Transport Infrastructure and the Decentralization of Cities in the People's Republic of China

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It is widely believed that transport infrastructure has important impacts on the development of cities. Until recently, however, there has been little systematic evidence with which to evaluate claims about the effects of transport infrastructure on the development of cities and regions. In this paper, we describe the evolution of transport infrastructure in the People's Republic of China and how it relates to the evolution of location patterns of population and production in Chinese cities and their surrounding regions. We summarize empirical evidence from Baum-Snow et al. (2017) on the causal effects of various types of transport infrastructure on the decentralization of cities in the People's Republic of China. Finally, we put our results in the context of the existing literature on the effects of infrastructure on productivity and the allocation of resources across locations.

Keywords: infrastructure, People's Republic of China, railroads, roads
JEL codes: O20, R40

I. Introduction

Over the past 2 decades, the People's Republic of China (PRC) has made huge investments in highways and railroads. Between 1990 and 2010, an average prefecture in the PRC saw its railroad network length increase from 151 kilometers (km) to 218 km. More dramatically, there were no limited access highways in

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the PRC in 1990, but by the end of 2010 there were 215 km of limited access highways in the average prefecture. The PRC is not alone. All over the world, developing countries are making enormous investments in transport infrastructure. The importance of infrastructure has also been recognized by development assistance agencies. For example, between 2012 and 2016, approximately 12% of the World Bank's lending was for transport-related projects (World Bank 2016).

It is widely believed that transport 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 of transport choices, conditional upon residential and firm location. Such infrastructure improvements may ultimately generate welfare benefits by reducing commuting and shipping costs. However, they may also affect the physical layout of cities and the organization of activities within cities, yet what evidence we have is primarily for the effects of roads on cities in the developed world (Baum-Snow 2007, Baum-Snow et al. 2017, Duranton and Turner 2011, Garcia-López and Holl 2015, Hsu and Zhang 2014). There has been little empirical investigation of these phenomena in a developing country context. Moreover, there is almost no evidence about the effects of modern railroads or the configuration of urban road and rail networks for promoting urban development.

This paper has two main goals. The first is to describe the evolution of location patterns of transport infrastructure, population, and production in the PRC, and how transport infrastructure is allocated between cities and their surrounding regions. The second is to describe our work in Baum-Snow et al. (2017) on the effects of transport infrastructure on the spatial distribution of population and production in urban areas in the PRC. Finally, we 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 the PRC, and summarize what is known about the ways that infrastructure affects the development of its cities.

The decentralization of cities is of interest for several reasons. First, the expansion of cities has immediate implications for land use, travel behavior, and the availability of agricultural land. Second, 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 traveled 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 business services that require less land to occupy central business districts (CBDs). In developed 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 occurred in the densest parts of cities.[1] More specifically, there is evidence that large cities with centers occupied by diverse and predominantly white collar industries are engines of economic growth. Thus, our interest in the role of infrastructure in the decentralization of cities is justified not only by the importance of the effects that decentralization 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 general motivations, understanding the effects of transport infrastructure on the decentralization of cities in the PRC is of interest for three reasons. First, over the past 20 years more than 100 million people in the PRC 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 the *hukou* (household registration) system, limit access to schools and health care for rural migrants and limit rural dwellers' ability to access urban housing and labor markets. To the extent that transport infrastructure facilitates the decentralization of cities, it may also reduce crowding and make cities in the PRC more open to rural migrants. Second, cities in the PRC have a history of centrally planned land allocation. A legacy of the planning economy is that some cities have centers dominated by large manufacturing establishments. An important feature of the process of urban growth and development is the decentralization of manufacturing to urban peripheries and its replacement by younger and 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 cities in the PRC 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, policy makers in the PRC are particularly interested in food security. To the extent that transport infrastructure causes the conversion of agricultural land to urban use, such transport expansions may also reduce food production.

Baum-Snow (2007) finds the extent of population decentralization due to radial urban highways in the United States (US) to have been slightly larger in magnitude than our estimates for cities in the PRC. Given the higher incomes and much higher rates of auto commuting in the US, the larger estimated impacts in the US are not surprising. Using data from the US, Duranton and Turner (2011) show that the amount of driving responds proportionately to the amount of road capacity available. Indeed, we have also seen this in the PRC's cities in which newly constructed highways quickly become congested. Duranton and Turner (2012) find

[1] See Rosenthal and Strange (2004) for a review of the empirical evidence on local spillovers.

that highways draw migrants to cities, consistent with our arguments for Chinese cities showing how highways can allow a city to accommodate more residents.

There exists a relevant descriptive literature about the process of decentralization of industrial production as countries grow and establish additional infrastructure. Henderson and Kuncoro (1996) show how manufacturing facilities near Jakarta decentralized with the establishment of a highway linking the Indonesian capital to nearby hinterlands. Deng et al. (2008) descriptively show how a similar process has occurred in several cities in the PRC. Thus, the narrative that industry decentralizes first to allow cities to specialize in more productive activities that require less land has been documented empirically, though descriptively, in several contexts.

While there is 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 (2016) shows that as the costs of shipping between interior African cities and nearby markets fall, these interior cities grow. Donaldson (forthcoming) finds very large effects of roads and railways on growth in Indian cities in the late 19th and early 20th centuries. Banerjee, Duflo, and Qian (2012) find moderate effects of railroads on rural gross domestic product (GDP) levels, but not on growth, in the PRC. Michaels (2008) finds consistent evidence that roads in the US affect factor shares and output levels in rural counties, which is also consistent with Chandra and Thompson's (2000) evidence. Duranton and Turner (2012) find small effects of roads on urban population growth between 1980 and 2000, suggesting small effects on productivity in the US during this period. They also find that marginal roads in the US are probably not welfare improving. Garcia-López and Holl (2015) find similar results for Spain between 1960 and 2010. This is broadly consistent with Duranton, Morrow, and Turner's (2014) evidence indicating that roads did not affect the value of intercity trade in the US in 2007. The dominant mechanism considered in these papers is that transport infrastructure lowers trade costs, thereby allowing cities to specialize 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, but decline with increases in income levels and the extent of the network.

II. Background and Basic Facts

Our study area consists of the 26 provinces that make up the eastern PRC. Provinces in the PRC comprise prefectures, which in turn are made up of three types of counties: *xian* (rural counties), *xianji shi* (county towns), and *qu* (urban districts). There are 257 prefectures in our study area and about 2,500 counties. Each prefecture contains at most one core city. Core cities are administrative units and consist of all 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 transport infrastructure contributes to decentralization in the PRC's cities. More precisely, we evaluate the extent to which transport infrastructure influences changes in the share of prefectural economic activity and population within 1990 prefectural city boundaries between 1990 and 2010.

