Table 2 describes these data. Between 1990 and 2005, total GDP increases by more than a factor of six. We also see that between 1990 and 2000 there was a marked decentralization of production. The 54% share of economic activity in 1990 core cities decreases to 45% in 2000, but then increases to 51% by 2005, almost its original 1990 level. Industrial GDP also increases more than six-fold between 1990 and 2005. However, manufacturing decentralizes much more rapidly than does overall GDP. In 1990, 64% of manufacturing occurs in 1990 city boundaries. This share decreases to 47% by 2000 before increasing slightly in 2005. Thus, Table 2 bears out our inspection of figure 6 and results based on lights at night data. There is rapid overall increase in GDP and a slight decentralization of economic all activity. There is a proportional increase in industrial GDP, and a much clearer pattern of decentralization. Together with the lights data, the GDP data suggest that Chinese cities are adopting the modern form of organization often seen in the West. Much production activity occurs in the centers of Western cities, but as countries become wealthier, manufacturing moves to the periphery of big cities.

Finally, we consider population growth and migration. We assemble population data from the 1990, 2000 and 2010 Chinese censuses of population. For 1990, we rely primarily on the 100% count Chinese census data aggregated to prefecture core city, rural county or county city level (China Statistics Press, 1992a). For 2000 and 2010, our census data are the 100% count aggregated to urban district and rural unit levels (China Statistics Press, 2002 & Lianxinwang Web Site, 2012). We note that in 1990 Chinese census data reports place of legal residence (hukou) rather than place of actual residence, so using census data to figure out the resident population is somewhat subtle. We also note that population data was not available for all prefectures and core cities in 2010, so our analysis of population is based on a sample of 210. More detail on data construction is available in BBHTZ.

The bottom panel of Figure 6 uses our data to illustrate population changes in China between 1990 and 2010. This figure is similar to the top panel of figure 6. 1990 core cities are outlined in blue. Light yellow regions experience population growth of less than -10%, i.e. decreases. The three successively darker shades of yellow illustrate higher rates of population growth; less than 10%, less than 25%, and less than 50%. Red and brown regions grow at less than 100% and at least 100%, respectively.

Unsurprisingly, this figure shows high rates of population growth near Hong Kong, Beijing and Shanghai. More generally, it shows high rates of population growth along the East coast. Perhaps more surprising, it shows a number of regions with high population growth in the interior and the West as well. Thus, the widely reported coastal migration of the Chinese population appears to be only a part of the story of migration in China. A second pattern is also clear. 1990 core cities experience higher rates of population growth than do surrounding areas of prefectures. Thus, while the large scale patterns of migration appear to be complicated, at a small scale they are clear. People are moving from the country to the city.

Panel C of Table 2 further describes our population data for the sample of 210 prefectures for which we have such data. The first row reports mean population for entire prefectures in 1990, 2000 and 2010. In 1990 an average prefecture was home to about 4 million people. This number grows to 4.7 million by 2010. Since prefectures cover the entire area of China, subject to gaps in our data, this also describes the growth of population in the whole country. The second line of this table reports the share of an average prefecture's population within the boundaries of the 1990 core city. The share of population in the 1990 core cities increases between 1990 and 2000 and between 2000 and 2010. In 1990, one person in four lived in a core city. By 2010, it is one person in three. Thus, consistent with what we saw in Figure 6, the population in core cities is growing much more rapidly than in the surrounding areas. Some simple calculations illuminate the scale of the rural to urban migration underlying these data. In 1990, an average core city had a population very close to 1 million. By 2010, this figure increases to about 1.5 million. Thus, an average core city accommodates 50% more residents in 2010 than 1990, half a million more people. With 282 prefectures in our study area, this suggests that the population of 1990 core cities increases by about 140 million between 1990 and 2010.

The final row of Table 2 refines this intuition by considering a different geographic unit. In particular, we consider only counties in each prefecture that are not in or adjacent to the 1990 core city. That is, the portion of the prefecture that is most remote from the prefectural city. We see that the population share of this part of an average prefecture decreases almost in lockstep with increases in the core city. The population share of the most remote parts of prefectures declines from 0.33 in 1990 to 0.28. Thus, much of the increase in urban population must be coming from this remote countryside. The fact that population decreases in the countryside do not quite completely account for population increase in the center means, mechanically, that the remaining suburban counties must account for the rest. Some simple calculations show that in an average prefecture, the population share of the `suburban counties' adjacent to but not contained in the 1990 core city must decrease from 0.43 in 1990 to 0.39 in 2010. Since population increases over this period, this means that the suburban population of an average prefecture changes from about 1.7 million in 1990 to about 1.8 million in 2010. That is, it stays just about constant. Therefore, our data show an enormous migration from the countryside into the major cities between 1990 and 2010.

3. Transportation infrastructure and the decentralization of Chinese cites

Our data describe three large changes in the Chinese economy between 1990 and 2010. First, we see an approximately six fold increase in GDP. Second, we see a huge migration of people from the countryside into the major cities. Third, we see a modest shift of economic activity from the old central cities into the surrounding countryside and a much larger decentralization of manufacturing. During the same time period, our data indicate a dramatic increase in the extent of the railroad network and the wholesale creation of a network of limited access highways. We now describe the results of BBHTZ on the role that highways and railroads played in the centralization of population and the decentralization of manufacturing in Chinese cities between 1990 and 2010.

3.1 Econometric Method

BBHTZ investigate the extent to which the road and rail network contributed to the decentralization of Chinese cities using an instrumental variable regressions analysis. We begin by describing this approach and provide some intuition about how it works.

BBHTZ conduct regressions of the following form

(1) ,

where the outcome of interest is the 1990 core city share of population, lights or economic activity, the infrastructure measure is one (or more) of our measures of road or rail infrastructure, and *B* is the parameter of interest.

Several comments about this equation are required. First, since we are taking logarithms of the dependent and explanatory variable, it turns out that the coefficient of interest, *B*, is the percentage change in the outcome variable that results from a 1% change in the infrastructure variable. Second, equation (1) uses log change in outcome between 1990 and 2000, 2005 or 2010 as the dependent variable and the terminal level of transportation infrastructure. In the case of highways, when 1990 levels are zero, the change from 1990 to *t* equals the level at *t*. For railroads, this is not the case since considerable infrastructure existed in 1990. BBHTZ discuss the rationale for this approach at length, along with associated issues in interpreting results. In short, it comes down the fact that the central planning of vintage 1990 urban areas rendered any market responses to the location of transport infrastructure impossible.

Third and more fundamentally, we must be concerned that infrastructure is not assigned to prefectures at random. To understand the importance of this issue, suppose that highways are assigned to prefectures by a planning authority to anticipate growth in core city population. In this case, estimates of Equation 1 will yield a positive coefficient: roads are built in prefectures where core city population grows. Alternatively, suppose that roads are assigned to prefectures at random. In this case, we expect estimates of equation 1 to return negative estimates of B. That is, we expect that by reducing transportation costs, additional roads allow population to decentralize and the share of core city population in the prefecture to decline.

