Transport Infrastructure, Urban Growth and Market Access in China

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January 1, 2015

1 Introduction

Little is known about the causal effects of transport infrastructure on urban growth, especially in developing countries. Despite a host of formal models that emphasize various mechanisms through which improved transport infrastructure may promote local growth, even less is known empirically about the relative importance of these mechanisms. Many developing countries are currently investing or considering investing billions of dollars in transport infrastructure improvements, with about 20% of World Bank lending going to transport infrastructure projects, more than for poverty reduction. Systematic evaluation of the causal effects of new highways and railroads that reduce intra and inter-regional travel costs informs these important policy decisions. Moreover, with almost half of the population of developing countries now living in cities, and this share rising rapidly, a better understanding of the drivers of urban growth in the developing world is central for informing policy that promotes the process of development.

This paper quantifies the causal effects of various types of investments in the road and railroad networks on economic growth in Chinese cities and regions. We separate out the influences of changes in access to markets that have come through better inter-regional and international transport links from the more direct effects of transport infrastructure on city level productivity, which may operate through various channels. Moreover, by separately considering effects of transportation on city and regional growth, we make progress on separating out the extent to which improved transport infrastructure promotes aggregate growth versus redistribution of economic activity. Critical to our evaluation is the use of pseudo-random variation in the allocation of transport networks to cities and their surrounding regions.

In order to recover estimates that are intuitive and directly applicable to policy, much of our analysis considers the causal effects of various measures of "market potential" on city and prefecture growth. We measure market potential as the aggregate GDP or employment accessible within various travel time bands of prefecture cities. To facilitate comparison of our results with some in the literature, we also adapt Hornbeck & Donaldson's (2014) adoption of Eaton & Kortum's (2002) model of interregional trade to the Chinese context. This model emphasizes how transport cost reductions can facilitate better exploitation of Ricardian gains to interregional domestic and external trade. It delivers useful guidance about the forms of estimation equations and structural interpretation of estimated effects of improved "market access" on local growth.

We find strong evidence that improved integration with nearby markets significantly promoted local growth in China since 1990. In particular, expansions of road infrastructure leading to a 10 percent increase in economic activity within a six hours' travel time led to an estimated 1.4 percent more rapid prefecture GDP growth and 1.1 percent more rapid prefecture city GDP growth. Expansions of road infrastructure leading to a 10 percent increase in population within six hours caused an estimated 1.6 percent increase in prefecture GDP growth and an imprecisely estimated 1.3 percent increase in prefecture city GDP growth. Estimated causal effects of more theoretically grounded measures of market access on local growth are consistent with these effects of more reduced form market potential measures.

While we find that improved regional integration promoted local GDP growth in China, we find no significant effects of regional integration on prefecture or city population growth. Instead, we find evidence that improved access to international ports promoted population growth. A 10 percent decline in travel time to an international port caused a 0.6 to 0.7 percent increase in prefecture and city population growth. The context of severe migration restrictions in many cities and policies promoting foreign investment in other cities is important for interpreting these results. In the early 1990s, China embarked on a national plan to promote foreign investment by permitting foreign companies to establish production plants primarily oriented toward exports in certain special development zones that typically had good port access. Such zones drew in many workers from elsewhere and may be an important driver of the population effects that we find. Otherwise, hukou migration restrictions have made rural-urban migration costly. The larger effects of domestic trade integration on GDP than population growth are consistent with institutional migration restrictions.

Our investigation of the effects of highways and railroads serving prefecture cities is less conclusive. While point estimates tend to be positive, they are generally imprecise. However, we do find that each radial railroad serving prefecture cities caused about 6% more rapid growth in prefecture and prefecture city populations. Given evidence in Baum-Snow et al. (2014) that railroads promoted decentralization of manufacturing activity toward peripheral areas of prefecture cities, this result indicates that railroads may also have facilitated growth in manufacturing.

It is important to recognize that our estimates come from comparing across regions in a context in which the fertility rate is constrained to be at most only slightly responsive to changes in local economic conditions because of the One Child Policy, which was implemented over the course of the 1980s. Therefore, the population results likely mostly reflect redistribution across regions rather than aggregate population growth. Joint with the result that domestic market potential does influence population, this observation suggests that the positive effects of domestic trade integration on GDP are primarily reflected in aggregate growth rather than simply redistribution. However, the population growth effects of improved access to the coast, with no discernible commensurate GDP effects, may simply reflect a relaxation of hukou restrictions in some such areas.

We recognize that there are many mechanisms through which improved market integration may promote growth, all of which cannot be tractably included in a simple model. For example, Fajgelbaum and Redding (2014) emphasize the rise of the nontraded sector and rising demand for traded manufacturing goods for facilitating structural change and urban growth. Topalova & Khandelwal (2011) provide evidence that lower trade costs has fostered innovation through competition in India. Lower cost access to intermediate inputs (Fujita, Krugman & Venables, 1999) and innovative ideas (Alvarez, Buera & Lucas, 2013; Buera & Oberfeld, 2014) are additional mechanisms through which trade may promote growth. Because of the many choices available for modeling interactions between regions, well-identified treatment effects can have multiple structural interpretations and be driven by many mechanisms. Such theoretical ambiguity prompts us to focus on recovering credible estimates of treatment effects of transport infrastructure improvements, while at the same time facilitating their interpretation in the contexts of the models of interregional trade in Eaton & Kortum (2002) and Fujita et al. (1999).