A. Transport Infrastructure in the PRC: Data and Basic Facts

To construct data describing the PRC's road and railroad infrastructure, we digitize large-scale national road maps. That is, we measure highways and railroads as lines on maps. We rely on national maps rather than more detailed provincial maps 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 in 2010. In all, we construct digital maps for the following networks: (i) limited access highways in 1995, 2000, 2005, and 2010; (ii) railroads in 1924, 1962, 1980, 1990, 1999, 2005, and 2010; and (iii) smaller highways in 1962, 1980, 1990, 1999, 2005, and 2010. We also construct data on the PRC's river networks.[2]

Figure 2 shows the development of the PRC's network of limited access highways. The construction of this network began in the early 1990s. 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, China to both Beijing and Shanghai were complete, with fragments scattered broadly throughout the country. The bottom left panel of Figure 2 shows the road network just 5 years later in 2005. 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. 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 a large majority of core prefecture cities, indicated by the tan regions, have been connected to the network.

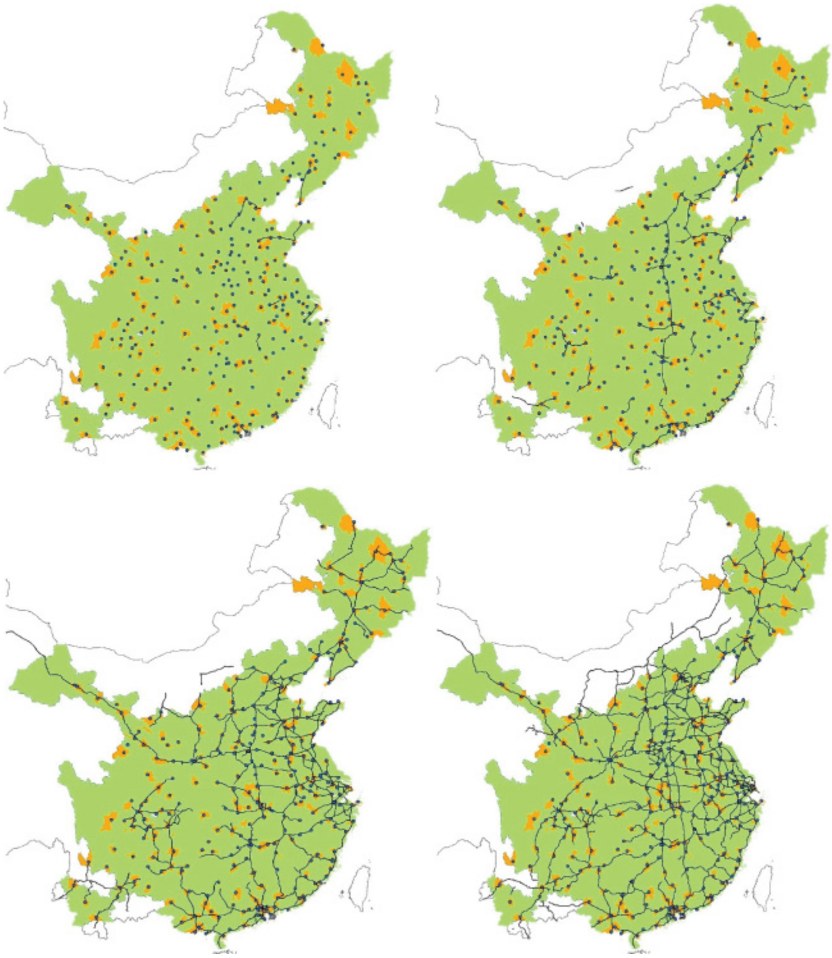
Figure 3 presents corresponding maps of the PRC's rail network. The top left panel shows the rail network in 1990. This network is concentrated in the northeast and while almost all core cities in this region are connected to the network, cities in the south and west of the PRC are much less likely to be connected. The top

[2]Detailed bibliographical information is available in Baum-Snow et al. (2017).

Figure 1. **Digital Maps of Beijing**

Notes: Construction of digital maps from paper source maps for the region around Beijing in 2010. The top panel shows a region around Beijing in a 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.
Source: Authors' illustration.

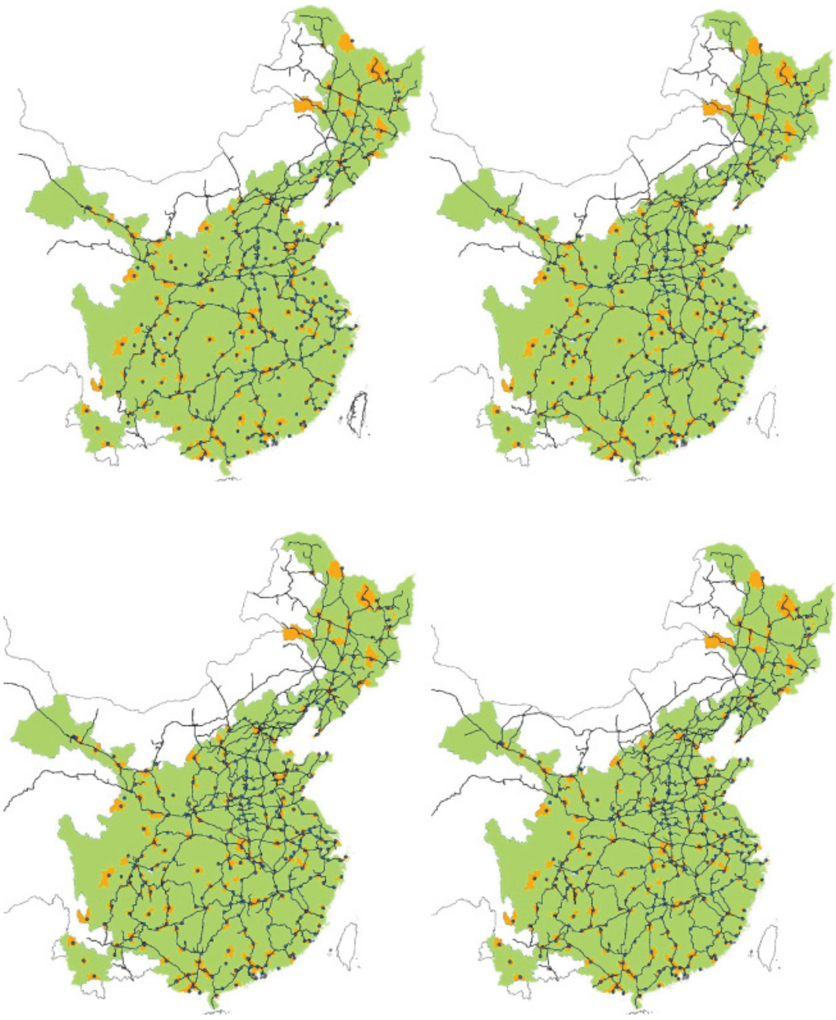
Figure 2. **Limited Access Highways in the People's Republic of China**



Note: The top left panel is for 1995, the top right is for 1999, the bottom left is for 2005, and the bottom right is for 2010. Green indicates the extent of our study area. Tan indicates 1990 prefecture city boundaries. Blue dots signify central business districts.
Source: Authors' illustration.