Therefore, the process by which roads are assigned to cities is fundamental to this investigation, and if we would like to understand the extent to which infrastructure causes decentralization, it is important that infrastructure be assigned randomly, rather than to growing cities, as is more likely. To resolve this problem BBHTZ rely on instrumental variables (IV) estimation. This estimation technique essentially randomizes across cities the amount of infrastructure that is received by relying on variation in historical infrastructure networks to predict modern networks. This process can be thought of as occurring in two stages. The first stage of this process picks out infrastructure that was assigned to cities at random, and the second stage estimation then recovers estimates of B that are `as if' infrastructure was assigned at random. An extensive discussion of this strategy is available in BBHTZ.

We note that while IV estimation is subtle, it is pervasive in applied microeconomics. Moreover, essentially the same IV estimation strategy employed in BBHTZ has been employed in several other papers, including Baum-Snow (2007), Duranton, Morrow and Turner (2011), Duranton and Turner (2011), Duranton and Turner (2012), Hsu and Zhang (2011) and Michaels (2008). This collection of papers gives us enough experience with this general estimation strategy to be confident that BBHTZ provide credible estimates of the causal effects of infrastructure on the spatial organization of Chinese cities.

3.2 The Effects of Infrastructure on Population Decentralization in Chinese Cities

In regressions like (1) where the outcome variable is change in log core city population between 1990 and 2010 and the infrastructure measure is the index of radial road capacity for major highways, BBHTZ find that each highway ray causes between a 3 and a 5.5 percent decrease in core city population, depending on the details of the regression. The corresponding estimates for the effect of highway rays on log change in core city population between 1990 and 2000 are similar, although they are not strictly comparable since there is a lower standard in 1999 for what constitutes a highway than in 2010.

We note that BBHTZ use a slightly different measure of highways than we have discussed here. Where we have discussed limited access highways in each year, the analysis in BBHTZ uses the union of limited access highways and the next smaller class of roads. Our discussion in Section 2 focused on limited access highways because BBHTZ's more extensive networks do not result in legible maps.

Consistent with evidence for the U.S. in Baum-Snow (2007) and Duranton and Turner (2012), differences between OLS and IV highway rays coefficients suggest that 1999 and 2010 radial road indices are not assigned to cities at random. Specifically, more roads are assigned to cities whose populations grow faster relative to the surrounding prefecture. Thus, more roads were built in prefectures containing rapidly growing core cities, even as these roads were causing population to decentralize from these cities. Results in BBHTZ show that while more rapidly growing Chinese cities received more transport infrastructure of various types, the decentralization that occurred because of this infrastructure is overwhelmed by the growth that precipitated the construction of this infrastructure.

In regressions like (1) where change in log core city population is the dependent variable, with one exception, adding additional measures of infrastructure does not affect BBHTZ's estimates of the effects of radial highways on prefectural city population. Adding measures of the total extent of the road network, of the extent of the rail network, or of radial rail capacity does not affect BBHTZ's estimates of the effect of radial road capacity on the decentralization of population. Ring roads, however, have an independent effect on population decentralization. Specifically, a core city with any peripheral ring road capacity experiences less population growth than core cities without such capacity. Providing a core city with some amount of ring road capacity results in about a 19 percent decrease in the city share of prefectural population. Note that this finding is subject to an important caveat. The nature of BBHTZ's estimation strategy of the effect of ring roads means that the estimated effect of ring roads is determined by a small number of cities, so we should be concerned that these cities are not representative of the whole sample. This concern does not arise for their estimates of the effects of the radial roads, the extent of the road network or measures of railroad infrastructure.

To sum up, the results reported in BBHTZ show that radial roads cause population decentralization, with each increment of radial road capacity causing a 3 to 5.5 percent decline in central city population over our study period. Their results also show that no other measure of the road or rail network, except for the presence of suburban ring roads, has any affect of population decentralization.

3.2 The Effects of Infrastructure on Production Decentralization in Chinese Cities

BBHTZ next investigate the effects of transportation infrastructure on the decentralization of production from central cities. Specifically, BBHTZ estimate versions of Equation 1 in which the outcome variable is the change in log GDP between 1990 and 2000 or between 1990 and 2005. They also conduct the corresponding regressions for industrial GDP and lights at night. For all three measures of economic activity they find that highway rays have no measurable effects on the decentralization of core city economic activity. A similar statement applies to highway network length, whether in the prefecture overall or just in suburban areas.

Unlike radial highways, railroads do cause economic activity to decentralize. Each railroad ray is estimated to displace 25 percent of core city industrial GDP and 16 percent of 1990 core city total GDP to prefecture remainders. The larger effect of railroad rays on industrial GDP indicates that it is rail induced decentralization of the industrial sector that drives rail induced decentralization of total GDP. These rail effects are large and statistically robust. Similar strong results hold for prefecture railroad network length, however, BBHTZ do not have the statistical power to jointly estimate the effects of these two railroad network measures in one regression. Results for lights at night are consistent with those for the other two GDP measures, but somewhat weaker. As with highways and population, results reported in BBHTZ suggest that more railroads have been assigned to central cities with more rapid GDP growth.

BBHTZ also investigate the effects of ring road capacity on the decentralization of lights, industrial GDP and GDP. For this investigation, they conduct regressions like equation (1), where the outcome variable is a measure of production and the ring roads as a measure of infrastructure. These regressions show large, statistically significant negative effects of the existence of a ring road on prefectural city economic activity. These significant effects of ring roads come in addition to persistent separate effects of highway rays on population 1990-2000 and railroad rays on the centralization of industrial GDP and GDP. Estimated effects of peripheral ring roads are about -0.79 log points for industrial GDP and -0.45 for GDP. These estimates are robust to including other transportation measures in the regression and to changes in the details of the regression equation. These estimates suggest enormous effects of peripheral ring roads on the decentralization of economic activity.

We believe railroads are important for industrial decentralization because they dominate trucking as the primary intercity shipping mode. More radial railroads provide more options for manufacturers to move out of central cities and maintain access to the national railroad network through sidings and ring road connections. Industrial decentralization is likely a desired reorganization of urban production activities since cheaper land and rural labor is well-suited for the land intensive low skilled manufacturing sector. At the same time, CBD land can be repurposed toward services which are less space intensive and typically benefit more from local agglomeration spillovers.

3.3 The effect of rivers and public transit on the decentralization in Chinese cities

BBHTZ's final inquiry is an investigation of the effects of public transit and waterways on decentralization. While there exists a large literature on the economic consequences of public transit, mostly using travel demand modeling, we know little about transit's effects on urban decentralization, particularly in developing countries. There is even less analysis of the effects of navigable waterways on urban form.