Our evidence on the effects of reduced transport costs for enhanced domestic market integration echoes some recent literature that improved market access, which increases the value of city output net of transportation costs, fosters local economic growth in developing country contexts. Donaldson (2014), Banerjee, Duflo, and Qian (2012) and Storeygard (2012) find that better linked hinterlands through colonial railroads in India, modern railroads in China and modern roads in Sub-Saharan Africa respectively have higher income levels. Donaldson and Hornbeck (2014) find similar results for rural counties in the late 19th century United States, though Faber (2014) finds the opposite for some rural counties served by roads in China. One important challenge in this literature is to find a source of pseudo-randomization in the allocation of transport infrastructure that allows for the recovery of causal relationships in the data.

Our study innovates on the existing literature about the effects of reduced domestic trade costs on local growth in several ways. First, we consider both highways and railroads.

Second we primarily examine cities, rather than rural counties or small towns. Third we examine the effects of transport infrastructure on the growth and redistribution output and population simultaneously, rather than on inferred income or the output of specific commodities. Finally, we examine the responses to various measures of the composition of output in the regions surrounding cities in various distance and travel time bands.

Even less evidence exists on the effects of transport networks on local economic growth through mechanisms internal to cities, and all such empirical work using data from many cities provides evidence from the United States. Most existing theoretical research which examines urban productivity growth, as in Lucas (1988), Black and Henderson (1999), Rossi-Hansberg and Wright (2007), and Duranton (2007), considers innovation and knowledge accumulation but not mechanisms related to transportation costs. Fernald (1999) and Duranton & Turner (2012) conceptualize environments in which transport improvements foster local growth through direct effects on total factor productivity and indirectly through reduced commuting times and associated improved amenity value for residents, which draws in additional residents and may spill over into higher TFP. However, neither of these studies is able to use direct measures of city output, nor do they examine effects of roads through improved market access, part of which they may be measuring since improved market access is potentially correlated with improved transport networks for use within cities. Beyond the possibility that decomposing the effects of improved urban transport infrastructure on growth through different channels is inherently interesting and important, our analysis is the first to facilitate a joint consideration of growth and redistribution.

The Chinese context is especially well-suited for our investigation for several reasons. Chinese cities have experienced large variation in expansions of internal transport networks and to market access since 1990. In 1990 China had no expressways. Almost all goods moved by rail or river and less than 5 percent of freight ton-miles moved by road. Since then, China has undertaken massive intercity expressway construction. Construction started slowly, with only a few highways complete by 2000, but sped up so that a national scale network was largely complete by 2010. Now, over 30% of freight ton-miles move by road. This highway construction program has left some cities with sophisticated internal transport networks and/or high quality links to nearby hinterland markets and much less transport development in and/or nearby other cities. Second, comprehensive data on output by sector and inputs exist for each city and rural county for our study period of 1990-2010.

Central for recovery of credible treatment effects, we have good sources of pseudo-randomization in highway treatments across cities and rural counties. The unique Chinese historical context allows us to construct plausibly exogenous instruments for cities' internal transport networks and their market access using two strategies. The first source of variation uses historical road networks. Roads in the Maoist period were used almost exclusively for within prefecture movement of agricultural products, while rails and rivers were used for inter-city shipment of manufactured goods. Historical roads provide right-of-ways facilitating lower cost highway construction over or alongside old roads, all of which has taken place since 1990.

This paper proceeds as follows. Section 2 discusses the unique Chinese context and the data. Section 3 describes the market potential and market access measures that we use for empirical investigation. Section 4 lays out our empirical strategy and estimation equations. Section 5 presents the results. Section 6 concludes.

2 Context and Data

Chinese cities represent an ideal laboratory for studying the causal effects of transport infrastructure on local economic growth and their various mechanisms. There is useful identifying variation across cities in the amount of transport infrastructure constructed since 1990, information on outcomes of interest over time at a disaggregate geographic scale and sources of plausibly exogenous variation in the allocation of transport networks between cities and nearby hinterlands.

In addition to data considerations, the unique history of the Chinese transition toward a market economy makes 1990 a good starting point for our analysis. While there were some market oriented reforms during the 1980s in the agricultural sector, Chinese cities remained fully centrally planned economies until the early 1990s. Even agricultural markets were sufficiently localized with fractured ownership such that very little trade in agricultural goods existed between prefectures. Housing and employment were provided by local governments for a planned industrial mix, with inter-prefectural trade flows largely proscribed in provincial capitals. There were no urban land markets allocating space to its most productive use. Given this environment in which interregional trade flows did not use roads, were very small, and did not follow market incentives, some of our empirical work below treats prefectures as if they existed in autarky in 1990. At least relative to 2010 - the final year of our analysis - it is reasonable to view 1990 as one of the final years before market forces began to determine an important fraction of inter-prefectural trade flows. Moreover, 1990 is one of the final years in which city structure and productivity was unlikely to respond to the nature of the internal transportation network.

