Roads, Railroads and Decentralization of Chinese Cities*

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

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1. Introduction

Developing countries spend huge sums on transportation infrastructure projects that shape their cities for decades to come. Currently, about 20 percent of World Bank lending goes for transportation infrastructure, more than the Bank's lending for social programs. In a modern city, highway and rail investments are central to land use planning and policy, the development of feeder roads and street networks, and the spatial layout of utilities. Transportation infrastructure generates direct welfare benefits through reduced commuting and shipping costs, changes urban form, and affects urban environmental costs and the supply of land available for agricultural production.

In the early 1990s, China began to build and upgrade its transportation infrastructure, particularly its highways. From a low level in 1990, investment in transportation infrastructure grew at approximately 15 percent a year, much of it in cities. As central planning constraints on economic activity relaxed, Chinese cities transformed; central cities were torn down and rebuilt, Maoist era residential and industrial buildings disappeared, and industries decentralized into previously agricultural areas. This happened during a period when economic growth averaged at least 10 percent a year, yielding a GDP per capita today of about $7750 (Penn World Tables).

We investigate how the extent and configuration of Chinese highway and railroad networks contributed to the relative decentralization of population and industrial production from central cities to suburban and ex-urban areas during this period. Since decentralization can precipitate infrastructure investments, we rely on exogenous variation in transportation networks predating China's conversion to a modern market-based economy to estimate the causal effects of this infrastructure on urban decentralization.

We find strong evidence that radial highways and suburban ring roads reduce population density in central cities. Our estimates indicate that each additional radial highway displaced about

4 percent of central city population to suburban regions and that the existence of some ring road capacity in a city reduced city population by about 20 percent. However, radial railroads did not influence the allocation of population between central cities and suburban regions. In addition, conditional on the radial and ring configuration of the highway network, urban population decentralization is not influenced by total kilometers of either highways or railroads.

In their classic work, Meyer, Kain and Wohl (1965) suggest that in mid-20th century America, "[a] circumferential highway … provides an almost ideal site for the performance of truck-to-rail transfers… Large parking lots for storing and moving containers for truck trailers, and rail sidings required to create piggyback or containerized trains are conveniently located there. Manufacturing and other businesses requiring transport inputs can be expected to locate reasonably close to these new transportation facilities" (Meyer et al., 1965, p19). Consistent with this intuition, we find that marginal radial railroads displace about 20% of central city industrial GDP, while the existence of some ring road capacity displaces about 50% of central city industrial GDP. These components of the urban transport network generate similar estimated responses of the residential and work locations of manufacturing workers. However, we find no effect of radial highways on the location of industrial production. That rail rays play such an important role in decentralization of production overall may be enhanced by China's unusually heavy historical reliance on railroads for long haul and even short haul freight (World Bank, 1982). In 1978, less than 5% of freight (in ton kilometers) in China was carried on roads. While this share increased over time, by 2005 it was still reportedly less than 15%, well below the U.S. where just over 40% of freight moved by road in 2007.[1]

[1] Since heavy, low value goods travel long distances by rail, shares by value are higher for truck (Redding & Turner, 2015). In 2009, about 30 percent of ton-km is reported to travel by road, mostly reflecting a discontinuous jump from 2008 (China Statistical Abstract, Table 16-9). The US number is for truck ton-miles as a fraction of all ton miles, to be comparable with Chinese data (2012 Statistical Abstract of the US, Table 1070).

We view this displacement as primarily involving decentralization of a given amount of prefecture industrial activity to suburban areas, but it can also entail a change in the composition of prefecture economic activity. Trying to separate out and quantify how China's investment in transport infrastructure differentially affected prefecture economic composition would be the subject of a different paper, which becomes clear from the discussion of the literature and our data below. Duranton et al. (2014) show that overall urban area industrial composition responds to infrastructure investments according to the weight-to-value ratios of products within sectors. With the caveat in mind, we explore briefly some of Meyer et al.'s ideas concerning differential responses of products to transport investments based on weight-to-value ratios.

Overall, the paper extends the initial work on population decentralization by Baum-Snow (2007a) to a developing country situation and introduces consideration of additional transport modes and decentralization of different types of economic activity. The paper addresses the distinct policy question of how infrastructure investments affect local urban form.[2] The developing country context is very different than Baum-Snow's U.S. analysis. While central cities in the U.S. experienced absolute declines in population after 1950, central cities in China saw large absolute and proportionate population gains after 1990 relative to their rural suburbs. Thus, rather than radial highways causing absolute decentralization, in China they retard the high rate of centralization.

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

[2] In a companion literature, Duranton and Turner (2011) find that driving within a city depends sensitively on the extent of the interstate highway network in the city, and slightly less sensitively on the extent of other road networks. Hsu and Zhang (2014) replicate this result using Japanese data.

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

Case studies suggest that migration of manufacturing to the urban periphery and beyond and the subsequent development of business and financial services in central cities all depend substantially on the ability of the transportation network to connect peripheral locations to the rest of the local economy (e.g. Lee, 1982; Hansen, 1987; Henderson, Kuncoro and Nasution, 1996). This paper is the first to investigate how different highway and railroad network configurations contribute to this transformation with a research design identifying causal effects.

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

2. The Context

Table 1 shows the growth of population and economic activity in core cities ('central cities') and residual portions of prefectures. Results in the left block indicate that population grew much more quickly in central cities than in surrounding regions between 1990 and 2010. Aggregate population growth was 54% in central cities relative to only 5% in city hinterlands. This is urbanization, the flow of migrants from rural counties into central cities primarily within prefectures.

We use lights at night data to describe the decentralization of economic activity for the complete sample of cities. While lights at night may also reflect residential development, Henderson, Storeygard and Weil (2012) show a strong relationship between growth in lights and GDP. The middle block of Table 1 shows that lights grew more quickly in suburban areas, especially in the 1990 to 2000 period, despite the much faster population growth in central cities. In the sample for which data are available or could be imputed, the right block of Table 1 presents industrial sector GDP growth. Suburban industrial GDP grew by 1673% between 1990 and 2010 relative to 873% for central cities, indicating relative decentralization of industry. We focus on industry since decentralization patterns for total GDP are similar and the service sector is not measured consistently over time. Figure 1 gives the spatial variation in the 1990-2010 changes. Prefecture boundaries are shown and central cities are visible when their growth differs. Figure 1a shows that almost all central city populations grew more rapidly than surrounding prefecture populations. Figure 1b shows that, unlike population, industrial GDP decentralized rapidly in most of the prefectures for which we can construct complete data.

The institutional context is critical to understanding these changes in spatial configurations. In 1990, the urban and rural sectors were under separate institutional and economic regimes. People held citizenship in either the urban or rural sector (as a birth right) and migration between the two sectors was rare and strictly controlled (Chan, 2001; Au and Henderson, 2006). Industry and land in the rural counties surrounding central cities were owned by local collectives. In cities, industry and land were owned by the state (Naughton, 2006). Chinese institutions at this time did not provide a formal mechanism for urban residents or firms to acquire the rural land rights to move out from the central city.

These institutional barriers to the mobility of labor and capital mean that roads and railroads in 1990 could not be used for commuting nor influence factory relocation to potential suburbs, a point made by Zhou and Logan (2007). Except for a few `special economic zones' created before 1990, housing, factory, and farm location patterns within areas defined as urban were largely unchanged from the 1960s. Only after 1990, with the advent of land and labor market reforms, could urban form change in response to market forces. Given that urban reforms start in the early 1990s and that 1990 is a census year, it is a natural base period for our analysis.

This change in economic regime during our study period is critical for two reasons. First, slower reforms and heavier state presence in housing markets in western China provided fewer opportunities for spatial allocations to respond to infrastructure, offering a nice comparison with the rest of China. Second, even without extensive growth in railroads since 1990, we are able to infer effects of railroad allocations on urban form on the basis of the regime switch in land and labor markets. We demonstrate below that market reforms allowed population decentralization to occur only once highways were built. Existing pre-1990 roads had no effect on population decentralization before 1990. Therefore, the logic of the regime switch says that pre-1990 railroads could not have led to changes in the locations of production facilities before 1990 either.

Of course the locations of railroads and highways are not randomized, and a key aspect of our estimation strategy must be to achieve pseudo-randomization. We return to this issue in Section 4.

3. Data

Our analysis focuses on constant boundary 1990 core cities of prefectures ('central cities'), and the surrounding prefecture regions from which they draw migrants. We define these regions because their attributes can be consistently measured over time and because they correspond closely to theoretical analogs in land use models summarized below. Our most complete sample is the 257 prefectures with urban and rural areas located in primarily ethnic Han provinces drawn to 2005 boundaries, as illustrated in Figure 1a. Figure 2 illustrates the spatial extent of 1990 core cities for the Beijing area and changes in their administrative boundaries during our study period.

We construct demographic data for the full sample using information from various population censuses. Incomplete GDP data in 1990 lead to a sample of 241 (out of 257) cities for which we observe industrial sector GDP in both 1990 and 2010. Prefecture level information on GDP in 1990 is much more limited. We use the national economic censuses from 1995 and 2008 for industrial employment information by location and industry type. We identify central business districts (CBDs) as the brightest cell in 1992 lights at night data in each central city.

We digitize large-scale national maps to construct railroad and highway networks for various years. Using these digital maps, we calculate radial and ring highway and railroad capacity measures and various measures of network extent. Our radial index is built as follows. We draw rings of radius 5km and 10km around the CBD of each central city and count the number of times a particular transportation network crosses each of these two rings. Our index of radial roads is the smaller of these two counts of intersections. Figure 3a illustrates this algorithm, in which the green area is the Beijing central city, city centers are shown by dots, 2010 high-grade highways are represented by red lines and the 5 and 10 km rings around each center are in black. Figure 3a indicates that our radial road index value is 6 for the 2010 high-grade highway network in Beijing, exactly the calculation by eye.[3] Calculating the ring road index is more involved. We look for the existence of any ring road capacity at 5-9 km, 9-15 km or 15-25 km from city centers outside of central cities in any of the four 90 degree quadrants. Figure 3b illustrates the process for the northwest quadrant of Beijing and two nearby cities for the 5-9 km donut demarcated by the two black circles. For each city, we draw two rays from the center, one to the west and the other to the northwest. We identify all intersections of the two rays with the road network within the 2 rings. In the case of Beijing there is one each. We then take the minimum of these two counts, which is still one. For the other two cities, the minimum is zero. We replicate this calculation for all quadrants for the three distance rings and sum to get an index. Because only 29 percent of prefectures had any ring road capacity in 2010, we use a simple indicator for the existence of any ring road capacity in all empirical work.

The Online Data Appendix provides data construction details. Table A1 shows summary statistics.

4. Empirical Strategy

4.1 Econometric Model

To motivate our estimating equations, we review the basics of urban land use theory. Equilibria of land use models typically entail most people commuting toward the city center to work and the strongest agglomeration spillovers between firms in the center. Higher rents nearer the city center

[3] We use all 2010 highway rays for the purpose of estimation. In total, Beijing has eleven 2010 highway rays.

capitalize both commuting costs for residents and higher agglomeration economies for firms. Residents and firms thus consume less land nearer the city center, ceteris paribus, so population densities are higher there. Holding the spatial distribution of employment fixed, a reduction in transport costs reduces the relative value of locations nearer to the city center for commuting purposes. For the same population, the city land rent and population density gradients typically shift down at the center and rotate in such a way that the city spreads out into the surrounding agricultural area, as transport costs fall. This occurs in simple models as well as those that allow for consumer heterogeneity and other extensions, as discussed in Duranton and Puga (2015).

Theoretical predictions on the impacts of transportation infrastructure on firm location are less clear. If firms locate near the periphery, they face lower land and labor costs because commuting is shorter for workers and land is cheaper. If firms locate in the center, they are more productive because of agglomeration economies but face higher costs. The equilibrium location pattern of firms that results from this tradeoff is complicated and sensitive to model assumptions and parameter values (Fujita and Ogawa, 1982), with inconclusive comparative statics with respect to transport costs.[4] As such, we organize empirical work on the location of industrial production around the hypotheses suggested by Meyer et al. (1965) that ring roads facilitate decentralization of manufacturing to peripheral locations with access to rail terminals and sidings.