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 rail network in 2005, which is more extensive than the 1999 network. Just as changes to the 1999 network allowed major northeastern cities to interact with smaller cities nearby, so did new rail lines built between 1999 and 2005. The bottom right panel of

Figure 3. **Railroads in the People's Republic of China**



Note: The top left panel is for 1995, the top right is for 1999, the bottom left is for 2005, and the bottom right is for 2010. Green indicates the extent of our study area. Tan indicates 1990 prefecture city boundaries. Blue dots signify central business districts.
Source: Authors' illustration.

Figure 3 shows the rail network in 2010. The main change from 2005 is the addition of an east–west line to connect the rail network in the central part of the country to the coastal network.

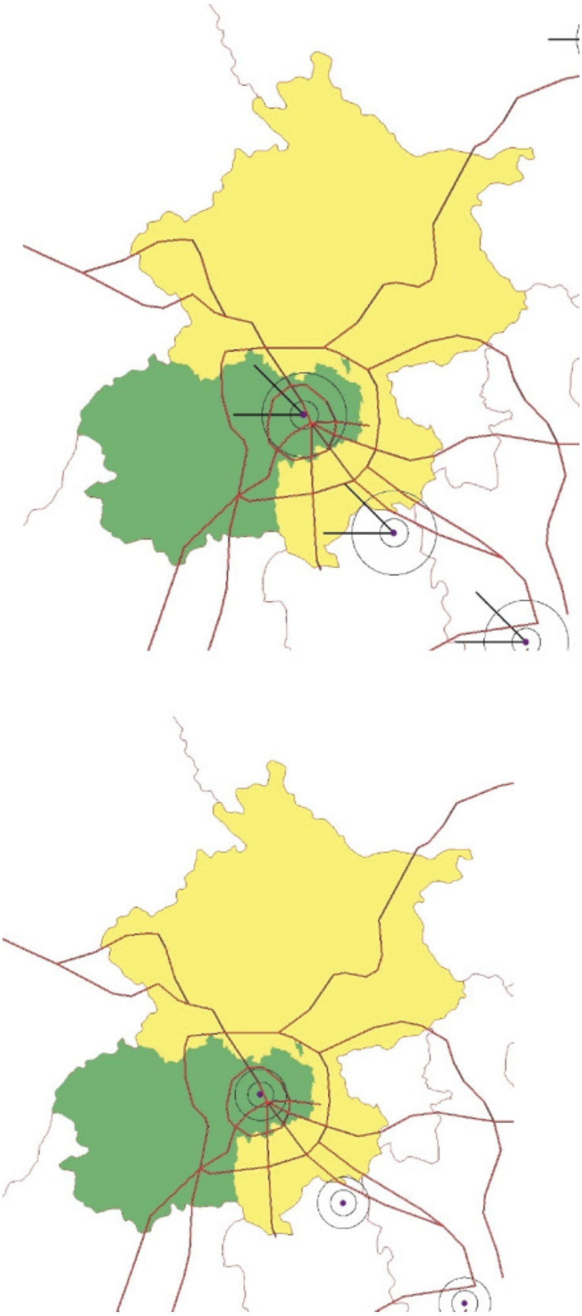
A few comments about these maps are in order. First, we can observe that the rail and highway networks are obviously different from one another. The rail network, while more extensive, grew more slowly. In addition to connecting major cities to each other, the rail network was designed to connect major 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, the PRC relies heavily on railroads for long-haul and even short-haul freight (World Bank 1982). In 1978, less than 5% of freight in the PRC (in terms of ton–distance units) was carried on highways. By 2004, this number had risen to almost 15%, but was still much lower than in the US. We will ultimately find that highways and railways have different effects on the decentralization of cities in the PRC. Highways affect the location of people within urban areas, while railroads affect the location of manufacturing. These different effects may reflect the intrinsic comparative advantages of highways and railroads 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 Baum-Snow et al. (2017) do not permit distinguishing between these two possibilities, the second alternative seems consistent with an inspection of the way the networks are laid out in the PRC.

To proceed with our investigation of how transport infrastructure affects the decentralization of cities in the PRC, we need measures that quantify the road and rail networks in each core city and its surrounding region. We construct three variables for each network. The first is simply the length of each network in each prefecture and in each 1990 core city. The second and third are radial and ring road indexes, respectively. The radial road index describes the ability of a network to carry traffic radially in and 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 CBD of each core city, one with a radius of 5 km and one with a radius of 10 km. We then count the number of times a transport network intersects each ring. The smaller of these two numbers is our measure of radial road capacity in the 5–10 km 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 a value of six, which is exactly what one would choose if doing the calculation by eye.

Calculating our ring road index is 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 km and 15 km from the CBD and count the number of times the transport network intersects each ray. The ring road capacity of the network in the northwest quadrant between 9 km and 15 km 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

Figure 4. **Construction of the Radial Road and Ring Road Indexes**



Notes: The top panel illustrates the construction of our radial road index. The bottom panel illustrates the construction of our ring road index.
Source: Authors' illustration.