Starting in the early 1990s, market forces have played an increasingly important role governing the workings of Chinese cities and their trade interactions. Urban land ownership started to be converted to 99 year leaseholds around 1992, with much of the proceeds of the associated land "sales" going to support local governments. Industrial production has primarily moved out of city centers to urban peripheries, thereby freeing up central space for denser residential and production activities (Baum-Snow et al., 2014). Given this particular institutional history, our estimates partly reflect the effects of new transport infrastructure in the context of a shift toward a market based economy.

China had essentially no limited access highways in 1990. Intercity roads had two lanes with free access and, in some places, were not even paved. Urban workers typically had short commutes, as most work places were close to or on factory grounds. Intercity movement of goods relied disproportionately on railroads well into the 2000s and almost exclusively on railroads in 1990. While much of the current railroad system was in place in 1990, China's entire expressway system, the National Trunk Highway System (NTHS), has been constructed since 1990.

Because we use 1962 roads as a source of identifying variation, it is important to understand how the national road and rail systems were used then. In 1962, roads existed primarily to move agricultural goods to local markets within prefectures 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. Lyons (1985, p. 312) states: "At least through the 1960s most roads in China (except perhaps those of military importance) were simple dirt roads built at the direction of county and commune authorities. According to Chinese reports of the early 1960s, most such roads were not fit for motor traffic and half of the entire network was impassable on rainy days." Lyons also notes that average truck speeds were below 30 km/hr due to poor road quality.

Figure 1 shows the national road networks in 1962, 1990, 2000 and 2010. Superimposed on the 1962 road network in the lower right panel is the "5-7 plan" from the early 1980s for linking major cities with expressways. These are straight line connections between nodes. We use the 1962 network to construct instruments for 2010 travel costs, assuming travel speeds of 25 kph on local roads and 90 kph on highways, as is explained in more detail below. Moving forward in time, we see the national highway system developing some between 1990 and 2000, and linked most of the country by 2010.

As it was the primary mode used for interregional trade and travel, the 1962 rail network was oriented to link manufacturing cities to raw materials and demand. Most large scale manufacturing activity in this era occurred in provincial capitals. These were also important administrative centers, since each province carried out most of its own economic planning, with little inter-provincial trade. As such, provincial capitals have different institutional and industrial histories from other cities, which is something we take into consideration in our empirical work below. Moreover, the 1962 railroad network was oriented to serve provincial capitals.

The validity of our empirical conclusions will rely on achieving pseudo-random variation in transport variables of interest. The possibility that highways may be allocated to faster growing cities, prefectures, and regions is a particular concern. We follow Duranton and Turner (2011, 2012) by using historical transportation networks to predict modern networks. We discuss the specifics of our identification strategy in Section 4. Especially for justifying the use of 1962 railroads as an instrument for modern railroads serving cities, we also lean on the context that Chinese interregional trade was under a planning regime in 1990.

Because prefecture and city populations are outcome variables of interest to us, it is important to understand the history of interregional population mobility in China. Before 2000, with the exception of a few coastal mega-cities, cities hosted few migrants. Migration was limited by the hukou system, which regulated and restricted between prefecture migration and imposed penalties for un-licensed migration. These restrictions were lifted in stages starting in the late 1990s and un-licensed migration is no longer illegal. However, the hukou system still restricts migrant access to formal housing markets, schools, health care, and social security (Chan, 2008), restrictions that are harsher in larger cities that are otherwise more attractive to migrants. Because of such migration restrictions, most migration in the 1990s occurred within prefectures, as farmers left the land and moved from rural to urban counties (Chan, 2005). Therefore, rising city productivity or demand for city output is likely to be partly reflected in rising real wages in some cities (Au & Henderson, 2006) rather than rising populations, as is the urbanization process in many developing countries. Restrictions on migration argue against using population measures as direct indicators of city productivity. However, population growth in Chinese cities is of interest for its own sake and because of labor's role in production. Yet, even with the hukou system, migration rates are likely to respond to changes in local output.

Despite migration restrictions, China experienced considerable rural to urban migration during our study period. In 1990 China's population was about 29% urban, rising to over 38% in 2010. Prefecture city population growth 1990-2010 was 36% on average relative to just 14% for full prefectures. This rate of urbanization could be seen as surprisingly low given the fact that GDP per capita has always been much higher in prefecture cities than in rural areas of prefectures. Though some GDP per capita differences across space may be compensated for with higher living costs and/or lower amenity values, the returns to rural-urban migration appear to have been high since at least 1990. In 1990, the ratio of GDP per capita in cities relative to rural areas was 2.4, falling slightly to 2.1 by 2010.

Table 1 Panels A and B presents summary statistics showing trends in population and GDP in prefectures and prefecture cities. Beyond the fact that cities have been growing much more rapidly in both population and GDP terms, it is important to recognize the very high rates of GDP growth China has experienced since 1990. This will partly manifest itself in larger estimated effects of various measures of market integration on GDP growth than on population growth.