Define y_{tC} and y_{tP} to be the population, employment or output in year t and central city C and prefecture P. x denotes a vector of observed control variables and r denotes transportation network measures. We use Δ_t to denote a first difference between 1990 and year t. A simple way

[4] In Fujita and Ogawa's (1982) model, high commuting costs imply no commuting and mixed land use while low commuting costs imply a monocentric city. However, no clear prediction exists for intermediate commuting costs.

to characterize the relationship between transportation infrastructure and decentralization is with a levels equation of the form:

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

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

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

In (2), $A_1{}'$ captures effects of infrastructure on combined prefecture and central city outcomes, whereas A_1 in (1) captures the effect of infrastructure on the allocation of the outcomes between central cities and prefecture remainders, holding the prefecture outcome constant in (1). Although we are primarily interested in estimating A_1, we will also present estimates of $A_1{}'$.

For a different perspective, we note that equation (2) can be decomposed into

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

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

Since y_{tP} is the sum of central city and prefecture remainder outcomes, $A_{a1}{}'$ captures some combination of the direct effect of infrastructure on the central city outcome and the indirect effect that operates through infrastructure's influence on the prefecture outcome. For example, roads may cause central city population to fall through displacement to the prefecture remainder and to rise because they draw in new population to the overall prefecture. Therefore, isolating the decentralization effects of infrastructure requires estimation of (1) rather than (2) or (2a). In practice, estimates of A'_{b1} are near 0. As a result, estimates of A_1, A_1' and A'_{a1} coincide for all outcomes and transport measures considered.

A complete characterization of the effects of infrastructure on locations of industrial output and employment in particular sectors requires at least four equations, one each for output or employment in each sector in the central city and the prefecture (or its remainder). One logical step is to express the effect of infrastructure on the sectoral allocation between central cities and prefecture remainders using $\ln y_{ktC} = A_0 + A_1 r_t + A_2 \ln y_{ktP} + B_0 x + \delta + \varepsilon_t$, in which y_{ktA} is employment or output in sector k at time t in region A. However, that formulation needs to account for the endogenous reallocation of prefecture activity across sectors, as in Duranton, Morrow & Turner (2014). In principle, one can simultaneously characterize such reallocation and decentralization effects by estimating versions of (2a) and (2b) for each sector. However, absence of prefecture-level data on output by sector lead us to estimate reduced-form relationships between infrastructure and central city sector-specific outcomes instead, as in:

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

Here, A_{1k} compounds the effects of infrastructure on decentralization of sector k with sectoral reallocation. Limited information about prefecture GDP leads us to measure y_{tP} as prefecture population or employment at time t, even if the outcome is central city industrial GDP. [5]

[5] Baum-Snow (2014) estimates a similar system of industry-specific equations for U.S. cities 1960-2000.

In addition to the probable endogeneity of y_{tP} noted above, there are two other challenges in using (1) and (1') directly for estimation. First, a necessary condition for an estimate of A_1 to be a causal effect of infrastructure is that our infrastructure variables be conditionally uncorrelated with the two error terms. We are concerned that historically productive central cities have been allocated more modern highways, so that a coefficient on highways would partly reflect this unobserved attractiveness rather than a causal effect. Second, while coefficients should describe approximate land use equilibria in Chinese cities in 2010, the 1990 planning process is probably better described by a larger set of variables, with the overlapping variables having different coefficients.

As a response to these issues, we specify levels equations for 1990 with different coefficients and first-differences to examine growth in $\ln y_{tC}$ to later years. For 1990, the equation is:

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

Subtracting (3) from (1) yields

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

First differencing removes time-invariant unobservables that may be correlated with r and drive decentralization, thereby strengthening identification. We follow an identical procedure for (1') when estimating the effects of infrastructure on industrial output.

There are practical difficulties in recovering the coefficients in (4) using our data. First, while our 1990 and 2010 highway measures are nominally the same, there is little resemblance between a highway in 2010 and a `national road' visible on our 1990 map. 1990 highways near major cities were almost universally one or two lane roads and were often unpaved. Treating the 1990 highway stock as zero allows us to more accurately measure the change in highways over our study period. We evaluate the validity of the zero initial stock assumption below.

As with highways, we include only the level of railroads at time t to recover their causal effects. That is, we assume that 1990 railroads have no effect on outcomes, or more formally that $A_1 + \Delta A_1 = 0$. The limited freedom of central city firms to decentralize to suburban regions in 1990, evidence for which we show below, justifies this assumption. Once economic reforms were in place, cities began to adjust to market equilibria with production decentralization. Our analysis of rails examines the extent to which the level of rail infrastructure shaped changes which only became possible after 1990. Since most intra-city rails in 2010 were built by 1990, we recover similar estimates whether we use 1990 or year t railroads as our infrastructure measure.[6] Because of the unique context, we see our analysis of the effects of highway construction between 1990 and later years on changes in urban form as comparable to our investigation of the effects of railroad levels in later years. Our primary estimation equation thus becomes

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

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

We rely on instrumental variables to address potential endogeneity of r_t. Conditional on appropriate controls, we require instruments that predict endogenous variables but are otherwise uncorrelated with the error term in our structural equation. Similar to Baum-Snow (2007a), Duranton and Turner (2011, 2012), Garcia-Lopez, Holl and Viladecans-Marsal (2015) and Hsu and Zhang (2014), we use information about networks in 1962 as instruments for r_t. We consider the validity of this class of instruments in Section 4.2.

[6] Nationally, network length increased by about 20 percent between 1990 and 2010, with some additional double-tracking of 1990 railroad lines. We cannot use the change in railroads as a predictor because we have do not have strong instruments for it, nor do we consider it to be the relevant measure given our discussion in Section 2.

We use migration shocks to handle the potential endogeneity of $\Delta_t lny_P$, following Bartik (1991) and Card (2001), where historical migration pathways help predict recent migration. The instrument is the interaction of the fraction of out-migrants from each province going to each prefecture between 1985 and 1990 with the total number of out-migrants from each province between 1995 and 2000. While not ideal because mechanically it can only predict 1995-2000 growth, it is all we can do with available data. Fortunately, it is a significant predictor of 1990-2010 prefecture population growth.[7] The identification assumption is that 1985-1990 internal migration flows are uncorrelated with unobservables (like productivity shocks) driving changes in central city population between 1990 and 2010. Because the instrument is based on data from the pre-market reform period, this assumption seems plausible. Controlling properly for population growth in estimation allows us to interpret infrastructure coefficients as only capturing decentralization.

We pursue two additional strategies to avoid relying exclusively on the Card instrument. First, we calculate bounds on estimates of A_1; second, we estimate a differenced version of the shares equation (2), which excludes prefecture population as an explanatory variable. While those estimates combine effects of transport investment on decentralization and prefecture growth, the latter turns out to be zero.

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

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[7] We do not have information on migrant origins or migration flows for any other time periods. Industry shift-share type instruments for prefecture population growth, as in Bartik (1991), are insufficiently strong.

In sum, our main regression specification includes three components. First, we include and instrument for the potentially endogenous transportation infrastructure measures at time t. Second, we include and instrument for prefecture population growth. Third, we include controls that are potentially correlated with instruments and outcomes. These are historical levels of prefecture population, central city and prefecture land areas, an indicator of whether the city is one of 4 provincial level cities or 26 provincial capitals, historical educational attainment levels and historical specialization in manufacturing. We emphasize that for IV regressions to return consistent estimates of A_1, we need only control for variables that are correlated with instruments and that influence outcomes of interest.

Effects of infrastructure on decentralization likely vary with city characteristics such as land-use planning policy, housing supply elasticity, the availability of alternatives to auto travel, and local *hukou* policies governing migration. Unfortunately, we have limited information on these specific items. We explore whether a slower pace of reform affects results by excluding cities in the West, where the state maintains a stronger role and the size of the state sector is larger. The fact that historical infrastructure is a strong predictor of modern infrastructure for various subsets of the sample, as established below, suggests that the treatment effects we estimate represent averages over a broad set of prefectures.

4.2 Instrument Validity and First Stages

To be valid instruments, 1962 transport network components must only predict recent central city growth through their influences on the location and configuration of the modern transportation network, conditional on control variables. In addition, they cannot be correlated with unobserved variables that influence highways and the post-1990 evolution of central city economies.

Selecting the set of appropriate control variables requires understanding the processes by which the 1962 transportation networks were established. Sino-Soviet planning featured nationalization of the housing stock in the 1950s and minimization of commuting by placing residents near work places. The strict institutional separation of the urban and rural sectors made suburbanization impossible. With little commuting, the 1962 road network outside of central cities served primarily to connect rural counties to the nation. Lyons (1985, p. 312) states: "At least through the 1960s most roads in China (except perhaps those of military importance) were simple dirt roads built at the direction of county and commune authorities. … most such roads were not fit for motor traffic and half of the entire network was impassable on rainy days." Lyons also notes that average truck speeds were below 30 km/hr due to poor road quality. All long-haul and most short-haul movement of goods was by rail. A major effort in the early 1960s aimed to facilitate transport within prefectures to and from villages. The People's Daily (June 11, 1963) stated: "The present effort at building roads aims at opening up commercial routes to the villages to facilitate the transport of locally-produced goods as part of the policy of priority given to agriculture. Better roads are being built by provincial governments, but most of them are being built at local initiative. They are rarely fit for motor traffic; on the better roads horses and ox-carts may travel; on others hand-carts … can be pushed or pulled by man" (Lippit, 1966 p. 115). Despite the low quality of vintage roads, the established right of ways provide a solid first stage.

The highway system built after 1990 is designed to serve a modern economy in cities where places of work and residence are separated and commutes are common. Since the strength of local agricultural ties between central cities and surrounding regions in 1962 could influence outcomes today as well, it is in principle important to control for either relative agricultural activity or its effective converse, relative industrial activity, in prefectures prior to 1990. Since 1982 is the earliest year with county-level census data, we include the share of prefecture employment in manufacturing in 1982 as a control. As shown in Table A2, this control is significantly negatively correlated with 1962 radial roads. 1982 controls for prefecture population and education are also important because they may directly predict subsequent changes in population and GDP allocation between cities and prefecture remainders. 1982 population is positively related to 1962 roads while 1982 fraction high school is negatively related to 1962 roads. We also control for log prefecture and central city areas and a provincial capital indicator throughout. Prefectures which were larger in area and provincial capitals had more 1962 road rays all else equal. Overall, our baseline controls explain 14 percent of the variation in 1962 radial roads (Table A2).

More than two-thirds of Chinese railroads were built before the People's Republic was established in 1949. Major trunk lines constructed in the early 20th century ran north-south and helped to link key political and commercial centers. Russian and Japanese investment financed a major expansion in Manchuria (northeast China) to facilitate extraction of agricultural goods and raw materials, and later helped to link emerging industrial centers (e.g. Shenyang and Changchun) with China proper. Between 1949 and 1962, much of the railroad investment was under Soviet influence and served to connect resource rich regions of the West with manufacturing centers in the East. After 1964, the 'Third Front' policy moved military and other strategic production westward, adding five strategic railroad lines. Because there was little trade between provinces (Lardy, 1978), provincial capitals were important trade nodes and therefore received main rail lines. Given the variety of actors and motives behind the construction of the pre-1962 network, it is plausible that much of the rail network was constructed without regard to its impact on the post-1990 internal re-organization of cities conditional on our base controls. As seen in Table A2, significantly more 1962 railroads existed in more populous (but not larger) and more highly educated prefectures, with a large positive relationship with provincial capitals and fraction working in manufacturing as well. Overall, our control variables explain 24 percent of the variation in 1962 radial railroads.

Columns 1-4 of Table 2 show representative first stage results for the three 2010 transportation network measures we emphasize and one for 1999, which we use in our consideration of dynamics. Instruments are individually strong conditional on the common controls used throughout, and each modern transport measure is predicted by its 1962 counterpart. Each 1962 road ray predicts about 0.35 of both 1999 and 2010 highway rays conditional on base controls and other instruments. Because the coefficient on 1962 radial roads is statistically identical in these two regressions, this instrument does not predict changes in roads between 1999 and 2010, noting that these road measures are not directly comparable. These facts mean that we cannot empirically isolate effects of radial highways built between 1999 and 2010. Each 1962 railroad ray predicts 0.37 railroad rays in 2010 and the existence of any 1962 ring road capacity increases the probability of such capacity in 2010 by 0.52.[8] For completeness, column 4 of Table 2 presents a representative first stage regression for prefecture population growth, for which we instrument in all base results.[9]

5. Results for Population Decentralization

5.1 Baseline

Table 3 reports baseline OLS estimates of empirical relationships between urban transport infrastructure and 1990-2010 central city population decentralization. We limit attention to two

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[8] As seen in Table A2, our base controls only explain 3 percent of the variation in the ring road indicator; as such, we are not as confident in our understanding of the data generating process for ring roads.