Table 1. **Railroad and Highway Network Growth in the People's Republic of China**

	Year					
	1962	**1980**	**1990**	**1999**	**2005**	**2010**
Panel A: Railroads						
Mean total km, central city	32	40	44	47	55	55
Mean total km, entire prefecture	99	139	151	177	214	218
Mean radial index	1.16	1.43	1.54	1.64	1.81	1.85
Share radial index > 0	0.52	0.60	0.67	0.68	0.76	0.76
Mean ring index	0.11	0.16	0.20	0.18	0.24	0.24
Share with ring index > 0	0.10	0.16	0.18	0.16	0.23	0.22
Mean peripheral ring index	0.02	0.02	0.03	0.04	0.05	0.04
Share with peripheral ring index > 0	0.02	0.02	0.03	0.04	0.05	0.04
Panel B: All Roads Visible on Maps						
Mean total km, central city	60	74	84	89	118	137
Mean total km, entire prefecture	349	463	517	469	649	746
Mean radial index	2.04	2.47	2.89	2.89	3.37	3.81
Share radial index > 0	0.79	0.84	0.94	0.88	0.93	0.94
Mean ring index	0.19	0.35	0.28	0.46	0.9	1.27
Share with ring index > 0	0.17	0.29	0.24	0.35	0.53	0.63
Mean peripheral ring index	0.05	0.14	0.09	0.18	0.27	0.44
Share with peripheral ring index > 0	0.05	0.11	0.08	0.13	0.21	0.29
Panel C: Express Highways Only						
Mean total km, central city	0	0	0	13	43	52
Mean total km, entire prefecture	0	0	0	49	160	215
Mean radial index	0	0	0	0.33	0.86	0.95
Share radial index > 0	0	0	0	0.19	0.46	0.46
Mean ring index	0	0	0	0.14	0.50	0.66
Share with ring index > 0	0	0	0	0.13	0.36	0.44
Mean peripheral ring index	0	0	0	0.05	0.12	0.16
Share with peripheral ring index > 0	0	0	0	0.05	0.12	0.14

km = kilometers.
Notes: Infrastructure measures are reported for the 257 prefectures with distinct prefecture cities in 2010. Central cities are defined using prefecture city geographies in 1990 or at the time of upgrading to prefecture city status. The types of roads that contribute to numbers in Panel B differ markedly over time, with single-lane dirt roads predominating in 1962 and 1980, and large highways predominating in 2010.
Source: Authors' calculations.

roads that lie between 15 km and 25 km from the CBD. To construct our ring road capacity index, we sum over all quadrants and the small and large donuts. We are also able to restrict attention to prefectural ring roads that lie outside 1990 core city boundaries. The construction of this measure of peripheral ring road capacity is the same as the one 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 cities in the PRC since 1990.

Table 1 uses our three city-level statistics—total kilometers, radial roads, and ring roads—to describe the evolution of transport infrastructure in prefectures and their core cities. Panel A describes the rail network. In 1962, an average prefecture had about 99 km of rail, of which 32 km was in the core city. The rail network grew steadily between 1962 and 2005, at which point an average prefecture contained about 214 km of rail, 55 km of which was in the core city. There was little change in the network between 2005 and 2010. The top panel of Table 1 bears out what we see in Figure 3. The rail network increased steadily over the 1990–2005 period, with much of the expansion devoted to rail lines that connect core cities to satellite cities just outside their administrative boundaries.

Panel A in Table 1 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 had increased 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 had declined to about one-quarter.

The final four rows of Panel A in Table 1 show that prefectures typically have little ring rail capacity. In 1990, an average prefecture had 0.2 units of ring rail capacity. This means that an average prefecture city in 1990 had a rail line that traveled about 18 degrees around its perimeter. With this said, only 18% of core cities had any ring rail capacity in 1990. Thus, Table 1 shows that almost all cities with ring rail capacity had exactly one unit, that is, a rail line traveling about 90 degrees around the CBD. Suburban ring rail capacity is even scarcer. In 1990, an average core city had 0.03 units of peripheral ring rail capacity and only about five core cities had any peripheral ring rails at all. Ring rail capacity increased gradually until 2005. Between 2005 and 2010, ring rail capacity actually dropped. 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 was the case between 2005 and 2010, the underlying network is little changed.

Data reported in Panel B in Table 1 is analogous to that in Panel A except it describes the evolution of the PRC's road network. Roads in our data were of different quality in different years depending on what appeared on the national maps that were digitized. In 1962 and 1980, almost all roads were single-lane dirt tracks that were unsuitable for trucks. By 1990, many of these had been paved. During the 1990s and 2000s, the express highway network was developed so that by 2010 about 35% of urban roads were express highways, with the rest being mostly wide boulevards with some limits on access. The result is that the average city had almost four radial highways in 2010, with almost all cities having at least one.

Panel C in Table 1 shows the growth in express highways. A comparison of Panels B and C suggests that much of the road improvements experienced in cities involved the construction of new or upgrading of existing roads to express highways. By 1999, an average prefecture had about 49 km of express highway, with about 13 km of this located in the prefecture's core city. Unlike the rail network, which appears to be mostly complete by 2005, the highway network continued to grow through 2010, when an average prefecture contained 215 km of limited access highways, of which 52 km were in the boundaries of the 1990 core city. As for railroads, the share of highways in prefectures' core cities falls slightly over time. The amount of radial express highway increased from 0.33 per city in 1999 to about 0.95 in 2010, and the share of cities with at least one radial express highway increased from 0.19 to about one-half. Unlike for the rail network, there was substantial ring road capacity by 2010. An average core city had more than twice as much ring road capacity as ring rail capacity in 2010, while almost two-thirds of all core cities had some ring road capacity. If we restrict attention to peripheral roads, the contrast with rail is even more dramatic.