BBHTZ estimate the effects of the number of buses and trolleys in 2005 on measures of urban decentralization. Because such data are only reported at the prefecture city level of geography, they cannot account for city boundary changes and use reported 2005 numbers without modification. Their results indicate that a 10% increase in a cities count of buses and trolleys causes a 0.35% increase core city population growth 1990-2010, holding prefecture population constant and the number of radial highways constant. This regression, like the others described above, is a variant of equation (1) and is estimated with instruments for highways and transit vehicles. More detail on the estimation strategy is provided in BBHTZ. These results provide the only statistical evidence we know of to supports the widely held belief that public transport contributes to urban compactness and counteracts the contribution of road infrastructure to suburbanization.

BBHTZ also investigate the effects of navigable rivers and canals on urban form using water travel measures analogous to those constructed for roads and railroads. Navigable waterways are an important shipping conduit for raw materials like coal and agricultural products, though less so for manufactures. About 75% of the cities in our sample have waterway rays. They find that waterway rays have a small and statistically insignificant effect on the decentralization of industrial GDP and total GDP. Similarly small and insignificant effects are found for kilometers of prefecture waterways and when population decentralization is instead used as an outcome. These results are consistent with waterways' role in shipping raw materials.

4. Policy Implications and Broader Lessons

We have so far described how the spatial organizations of population, production and infrastructure have evolved in Chinese cities between 1990 and 2010. We have also reported our findings from BBHTZ on the extent to which transportation infrastructure has affected the organization of population and production in Chinese cites. Broadly, we find that radial railroads and ring roads have caused decentralization of economic activity, while radial roads and ring roads have caused the decentralization of population. However, public transit causes population to centralize.

In this section we argue that our evidence broadly indicates the existence of potentially large welfare gains from the Chinese urban transport infrastructure improvements since 1990. They have allowed cities to accommodate more migrants and have facilitated movement toward a more efficient spatial organization of production. As China continues to upgrade its urban transport infrastructure, additional welfare gains are available. Below, our review of the existing empirical literature on urban transportation, urban decentralization, urban growth and the associated welfare implications, reveals that while the large welfare gains associated with urban transport now being enjoyed by urban Chinese residents will dissipate with additional infrastructure, that level of development is some time off.

4.1 Rough Quantification of the Benefits of Urban Transport Improvements

It has long been the case that incomes and productivity in Chinese cities have exceeded those in surrounding rural regions. Among the 134 regions for which we could GDP per capita in core cities and surrounding prefectures, urban GDP per capita was almost 3 times as large as rural GDP per capital in 1990. Likely because of the huge amount of migration that ensued over the following decade largely as a result of the associated urban wage premium, this ratio fell to about 2 by 2000.[6] While we do not have GDP data for 2010, evidence from 2005 indicates that the urban wage and productivity premia persist. Therefore, the ability of cities to accommodate additional migrants who can participate in the more productive urban sector likely leads to economic growth and improved welfare for rural migrants. Moreover, we have shown that railroad infrastructure in particular has facilitated the re-organization of urban economies around innovation rather than manufacturing, thereby growing urban GDP (while holding population constant) and the consequently improving the welfare of urban residents.

We roughly quantify the gains that urban transport improvements in Chinese cities have brought through an accounting exercise using our estimates of the decentralization effects of highways and railroads. We have shown that highways cause the decentralization of a fixed prefecture population away from the core city. However, as urban-rural migration has increased population pressure on core cities, highways thus have also facilitated the accommodation of more migrants. Each radial highway causes about 5 percent of the core city population to decentralize holding the population of the broader region constant. Urban theory indicates that in a fixed population region everyone would benefit from the additional road because it decreases commuting costs and allows households to consume more space. The result is the consumption of more space per household and more of other goods as well, a clear welfare gain. The empirical observation that people choose to decentralize with the installment of additional highway infrastructure is evidence that they are better off by doing so. This means that each radial highway allows the central city to grow 5 percent in population without increasing crowding and without reducing consumer welfare of metro area residents as it essentially extends the metro area boundary without imposing any additional commuting costs on the most peripheral residents. To the extent that wages and incomes of urban residents exceed those of rural residents, each new radial highway allows the core city population to grow by an additional 5 percent via migration from rural areas. These migrants are better off because they enjoy higher incomes while the incumbent city residents are no worse off.

A similar argument can be made that radial railroads have improved welfare by allowing GDP (particularly industrial GDP) to decentralize. The decentralization of production out of core cities has freed up space for additional central city production. Because more space gets integrated into the urban area, this allows total metro area GDP to increase, given that land is an important factor of production. Beyond this mechanical process, the decentralization of industrial GDP allows the central

[6] Among the 134 prefectures for which we have data, the average ratio of urban to rural GDP per capita in 1990 was 2.89, falling to 2.02 in 2000. The ratio of the aggregates fell from 2.80 to 1.68.

city industry mix to shift toward more innovation and greater productivity. Therefore, the estimated displacement of 17 percent of central city total GDP for each radial railroad facilitates growth of total urban area GDP by more than 17 percent as the spatial organization of production by industry becomes more optimal. Each ring-road facilitates both core city population growth and production decentralization, generating welfare benefits through both margins discussed above.

Table 3 reports the amount of infrastructure in 2010 and the rough amounts of additional population, industrial GDP and GDP that has been accommodated in central cities as a result of this infrastructure, relative to having no highways or railroads. The results reported on Columns (3)-(6) are the additional quantities accommodated for the infrastructure reported in Columns (1)-(3). We calculate these numbers for cities at various points in the 2010 population distribution and in aggregate over the full sample of 205 cities for which we could build consistent data.[7] Estimated effects used to calculate numbers in Columns (3)-(6) are taken from BBHTZ and include the effects of ring-roads estimated jointly with radial highways and railroads. We apply these estimated effects of transport infrastructure on core city population, industrial GDP and total GDP from 1990. We note that using 1990 as a base implies that the resulting projections of population and GDP components accommodated by infrastructure are rather conservative. With the rapid post-1990 growth in urban population and GDP, and the fact that much of the transport infrastructure was installed many years after 1990, it also may be appropriate to use larger numbers from later years as a base instead.

Because the 1990 urban highway infrastructure was essentially 0, we can think of the additional accommodated central city population reported in Column (4) as being due to highway construction since 1990. Because central planning determined the spatial organization of production in 1990, and in most cities inefficiently allocated land-intensive industrial production to city centers, we can also think of the additional industrial GDP and GDP accommodated through the number of 2010 railroads and ring-roads as being relative to 1990 when the location of production did not respond much if at all to urban transport infrastructure.

The first three columns of Table 3 show that, consistent with our discussion in Section 2, the 205 cities for which we could carry out this exercise had an average of 3 highway rays, 1.8 railroad rays and 0.2 ring roads in 2010, with significant variation in this infrastructure. Column (4) shows that a large portion of most of the indicated cities' 2010 population is able to be accommodated by in these cities because of their transport infrastructure. The indicated city with the largest percentage is Beijing,

[7] Because of GDP data is only available for contemporaneous geographies for most core cities, our GDP and industrial GDP information for 42 cities in 2005 use 2005 core prefecture city geographies which differ from the 1990 geographies for which we report population projections.

where we find that 4.4 million of the 13 million residents in 2010 are able to live there because of the high number of 11 radial highways. Over our full sample of 205 cities, the final two rows of Table 3 show that 50 of 316 million people are accommodated, or about 16 percent of their aggregate 2010 population.