[9] Relevant 1962 transport network coefficients are statistically significant at the 5 percent level with the correct sign for 8 of the 12 1990 central city population tercile/transport network measure pairs. Similarly, such measures work for 6 of the 8 East vs Center/West region by transport measure pairs. 1962 highway rays coefficients are insignificant at the 5 percent level for medium sized and Eastern cities when 2010 rays is the outcome, and small cities when 1999 rays is the outcome (with marginal insignificance for Eastern cities). The 1962 railroad rays coefficient for medium sized cities is insignificant when 2010 railroad rays is the outcome. The 1962 ring capacity indicator is insignificant for large cities and non-Eastern cities when 2010 ring capacity is the outcome.

network measures at a time because of the inability to instrument with any power for more. OLS coefficients on radial highways are small, as are coefficients on other transport network attributes. For radial highways and ring roads, the small and/or insignificant effects reflect a classic identification problem. While we expect rays and ring roads to lead to slower central city growth, such investments may be allocated to faster growing central cities.

Table 4 reports IV estimates of (5) with the same format as Table 3. Column 1 has no controls and an estimated zero coefficient on radial highways. Column 2 adds the base controls and reports a coefficient of -0.042 on radial highways, significant at the 6% level. The control variable that influences the radial highways' coefficient the most is log of 1982 prefecture population. More populous prefectures had more roads in 1962 and experienced more rapid central city population growth, reflecting that growth was fueled by within prefecture migration. Absent the control for 1982 prefecture population, the coefficient on highway rays reflects both the negative causal effect of this infrastructure and the positive effects of the omitted variable. Adding controls for other transport infrastructure generally sharpens this coefficient and allows us to investigate heterogeneity of effects. Additions of total kilometers of highways in the prefecture remainder (column 3) or the entire prefecture (unreported) yield coefficients of zero on these variables. Column 4 adds the count of radial railroads, which also has no effect on central city population. Nor does a control for total kilometers of railroads (unreported).

Table 4 columns 5 and 6 introduce ring roads and contain key results. Understanding the effects of ring roads on urban form is important for policymakers. While China is one of the few contexts for which exogenous variation in ring road capacity across cities is available, there are some limitations. In particular, few roads in 1962 look like ring roads. Even in 2010 only 29 percent of cities in our sample have some ring road capacity. In these cities, these roads serve an average of only about 38 percent of the circumference of the city. In 1962 only 5 percent of our cities register any ring road capacity with a maximum of 25% circumference covered. Therefore, these IV results must be viewed with some caution, although the point estimates are large.

Conditional on highway rays, ring road capacity reduces central city populations by about 25%, although the joint F on the first stage (4.1) is low. Because of low power in the first stage, we cannot identify an additional separate interaction effect between rays and rings. We also note that rings roads and rays may be substitutes in designing urban transport networks, which may be why controlling for ring roads enhances and sharpens the highway ray effect in column 6 relative to column 2, raising the coefficient in magnitude from -0.042 to -0.059.

Coefficients on non-transportation related covariates are also of interest. In column 2, a 1% increase in prefecture 1990-2010 population growth leads to a 0.81% increase in 1990-2010 central city growth holding 1982 prefecture population constant. A persistent 1% increase in 1982 prefecture population, however, is associated with just a 0.11% increase in 1990-2010 central city population growth. The growth elasticity is higher than related estimates in Baum-Snow (2007a) for U.S. metro areas, reflecting the rapid urbanization of China in the study period. Conditional on other controls, more spacious central cities grew more slowly. Population in provincial capitals grew more quickly, which may reflect political influence. The 1982 controls for prefecture education and manufacturing share are insignificant. Coefficients on control variables are similar for OLS results in Table 3 (unreported).

Consistent with evidence in Baum-Snow (2007a) and Duranton and Turner (2012) for the U.S., differences between OLS and IV highway ray and ring road coefficients suggest that our highway indices are endogenous. While more highways were built in central cities with more rapidly growing populations relative to their surrounding prefectures, these roads were themselves causing population to decentralize. The decentralization that occurred because of this infrastructure is more than offset by the growth that precipitated construction of this infrastructure. As a result, the use of pseudo-random variation from the 1962 network is essential to estimating the true causal effects of these transportation improvements.

We do not have detailed information on individual cities' institutions governing land markets, supply constraints and market reforms. However, we do know that in general cities in the West have been slower to introduce reforms. They are also poorer, with lower automobile use. Table 5 repeats Table 4 but excluding cities in the West. The radial highway effects in columns 2-6 increase to at least -0.059 and the ring road effects in Columns 5 and 6 to at least -0.213. The effect of highway infrastructure investments on central city population growth is somewhat stronger in coastal and center region cities than in the West, where reform is slower.

5.2 Robustness

The validity of the 'no initial highways' assumption employed so far rests on the assumptions that 1990 roads were not highways and that pre-reform urban China did not permit market responses to cross-city differences in transportation networks. Table 6 Panel A columns 1 and 4 (column 4 drops the West) includes 1990 road rays as an additional (un-instrumented) control. This approximates the exact first-difference specification in (4), and also addresses the possibility that some 1990 roads may persist and affect decentralization. The technical problem with adding the 1990 control is that 1962 and 1990 rays are strongly correlated, so that the first stage F-statistic is low. Noting that, the coefficient on 1990 roads is an insignificant 0.05 while that on 2010 roads increases to -0.081. These results suggest that 1990 road rays do not contribute to decentralization, while 2010 highway rays do. This supports estimation of (5) rather than (4).[10]

An alternative way to test the validity of the no initial highways assumption is to show that cities did not decentralize in response to old roads during the pre-reform period. To address this hypothesis, Table A3 reports the impact of 1980 road rays and the highly correlated 1990 rays on decentralization during the 1982 to 1990 pre-urban reform period.[11] These estimates are analogous to those in Table 4 column 2, but for the 1982-1990 period. Estimated effects of 1980 or 1990 road rays on 1982-1990 decentralization in columns 1 and 2 respectively are indistinguishable from zero, evidence that roads only started to cause decentralization after the urban market reforms of the early 1990s. We already know rails are not related to population decentralization. Therefore, in columns 3-6 of Table A3 we show that, ceteris paribus, 1980 and 1990 transport infrastructure had no effects on 1990 levels of central city population or industrial GDP. However, in the last column they have a strong impact on central city 2010 industrial GDP. In summary, infrastructure effects on urban form are a post 1990 phenomenon.

In columns 2 and 5 of Panel A in Table 6, we add controls for 1982 *central city* population, the fraction with a high school degree, and the fraction employed in manufacturing. We refrain from using such controls in our prime specifications because of concerns with introducing variables that are serially correlated with 1990 central city population. Offsetting this is the desire to control for variables that could affect subsequent central city growth and be correlated with our instruments. In column 2 the radial highways coefficient is 15% smaller than in Table 4 column 2

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

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

but in column 5, where we drop western prefectures, the coefficient is only 7% smaller than in Table 5 column 2. Given that added controls increase the length of the variable list and can be thought of as objectionable, we conclude that the results are robust with respect to them.

Finally, one might worry that larger cities drive our results, under the notion that small cities lack measured 'suburbs' to which people can decentralize. This is mostly a measurement issue, as land-use models do not suggest that differential effects should exist per se. Table 6 Panel A Columns 3 and 6 exclude cities in the top 5% of prefecture population in 1990. Both coefficients are modestly enhanced, suggesting that results are not driven by the largest cities.

In Table 6, Panel B presents estimates of coefficients in differenced versions of (2a), (2b) and (2) for the full sample (columns 1-3) and excluding the West (columns 4-6). Column (2) relates transport infrastructure to central city population shares, confounding decentralization with overall prefecture growth effects. Columns (2a) and (2b) separate out effects of infrastructure on central city and prefecture populations, although the former does not identify the coefficient of interest in equation (1) because (2a) does not hold prefecture population constant.

The key result in Panel B of Table 6 is in column 2, which shows no prefecture growth effects of radial highways. This means that the coefficients on radial rays in columns 1 and 3 fully reflect decentralization effects, because prefecture population growth is not correlated with the instrument. Consistent with this logic, radial highways coefficients of -0.048 and -0.041 in Panel B columns 1 and 3 are very close to our headline estimate of -0.042 in Table 4 Column 2. Dropping the West, coefficients of -0.066 and -0.059 in columns 4 and 6 are very close to -0.060 in Table 5 column 2.

We also estimate bounds on our coefficient of interest as an alternative to instrumenting for prefecture population growth. It is straightforward to show that the true value of A_1 is bounded by the estimate arising from estimating (5) when $\Delta_t \ln y_P$ is included and when it is not.[12] Using the specification in Table 4 column 2, when $\Delta_t \ln y_P$ is included (uninstrumented) the coefficient on highway rays is -0.041 and when it is excluded the coefficient is -0.048 (Table 6 Panel B, column 1). These bounds are tight, bookending our headline estimate of -0.042.

5.3 Dynamics

Our data also allow for a limited investigation of the rate at which decentralization occurs in response to changes in the road network. The first two columns in Panel A of Table 7 report estimates of the effects on 1990-2010 population decentralization of radial roads in place by 2005 and 1999 respectively. Coefficients on the two highway measures are similar to those in Table 4, noting from Section 4.2 that 1962 radial roads predict 1999 radial highways but not post-1999 radial highway growth. Importantly, this suggests a refinement in interpretation. Since our first stage predicts radial roads built by 1999, regardless of the nominal year of the endogenous radial road variable, our second stage results must also describe the effect of radial roads built by 1999, also regardless of the nominal year of the endogenous radial road variable.

Column 3 of Panel A of Table 7 shows the effect of radial roads in place by 1999 on 1990-2000 decentralization, while column 4 shows their effect on 2000-2010 decentralization. Other details of the regressions are analogous to our preferred specification in column 2 of Table 4, except for column 4 where we are not able to instrument for prefecture population growth.

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[12] The logic of this bounding argument is seen in the following simple example. Suppose the structural equation for central city population is $\Delta_t \ln y_C = \alpha_0 + \alpha_1 r_t + \alpha_2 \Delta_t \ln y_P + u$, where r_t is instrumented with r^{62}, which is uncorrelated with u. The IV estimate of α_1 excluding $\Delta_t \ln y_P$ from the regression equals $\alpha_1 + \alpha_2 Cov(r^{62}, \Delta_t \ln y_P) / Cov(r_t, r^{62})$. This expression reflects the possibility that infrastructure promotes prefecture population growth, which includes some central city population growth as well. The IV estimate of α_1 including $\Delta_t \ln y_P$ in the regression equals $\alpha_1 - Cov(r^{62}, \Delta_t \ln y_P) Cov(\Delta_t \ln y_P, u) / D$, $D > 0$, where mechanically $Cov(\Delta_t \ln y_P, u) > 0$. Therefore, regardless of the sign of $Cov(r^{62}, \Delta_t \ln y_P)$, these are bounds on the true value of α_1.

Estimated decentralization responses are -0.023 and -0.018 over the 1990-2000 and 2000-2010 periods respectively, adding up to the full 1990-2010 decentralization response reported in column 2. This suggests that about half of the total 1990-2010 decentralization caused by radial highways built between 1990-1999 occurred by 1999 and half occurred between 2000 and 2010.[13] Results in Panel B that drop cities in the West show roughly the same pattern, though with somewhat stronger effects of 1999 radial highways in the first decade relative to the second decade.

6. Decentralization of Production

We begin this section by examining the effects of transportation networks on the 1990-2010 growth of central city industrial GDP. We then use the 1995 and 2008 industrial censuses to confirm that the same patterns hold for growth of central city industrial employment. We square these results with the population results reported in Section 5 by showing similar effects on the residential locations of people employed in industry. Finally, we comment on the determinants of employment decentralization as a function of weight to value ratios.