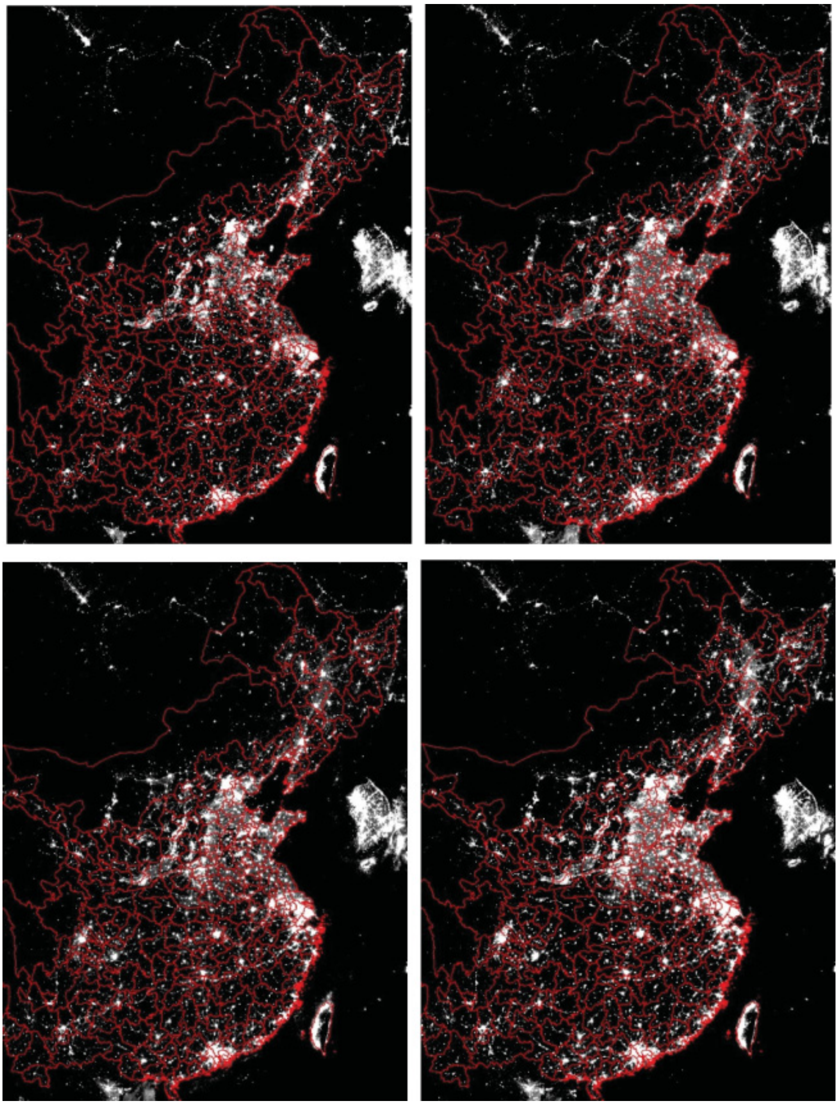
Table 1 confirms the impressions formed by inspection of Figures 2 and 3. The rail network grew rapidly over the review period and was largely completed by 2005, while the limited access highway network grew much faster than the rail network and this growth continued through 2010. More subtly, the rail network is relatively more specialized in radial capacity and the highway network is relatively more specialized in ring capacity. In the PRC, people and goods moving in and out of CBDs are more likely to travel by rail. If they are moving around city centers, they are more likely to travel by highway.

B. Population and Production in the PRC: 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 PRC censuses and yearbooks. We have one measure of population taken from various PRC 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 the PRC (National Geophysical Data Center 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 to 63. The codes for 0 to 62 indicate intensity, while 63 is a topcode. Although it is common in developed countries, topcoding is rare in the PRC during our study period. Henderson, Storeygard, and Weil (2012) show that lights at night are a good proxy for GDP at the country level. As we discuss below, lights and GDP are also strongly correlated at the prefecture level in the PRC. While lights at night are related to production, they are surely also related to other human activities, including those occurring in residences, which may not be directly related to production. Thus, while lights at night give us a more detailed picture of where activity occurs 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, 2000, 2005, and 2009. Lighter shades indicate higher nighttime intensity of light and red

Figure 5. **Lights at Night in the Eastern People's Republic of China**



Notes: The top left panel is for 1992, the top right is for 2000, the bottom left is for 2005, and the bottom right is for 2010.
Source: Authors' illustration.

indicates prefecture boundaries. These images show that lights are concentrated in the northeastern part of the country in much the same area where 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 in the western PRC it grows less dramatically. While the major cities such as Beijing; Shanghai;

Table 2. **Prefecture and Central City Growth in the People's Republic of China**

	1990–1992	**1995**	**2000**	**2005**	**2009–2010**
Panel A: Lights and Geographic Shares					
Entire prefecture (1992 = 1)	1	1.43	1.59	1.88	2.41
Central city share of prefecture	0.38	0.33	0.33	0.33	0.32
Panel B: GDP and Geographic Shares (189 Prefectures)					
All GDP: Entire prefecture (CNY100 million)	34	n.a.	112	213	404
All GDP: Central city share of prefecture	0.45	n.a.	0.41	n.a.	0.45
All GDP: Prefecture outside central city share	0.55	n.a.	0.59	n.a.	0.55
Industrial GDP: Entire prefecture (CNY100 million)	16	n.a.	53	107	207
Industrial GDP: Central city share of prefecture	0.59	n.a.	0.45	n.a.	0.44
Industrial GDP: Prefecture outside central city share	0.41	n.a.	0.55	n.a.	0.56
Panel C: Population and Geographic Shares					
Entire prefecture (millions)	3.91	n.a.	4.27	n.a.	4.57
Central city share of prefecture	0.24	n.a.	0.28	n.a.	0.32
Prefecture outside central city share	0.76	n.a.	0.72	n.a.	0.68

CNY = Chinese yuan, GDP = gross domestic product, n.a. = not available.
Notes: Reported numbers in Panels A and C are averages across prefectures in the primary estimation sample of 257. Reported numbers in Panel B use the sample of 189 prefectures for which we have full GDP information in 1990. Missing GDP fractions in 2005 are because we have fewer than 189 observations for prefecture cities in this year only. GDP is reported using provincial deflators.

and Hong Kong, China clearly grow over our study period, growth is not confined to these cities. Small cities all over the country grow rapidly as well.

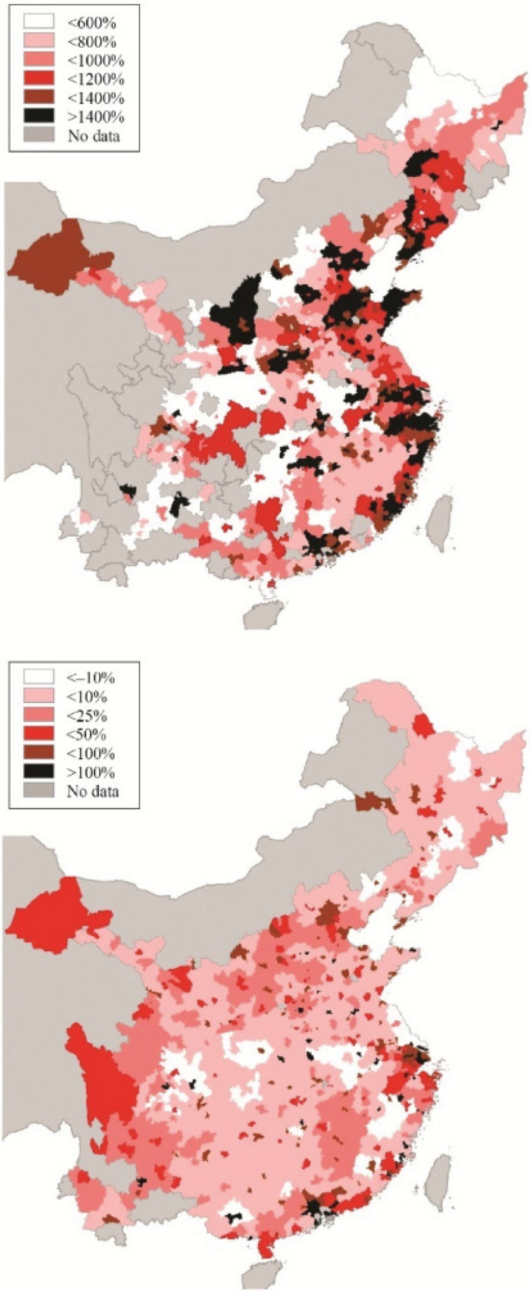
Panel A in Table 2 quantifies this growth in lights. The first row of this table reports the total amount of light in our study area, with 1992 normalized to 1. Consistent with inspection of the images in Figure 5, we see a steady, rapid increase in the total amount of light in the PRC, with almost 2.5 times as much light in 2010 as in 1992. The second row of Panel A in Table 2 reports the share of all lights 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 them.