Columns (5) and (6) of Table 3 show the amount of industrial and total GDP that has decentralized since 1990 because of the existence radial railroads and the construction of ring-roads. Since the industry mix in central cities has shifted away from industry and toward services, we focus on the total GDP results in Column (6). We treat these as a lower bound on the effects of transport infrastructure since they largely reflect the decentralization of manufacturing which has been replaced with more productive industries per unit land. Because Nanping and Qiqiha'er had no radial railroads or ring-roads, none of their GDP is predicted to be accommodated by transport infrastructure. However, at least 3 percent of Shanghai's and 9 percent of Beijing's we calculate is related to their rail infrastructure. In aggregate, our estimates indicate that at least 4 percent of central city GDP in 2010 for the 205 cities in this sample is accommodated by cities' transport infrastructure, likely considerably more.

One way to get a sense of the extent to which the displacement of central city industrial production has facilitated production in other industries is to examine how the ratio of total GDP to industrial GDP has changed over time in central cities. In 1990, about 60 percent of central city GDP consisted of industrial GDP. By 2005, this fraction drops to about 50 percent. Over the same period, the fraction of prefecture remainder GDP that was industrial grew from about 40 percent to about 50 percent.[8] The fact that each unit of industrial GDP that left central cities was replaced by about 1.25 units of GDP in other sectors is a rough estimate of an expansion factor that we can apply to the projected central city industrial GDP losses reported in Column (5). Column (7) of Table 3 reports the implied additional amount of total GDP accommodated in central cities as a result of the indicated transport infrastructure using this expansion factor of 1.25 on the industrial GDP projections from Column (5).

Given the evidence that large fractions of population and GDP in many Chinese cities are accommodated by the existing transport infrastructure, it is natural to investigate the extent to which future expansions might facilitate urban growth by allowing cities to accommodate additional population and production. With the current introduction of a nationwide high-speed rail system that is almost entirely in addition to the existing rail network, and the continued expansion of the national

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[8] These calculations use the 108 prefectures for which we have prefecture level GDP data in 1990. Central city fractions using the broader sample of 205 are similar, as can be calculated using numbers reported in Table 4.

highway network, there remains the potential for resulting big changes in Chinese urban economies. Table 4 explores the effects of 5 different proposed transport infrastructure additions: one additional radial highway to each city, one additional radial railroad to each city, ring-roads to cities without them, construction such that each city has at least 3 highway and 2 railroad rays, and construction such that each city has at least 3 highway, 2 railroad rays and one ring road. We choose a benchmark of 3 highway rays and 2 railroad rays because this is near the median of the cities in our sample. Table 4 reports the additional population, industrial GDP and total GDP that is projected to be accommodated with these additional infrastructure improvements. Projections are calculated using 2005 for GDP and 2010 for population as a base and regression coefficients from a model that includes ring-roads, highway rays and/or railroad rays.

In general, evidence in Table 4 indicates that the most potential urban growth would be facilitated with the construction of additional ring-roads. Because ring-roads have large effects on the spatial distributions of both population and GDP, they appear to be particularly conducive to urban development. We caution that because a small fraction of cities have ring-roads in the data, this conclusion relies on extrapolating from these few experiences to many other cities. However, the distribution of cities with pseudo-randomly assigned ring-roads, achieved through our IV estimation strategy, is reasonably well distributed throughout the population distribution.

Projections based on our estimates indicate that constructing ring-roads for all cities would lead to the accommodation of an additional 50 million people, about 16 percent of the current aggregate population of our sample of 205 cities explored. Even more striking, providing a ring-road to each city we project would allow aggregate urban GDP to grow by 35 percent as industries that benefit less from being centrally located in cities are freed to decentralize. This represents the bulk of the projected effects of building up the infrastructure of each city to have 3 highway rays and 2 railroad rays in addition. In contrast, constructing one additional radial highway in each city would accommodate about 5 percent more population in central cities and one additional radial railroad would accommodate 18 percent additional GDP. While it is likely that ring roads are more costly to construct, as they are typically longer than radial infrastructure, the higher returns may make these higher costs worthwhile. Moreover, if ring-roads are constructed beyond core city boundaries, land acquisition costs and logistical difficulties may be more manageable if ring-road construction is undertaken sooner.

4.2 Other Evidence on the Effects of Transport Infrastructure Investments

A common theme among our discussion and evidence is that there remains a huge potential in Chinese cities for the decentralization of certain types of production activity to urban peripheries in order to free up urban space for more productive activities. There also remains additional opportunity for urban areas to accommodate additional rural population by spreading out spatially, expansions that can only occur with additional transport infrastructure. These results are the only extant empirical results that describe the effect of transportation infrastructure on urban form in a developing country using recent data. However, there is a recent literature that investigates consequences of infrastructure construction in other contexts. In this sub-section, we briefly review this evidence from elsewhere in the literature. As a whole, other papers in the economics literature suggest that while the returns to highway and rail construction are likely to abate with Chinese economic growth, they are likely to remain sizable.

Baum-Snow (2007) finds the extent of population decentralization due to radial urban highways in the United States to have been slightly larger in magnitude than our estimates for Chinese cities. Given the higher incomes and associated much higher rates of auto commuting in the United States, this higher estimate is not surprising. This study indicates that radial highways in Chinese cities may increase in value as incomes rise. Also using data from the United States, Duranton & Turner (2011) shows that the amount of driving responds very closely to the amount of road capacity available. Indeed, we have seen this even in current Chinese cities, in which newly constructed highways quickly become congested. In Duranton & Turner (2012), they find using similar data that highways draw population to cities, consistent with our arguments for Chinese cities showing how highways can accommodate more urban residents. However, because urban-rural wage and productivity gaps are not as large in the United States as in China, the resulting welfare gains are smaller than we predict would result in Chinese cities.

There exists a relevant descriptive literature about the process of the decentralization of industrial production as countries grow and establish additional infrastructure. Henderson, Kuncoro & Nasution (2011) show how manufacturing facilities near Jakarta, Indonesia decentralized with the establishment of a highway linking the city to nearby hinterlands. Deng et al. (2008) descriptively shows how a similar process has occurred in several Chinese cities. That is, the narrative that industry decentralizes first to allow cities to specialize in less land intensive and more productive activities has been documented empirically, though descriptively, in several contexts.