6.1 Central City Industrial GDP

Panel A of Table 8 reports IV estimates of the effects of elements of transport networks on central city industrial production between 1990 and 2010, holding prefecture population constant. To see the degree of bias in OLS estimates, Panel B shows the corresponding OLS coefficients for each column in Panel A. We use the same set of controls as for our analysis of population decentralization. Commensurate with our discussion in Section 4.1, estimates in Table 8, while indicating decentralization, may also reflect shifts in prefecture sectoral composition.

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

Results in columns 1, 3 and 6 of Panel A of Table 8 reveal that highway rays have insignificant effects on central city industrial GDP, regardless of other elements of the transportation network. In contrast, results in column 2 show the central role of radial railroads for facilitating central cities' loss of industry. Each radial railroad causes about a 24% decline in the growth of central city industrial GDP. Column 4 reports a 'horse race' between rail rays and total kilometers of the rail network in the prefecture remainder. Rail rays win with the rail rays coefficient little changed and an insignificant coefficient for kilometers. We obtain the same result if we control for total kilometers of rails in the entire prefecture, rather than just the remainder.

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

As with our analysis of population decentralization above, OLS estimates in Table 8 Panel B appear to be positively biased, reflecting the assignment of railroads and ring roads to central cities with more rapid GDP growth. For example, the OLS rail rays and ring roads coefficients in column 7 are -0.041 and -0.145 respectively, compared to the IV estimates of -0.24 and -0.71.

From our discussion in Section 4.2 of the processes by which 1962 roads and railroads were assigned, the crucial control variables in Table 8 differ from those for population decentralization. Instead of 1982 prefecture population, the most important controls are the provincial capital indicator and 1982 prefecture manufacturing employment share, driving differences between the no-controls IV coefficient on rail rays of -0.34 in column 8 and the primary estimate of -0.24 in column 2. Some results on controls also differ. 1982 education share now has significant coefficients in some cases and signs of area coefficients reverse. Central city industrial GDP growth is lower in prefectures with higher education in 1982; perhaps service sector development is positively influenced by the local human capital stock. A greater share of manufacturing in 1982 also leads to lower central city industrial GDP growth, perhaps due to convergence.

Table 8 indicates that radial rails and ring roads caused some combination of industrial GDP decentralization and reallocation of production toward other sectors. Unfortunately, the limited quality of our prefecture GDP data and an inability to find a viable instrument for GDP growth precludes a serious investigation of the extent to which the second mechanism is important.

6.2 Decentralization of Residents and Jobs

Results in Tables 4 and 8 reveal that while roads matter for the location of people, in China rails matter for the location of industrial production. Because production requires workers, these differing roles may seem mutually inconsistent. However, Table 9 indicates that our estimated effects of radial highways and rails are in fact consistent. Table 9 shows that radial railroads caused similar declines in central city *residents* employed in manufacturing as declines in industrial GDP and firm manufacturing employment. Pairs of regressions in Table 9 are identical except for the prefecture growth control. Odd columns use population and even columns employment. Our population-based Card instrument predicts employment less well in the first stage in even-numbered columns.

Columns 1 and 2 confirm that radial highways contribute to decentralization of population but radial rails do not. Columns 3 and 4 examine the effects of transport on the decentralization of the residential locations of workers. Estimated effects of infrastructure on residential location are almost the same as for population. However, columns 5 and 6 reveal that, unlike for all workers, radial rails caused a dramatic decline in central city residents working in manufacturing. Each radial rail causes about 35 percent of central city residents working in manufacturing to move to the prefecture remainder or switch sectors, with no significant effect of radial highways. Results in columns 7 and 8 indicate that each radial railroad caused about 28 percent of central city manufacturing jobs to leave, with no effect for highways. These effects are similar to the estimated -0.24 reported in Table 8 for the effect of rail rays on central city industrial GDP.

Without reliable data on the location of non-manufacturing employment, we cannot have a complete picture of how infrastructure affected the distribution of population and employment by location and sector. However, we can try to make inferences. The population decentralization promoted by highways could either reflect more intensive commuting from suburbs to central cities or decentralization of non-manufacturing jobs. There is little systematic data about commuting mode choice for China; but based on various sources, it seems that the fraction commuting by car or transit is still very limited.[14] If those in non-manufacturing compared to manufacturing jobs have similar commuting patterns, this suggests that highways promote decentralization of service jobs and workers, while rails promote decentralization of manufacturing jobs and workers and potentially some sectoral shift in prefecture economic activity. 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.

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

In Table 10, we further investigate effects of infrastructure on central city manufacturing employment. Columns 1-4 show effects on 1990-2010 growth in central city residents working in manufacturing and columns 5-8 show effects on 1995-2008 growth in the central city manufacturing jobs. Results are similar. While highway rays have no effect on central city industry, each rail ray causes about a 30 percent decline in residents working in manufacturing or in manufacturing jobs. In column 4 ring road capacity reduces central city residents working in manufacturing by about an additional 62 percent ($1-e^{-0.977}$). However, results in column 8 for effects of ring road capacity on central city manufacturing jobs are weaker.[15]

Meyer et al. (1965) suggest detailed patterns for the exodus of industry from central cities in the U.S. in the 1950s and 1960s. They thought large plant heavy industry would be slower to leave central cities and would, for a while, continue to rely on central city rails. However, intermediate weight footloose production would move to city fringes, where ring roads facilitate the trucking of goods to suburban rail sidings. Low weight products could rely more on trucking for long-haul moves, with radial highways providing quick exit to inter-regional highways and ring roads providing connections. We investigate how infrastructure influenced central city employment in five industry groups characterized by weight to value ratios of their output shipments.[16]

Based on specifications analogous to those in Table 10 columns 6-8, results in Table A3 indicate that heavy goods respond the least to railroads, while low weight goods such as textiles, apparel, leather and high tech respond the most. Radial highways play no role for heavy and medium weight goods but each radial highway reduces central city employment in the lightest weight industries by 20-25 percent. Horse races between rail and highway rays have no statistical

[15] Online Appendix Tables O1-O3 show results analogous to those in Tables 8-10 for non-West cities are similar.
[16] We use Duranton, Morrow and Turner's (2014) table relating weight to value for shipments of goods by U.S. industries. Land use intensity could be a key factor driving responses, but we know of no data on such land intensities.

power (unreported). Ring road effects are large in most industries, but are only significant for high tech, which could be the poster-child for the Meyer et al. hypothesis on the role of ring roads.

7. Conclusions

Our analysis suggests that transportation infrastructure networks had profound and long-lasting impacts on urban form in China. Both radial highways and ring roads promoted substantial population decentralization out of central cities. On the other hand, radial railroads and ring roads both promoted the decentralization of industrial production and its workforce.

These results come with caveats. First, they depend on the pseudo-randomization of transport infrastructure by our 1962 network instruments conditional on control variables. Serially-correlated unobservables that predict both residualized 1962 networks and post-1990 changes in urban form would invalidate our identification strategy. We believe the unique context of China's transition to a market economy limits this concern. Second, the efficacy of the instrument for ring roads is limited. Results are strong and intriguing, but more evidence on the effects of ring roads is essential to our understanding of transport networks.

Our results also point to welfare gains. Given that we find that infrastructure influences prefecture population, we reason likely welfare consequences in a closed city environment. New infrastructure lowers the cost of accessing space, allowing consumption of more space through standard substitution effects. Living costs decline with cheaper housing and lower commuting costs per unit distance. Cheaper space increases firms' allocation of space per worker, thereby increasing real wages and improving residents' welfare. Baum-Snow (2007b) simulates welfare gains of 2-3% per additional highway ray for U.S. cities based on commuting cost effects. With less commuting in China, these might be smaller. But there are also potential productivity gains from rails facilitating the movement of industrial production out of central cities, freeing up space for less land intensive activities such as tradable services that benefit more from agglomeration spillovers. Quantification of the size of these forces is an important area for future research. We hope that estimates in this paper can be a useful input into such calculations.

References

Arzaghi M. and J.V. Henderson, 2008. Networking Off Madison Avenue, *Review of Economic Studies* 75, 1011-1038.

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

Bartik, T., 1991. Who Benefits from State and Local Economic Development Policies? Kalamazoo (MI):W.E. Upjohn Institute for Employment Research

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

Baum-Snow, N., 2007b. Suburbanization and transportation in the monocentric model, *Journal of Urban Economics* 62, 405-423.

Baum-Snow, N., 2014. Urban Transport Expansions, Employment Decentralization, and the Spatial Scope of Agglomeration Economies, manuscript.

Card, David, 2001. Immigrant Inflows, Native Outflows and the Local Labor Market Impacts of Higher Immigration, *Journal of Labor Economics,* 19:1, 22-64.

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

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

Duranton G. and D. Puga, 2001. Nursery Cities: Urban Diversity, Process Innovation, and the Life Cycle of Products, *American Economic Review,* 91, 1454-1477.

Duranton G. and D. Puga, 2015. Urban land use in *Handbook of Regional and Urban Economics, Vol 5,* G. Duranton, J.V. Henderson, W. Strange (eds.), Amsterdam: Elsevier.

Duranton, G., P. M. Morrow, and M. A. Turner, 2014. Roads and trade: Evidence from U.S. cities, *Review of Economic Studies,* 81:2,681-724.

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

Duranton, G. and M. A. Turner, 2012. Urban growth and transportation, *Review of Economic Studies*, 79, 1407-1440.

Fujita, M. and H. Ogawa, 1982. Multiple Equilibria and Structural Transition of Non-Monocentric Urban Configurations. *Regional Science and Urban Economics*, 12, 161-196.

García-López, M.A., A Holl and E. Viladecans-Marsal, 2015. Suburbanization and the highways: when the Romans, the Bourbons and the first cars still shape Spanish cities, Journal of Urban Economics, 85, 52-67.

Hansen, E.R., 1987. Industrial Location choice in Sao Paulo, *Regional Science and Urban Economics*, 17, 89-108.

Henderson, J.V., A. Kuncoro and D. Nasution, 1996. The Dynamics of Jabotabek Development, *Bulletin of Indonesian Economic Studies*.

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

Hsu, W-T and H. Zhang, 2014. The Fundamental Law of Highway Congestion: Evidence from Japanese Expressways, *Journal of Urban Economics*, 81, 65-76.

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

Kolko, J., 2000. *Essays on information technology, Cities and Location Choice,* PhD thesis, Harvard University.
Lardy, N.R. 1978. *Economic Growth and Distribution in China.* Cambridge: Cambridge University Press.
Lee, K.S., 1982. A model of intra-industry employment location: an application to Bogota Colombia, *Journal of Urban Economics*, 12, 263-279.
Lippit, V.D., 1966. Development of Transportation in Communist China, *The China Quarterly*, 27, 101-119.
Lucas, R.E., 1988. On the mechanics of economic development, *Journal of Monetary Economics*, 22, 3-42.
Lyons, 1985. Transportation in Chinese Development, 1952-1982. *Journal of Developing Areas,* 19:2, 305-328.
Marshall, A., 1890. *Principles of Economics,* MacMillan: London.
Meyer, J.R., J.F. Kain and M. Wohl. 1965. *The Urban Transportation Problem*. Cambridge: Harvard University Press.
Naughton, B. (2006) *The Chinese Economy: Transitions and Growth*, Cambridge, MIT Press.
Redding, S. J. and Turner M. A., 2015. Transportation Costs and the Spatial Organization of Economic Activity, *Handbook of Urban and Regional Economics Volume 5,* G. Duranton, J.V.Henderson and W. Strange (eds), Amsterdam: Elsevier
Rothenberg, Alexander D., 2013. Transport Infrastructure and Firm Location Choice in Equilibrium: Evidence from Indonesia's Highways, manuscript.
Swartz, A., 1992. Corporate service linkages in large metropolitan areas, *Urban Affairs Quarterly*, 28, 276-296.
World Bank, 1982. *China – Socialist economic development* (Vol. 7 of 9): Annex F: The transport sector.
Zhou Y and J. R. Logan, 2007. Growth on the Edge: The New Chinese Metropolis Pp. 140-160 in John R. Logan (editor), *Urban China in Transition*. London: Blackwell Publishers.
Zhou, S., L. Deng and M. Huang, 2013. Spatial Analysis of Commuting Mode Choice in Guangzhou, China, *Chin Geogra Sci*, 23:3, 353-364.