We now turn our attention to direct GDP measures. For 1990, we use GDP and industrial sector GDP information from various national and provincial data year books (China Statistics Press 1992b, 1992c). For 2000–2010, we use output information from the University of Michigan's Online China Data Archive at the rural county, county city, and core prefecture city levels according to contemporaneous definitions. We supplement these data with prefecture-level printed yearbooks. We note that prefecture-level GDP data is not available for our full sample in all years. Therefore, reports on GDP in Panel B in Table 2 use a sample of 189 prefectures.[3]

The top panel of Figure 6 shows the percentage change in GDP between 1990 and 2010 for constant boundary core cities and for the residual portion of each

[3]More detail about data construction is available in Baum-Snow et al. (2017).

Figure 6. **Changes in Gross Domestic Product and Population at the Prefecture Level**



Notes: The top panel shows the percentage change in gross domestic product between 1990 and 2010 in 1990 prefecture cities and in the residual prefectures. The bottom panel shows the corresponding changes in population between 1990 and 2010.
Source: Authors' illustration.

prefecture. Gray signifies missing data. For cities and prefectures, GDP growth rates are assigned to one of six color-coded categories: (i) less than 600%; (ii) less than 800%; (iii) less than 1,000%; (iv) less than 1,200%; (v) less than 1,400%; and (vi) at least 1,400%. Lighter colors indicate lower growth rates. While our GDP map is somewhat incomplete, as expected it shows that development was faster along the coast, both in prefecture 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 vice versa.

We separately observe the industrial component of GDP in the tabular data. Indeed, we believe that industrial GDP is better measured than overall GDP, especially in earlier years. For this reason and because GDP results can be inferred from industrial GDP results as described below, the regression analysis will only look at industrial GDP. Industrial GDP accounts for 46% of measured total GDP in 1990, rising to 51% in 2010. Panel B in Table 2 describes these data. Between 1990 and 2010, prefecture mean GDP increased by about a factor of 12. We also see that between 1990 and 2010 there was a marked decentralization of industrial production. The 59% share of industrial GDP in 1990 core cities decreased to 46% in 2000 and to 44% in 2010. This decentralization is more rapid than for overall GDP, which has a stable central city share of about 45% throughout our study period.

Overall, Table 2 bears out our inspection of Figure 6 and our results based on lights-at-night data. There is a rapid overall increase in GDP and a decentralization of economic activity focused on industry. Together with the lights-at-night data, the GDP data suggest that the PRC's cities are adopting a modern form of organization often seen in developed countries. Much production activity occurs in the CBDs of cities in developed countries, 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 population censuses. For 1990, we rely primarily on the 100% count Chinese census data aggregated to the prefecture core city, rural county, and county city levels (China Statistics Press 1992a). For 2000 and 2010, our census data are the 100% count aggregated to the urban district and rural unit levels (China Statistics Press 2002, Lianxinwang 2012). We note that in 1990, census data reports place of legal residence rather than place of actual residence; therefore, using census data to figure out the resident population is a subtle exercise. More detail on data construction is available in Baum-Snow et al. (2017).

The bottom panel of Figure 6 uses our data to illustrate population changes in the PRC between 1990 and 2010. This figure is similar to the top panel of Figure 6. Lighter colors indicate slower rates of population growth.

Unsurprisingly, this figure shows high rates of population growth near Beijing; Shanghai; and Hong Kong, China. Generally, it shows high rates of population growth along the PRC's east coast. Perhaps more surprising, it shows a number of regions with high population growth in the interior and the western parts of the PRC as well. Thus, the widely reported coastal migration of the Chinese population appears to be only a part of the story of migration in the PRC. A second pattern is also clear: 1990 core cities experienced higher rates of population growth than the surrounding areas of prefectures during the study period. Thus, while the large-scale patterns of migration appear to be complicated, at a small scale they are clear. People are moving from the countryside to the city.

Panel C in Table 2 further describes our population 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 had grown to 4.6 million by 2010. The second row reports the share of an average prefecture's population within the boundaries of the 1990 core city. The share of population in 1990 core cities increases between 1990 and 2000, and again between 2000 and 2010. In 1990, one person in four lived in a core city. By 2010, one person in three did. 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 had increased to about 1.5 million. With 257 prefectures in our primary sample, this suggests that the population of 1990 core cities increased by about 127 million between 1990 and 2010.

III. Transport Infrastructure and the Decentralization of Cities in the PRC

Our data describe three significant changes in the PRC's economy between 1990 and 2010. First, we see a large increase in GDP. Second, we see a huge migration of people from the countryside to the major cities. Third, we see a dramatic decentralization of manufacturing. That the decentralization of manufacturing GDP is so much larger than of total GDP suggests a countervailing centralization of services. During the same 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 Baum-Snow et al. (2017) on the role that highways and railroads played in the centralization of population and the decentralization of manufacturing in the PRC's cities between 1990 and 2010.

A. Econometric Method

Baum-Snow et al. (2017) investigate the extent to which road and rail networks contributed to the decentralization of cities in the PRC using instrumental variable (IV) regressions analysis. We begin by describing our approach and providing some intuition about how it works.

Baum-Snow et al. (2017) conduct regressions of the following form using information for prefectures indexed by i:

$$\Delta_t \ln(Outcome_i) = A + B \times (Infrastructure_{it}) + C \times Controls_i + error_i \qquad (1)$$

Here, Δ_t indicates the 1990–2010 difference, and the outcomes of interest are core city population and industrial GDP. The infrastructure measure is one (or more) of our measures of road or rail infrastructure described in Panels A and B of Table 1 as of 2010. B is the parameter of interest. Control variables include the 1990–2010 change in log prefecture population, which we include so that B captures the extent to which infrastructure reallocates economic activity between cities and prefecture remainders holding the total scale constant. Excluding this control would make B capture a combination of the effects of infrastructure on prefecture size and the allocation of economic activity between central cities and prefecture remainders. Other control variables measure city and prefecture size plus 1982 prefecture economic conditions. The reasons for including these variables are explained below in our discussion of the identification strategy.