While there remains much ongoing research and debate about the most relevant mechanisms, a number of recent papers argue convincingly that reductions in transport costs promote economic growth. Using lights at night data, Storeygard (2011) shows that as the costs of shipping between interior African cities and nearby markets fall, these interior cities grow. Donaldson (2011) finds very large effects of roads and rails on growth in Indian cities of the late 19th and early 20th centuries. Banerjee, Duflo & Qian (2012) find moderate effects of railroads on rural GDP levels but not growth in China. Michaels (2008) finds consistent evidence for the United States that roads affect factor shares and output levels in rural counties, also consistent with Chandra and Thompson's (2001) evidence.. Duranton and Turner (2012) find small effects of roads on urban population growth, suggesting small effects on productivity in US 1980-2000. They also find that marginal roads in the U.S. are probably not welfare improving. Holl et al. (2011) find similar results for modern Spain. This is broadly consistent with Duranton, Morrow and Turner's (2011) evidence indicating that roads do not affect the value of intercity trade in US in 2007. The dominant mechanism considered in these papers is that transport infrastructure lowers trade costs, thereby allowing cities to specialize better in the production activities for which they have comparative advantages.

In general, evidence from the literature suggests that returns to infrastructure are large in poor countries, and decline with income and the extent of the network. For China, this means that while the marginal returns are decreasing to new roads and railroads, more additions are still likely to considerably improve welfare and productivity.

5. Conclusions

China massively expanded its urban and rural transportation infrastructure since 1990. While most of the expansion has come in the form of new and better highways, the railroad network has also been upgraded and expanded and new ring-roads have been established around some cities. The consequences of this expansion have been cities that have been able to accommodate more people and experienced movements toward more efficient organizations of the locations of different types of production.

We find that railroads in Chinese cities have decentralized production and roads have decentralized population. While the radial layout of highways is what is important, evidence is less clear on exactly what nature of the railroad network, if any, is important for spurring the decentralization of industrial production. Ring-roads appear to encourage the decentralization of both population and production.

It is likely that transportation infrastructure generates the highest economic returns in poor places. As China grows and modernizes, we expect its returns to new transport infrastructure, which have been quite large, to abate. This comes for two reasons. First, the economy of richer countries rely less on the shipping of raw materials and manufacturing goods and more on communication and human capital. Second, each additional unit of infrastructure is less useful than the previous unit. Much of the first-order improvements in economic conditions available associated with transport infrastructure have likely already been realized in Chinese cities. Nevertheless, we project that additional urban transportation infrastructure will be welfare enhancing for existing Chinese urban residents and to new arrivals from the countryside.

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Figure 1: Construction of digital maps from paper source maps for a region around Beijing for 2010. The top panel shows a region around our Beijing in our 2010 National road map. The bottom panel shows the resulting digital road map. The green region in the right panel indicates the extent of the 1990 prefectural city. The yellow region indicates expansion of this administrative region by 2005.

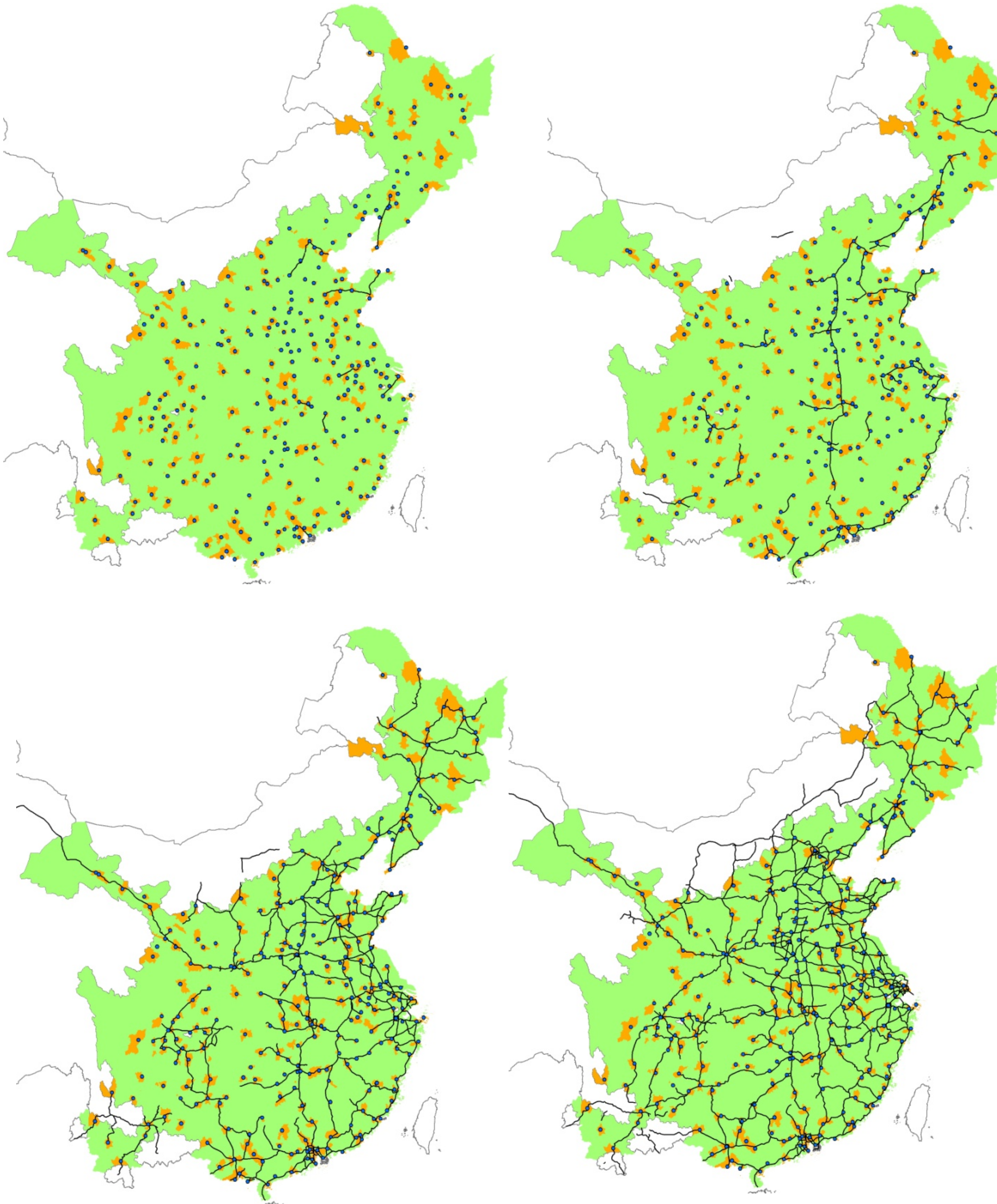

Figure 2: The extent of limited access highways in China. Top left is 1995, top right is 1999,bottom left is 2005 and bottom right is 2010. Green indicates the extent of our study area. Tan indicates 1990 prefectural city boundaries. Blue dots signify central business districts.