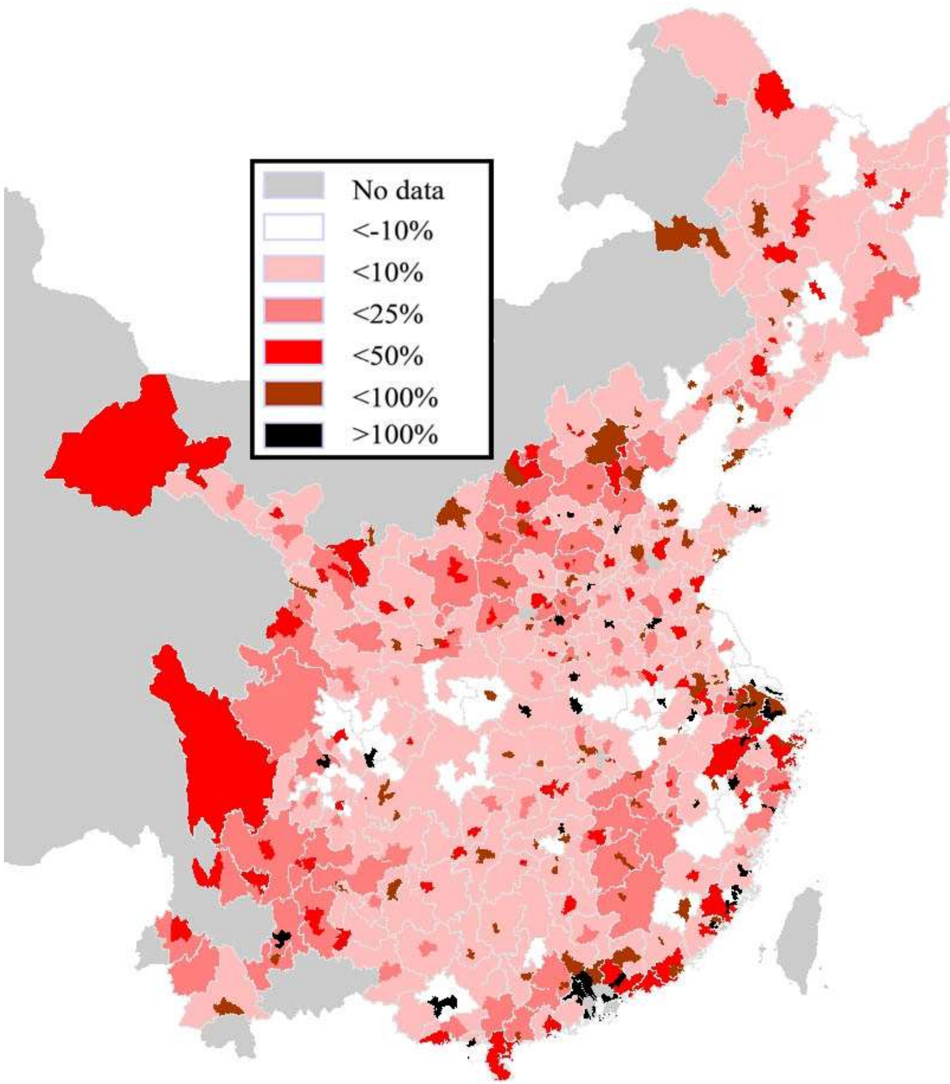

Figure 1a: 1990-2010 Population Growth in Central Cities and Prefecture Remainders

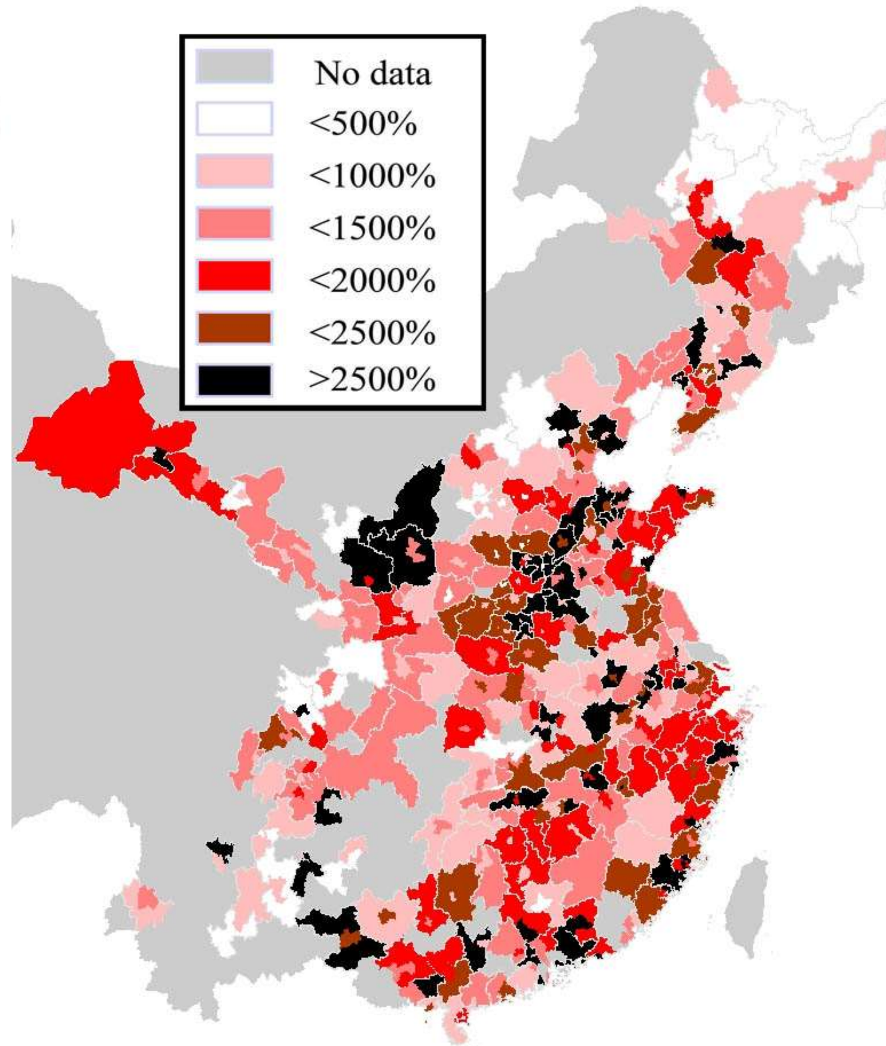

Figure 1b: 1990-2010 Industrial Sector GDP Growth in Central Cities and Prefecture Remainders

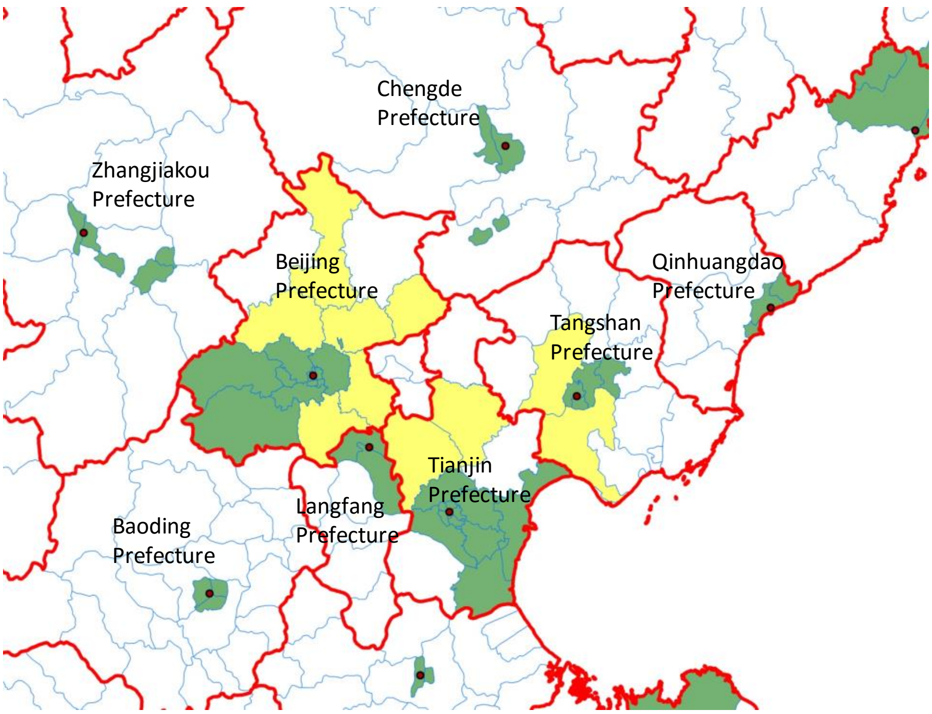

Figure 2: Beijing Area Political Geography Thick lines indicate 2005 definition prefecture boundaries and thin lines indicate county/urban district boundaries. Dark shaded regions are 1990 central cities and light shaded regions are 1990-2010 central city expansions.

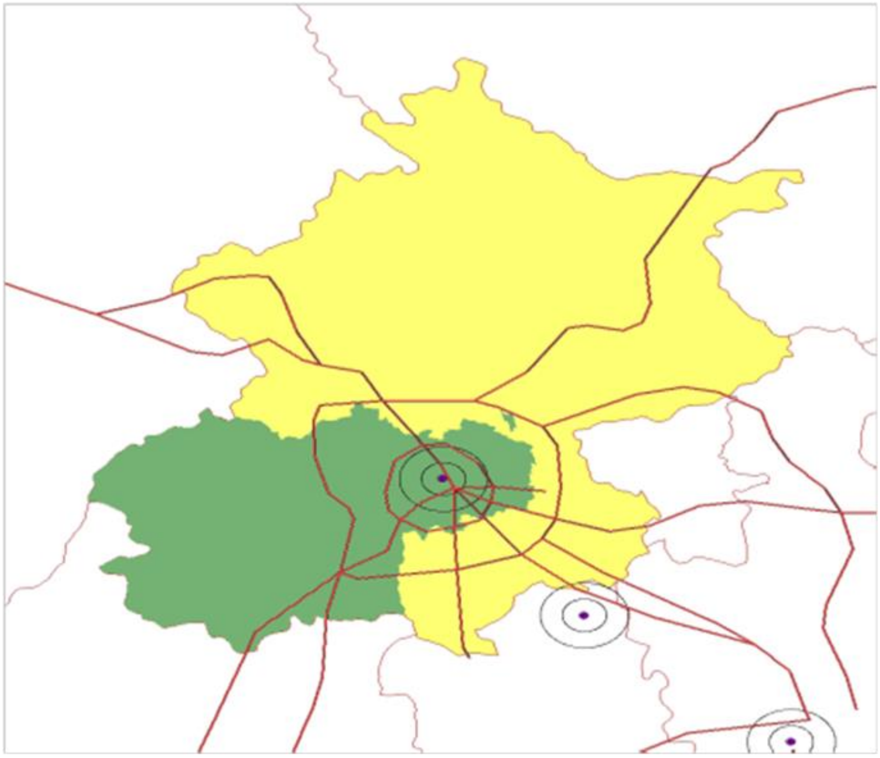

Figure 3a: Radial Road Index for the Beijing Region
Index is the minimum count of roads crossing the indicated 5km and 10 km CBD distance rings.