2.1 Data

Chinese administrative geography dictates the spatial units that we use in our analysis. Provinces are broken into prefectures which themselves are divided into urban districts, county cities and rural counties. We use city and prefecture geographic units for our analysis. Our cities are urban district agglomerations as of 2010. Over the course of our study period, the boundaries of a number of counties and prefectures changed and new prefectural cities were created, requiring painstaking work establishing county level correspondences over time. We examine 282 prefectures in Han China (about half the land area of China), omitting minority areas for data and contextual reasons, the 3 cities directly governed by provinces, and one island prefecture. Our study area covers over 85% of China's population. We designate the largest county city as the main city in each of the 18 prefectures without an official prefecture city.

We use two primary types of data: tabular data from the census and city and provincial yearbooks for 1982. 1990, 2000 and 2010 and a series of large scale national rail and road maps from 1924, 1962, 1980, 1990, 1999, 2005 and 2010. The remainder of this section provides some detail.

Information on output is reported for many prefecture cities and county cities, and some prefectures, back to 1990. For 1990, we obtain GDP and industrial sector GDP information from various national and provincial data yearbooks. In 2000 and 2010 we use output information from the University of Michigan's Online China Data Archive at the rural county, county city or city proper levels or yearbooks that also break out data to the urban district level for a few cities. For GDP data, we face a city coverage problem. For prefectures and cities that undergo major boundary changes we do not have a detailed breakdown of GDP data at the county level to fully construct 1990 numbers, especially at the prefecture level. Because many cities' 2010 geographies include regions which were rural counties in 1990, in many cases we do not have detailed rural county data to fully construct 1990 GDP data within 2010 city boundaries.

To construct 1990 prefecture and city level GDP numbers, we impute GDP by sector for each spatial unit with missing data using the following procedure. We begin by subtracting reported GDP by sector for prefectures and cities for which we have data from reported provincial aggregates. In each residual region, we allocate the residual GDP by sector according to reported value added by sector in the 1990 "Fenxian" data set describing rural counties and county cities. For spatial units without Fenxian data, we allocate this residual according to employment shares by industry. We repeat this same procedure to impute GDP information for rural portions of prefectures and individual urban districts in cities for which we have aggregate GDP information. For the few rural counties missing GDP information in 2000 and 2010, we predict GDP by sector from a regression of sectoral GDP on employment by industry among rural counties only.

We use 100% count National Population Census data from 1990, 2000 and 2010 to construct city and prefecture population and employment by industry. Individual-level 0.3 percent to 1 percent sample data drawn from censuses in 1982, 1990, 2000 and 2010 enable us to construct estimates of key demographic variables at the county and urban district levels. We observe these individuals' age, gender, educational attainment, occupation and sector, as well as their residency (or hukou). The latter is critical to identifying migrants. In addition, for the 2000 and 2010 census, we also know the province of birth for all individuals, which will be useful as we try to break down inter and intra-provincial population flows.

To describe the Chinese road and railroad network, we digitize a series of large scale national paper maps. We select maps from the same publisher drawn using the same projection and with similar legends to have some consistency across time. However, details of what roads are recorded and their characteristics do change over time. Using the digital maps, we calculate travel times between each pair of prefecture cities over the highway and railroad networks in each year. For constructing market potential and market access measures, we utilize travel time matrices assuming that all travel between prefecture cities occurs on the same mode, whichever is fastest.

To calculate radial road and rail indexes for measuring transportation infrastructure that is internal to cities, we draw rings of radius 5km and 10km around the CBD of each central city. We then count the number of times a particular transportation network crosses each of the 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, excluding segments which do not come sufficiently close to the center. These are the same measures used in Baum-Snow et al. (2014).

Summary statistics in Table 1 Panel C show a modest increase in the number of radial mostly unimproved roads serving cities between 1962 and 1990, from an average of 2.0 to 2.9. Because these vintage 1990 roads were not suitable for long distance truck travel, we treat them as providing essentially 0 transport infrastructure relative to that provided by the limited access highways constructed after 1990. In 2010, the average city in our sample had 3.8 radial highways, which we also treat as the difference between 1990 and 2010. Unlike roads, railroads were not upgraded nearly as much between 1990 and 2010. Cities in our sample had on average 1.5 radial railroads in 1990 and 1.8 radial railroads in 2010.

Henderson, Storeygard and Weil (2011) show that lights at night are a good proxy for GDP at the national level, and this appears to be the case for prefecture units in China. We rely on six 'lights at night' images of China (NGDC 1992-2009) For each cell, these data report an intensity of nighttime lights ranging from 0-63, with 63 being 'a topcode', occurring rarely in China. We use the 1992 lights data to identify the central business district (CBD) in each prefecture city, picking the brightest cell in 1992.