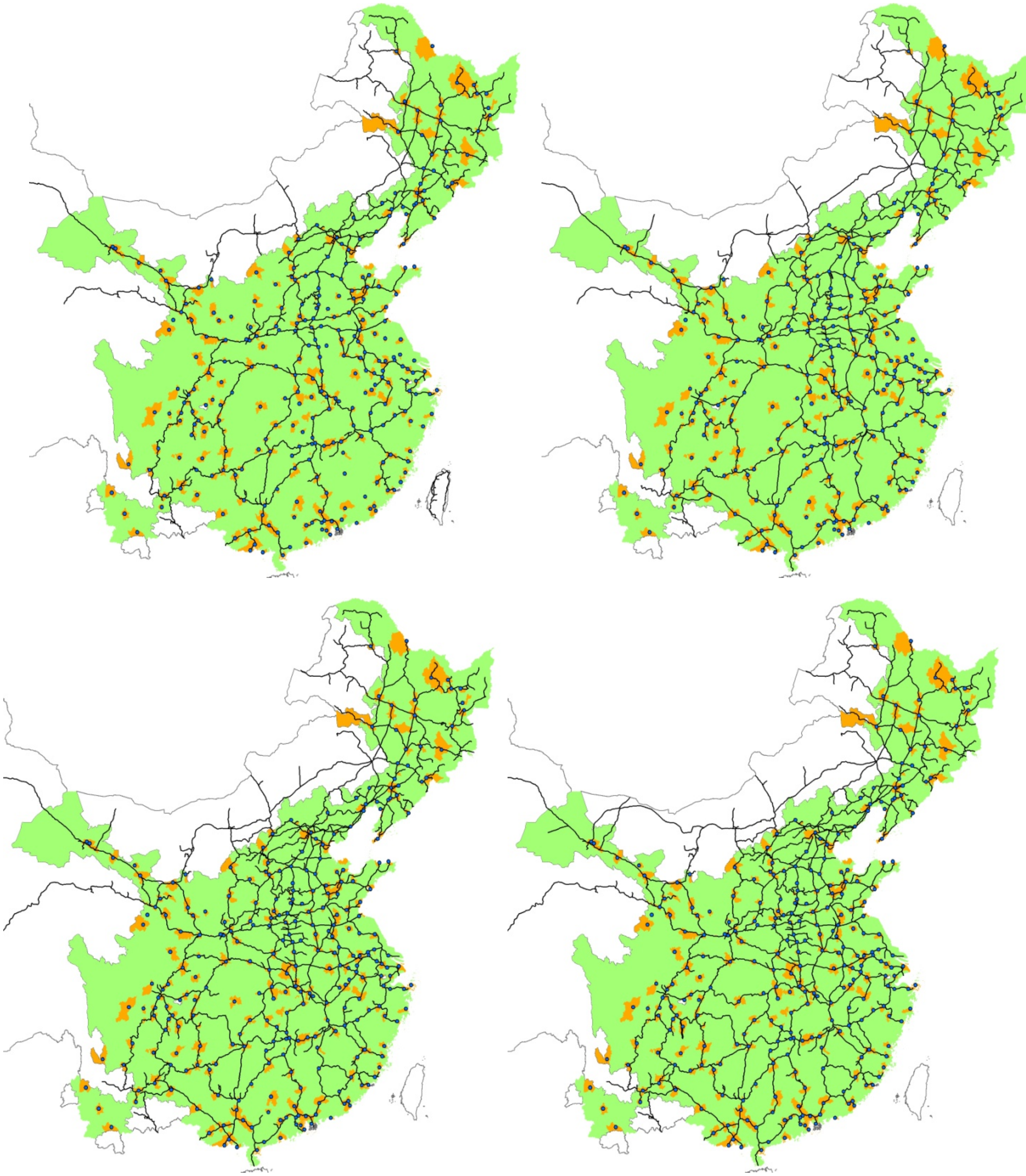

Figure 3: The extent of railroads in China. Top left is 1990, top right is 1999,bottom left is 2005 and bottom right is 2010. Green indicates the extent of our study area. Tan indicates 1990 prefectural city boundaries. Blue dots signify central business districts.

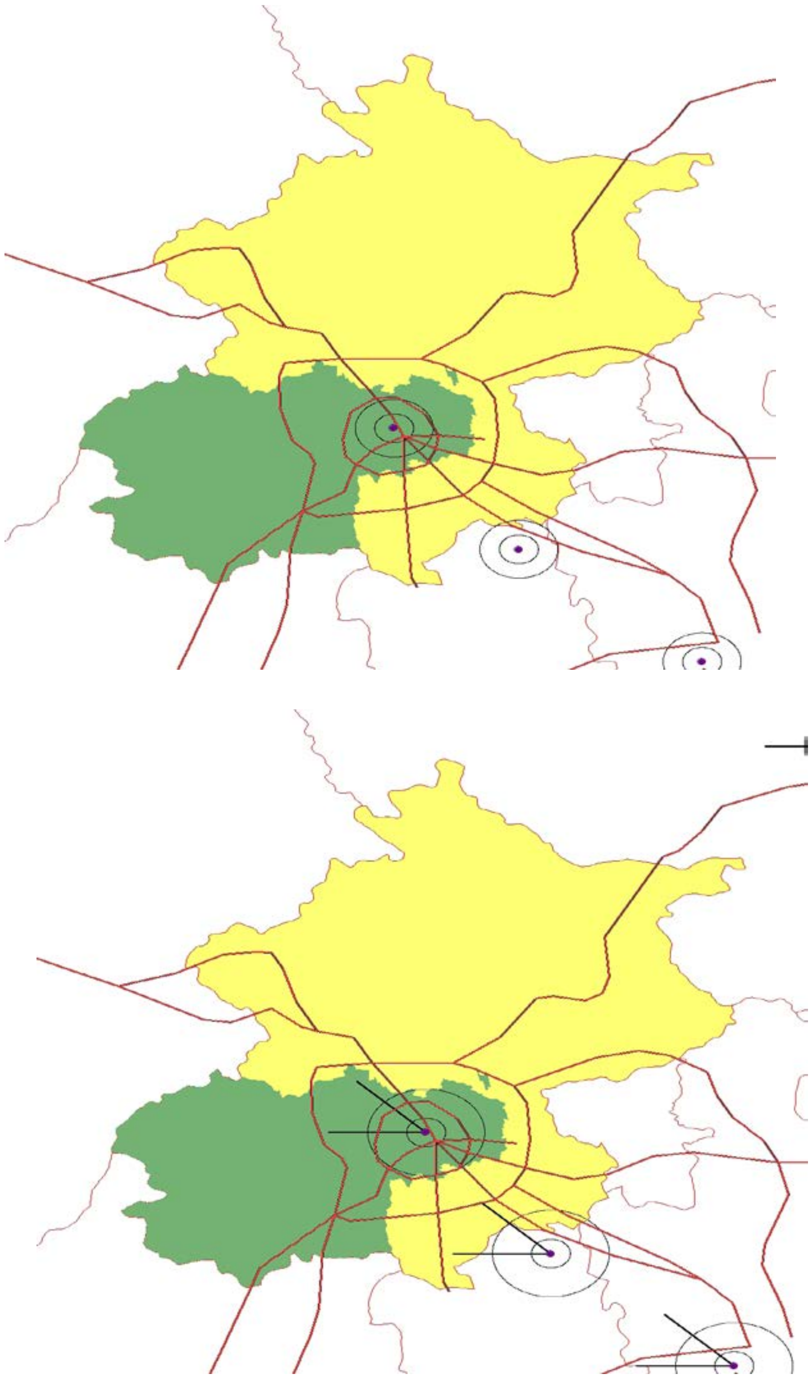

Figure 4: Construction of radial road index and ring road index. The top panel illustrates the construction of our radial road index. The bottom panel illustrates the construction of our ring road index.