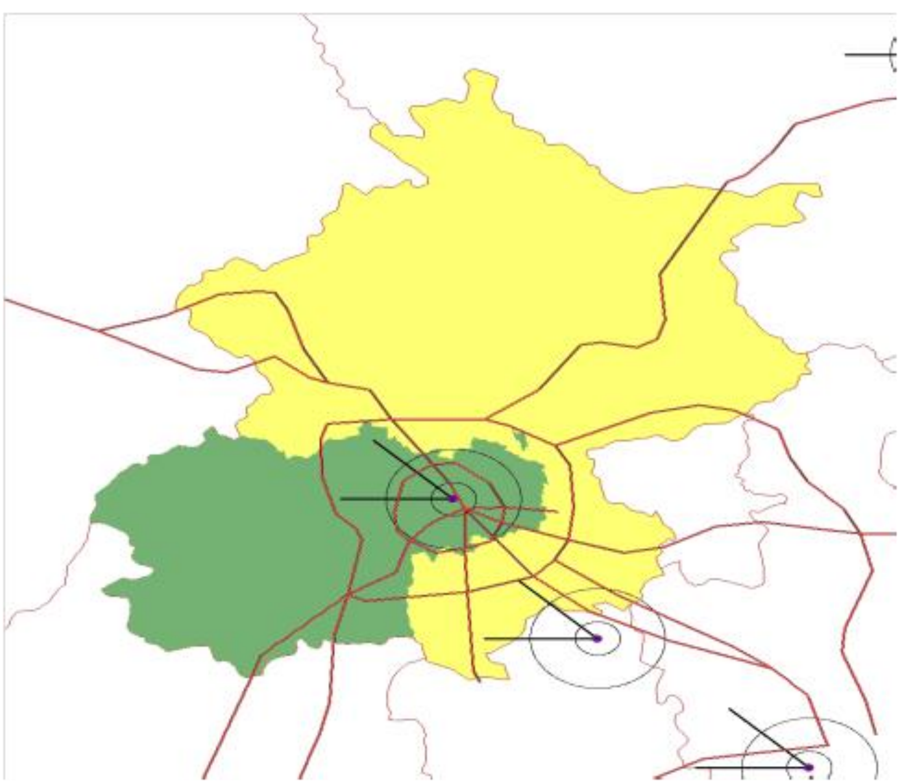

Figure 3b: Ring Road Index for the Beijing Region
Index for the NW quadrant 5-9 km from CBD is the minimum count of roads crossing both indicated rays between the two indicated CBD distance radii.

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

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

Notes: The 257 prefectures used to build the numbers in the first four columns is our primary sample. We do not include 1990 means for lights because levels of lights are difficult to interpret. The smaller sample for the final two columns reflects data limitations. Of the 189 prefectures, statistics for 93 prefecture remainders include imputed information for 1990. Industrial GDP is deflated with provincial deflators and is in 100 million RMB.

Table 2: First Stage Regressions

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

Notes: Each column shows coefficients from a separate OLS regression of the variable listed at top on the variables listed at left. The final covariate is the instrument for 1990-2010 prefecture population growth constructed using 1985-1990 migration pathways, as is explained in the text. Standard errors in parentheses are clustered by province. *** p<0.01, ** p<0.05, * p<0.1

Table 3: OLS Relationships Between Tansport Infrastructure and Population Outcomes

	Δ ln(CC Pop) 1990-2010					
	(1)	(2)	(3)	(4)	(5)	(6)
2010 radial highways	0.0097	-0.0114**	-0.0118**	-0.0123**		-0.0108*
	(0.0088)	(0.0050)	(0.0050)	(0.0048)		(0.0055)
ln(highway kms in prefecture remainder, 2010)			0.0221			
			(0.0276)			
2010 radial railroads				0.0105		
				(0.0100)		
2010 ring road indicator					0.0320	0.0273
					(0.0322)	(0.0323)
Δ ln(Pref Pop) 1990-2010		0.9212***	0.9113***	0.9221***	0.9075***	0.9230***
		(0.0641)	(0.0691)	(0.0650)	(0.0655)	(0.0630)
Base controls	No	Yes	Yes	Yes	Yes	Yes
Observations	257	257	257	257	257	257
R-squared	0.004	0.490	0.491	0.492	0.488	0.492

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

Table 4: IV Estimates of Effects of Transport Infrastructure on Population Outcomes

	Δ ln(CC Pop) 1990-2010					
	(1)	(2)	(3)	(4)	(5)	(6)
2010 radial highways	-0.0067	-0.0423*	-0.0448**	-0.0412*		-0.0587**
	(0.0186)	(0.0223)	(0.0228)	(0.0246)		(0.0259)
ln(highway kms in prefecture remainder, 2010)			0.0885			
			(0.0797)			
2010 radial railroads				-0.0105		
				(0.0485)		
2010 ring road indicator					-0.1873**	-0.2520**
					(0.0916)	(0.1111)
ln(central city area)		-0.1178***	-0.0966***	-0.1188***	-0.1620***	-0.1662***
		(0.0191)	(0.0225)	(0.0205)	(0.0295)	(0.0336)
ln(prefecture area)		0.0508***	-0.0335	0.0495**	0.0388	0.0566**
		(0.0178)	(0.0848)	(0.0194)	(0.0283)	(0.0249)
provincial capital indicator		0.1751**	0.1864**	0.1798**	0.1393**	0.2233***
		(0.0724)	(0.0733)	(0.0766)	(0.0574)	(0.0738)
ln(prefecture population, 1982)		0.1101***	0.0784	0.1140***	0.0699**	0.1387***
		(0.0365)	(0.0549)	(0.0304)	(0.0349)	(0.0443)
fraction high school or more		-0.3790	-0.4185	-0.3062	-0.4779	-0.2465
in prefecture, 1982		(0.3415)	(0.3489)	(0.5070)	(0.4516)	(0.4257)
share employed in manufacturing		-0.2845	-0.2652	-0.2881	-0.0415	-0.2884
in prefecture, 1982		(0.2544)	(0.2717)	(0.2465)	(0.2486)	(0.2904)
Δ ln(Pref Pop) 1990-2010		0.8124***	0.7555***	0.7975***	0.6228***	0.7752***
		(0.1389)	(0.1801)	(0.1657)	(0.1479)	(0.1733)
constant	0.4349***	-0.7535	-0.1754	-0.7846	0.1749	-0.7697
	(0.0971)	(0.5667)	(0.9525)	(0.5151)	(0.5207)	(0.5826)
Observations	257	257	257	257	257	257
First stage F	36.2	13.1	8.81	7.02	7.13	4.05

Notes: Each column shows coefficients from a separate IV regression of the variable listed at top on variables listed at left. All columns have first stages for infrastructure variables and the change in prefecture population 1990-2010. First stage results are in Table 2. Standard errors in parentheses are clustered by province.

Table 5: IV Estimates of Effects of Transport Infrastruture on Population Outcomes Excluding the West

	Δ ln(CC Pop) 1990-2010					
	(1)	(2)	(3)	(4)	(5)	(6)
2010 radial highways	-0.0105	-0.0595**	-0.0606**	-0.0593**		-0.0821***
	(0.0205)	(0.0237)	(0.0245)	(0.0257)		(0.0274)
ln(highway kms in prefecture remainder, 2010)			0.0487			
			(0.0825)			
2010 radial railroads				-0.0015		
				(0.0539)		
2010 ring road indicator					-0.2125**	-0.3156**
					(0.1043)	(0.1365)
Δ ln(Pref Pop) 1990-2010		0.9121***	0.8780***	0.9098***	0.6512***	0.9123***
		(0.1609)	(0.1999)	(0.1932)	(0.1280)	(0.2015)
Base controls	Yes	Yes	Yes	Yes	Yes	Yes
Observations	208	208	208	208	208	208
First stage F	14.2	11.5	7.99	6.40	5.27	3.00

Notes: Regressions are analogous to those in Table 4, except they use a smaller sample that excludes the West.

Table 6: Robustness Checks for Table 4

Panel A: Adjustments to Control Variables and Sample

	Δ ln(CC Pop) 1990-2010					
			drop top 5%	drop west		drop top 5% and drop west
	(1)	(2)	(3)	(4)	(5)	(6)
2010 radial highways	-0.0814*	-0.0362*	-0.0503**	-0.1466*	-0.0554**	-0.0676***
	(0.0460)	(0.0198)	(0.0255)	(0.0822)	(0.0240)	(0.0260)
1990 radial roads	0.0502			0.0891		
	(0.0335)			(0.0644)		
Δ ln(Pref Pop) 1990-2010	0.8976***	0.7368***	0.9249***	1.1325***	0.8689***	0.9570***
	(0.1869)	(0.1503)	(0.1010)	(0.2920)	(0.2003)	(0.1170)
Base controls	Yes	Yes	Yes	Yes	Yes	Yes
Extra controls	No	Yes	No	No	Yes	No
Observations	257	257	242	208	208	196
First stage F	2.988	10.70	12.67	1.290	9.584	9.619

Panel B: Different Outcome Variables 1990-2010 and Excluding Δln(Pref Pop) 1990-2010 from Regressions

	Δ ln(CC Pop)	Δ ln(Pref Pop)	Δ ln(CC Share)	Δ ln(CC Pop)	Δ ln(Pref Pop)	Δ ln(CC Share)
					drop west	
	(1)	(2)	(3)	(4)	(5)	(6)
2010 radial highways	-0.0477	-0.0067	-0.0410*	-0.0663	-0.0075	-0.0588**
	(0.0309)	(0.0198)	(0.0221)	(0.0442)	(0.0284)	(0.0233)
Base controls	Yes	Yes	Yes	Yes	Yes	Yes
Extra controls	No	Yes	No	No	Yes	No
Observations	257	257	257	208	208	208
First stage F	19.68	19.68	19.68	13.12	13.12	13.12

Notes: Each column shows coefficients from a separate IV regression of the variable listed at top on the number of radial highways in 2010 and the set of indicated additional controls. Base controls are the same as in Table 3. Extra controls in columns 2 and 5 of Panel A are ln(distance to the coast), 1982 fraction of prefecture high school or more population living in the central city and 1982 fraction of prefecture manufacturing employment living in the central city. First stage results for radial highways and Δln(Pref Pop) 1990-2010 are in Table 2. Standard errors in parentheses are clustered by province.

Table 7: Time Pattern of Responses to Highway Treatments

Panel A: Full Sample

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

Panel B: Excluding the West

	Δ ln(CC Pop)			
	1990-2010		1990-2000	2000-2010
	(1)	(2)	(3)	(4)
radial highways in year t	-0.0595**	-0.0536***	-0.0373***	-0.0152
	(0.0241)	(0.0190)	(0.0144)	(0.0119)
year t	2005	1999	1999	1999
First Stage F	10.0	9.94	7.04	19.5

Notes: Entries show coefficients from IV regressions of the central city population growth rate during the indicated period on radial highways measured as of the indicated year using analogous specifications to that in column 2 of Table 4. Δln(Pref Pop) matches the timing of Δln(CC Pop). All regressions except those in column 4 instrument for Δln(Pref Pop). It is included as an uninstrumneted control in column 4.

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

Panel A: IV Results

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

Panel B: OLS Coefficients on Transport Measures

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

Notes: In Panel A, road and rail network measures in 1962 instrument for these measures in 2010 while predicted migration flows instrument for Δln(Pref Pop) 1990-2010. Regression specification in Panel B are the same as Panel A except no variables are instrumented for. Standard errors in parentheses are clustered by province.

Table 9: Population Versus Employment Decentralization

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

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

Table 10. Infrastructure and Central City Manufacturing Employment

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

Notes: Regressions in Columns 1-4 are analogous to those in Table 9 column 5, though with different transport measures considered. Regressions in Columns 5-8 are analogous to those in Table 9 column 7.

Table A1: Summary Statistics

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

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

Table A2: Relationships Between Control Variables and 1962 Transport Instruments

	Radial Roads	ln(road kms in prefecture remainder)	Radial Railroads	Ring Road Indicator
ln(central city area)	-0.1334	-0.2240***	-0.0967	-0.0280
	(0.1031)	(0.0273)	(0.0633)	(0.0249)
ln(prefecture area)	0.3240***	1.0655***	0.0024	-0.0042
	(0.1159)	(0.0634)	(0.1282)	(0.0369)
provincial capital indicator	0.8970**	-0.2317	0.4834	-0.0447*
	(0.3619)	(0.1404)	(0.3810)	(0.0225)
ln(prefecture population, 1982)	0.3301**	0.3718***	0.3894***	-0.0032
	(0.1289)	(0.0925)	(0.1329)	(0.0264)
fraction high school or more	-6.4366**	-0.0681	8.7351***	0.6250**
in prefecture, 1982	(2.7832)	(0.9130)	(2.8337)	(0.2618)
share employed in manufacturing	-0.4176	0.4316	1.3155	-0.2647
in prefecture, 1982	(1.7541)	(0.7472)	(1.0647)	(0.1597)
constant	-4.2377**	-8.5481***	-5.1786***	0.3005
	(1.9068)	(1.4069)	(1.5983)	(0.3417)
Observations	257	257	257	257
R-Squared	0.1430	0.6869	0.2362	0.0306

Notes: Each regression is of a different instrument listed at top, measured as of 1962, on base specification controls.