3 Measuring Trade Integration

In this section, we first develop a standard model that delivers summary measures of access to nearby markets that can be calculated with our data. While we empirically consider the effects of transport infrastructure on urban growth through mechanisms that are both internal and external to cities, we focus the formal model on mechanisms that involve interregional interactions. We do so because the theory is well developed and delivers tractable estimation equations. In the empirical work, we also consider alternative measures of interregional trade linkages, as we explain further in Section 3.3 below.

3.1 Market Access

We adopt a model that delivers measures of domestic and external market access for each prefecture that predict local GDP and population levels in equilibrium. They thus capture two mechanism through which trade integration can lead to local economic growth. Reductions in shipping costs and the associated increases in market access facilitate better exploitation of comparative advantages in production and Ricardian gains from trade both domestically and through external trade. Because the model we adopt is unlikely to capture the only mechanisms driving variation in local economic activity, we emphasize that we will still find it important to isolate variation in market access measures that are likely exogenous in a much broader class of models or, equivalently, that are unrelated to other mechanisms that may generate variation in economic activity across locations. The theoretical framework we propose primarily serves to justify one set of market access measures that we use and, if desired, facilitate structural interpretation of coefficient estimates.

Our framework is very similar to Donaldson & Hornbeck's (2014) adaptation of Eaton & Kortum (2002) to estimate the effects of improvements in market access in the late 19th century United States on local economic growth, particularly in agriculture. Our primary innovation is to incorporate external trade in addition to the internal trade that is the focus of the model, as we suspect that the opening up of China to world markets disproportionately benefited cities with lower cost access to coastal ports.[1]

Consumers have constant elasticity of substitution preferences over product varieties of exogenous mass n. Each product variety j receives a Fréchet distributed productivity draw $z_o(j)$ at each location of production o, in which the shift parameter T_o is location specific whereas the dispersion parameter θ is common across locations. Production is Cobb-Douglas over land, labor and capital with associated marginal cost $\frac{q_o^\alpha w_o^\gamma r^{1-\alpha-\gamma}}{z_o}$. Here, q_o is land rent, w_o is wage and r is the national capital rental rate. Perfect competition ensures that income in each location is the aggregate value of trade flows to all locations, net of shipping costs. We denote domestic origin locations with o subscripts, domestic destination locations with d subscripts, and the rest of the world with x subscripts. Capital is fully elastically supplied to each location.

Given the properties of the Fréchet distribution and the fact that consumers in each

[1] Future versions of our analysis will consider an economy with multiple sectors.

location shop around for the lowest cost producer of each variety, Eaton & Kortum (2002) demonstrate that the equilibrium value of trade flows between each pair of domestic origin and destination locations is given by

$$X_{od} = \kappa_1 T_o (q_o^a w_o^\gamma)^{-\theta} \tau_{od}^{-\theta} \frac{Y_d}{CMA_d}. \tag{1}$$

In (1), Y_d is destination income or GDP and $\tau_{od} - 1$ is the fraction of the value required to ship each unit of exports from o to d.[2] CMA_d denotes "consumer market access", which summarizes how accessible competing markets are for provision of goods to d.

$$CMA_d \equiv \kappa_1 \sum_o T_o (q_o^a w_o^\gamma)^{-\theta} \tau_{od}^{-\theta} + \kappa_1 T_x (q_x^a w_x^\gamma)^{-\theta} \tau_{xd}^{-\theta} = P_d^{-\theta}$$

From (1), we see that more productive and lower cost origins ship more everywhere, more is shipped to nearer destinations with lower values of τ_{od}, to those destinations with more income, and to those destinations with less competition from other locations. If θ is higher, that means less productivity dispersion, so it is less likely that any given origin is going to have a comparative advantage in producing as many varieties. CMA_d is closely related to the price index P_d for location d. In particular, it aggregates the marginal production costs across locations that supply goods to d. Prices are lower, and consumer market access is higher, in locations that are better linked to other productive locations.

Summing over the value of all trade flows from o to d and x, we derive an expression for total income or GDP at o:

$$Y_o = \kappa_1 T_o (q_o^a w_o^\gamma)^{-\theta} \left(\sum_d \tau_{od}^{-\theta} \frac{Y_d}{CMA_d} + \frac{\tau_{ox}^{-\theta} E}{\sum_o \kappa_1 T_o (q_o^a w_o^\gamma)^{-\theta} \tau_{ox}^{-\theta}} \right) \tag{2}$$

The second term within brackets is derived by setting Chinese exports E equal to the sum

of the value of all trade flows to x. We see that GDP is decreasing in local production costs and increasing in destinations' GDP. If nearby destinations have greater consumer market access, total income is reduced because of greater nearby export competition. Denoting the term in brackets as "firm market access" FMA_o, and inverting (2) to substitute for

[2] $\kappa_1 = [\Gamma(\frac{\theta+1-\sigma}{\theta})]^{-\theta/(1-\sigma)} r^{-(1-\alpha-\gamma)/\theta}$ where σ is the elasticity of substitution parameter in preferences, r is the cost of capital and $\Gamma(\cdot)$ is that Gamma function.