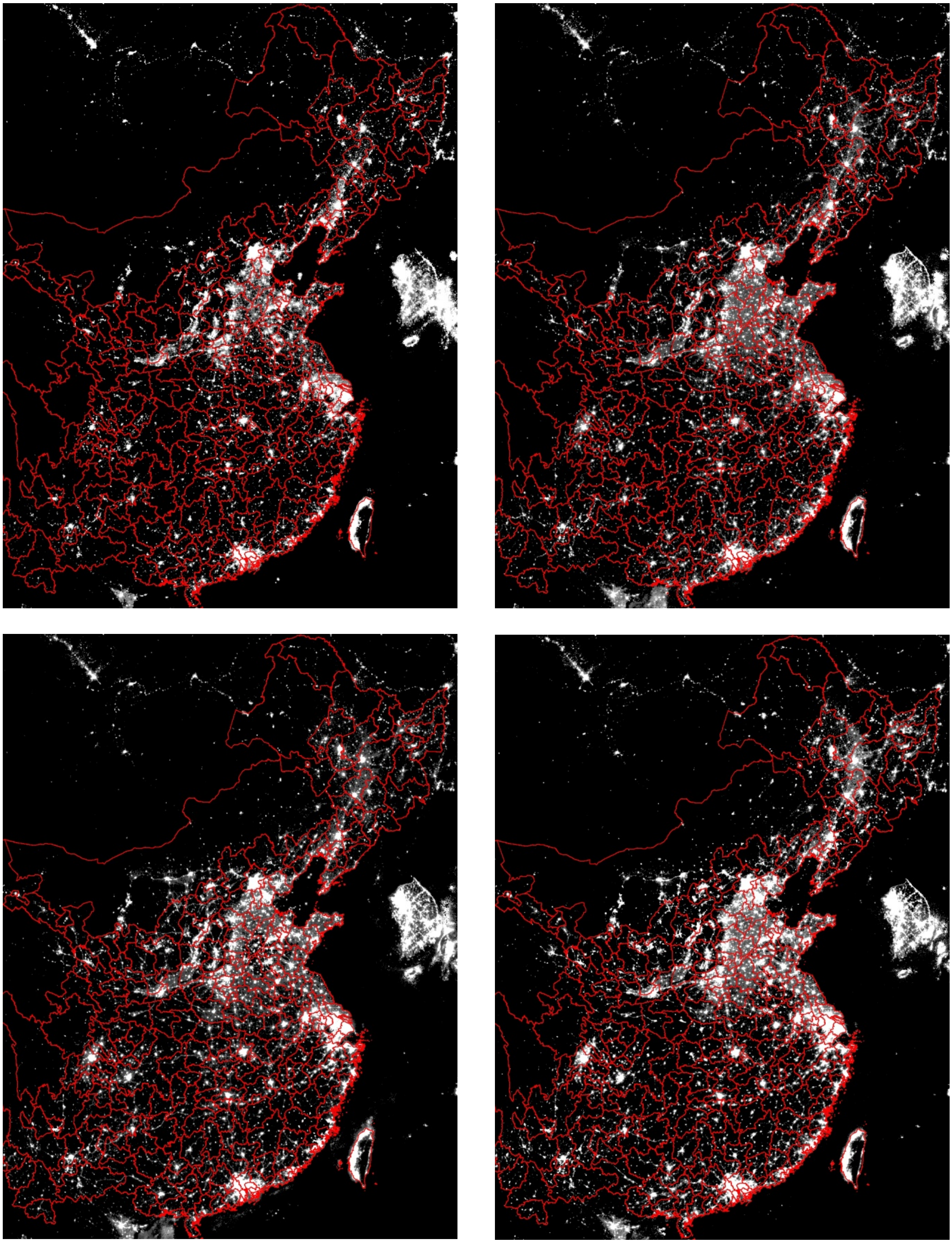

Figure 5: Lights at night in Eastern China: 1992 at top left, 2000 at top right, 2005 at bottom left, 2010 at bottom right

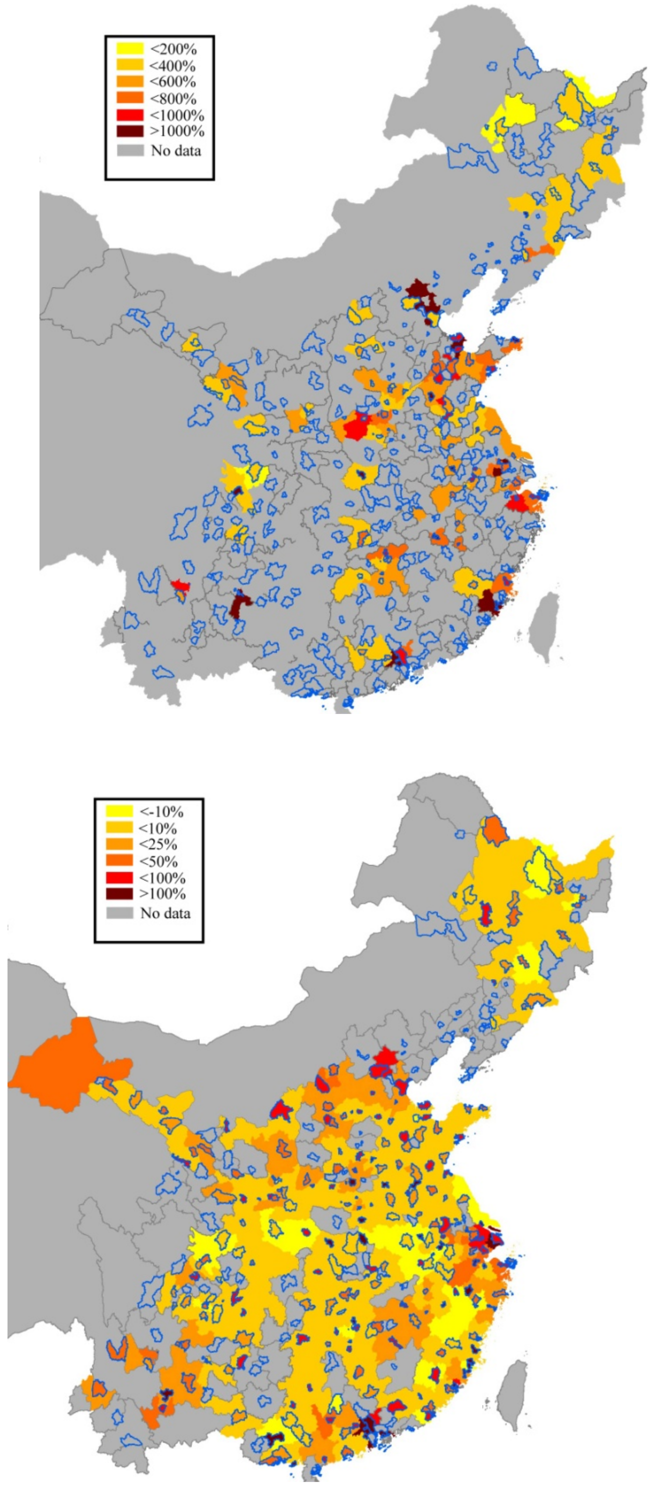

Figure 6: Top panel shows percentage change in GDP between 1990 and 2005 in 1990 prefectural cities, outlined in blue, and in residual prefecture. Bottom panel shows corresponding changes in population between 1990 and 2010.