Table A3: IV Estimates of Effects of Roads on Pre-Reform Population Growth and Industrial GDP

	Δ ln(CC Pop) 1982-1990		ln(1990 CC Pop)		ln(1990 Ind. GDP)		ln(2010 Ind. GDP)
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
radial roads in 1980	0.0321						
	(0.0249)						
radial roads in 1990		0.0494					
		(0.0388)					
radial railroads in 1980			0.0218		0.0190		
			(0.0393)		(0.0636)		
radial railroads in 1990				0.0243		0.0208	
				(0.0439)		(0.0695)	
radial railroads in 2010							-0.2097**
							(0.1033)
Δ ln(Pref Pop) 1982-1990	1.4539***	1.4800***					
	(0.2496)	(0.2331)					
ln(1990 Pref Pop)			0.6230***	0.6186***	0.5821***	0.5786***	
			(0.0478)	(0.0481)	(0.1093)	(0.1151)	
ln(2010 Pref Pop)							0.7864***
							(0.1069)
Base Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	257	257	257	257	241	241	257
First stage F	60.4	16.7	110	76	101	75.3	53

Notes: Each column shows coefficients from a separate IV regression of the variable listed at top on the variables listed at left. Base controls are listed in the notes to Table 3. Counterparts measured as of 1962 instrument for transport measures. Standard errors in parerentheses are clustered by province.

Table A4: Employment Decentralization by Industrial Sector - Generalized Shares Specifications

Panel A: High and Medium Weight to Value Ratio Industries

	Heavy weight (food, wood & paper, chemicals, non-metallic, primary metals: SIC13-16,20,22,25-28,31-33)			Medium weight (fab. metals, furniture, plastics, rubber, printing: SIC 21, 23, 24, 29, 30, 34)		
Weight to Value Ratio	0.51 to 0.80			0.22 to 0.35		
	(1)	(2)	(3)	(4)	(5)	(6)
2010 radial highways		-0.0150			0.0654	
		(0.0743)			(0.0989)	
2010 radial railroads	-0.1355*		-0.1342*	-0.2479**		-0.2442**
	(0.0733)		(0.0713)	(0.1231)		(0.1194)
2010 ring road indicator		-0.0866	-0.1439		-0.2070	-0.4136
		(0.3181)	(0.3200)		(0.4177)	(0.4189)
Observations	257	257	257	257	257	257
First stage F	21.5	4.05	4.26	21.5	4.05	4.26

Panel B: Low Weight to Value Ratio Industries

	Textiles, apparel, leather (SIC 17-19)				High tech (SIC 368, 376, 40, 411, 412, 414, 419)			Elec. & non-elec. machinery & equip (non-high tech) [SIC 35-39 (exc. 368, 376), 413, 415]		
Weight to Value Ratio	0.06 to 0.25				0.01			0.12-0.13		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
2010 radial highways	-0.2341*		-0.2959**			-0.2175			-0.0325	
	(0.1291)		(0.1366)			(0.3360)			(0.1116)	
2010 radial railroads		-0.4649**		-0.4571**	-0.6545***		-0.6358**	-0.2360**		-0.2332**
		(0.1885)		(0.2018)	(0.2220)		(0.2872)	(0.1019)		(0.1059)
2010 ring road indicator			-0.9503	-0.8753		-2.0085*	-2.1182*		-0.2328	-0.3251
			(0.6415)	(0.5683)		(1.0631)	(1.1235)		(0.3184)	(0.2937)
Observations	257	257	257	257	257	257	257	257	257	257
First stage F	13.1	21.5	4.05	4.26	21.5	4.05	4.26	21.5	4.05	4.26

Notes: Each column reports coefficients from an IV regression of the 1995-2008 change in ln employment in the indicated manufacturing industries on indicated transport measures and controls. Control variables are the same as in Table 4 Column 2. Panel A does not show the effects of radial highways alone, but as columns 2 and 5 suggest the effects are small and insignificant. Standard errors in parentheses are clustered by province.

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Data Appendix

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

Chinese restrictions on internal migration impose larger barriers to population migration from one prefecture to another than from the rural to the urban part of a prefecture. This fact, together with the fact that the set of prefectures corresponds to the set of cities, suggests that the rural portion of prefectures represents the `hinterland' from which core cities have drawn many migrants, especially in the 1990s (Chan 2001, 2005). Thus, our analysis primarily focuses on two geographic units: constant boundary 1990 core cities ('central cities'), and the surrounding prefecture regions from which they draw many migrants.

Our most complete sample is a set of 257 prefectures in primarily Han provinces of China drawn to 2005 boundaries. Of the 286 total prefecture units in this region, we exclude three because their central cities coincide with their full prefectures, precluding any analysis of decentralization, eight because they had fewer than 50,000 inhabitants in 1990 and 18 because they do not include a core city by 2005. Our study area contains about 85% of China's population. We exclude the less developed non-Han territories in the West because data availability is much poorer in these regions.

Core cities are typically much smaller than prefectures and they sometimes consist of many urban districts. In Figure 2, 1990 core cities are shaded green while urban districts added between 1990 and 2010 are shaded yellow. Whereas the extant literature sometimes treats the entire prefecture as the statistical city (e.g., Deng et al. 2008), inspection of Figure 2 reveals that this is not a defensible geography for cities.

We define `central city' and `hinterland' pairs. Ours is the first study to develop data for China to analyze the allocations of population, employment and economic activity between consistently defined central cities and surrounding prefecture areas. We construct constant boundary central cities by describing core cities in 1990 as a collection of 2005-definition counties. For core cities that existed in 1990, our 1990 central cities consist of all 2005 year units that were designated as urban districts in 1990, or that overlap with 1990 counties having this designation. However, 88 of the 257 core cities in our sample did not exist as core cities in 1990. That is, in 1990 these 2005-definition prefectures did not contain a single urban district. We call such cities 'promoted'. For these, central cities consist of the county cities or rural counties first promoted to urban status. In 1990, most of these yet to be promoted central cities were already treated as urban counties in the relevant Chinese statistical yearbooks, indicating the intention to promote. Of the promoted cities in our sample, 18 experienced boundary changes between 1990 and 2010, while 52 sampled incumbent cities experienced boundary changes. By carefully tracking these changes, we are able to follow constant boundary central cities and prefectures through the four cross-sections covered by our data, 1990, 2000, 2005 and 2010.

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

GDP: Most prefecture level cities and some large county cities report GDP back to 1990. Less complete GDP information is available at the prefecture level. 1990 GDP and industrial sector GDP information comes from national and provincial printed data year books (China Statistics Press, 1992b and 1992c). In 2010 we use GDP information from the University of Michigan's Online China Data Archive. These data describe rural counties, county cities and core cities according to contemporaneous definitions. Because we do not have a comprehensive source for GDP information disaggregated below the core city level in 1990 and there are a few missing observations in the 2010 data, we have a sample of 241 out of 257 cities for which we observe industrial sector GDP in both 1990 and 2010.

Industrial Employment: We use the first and second national economic censuses of China from 1995 and 2008 for detailed industrial employment data by central city and prefecture remainder. We aggregate establishment level information into data on the number of workers by location and industry type. Our discussion of grouping of industries into types later in the paper is based on weight to value ratios of output in each narrow industry category, except for high tech, for which we use the Chinese definition. We take weight to value ratios for other manufactures from the U.S., following Duranton, Morrow and Turner (2014). Given that most of these products are internationally traded, such ratios from U.S. sources are likely to apply reasonably closely in China as well.

Infrastructure: To describe the Chinese road and railroad network, we digitize a series of large scale national transportation maps. This involves scanning large paper maps, projecting the resulting image and electronically tracing each of the transportation networks of interest. The resulting tracings are our digital road and railroad maps. We rely on national maps rather than more detailed provincial maps to ensure consistency within each cross-section. To improve consistency across time, when possible, we selected maps from the same publisher, drawn using the same projection, the same scale and with similar legends. However, the physical characteristics of recorded highways change over time. For example, 1990 and 1962 'highways' are typically two-lane free access roads, many of which are not all-weather or even paved.

In this way we are able to construct digital maps for railroad and highway networks for each of the following years: 2010 from SinoMaps Press (2010), 2005 from SinoMaps Press (2005); 1999 from Planet Maps Press (1999); 1990 from SinoMaps Press (1990); 1980 from SinoMaps Press (1982); and 1962 from SinoMaps Press (1962).

Using these digital maps, we calculate radial and ring highway and railroad capacity measures, and the total length of each transportation network within each prefecture and 1990-definition central city. For highways in 2010, we use the union of high-grade highways (*gao dengji gonglu*), national highways (*guo dao*), and general highways (*yi ban gonglu*) indicated on our 2010 road map. Using Google Earth for a sample of randomly selected points in 20 cities, we find general highways average 3.7 lanes, versus 4.3 lanes for high-grade highways. However general and national highways were usually not limited access. We use the union of the high-grade highway and high-grade highway under construction (*gao deng ji gonglu* and *wei cheng gao deng* *ji gonglu*) plus highway and highway under construction (*gonglu* and *wei cheng gonglu*) for the 2005 network. These are the only two types of roads indicated on our 2005 map. From the 1999 map, we use the union of the national and high grade highways networks in place and under construction (*gao su, gao deng ji gonglu, jianzhuzhong gao su, gao dengji gonglu, guo jia ji gonglu).* Finally, our measure of 1962 roads is based on the single highway network (*gong lu*) described in our 1962 road map. While all of the roads we study from 1999 forward are highways, the unavoidable inconsistencies between 2010 maps and earlier years mean that our highway measures are not directly comparable over time. Most maps only have one railroad classification.

The calculation of the radial and ring road and rail ray indices are described in the text. Here we elaborate for clarity. We first draw rings of radius 5km and 10km around the central business district (CBD) of each central city. We then count the number of times a particular transportation network crosses each of these two rings. Our index of radial roads is the smaller of these two counts of intersections. Thus, this index measures the number of radial segments a particular network provides, while excluding segments that do not come sufficiently close to the city center. Figure 3a illustrates this algorithm. In this figure, the green area is the Beijing central city, the locations of CBDs are given by dots, the 2010 high grade highway network is represented by red lines and the two relevant rings around each CBD are in black. Figure 3a indicates that our radial road index value is 6 for the 2010 high grade highway network in Beijing. The process for counting rail rays is the same.

For the ring road index, our goal is to generate an index number to measure the capacity of a particular network to move traffic in a circle around the CBD. We proceed quadrant by quadrant. Figure 3b illustrates the calculation of our ring road index for the 2010 national road network for the northwest quadrant of Beijing and two nearby cities. For each city, we begin by drawing two rays from the CBD, one to the west and the other to the northwest. We next restrict attention to intersections that lie between 5 and 9 km from the center. In the figure, these are areas bounded by the two black circles. We next identify all intersections of each ray with the road network within the rings. In the case of Beijing there is one each. The northwest quadrant ring road index for the 5 to 9 km ring is the minimum of these two counts of intersections, which is still one each. For the other cities shown, the minimum is zero. To finish our calculation of the ring road index in the 5 to 9 km annulus centered on the CBD, we replicate this calculation for each of the four quadrants and sum the resulting quadrant by quadrant index numbers. Thus, a one unit increment in this index reflects a single road traveling about 45 degrees around the center while remaining between 5 and 9 km from the center. We replicate this calculation for roads that lie between 9 and 15 km from the CBD and 15-25 km from the CBD. In our empirical work, we sum the results of these three calculations and restrict attention to roads that lie outside the central city. Because few cities had circumferential road infrastructure in 2010, we use an indicator of the existence of any ring road segment outside the central city as our primary ring road measure.

Lights at Night: We use satellite data primarily as a source for lights at night. For Table 1, we used lights at night images of China (NGDC 1992-2010) from 1992, 2000, and 2010. For each cell, these data report an intensity of night time lights ranging from 0 to 63. The codes 0-62 indicate intensity, while 63 is a top code. Top coding is rare in China, although it is common in cities of Western countries.