$\kappa_1 T_o (q_o^a w_o^\gamma)^{-\theta}$ within FMA_o, and substituting for $\kappa_1 T_x (q_x^a w_x^\gamma)^{-\theta}$ in CMA_d using aggregate import flows, we have the following equations, which reveal that $FMA_o = CMA_o = MA_o$ if imports equal exports.

$$\begin{aligned} FMA_o &= \sum_d \tau_{od}^{-\theta} \frac{Y_d}{CMA_d} + \frac{\tau_{ox}^{-\theta} E}{\sum_d \left[\frac{Y_d}{FMA_d} \tau_{dx}^{-\theta}\right]} \\ CMA_d &= \sum_o \tau_{od}^{-\theta} \frac{Y_o}{FMA_o} + \frac{\tau_{xd}^{-\theta} I}{\sum_o \left[\frac{Y_o}{CMA_o} \tau_{xo}^{-\theta}\right]} \end{aligned} \tag{3}$$

The use of output information on domestic regions married with trade flow information to and from external markets allows us to construct measures of market access that can be decomposed, as seen in (3). This is new to the literature.

Using (2) and the unified market access definition, we derive structural equations that relate market access to GDP and population conditional on location fundamentals. We initially do so assuming free mobility across prefectures with national utility level $\overline{U}$, which is probably a strong assumption for China, and no agglomeration economies in production or costs to consumers of agglomerating.

$$\ln Y_o = \frac{1}{1+\alpha\theta} \ln(\kappa_1 T_o) + \frac{\alpha\theta}{1+\alpha\theta} \ln(L_o/\alpha) - \frac{\gamma\theta}{1+\alpha\theta} \ln \overline{U} + \frac{1+\gamma}{1+\alpha\theta} \ln MA_o \tag{4}$$

The following closely related estimation equation arises for population or employment.

$$\ln N_o = \frac{1}{1+\alpha\theta} \ln(\kappa_1 T_o) - \ln\gamma + \frac{\alpha\theta}{1+\alpha\theta} \ln(L_o/\alpha) - \frac{\gamma\theta - 1 - \alpha\theta}{1+\alpha\theta} \ln \overline{U} + (\frac{1+\gamma}{1+\alpha\theta} + \frac{1}{\theta}) \ln MA_o \tag{5}$$

Equations (4) and (5) suggest regressing the change in log GDP or log population on the change in log market access, which assumes productivity and land endowments grow at the same rate in each location. Locations with greater market access benefit from having greater demand for their products. They also benefit from having lower prices, which draws in additional population beyond the direct effect on GDP. In principle one can recover an estimate of the Fréchet productivity dispersion parameter θ by comparing the two results.

In the empirical work, we consider two varieties of market access. The first conforms with (3). Replacing Y with $\frac{w_o N_o}{\gamma} = \frac{\overline{U} CMA_o^{-1/\theta} N_o}{\gamma}$, we derive the following population or employment version of market access.

$$\widetilde{MA}_o = \kappa_3 \sum_d \tau_{od}^{-\theta} N_d \widetilde{MA}_d^{-\frac{1+\theta}{\theta}} + \frac{E\tau_{ox}^{-\theta}}{\kappa_3 \sum_d \left[\tau_{dx}^{-\theta} N_d \widetilde{MA}_d^{-\frac{1+\theta}{\theta}} \right]} \tag{6}$$

Note that because of the coefficient $\kappa_3 = \frac{\overline{U}}{\gamma}$, there is no overidentification available from using both versions of market access. However, we think that we have better measures of population and employment than of GDP, and our results using $\widetilde{MA}$ may be more easily applicable to environments in which GDP data is not available. For the purpose of constructing a unified version of $\widetilde{MA}_o$ that includes both domestic and external components, we set κ_3 to 1.

It is also worth considering the nature of equilibrium if population is immobile, as is at least partially true in China because of the hukou system. The equation analogous to (2) with no population mobility, as in Alder (2014) is

$$\begin{aligned} \ln Y_o \;=\; & \frac{1}{1+\gamma\theta+\alpha\theta} \ln(\kappa_1 T_o) - \frac{\alpha\theta}{1+\gamma\theta+\alpha\theta} \ln(\alpha/L_o) - \frac{\gamma\theta}{1+\gamma\theta+\alpha\theta} \ln\gamma \\ & + \frac{\gamma\theta}{1+\theta\gamma+\theta\alpha} \ln N_o + \frac{1}{1+\gamma\theta+\alpha\theta} \ln MA_o. \end{aligned} \tag{7}$$

Most of our empirical investigation does not control for population. Instead, in order to understand effects of infrastructure on per-capita GDP, we consider ratios of estimated effects of improved market access on GDP and population.

The environment used to derive these expressions for market access probably does not apply very well to China as of 1990, especially if considering travel by road. In 1990 there was very little inter-prefectural trade by road, with railroads primarily facilitating trade between prefectures and provincial capitals. Therefore, when considering road travel, many prefectures were approximately in autarky in 1990. From (3) and (6), we thus see that reasonable measures of market access for 1990 may be:

$$MA_o^{1990} = \sqrt{Y_o^{1990}}; \widetilde{MA}_o^{1990} = (\kappa_3 N_o)^{\frac{\theta}{1+2\theta}} . \tag{8}$$

We use this result in the empirical work to measure 1990 market access.