Table 1: Railroad and Highway Network Growth Over Time

	Year					
	1962	1980	1990	1999	2005	2010
Panel A: Railroads						
Mean total km 1990 Central City	29.67	39.45	42.12	47.05	55.36	55.47
Mean total km entire prefecture	93.39	132.96	142.03	173.68	207.38	209.17
Mean radial index	1.01	1.40	1.48	1.63	1.73	1.78
Share radial index>0	0.47	0.58	0.66	0.64	0.74	0.76
Mean ring index	0.10	0.16	0.14	0.18	0.25	0.19
Share with ring index>0	0.10	0.15	0.13	0.17	0.23	0.18
Mean peripheral ring index	0.01	0.02	0.02	0.04	0.04	0.03
Share with peripheral ring index>0	0.01	0.02	0.02	0.04	0.04	0.03
Panel B: Express Highways						
Mean total km 1990 Central City	0	0	0	12.84	45.08	53.92
Mean total km entire prefecture	0	0	0	47.39	164.91	222.09
Mean radial index	0	0	0	0.31	0.88	0.99
Share radial index>0	0	0	0	0.18	0.46	0.48
Mean ring index	0	0	0	0.13	0.51	0.66
Share with ring index>0	0	0	0	0.12	0.37	0.43
Mean peripheral ring index	0	0	0	0.05	0.13	0.17
Share with peripheral ring index>0	0	0	0	0.05	0.12	0.14

Notes: Infrastructure measures are reported for the 210 prefectures and central cities for which we have consistent population data in 1990, 2000 and 2010.

Table 2: Prefecture and Central City Growth Over Time

	1990/2	1995	2000	2005	2010
Panel A: Lights & Geographic Shares, Full Sample of 257 Prefectures					
Entire prefecture (1992=1)	1	1.43	1.59	1.88	2.41
1990 central city share of prefecture	0.38	0.33	0.33	0.33	0.32
Prefecture outside 1990 central city share	0.62	0.67	0.67	0.67	0.68
5km radius of CBD share	0.11	0.08	0.08	0.08	0.06
Panel B: GDP & Geographic Shares, Sample of 108 Prefectures					
All GDP: Entire prefecture (100 millions of yuan)	38.0	na.	129.7	252.4	na.
All GDP: 1990 central city share of prefecture	0.54	na.	0.45	0.51	na.
All GDP: Prefecture outside 1990 central city share	0.46	na.	0.55	0.49	na.
Industrial GDP: Entire prefecture (100 millions of yuan)	19.3	na.	61.9	126.3	na.
Industrial GDP: 1990 central city share of prefecture	0.64	na.	0.47	0.50	na.
Industrial GDP: Prefecture outside 1990 central city share	0.36	na.	0.53	0.50	na.
Panel C: Population & Geographic Shares, Sample of 210 Prefectures					
Entire prefecture (millions)	3.98	na.	4.37	na.	4.66
1990 central city share of prefecture	0.25	na.	0.29	na.	0.33
Prefecture outside 1990 central city share	0.75	na.	0.71	na.	0.67
Prefecture outside 1990 city proper and suburbs share	0.32	na.	0.30	na.	0.28

Notes: Population, GDP and industrial GDP totals are averages across prefectures. Geographic shares are calculated using nationwide aggregates.

Table 3: Projected Additional Urban Population and GDP Accommodated by 2010 Transport Infrastructure
205 Cities With Population Data in 2010 & GDP Data in 2005

	2010 Infrastructure			Associated Core City Accommodation of (2010 or 2005 Totals)			
	Highway Rays	Railroad Rays	Ring Road Outside City	Population (millions)	Industrial GDP (100 millions)	Total GDP (100 millions)	Total GDP, Alternative
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
10th Percentile City	6	0	0	0.15	0	0	0
(Nanping)				(0.47)	(13.42)	(27.22)	
25th Percentile City	0	0	1	0.09	2.39	1.77	2.99
(Qitaihe)				(0.62)	(12.60)	(22.43)	
50th Percentile City	5	4	0	0.19	9.07	9.20	11.34
(Mudanijiang)				(0.97)	(12.06)	(30.91)	
75th Percentile City	4	0	0	0.31	0.00	0.00	0
(Qiqiha'er)				(1.55)	(20.70)	(76.50)	
90th Percentile City	6	3	0	0.54	12.89	12.88	16.11
(Guiyang)				(3.04)	(54.82)	(118.98)	
Beijing	11	2	0	4.37	89.41	101.12	111.77
				(12.95)	(272.70)	(1094.56)	
Shanghai	4	3	0	2.16	278.24	289.55	347.79
				(16.36)	(4408.75)	(9058.46)	
Aggregate for 205 Cities	609	369	44	49.7	1706.4	1793.8	2132.97
				(316.3)	(24788.8)	(49349.2)	

Notes: Percentiles are in the 2010 population distribution. Entries in Columns (4)-(7) show projected additional population and GDP based on estimated effects of transport infrastructure on decentralization of these variables. Projections apply 2010 infrastructure levels to 1990 population and GDP numbers. Projections in Column (7) are calculated by multiplying those in Column (5) by 1.25. See the text for details. The 205 cities used in this calculation contain 84 percent of the population of the 257 large core prefecture cities in Han China as of year 2000.

Table 4: Projected Aggregate Effects of Various Infrastructure Plans
205 Cities With Population Data in 2010 & GDP Data in 2005

	Population	Industrial GDP	Total GDP
1 Additional Radial Highway	17.1	0	0
1 Additional Radial Railroad	0	6,941	8,883
Giving All Cities Without One a Ring Road	50.3	14,969	17,353
At least 3 Highway and 2 Railroad Rays	9.8	3,269	4,011
At least 3 Highway and 2 Railroad Rays & Ring Road	60.1	18,237	21,363
1990 Actual Aggregates	203.9	2,166	3,698
2005/2010 Actual Aggregates	316.3	24,789	49,349

Notes: Projections are calculated using 2005 or 2010 numbers as base levels.