The coefficient of interest, B, is the percentage of central city population or industrial GDP displaced to prefecture remainders for each unit change in the infrastructure variable. For highways, we treat the number of 2010 rays as identical to the 1990–2010 change because the types of roads that appear on our map in 2010 are of much higher quality than those in 1990.[4] However, considerable railroad infrastructure existed in 1990. As is discussed in Baum-Snow et al. (2017), we also use 2010 as the measurement year for railroads because in 1990 the central planning regime in the PRC rendered any market responses to the location of transport infrastructure impossible at that time. Only after 1990 did market forces begin to influence the allocation of land to different uses in urban areas.

We must be fundamentally concerned that infrastructure was assigned to prefectures in ways that are driven by or correlated with unobserved factors in the error term that drive shifts in the allocation of economic activity between central cities and prefecture remainders. For example, suppose that highways are assigned to prefectures by a planning authority in response to anticipated growth in core city population. In this case, estimates of equation (1) will yield a positive coefficient: roads are built in prefectures where the core city population grows. Alternatively, suppose that roads are assigned to prefectures at random. In this case, we expect the estimation of equation (1) to return negative estimates of B. That is, we expect that by reducing transport costs, additional roads allow the population to decentralize and the share of the core city population in the prefecture to decline.

Therefore, the process by which roads are assigned to cities is fundamental to this investigation. To understand the extent to which infrastructure causes

[4]The empirical analysis in Baum-Snow et al. (2017) uses 2010 radial and ring road capacities for all types of roads we observe on the map, not just express highways.

decentralization, it is important to examine cases in which infrastructure was either assigned randomly or by a process that is unrelated to variables for which we cannot control but may affect outcomes of interest. To resolve this problem, Baum-Snow et al. (2017) rely on an IV estimation. Our implementation of this technique essentially randomizes across cities the amount of infrastructure that is received by relying on variations 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 in a way that is plausibly unrelated to unobservables that predict central city growth or decentralization. We use as instruments infrastructure variables measured as of 1962.

As is discussed at length in Baum-Snow et al. (2017), roads in the PRC in 1962 were of low quality and primarily existed to move local agricultural goods to market and not to facilitate travel within urban areas. However, their existence established rights of way over which modern highways could be built at lower cost. A credible IV estimation in this case thus requires inclusion of control variables that may be correlated with prefecture agricultural productivity, as this may predict subsequent city or prefecture growth. Similarly, because railroads in 1962 were disproportionately allocated to serve provincial capitals and manufacturing-oriented cities, we control for these two factors as well. All such control variables use measures from 1982. The second estimation stage uses quasi-randomized infrastructure measures that come out of the first estimation stage to recover estimates of B that are "as if" infrastructure had been assigned at random.

Our IV estimates capture the extent of decentralization in prefectures that received more 2010 infrastructure only because of 1962 infrastructure differences, holding constant the prefecture industry mix, historical population, and central city area. To the extent that roads or railroads cause cities of different profiles to decentralize at different rates, we can only recover one local average treatment effect per type of infrastructure with this procedure (Imbens and Angrist 1994). Wrapped into these local average treatment effects are likely to be cocktails of treatment effects that depend on underlying observed and unobserved prefecture heterogeneity. That is, our estimated treatment effects apply only to the set of prefectures for which 1962 infrastructure affected 2010 infrastructure. Attempts to unpack which types of prefecture are most affected by infrastructure reveals that more developed areas in the eastern PRC experienced larger decentralization effects of infrastructure than other areas. Moreover, infrastructure responses primarily occurred within 10 years of construction. However, our results are not driven by the largest cities. Limited statistical power precludes us from disaggregating heterogeneity in treatment effects much further. We note that as with any IV estimator in which the treatment is not truly randomized with full compliance, our estimates apply only to the types of cities that experienced infrastructure upgrades because of the level of infrastructure in place in 1962. It may well be that some cities with fewer gains to be made from upgrades chose not to do so, even though 1962 roads and rails gave them lower-cost infrastructure upgrade options. That is, we can only recover "treatment-on-the-treated" type estimates.

We note that while IV estimation is subtle, it is pervasive in applied microeconomics. Moreover, similar IV estimation strategies have been successfully employed in other papers looking at the effects of transport infrastructure, including Baum-Snow (2007); Duranton, Morrow, and Turner (2014); Duranton and Turner (2011); Duranton and Turner (2012); Hsu and Zhang (2014); and Michaels (2008). This collection of papers gives us enough experience with the general estimation strategy to be confident that Baum-Snow et al. (2017) provide credible estimates of the causal effects of infrastructure on the spatial organization of cities in the PRC.

B. The Effects of Infrastructure on Population Decentralization in Cities in the PRC

In regressions like equation (1) where the outcome variable is the change in log core city population between 1990 and 2010, and the infrastructure measure is the index of radial road capacity for major highways, Baum-Snow et al. (2017) find that each highway ray causes a 4%–6% decrease in core city population depending on the details of the regression. Additionally, the existence of some ring road capacity decentralizes about 25% of core city population to prefecture remainders. We find no discernable effects on population decentralization of any other transport measures studied, including radial rail capacity, the extent of the prefecture road network, the extent of the rail prefecture network, or ring rail capacity.

Consistent with evidence for the US in Baum-Snow (2007) and Duranton and Turner (2012), differences between ordinary least squares and IV highway ray coefficients suggest that the 1999 and 2010 radial road indexes 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 populations to decentralize from these cities. Results in Baum-Snow et al. (2017) show that while more rapidly growing cities in the PRC received more transport infrastructure of various types, the decentralization that occurred because of this infrastructure was overwhelmed by the growth that precipitated the construction of this infrastructure.

C. The Effects of Infrastructure on Production Decentralization in Cities in the PRC

Baum-Snow et al. (2017) also investigate the effects of transport infrastructure on the decentralization of production from central cities. Specifically, they estimated versions of equation (1) in which the outcome variable is the change in log industrial GDP between 1990 and 2010. With industrial GDP measured much more precisely than entire GDP in 1990, we focus here on estimating effects on the industrial GDP measure. To maintain consistency in regression specification, we use the same set of control variables as in the population analysis described in section III.B. We lose 16 prefectures from the sample for which we do not observe 1990 GDP information.