3.2 Extensions and Alternative Measures

Two additional extensions of the model are worthy of consideration. First, the existence of agglomeration economies (Rosenthal and Strange, 2004) would mean that T_o is increasing in population rather than fixed over time, contributing an additional additive term to the coefficient on $\ln N_o$ in (7) and acting as a multiplier to increase the influence of market access on GDP and population in (4) and (5). However, city costs are also increasing in population, which pushes in the other direction by making the denominator in the condition $\overline{U} = \frac{w_o}{P_o}$ increasing in city size. However, empirical evidence that the elasticity of productivity with respect to population and the elasticity of city costs with respect to population are comparable (Combes, Duranton & Gobillon, 2012), meaning that these considerations may not be quantitatively important for our purposes.

Alternative tractable models that generate similar structural relationships between local economic activity and connections to nearby markets include Redding & Venables' (2004), Hanson's (2005) and Head & Mayer's (2005) adaptations of Fujita, Krugman & Venables' (1999) "New Economic Geography" model. These earlier models begin with the assumption that each region specializes in a product and has an endogenous mass of "firms" producing different varieties using a Cobb-Douglas technology plus a fixed cost. Given the evidence of urban scale externalities and that these externalities are larger within narrow industry categories, it may be natural to think of cities as specializing in related products. Firms use immobile labor, mobile capital and a composite intermediate input imported from other locations as factors of production. Monopolistic competition delivers a fixed markup over marginal cost but 0 profits in equilibrium. The analog to market access in these studies is "market potential", given by

$$MP_o = \sum_d Y_d \left(\frac{I_d}{\tau_{od}}\right)^{\sigma-1}, \tag{9}$$

where I_d is location d's price index and $\sigma > 1$ is the CES parameter of the utility function. Total income in location o is log-linear in this market potential. We also use market potential type measures in our empirical investigation of the importance of trade integration for urban growth.

While the theoretical framework for market access has the advantage of clarifying how better market integration can lead to local growth and provides useful guidance about estimation equations, there may be other ways in which improved market integration promotes growth. Cobb Douglas production, Fréchet distributed productivity draws and CES preferences are all useful approximations that are likely only roughly accurate. More fundamentally, additional mechanisms may exist through which trade integration causes growth. For example, Fajgelbaum and Redding (2014) emphasize the rise of the nontraded sector and rising demand for traded manufacturing goods for facilitating structural change and urban growth. Lower trade costs may foster innovation through competition. Topalova & Khandelwal (2011) provide evidence that Indian firms became more productive with the lowering of trade barriers because of increased competition from abroad. We do not explicitly incorporate intermediate inputs to production, nor do we differentiate between different sectors in production. Because of all of these potentially important mechanisms that are not addressed theoretically, we view our proposed market access formulation as highlighting some but not all of the mechanisms through which the treatment effects of reduced interregional travel costs on GDP and population that we find may be operating. In our empirical work we wish to allow for maximum flexibility in the underlying data generating process and focus on recovering credible treatment effects.

3.3 Empirical Measures of Market Potential and Market Access

Because we wish to be as agnostic as possible about the underlying data generating process, much of the empirical work below uses intuitive measures of market potential based on (9). In particular, we calculate aggregate GDP and population within 3 hour travel time bands from the centroid of each prefecture city over the road network in each year. We construct these measures using data at county/urban district level of geography excluding the origin city or prefecture. For the purpose of constructing instruments, we use the 1962 road network seen in Figure 1 assuming travel at highway speeds married with employment from the 1982 census. As in Redding & Venables (2004), Hanson (2005) and Head & Mayer (2005), we constrain I_d to be a constant. The use of these measures facilitates a policy relevant interpretation of treatment effect estimates while accommodating their structural interpretation in the context of (9) without having to impose σ or a particular mapping between travel time and τ.

Figure 2 depicts how one market potential measure we use, population within 6 hours driving time, changed between 1982 and 2010. Shading is done by ranking within year and does not reflect the secular increase in market potential over time. The bottom right panel, using 1962 and 1982 information, shows a lot of variation across prefectures in population market potential. We see more clustered high market potential areas with the more homogenous dense local road network in the most developed part of the country in 1990. Considerable heterogeneity emerges by 2000 with the partially completed expressway network especially serving a spine down the middle of the country, with a return to more homogeneity across space in market potential as the expressway network becomes well built out. Analogous figures for analogously constructed GDP based market potential look quite similar. Summary statistics in Table 1 Panel C show very large increases in market potential over time after 1990.

In addition to measuring access to nearby markets, we also construct an intuitive measure of access to international markets. We calculate the road travel time from each prefecture city to the nearest of the nine largest international ports by value of shipments. As seen in Table 1 Panel C, the log time to nearest port declined by 1.3 on average between 1990 and 2010, and the standard deviation in this measure also declined from 1.5 to 1.3. That is, much of the country gained considerably better access to external markets between 1990 and 2010.