We also use the 1992 lights at night data to identify the CBD location in each 1990 central city. To accomplish this, we select the brightest cell in each central city. If there is not a single brightest cell, we break ties with the sum of light in successively larger rings surrounding each brightest cell. The left part of Figure 4 illustrates lights information and the resulting CBDs for

Beijing and four nearby central cities. White-gray areas show three intensities of light from the 1992 lights at night data and dots identify CBDs. As the figure demonstrates, our algorithm identifies points that look like the most central point of the 1992 lights data. The right part of Figure 4 shows lights at night for the same area in 2009. In spite of the fact that light increases enormously over the intervening 17 years, 1992 city centers are still clearly brightest in 2009 as well. These points also tend be centrally located in the central cities' road networks. Our 1992 CBDs are also almost always within a few kilometers of an old walled city. If they are not, it is usually because the old walled city is at one sub-center while our calculated CBD is at another.

References

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

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

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

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

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

China Statistics Press , 2002. 2000 Census County Statistics.

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

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

National Geophysical Data Center, 4 DMSP-OLS Nighttime Lights Time Series, 1992-2005.

Planet Map Press , *Map of the Peoples Republic of China*, scale 1:6000000, as of Jan 1999, published in March 1999, Peoples Liberation Army, Factory 1206, distributed by Xinhua bookstore.

SinoMaps press, Map of the Peoples Republic of China, scale 1:4000000, as of 1980, publication date October 1982, Shanxi, *Zhong guo di zhi tu zhi yin chang*.

SinoMaps press, *Map of the Peoples Republic of China*, scale 1:4000000, as of August 1990, publication date August 1990, Hebei, *Zhong guo di zhi tu zhi yin chang*.

SinoMaps press, *Map of the Peoples Republic of China*, scale 1:4500000, as of March 2005, published June 2006, Peoples Liberation Army, Factory 1206, distributed by Xinhua bookstore.

SinoMaps press, *Map of the Peoples Republic of China*, scale 1:4500000, as of Jan 2010, published Jan 2010, Peoples Liberation Army, Factory 1206, distributed by Xinhua bookstore.

Table O1: Effects of Transport on Industrial Sector GDP, 1990-2010 Excluding the West

Panel A: IV Results

	Δln(Central City Industrial GDP) 1990-2010							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
2010 radial highways	0.0638		0.1053			0.0246		
	(0.0566)		(0.0695)			(0.0772)		
2010 radial railroads		-0.2039*	-0.2455*	-0.1752*			-0.2073	-0.3549***
		(0.1067)	(0.1350)	(0.0954)			(0.1286)	(0.0811)
ln(railroad kms in prefecture				-0.0695				
remainder, 2010)				(0.0978)				
2010 ring road indicator					-0.5767*	-0.5461	-0.7944**	
					(0.3342)	(0.3755)	(0.3609)	
ln(central city area)	0.1041*	0.0910	0.0715	0.0631	-0.0038	-0.0011	-0.0704	
	(0.0626)	(0.0575)	(0.0769)	(0.0561)	(0.0660)	(0.0701)	(0.0746)	
ln(prefecture area)	-0.3230***	-0.2831***	-0.3448**	-0.2033	-0.2807***	-0.2955***	-0.2767***	
	(0.1144)	(0.0983)	(0.1413)	(0.1700)	(0.0794)	(0.1046)	(0.0963)	
provincial capital indicator	0.3008*	0.5619***	0.4262**	0.5700***	0.4296***	0.3888**	0.6016**	
	(0.1586)	(0.1879)	(0.2051)	(0.1815)	(0.1653)	(0.1955)	(0.2344)	
ln(prefecture population, 1982)	-0.0607	0.0675	-0.0299	0.0656	0.0194	-0.0071	0.0870	
	(0.1108)	(0.1267)	(0.1197)	(0.1292)	(0.0939)	(0.1086)	(0.1226)	
fraction high school or more	-5.9098***	-3.9956**	-3.6752**	-3.9382**	-5.8230***	-5.8401***	-3.8970*	
in prefecture, 1982	(1.4205)	(1.7543)	(1.8353)	(1.7114)	(1.6008)	(1.5659)	(2.1586)	
share employed in manufacturing	-0.9168	-1.4129**	-0.9452	-1.4500**	-1.1373**	-1.0234**	-1.2971**	
in prefecture, 1982	(0.6821)	(0.6585)	(0.7703)	(0.6398)	(0.5579)	(0.5065)	(0.5644)	
Δ ln(Pref Pop) 1990-2010	-0.7295	-0.7498	-1.1854*	-0.7636*	-0.6598*	-0.7411*	-0.9786*	
	(0.4748)	(0.4745)	(0.7030)	(0.4495)	(0.3800)	(0.4194)	(0.5786)	
constant	7.0429***	5.2941***	7.1140***	5.0499**	6.6391***	7.0516***	6.3453***	3.8657***
	(1.6877)	(1.8062)	(2.0338)	(1.9784)	(1.5659)	(1.8207)	(2.0441)	(0.1572)
Observations	198	198	198	198	198	198	198	198
First stage F	10.9	32.9	5.71	4.58	4.85	3.02	2.49	89.0

Panel B: OLS Coefficients on Transport Measures

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
2010 radial highways	-0.0043		-0.0028			-0.0113		
	(0.0181)		(0.0173)			(0.0197)		
2010 radial railroads		-0.0159	-0.0153	-0.0153			-0.0193	-0.0714*
		(0.0342)	(0.0333)	(0.0359)			(0.0326)	(0.0345)
ln(railroad kms in prefecture				-0.0035				
remainder, 2010)				(0.0459)				
2010 ring road indicator					-0.1952**	-0.2015**	-0.1977**	
					(0.0907)	(0.0938)	(0.0906)	

Notes: These regressions are analogous to those in Table 8, except this sample excludes prefectures in the West.

Table O2: Population Versus Employment Decentralization Excluding the West

	Δln(CC Pop) 1990-2010		Δln(CC Working Residents) 1990-2010		Δln(CC Residents Working in Manuf.) 1990-2010		Δln(CC Manufacturing Employment) 1995-2008	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
2010 radial highways	-0.0593**	-0.0855**	-0.0538	-0.0858**	0.0828	0.0586	0.0441	0.0386
	(0.0257)	(0.0351)	(0.0381)	(0.0368)	(0.1371)	(0.1412)	(0.1186)	(0.1283)
2010 radial railroads	-0.0015	0.0062	-0.0390	-0.0296	-0.3414*	-0.3342*	-0.2784**	-0.2767*
	(0.0539)	(0.0617)	(0.0596)	(0.0646)	(0.1778)	(0.1776)	(0.1403)	(0.1415)
ln(central city area)	-0.1121***	-0.1056***	-0.0425*	-0.0347	0.2343***	0.2402***	0.1575***	0.1588***
	(0.0231)	(0.0293)	(0.0247)	(0.0287)	(0.0729)	(0.0702)	(0.0573)	(0.0571)
ln(prefecture area)	0.0719***	0.0347	0.0883***	0.0431	-0.3942***	-0.4285***	-0.3733***	-0.3811***
	(0.0271)	(0.0299)	(0.0336)	(0.0302)	(0.1252)	(0.1053)	(0.1123)	(0.0938)
provincial capital indicator	0.2468***	0.3352***	0.2209**	0.3286***	-0.0836	-0.0021	0.0270	0.0455
	(0.0863)	(0.0789)	(0.1104)	(0.0835)	(0.1870)	(0.1930)	(0.1759)	(0.1762)
ln(prefecture population, 1982)	0.1134***	0.1535***	0.1106***	0.1594***	0.4740***	0.5110***	0.2691**	0.2775*
	(0.0389)	(0.0506)	(0.0397)	(0.0457)	(0.1670)	(0.1797)	(0.1282)	(0.1436)
fraction high school or more	-0.8824	-0.3589	-2.1162**	-1.4790**	-7.2975***	-6.8148***	-3.2071	-3.0976*
in prefecture, 1982	(0.6417)	(0.5988)	(1.0096)	(0.7109)	(2.0465)	(1.9624)	(1.9774)	(1.8338)
share employed in manufacturing	-0.4477*	-0.7307**	-0.3784	-0.7229**	-0.4485	-0.7094	0.2162	0.1570
in prefecture, 1982	(0.2380)	(0.3244)	(0.3192)	(0.3388)	(1.0496)	(1.1166)	(0.7934)	(0.8456)
Δ ln(Pref Pop) 1990-2010	0.9098***		1.1074***		0.8388		0.1903	
	(0.1932)		(0.2306)		(0.6886)		(0.5784)	
Δ ln(Pref Emp) 1990-2010		0.9248***		1.1257***		0.8527		0.1934
		(0.2713)		(0.2949)		(0.6309)		(0.5767)
Constant	-0.8969	-1.0749	-1.5140**	-1.7306**	-4.0466	-4.2107*	-0.5969	-0.6341
	(0.6662)	(0.8701)	(0.6658)	(0.7737)	(2.5613)	(2.5386)	(2.2472)	(2.3250)
Observations	208	208	208	208	208	208	208	208
First stage F	6.40	3.11	6.40	3.11	6.40	3.11	6.40	3.11

Notes: Regressions are analogous to those in Table 9 except the sample excludes prefectures in the West.

Table O3. Infrastructure and Central City Manufacturing Employment Excluding the West

	Δln(Central City Residents Working in Manufacturing) 1990-2010				Δln(Central City Manufacturing Employment) 1995-2008			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
2010 radial highways	0.0348		-0.0285		0.0049		-0.0034	
	(0.1009)		(0.1291)		(0.1046)		(0.1135)	
2010 radial railroads		-0.3137**		-0.2991**		-0.2636**		-0.2591**
		(0.1353)		(0.1523)		(0.1095)		(0.1041)
2010 ring road indicator			-0.8829**	-1.1198***			-0.1165	-0.3485
			(0.3894)	(0.3521)			(0.3035)	(0.3024)
ln(central city area)	0.2704***	0.2470***	0.0988	0.0207	0.1869***	0.1643***	0.1643**	0.0938
	(0.0492)	(0.0580)	(0.0734)	(0.0867)	(0.0411)	(0.0561)	(0.0657)	(0.0711)
ln(prefecture area)	-0.3658***	-0.3470***	-0.3113**	-0.3235***	-0.3501***	-0.3482***	-0.3429***	-0.3408***
	(0.1275)	(0.1069)	(0.1260)	(0.1180)	(0.1099)	(0.0790)	(0.1133)	(0.0840)
provincial capital indicator	-0.2950*	0.0184	-0.1480	0.0714	-0.1454	0.0813	-0.1260	0.0978
	(0.1701)	(0.1807)	(0.2394)	(0.2425)	(0.1632)	(0.1816)	(0.1758)	(0.1878)
ln(prefecture population, 1982)	0.4020**	0.5552***	0.4826***	0.5635***	0.2104	0.3124***	0.2210	0.3150***
	(0.1689)	(0.1168)	(0.1605)	(0.1002)	(0.1287)	(0.0713)	(0.1400)	(0.0631)
fraction high school or more	-9.6079***	-7.3664***	-9.7021***	-7.7082***	-5.0911***	-3.2437*	-5.1035***	-3.3501*
in prefecture, 1982	(1.9079)	(2.0371)	(1.7139)	(1.8028)	(1.3865)	(1.8574)	(1.3769)	(1.8481)
share employed in manufacturing	-0.3598	-0.8078	-0.4243	-0.5033	0.2886	0.0250	0.2800	0.1198
in prefecture, 1982	(1.0076)	(0.8706)	(0.8865)	(0.7507)	(0.7920)	(0.9416)	(0.7724)	(0.9163)
Δ ln(Pref Pop) 1990-2010	1.3775***	1.1582***	1.3781***	0.8942*	0.6296	0.3603	0.6296	0.2781
	(0.4035)	(0.3802)	(0.4386)	(0.4769)	(0.4028)	(0.4089)	(0.3996)	(0.4307)
Constant	-3.7495*	-5.5246***	-3.7266*	-3.9149**	-0.3546	-1.3835	-0.3516	-0.8825
	(2.0508)	(1.4392)	(1.9127)	(1.5756)	(2.0313)	(1.1516)	(2.0096)	(1.0931)
Observations	208	208	208	208	208	208	208	208
First stage F	11.5	32.9	3.00	2.85	11.5	32.9	3.00	2.85

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