Results indicate that neither highway rays nor network length have measurable effects on the decentralization of core city economic activity. However, railroads cause economic activity to decentralize. Each railroad ray is estimated to displace 24%–34% of core city industrial GDP. Because industrial GDP is about half of total GDP, and we find that these effects primarily apply to the industrial sector, railways' effects on total GDP are about half as large. Similar strong results hold for prefecture railroad network length. However, Baum-Snow et al. (2017) do not have the statistical power to jointly estimate the effects of these two railroad network measures in one regression. Baum-Snow et al. (2017) find large additional statistically significant negative effects of the existence of a ring road on prefecture city economic activity in addition to the effects of rail rays. The estimated effect of peripheral ring road capacity on industrial GDP is -0.71 log points in addition to -0.236 log points for each radial railroad. These estimates are robust to including other transport measures in the regression and to minor changes in the details of the regression equation. As with highways and population, results reported in Baum-Snow et al. (2017) suggest that more railroads have been assigned to central cities with more rapid GDP growth.

We believe that 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 that are less land intensive and typically benefit more from local agglomeration spillovers.

D. Employment versus Population

Evidence in Baum-Snow et al. (2017) indicates that radial roads cause population decentralization, radial railroads cause industrial decentralization, and ring roads cause both. While this might seem contradictory since industrial employment that has decentralized because of railroads requires more suburban workers, these results can be squared by looking at decentralization effects on employment by industry. Estimated effects of roads and railroads on the number of working residents are very similar to those reported in section III.B for population.

However, estimated effects on employment in manufacturing only are similar to those reported for industrial GDP in section III.C, whether employment is aggregated to residential or work locations. This suggests that railroads did indeed cause some people to decentralize (or to not move to cities when they otherwise would have), while radial roads promoted either more intensive commuting from suburbs to central cities or the decentralization of nonmanufacturing jobs. We thus have evidence that highways promote decentralization of service jobs and workers, while rails promote decentralization of manufacturing jobs and workers. That railroads do not affect the allocation of the 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.

E. Other Effects of Infrastructure

Baum-Snow et al. (2017) make two further findings. The first is that neither road nor railroad infrastructure influences prefecture population levels. In a regression like equation (1) where the dependent variable is a change in prefectural population rather than central city population, the coefficient on radial highways is small and statistically indistinguishable from zero. They obtain similar results for other infrastructure measures.

This clarifies the interpretation of their results in an important way. Regressions showing changes in the central city share of population or GDP could reflect increases in suburban population or GDP, decreases in central city population or GDP, or the migration of activity from CBDs to the suburbs. The fact that the overall level of prefectural population and GDP does not depend on within-prefecture measures of infrastructure tells us the effects of this infrastructure are purely redistributive. Within-prefecture infrastructure appears to operate primarily by reorganizing activity within the prefecture by encouraging the radial migration of population and GDP that we have discussed at length.

Finally, Baum-Snow et al. (2017) investigate the extent to which the effects of infrastructure on industry location differ by industry. To accomplish this, they perform regressions like those for industrial GDP, like equation (1), where the dependent variable is the change in sectoral employment decentralization. They partition manufacturing sectors into three groups based on the weight of a given value of output using data from Duranton, Morrow, and Turner (2014). For example, primary metals and wood and paper processing are in the "heavy" category, fabricated metals and furniture are in the "medium" category, and textiles and high-tech are in the "low" category.

Given our results for overall industrial output, we expect that certain industries decentralize in response to radial railroads and ring highway capacity, but do not respond to other infrastructure measures. This is broadly true, though the more disaggregated analysis suggests a slightly subtler story. All three weight classes respond to radial railroads, although light goods respond more than medium goods, which in turn respond more than heavy goods. The effect of ring roads on decentralization is most pronounced for high-tech goods. Medium-weight goods also decentralize in response to radial highways. This suggests that heavy goods manufacturing is often stuck in place by big, immobile capital investment, while other classes of manufacturing are more footloose and able to decentralize to find cheaper land.

IV. Policy Implications and Broader Lessons

We have so far described how the spatial organizations of population, production, and infrastructure evolved in cities in the PRC between 1990 and 2010. We have also reported our findings from Baum-Snow et al. (2017) on the extent to which transport infrastructure has affected the organization of population and production in Chinese cities. Broadly, we find that radial railroads and ring roads have caused the decentralization of economic activity, while radial roads and ring roads have caused the decentralization of populations. There is some heterogeneity across industries in how they respond to infrastructure. There is no evidence that prefecture-level infrastructure affects the population level or GDP within a prefecture. Thus, the decentralization effect described in Baum-Snow et al. (2017) probably reflects the radial migration of central city populations and manufacturing.

The data conspire against a compelling welfare assessment of infrastructure construction in the PRC between 1990 and 2010. Consider the following two facts. First, we have established that there are high levels of mobility in the PRC. We estimated that approximately 127 million people migrated into central cities in the PRC between 1990 and 2010. Second, there is no evidence that prefecture-level infrastructure affects the overall level of prefecture population. If we take the high rates of population mobility as evidence that mobility costs are low, then the fact that people are not attracted to prefectures with better infrastructure should indicate that these policy innovations are not making the prefectures better places to live. That is, infrastructure investments are not improving welfare, at least at the margin.

On the other hand, we can calculate from Table 1 that GDP per person in urban areas in 2010 was nearly double that in rural areas. This ratio is much higher than the rural–urban wage gap in developed countries (World Bank 2009). If, as the high level of mobility in the PRC suggests, mobility is not costly, such a wide gap can be sustained only if cities in the PRC are sufficiently more unpleasant than the countryside to offset wage differences, or if there is some institutional barrier to migration. Given the existence of the *hukou* system, it is natural to suspect that institutional barriers to migration help preserve the large rural–urban wage gap. However, this calls into question the logic of the preceding paragraph. If people are not able to move to exploit the large rural–urban wage gap, then prefecture-level infrastructure could, in principle, have large effects on welfare without affecting prefectural-level population. Until we are able to resolve these conflicting lines of argument, any welfare analysis of infrastructure expansion in the PRC is necessarily quite speculative.

On a purely theoretical basis, there is good reason to think that the PRC's infrastructure expansion improved welfare. Transport infrastructure reduces transport costs and allows firms and people to consume more land while holding the cost of travel constant. This reduction in land costs reduces the costs of both housing and production, thereby increasing real incomes and profits. Using US data and a simulation model, Baum-Snow (2007) indicates welfare gains of 2%–3% per additional highway ray for US cities as a consequence of these effects. It is not clear whether we should expect these effects to be larger or smaller in the PRC. Similarly, we expect an analogous effect on production but have no basis for quantifying its magnitude.

More generally, while it is clear on theoretical grounds that improvements to infrastructure increase welfare, it is less clear if this increase is sufficient to justify the associated costs.

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