As in Donaldson & Hornbeck (2014) and Alder (2014), we construct GDP and population based measures of domestic and trade market access in 1990, 2000 and 2010 by numerically solving the recursive equations (3) and (6) using prefecture level aggregates. For instruments, we construct analogous measures using 1962 networks and 1982 quantities. For the Fréchet dispersion parameter θ, we use 5 for most of our results, as is consistent with the literature.

To measure τ_{od} for a given year, we use the travel time between o and d and the cost of shipping per unit distance at a typical speed. To calculate this, we need an estimate of ρ in the equation $\tau_{od} = 1 + \rho t_{od}$, where t_{od} is the time it takes to travel from o to d. We take the travel time over the road network that existed in each year between each pair of prefecture cities, assigning travel speeds of 90 kph on high grade highways, 25 kph on other roads, and 15 kph overland. Travel times within prefectures are set to 0.[3] Redding and Turner (2014) find that the value of the contents of a typical standard shipping container is about $200,000 (USD, 2005). Limao & Venables (2001) find that the cost of shipping 1 ton of freight overland for 1000 miles is about $2,100, or about 2% of its value. Travel along the 1990 road network at 25 kph from Beijing to Shanghai, about 1000 km, took 3200 minutes

[3] While this assumption is clearly not accurate, most trade has an origin or destination in or passes through prefecture capitals. Within prefecture shipping costs are dwarfed by costs of shipping between prefectures.

or 2% of value per 2960 minutes of travel in 1990. Based on this, one reasonable choice of ρ is 0.02 per 2960 minutes of travel, though we study sensitivity to much higher values of ρ. To measure τ_{ox} and τ_{xd}, we assume that output is shipped via the port with the lowest shipping cost from each Chinese destination. That is, $\tau_{ox} = \min_p[\tau_{op}]\tau_{px}$. From the port, we assume that shipping occurs overwater to Los Angeles using Limao & Venables' (2001) estimate of \$300 per 1000 miles at sea, or \$3150 and 1.5 percent of value to Los Angeles, meaning $\tau_{px} = \tau_{xp} = 1.015$. τ_{op} is calculated analogously to τ_{od}. We constrain international shipping from each prefecture to happen via the most accessible of the nine highest volume international ports in China.

Figure 3 maps the primary population based measure of market access used in the analysis. Qualitatively, Figure 3 looks much like Figure 2, with more variation over space in the instrument and in 2000 than in 1990 and 2010. However, because calculation of market access uses information from all prefectures simultaneously, the market access maps are somewhat smoother than their market potential counterparts. Figure 4 breaks out total 2010 population market access into its domestic and external components. As should be expected, the domestic component is highest in the heartland central to eastern portion of China, whereas the external component is greatest along the coast. Summary statistics about market access variables used in the empirical work are in Table 3 Panel C. They show big increases in both components of market access between 1990 and 2010, with almost 0 external market access existing for the average prefecture in 1990. Moreover, they show declines in the dispersion in market access across prefectures as the express highway network now links faraway prefectures that were closer to autarky in 1990.

While we have constructed measures of market potential and market access over the road network for 1990, it is important to recognize that these statistics likely do not capture anything of much relevance to the actual situation at the time. With most of the 1990 road system unsuitable for truck travel and very little opportunity for inter-prefectural trade because of the planned economy, we prefer to think of 1990 prefectures as existing approximately in autarky rather than trading with nearby prefectures.

Table 2 presents correlations between the four measures of market potential and market access we use in the empirical work and market access measures constructed using different parameter values. In each year, market access measures are all mutually correlated with coefficients of at least 0.91 regardless of whether they are built using population or GDP and the choices of θ and ρ. However, the market potential measures, while strongly correlated with each other, have correlations with the market access measures used in the empirical work of only between 0.67 and 0.78 in 2010 for example. Therefore, while one set of market access measures is likely enough to represent all for the purposes of carrying out empirical work, additional investigation of the effects of market potential will be important and revealing.

3.4 Internal Transportation Infrastructure

We also empirically consider the how improved transportation networks that are internal to cities may promote urban growth. This effect may occur through various mechanisms. In an environment with limited migration and monocentric city structure, additional roads lower commuting costs, thereby prompting an outward labor supply shift, greater output and welfare gains. In an environment with free migration and monocentricity, additional roads draw in additional population to cities, which increases incumbents' productivity through agglomeration economies (Duranton & Turner, 2012). However, these additional residents may sufficiently bid up land prices such that welfare does not change even as TFP, GDP and wages grow (Henderson, 1974). This is one fundamental challenge of urbanization in developing countries. After infrastructure improvements, cities draw in "too much" population, so as to congest away productivity gains from additional agglomeration economies. It also points to the empirical prediction that while new transport infrastructure that is internal to cities may cause GDP and population growth, they may not cause real wages to grow.

While the monocentric environment can be modeled elegantly and delivers clear theoretical predictions, actual city structures worldwide feature considerable decentralized production activity. Empirical evidence for China and the United States indicates that transport infrastructure decentralizes many types of production in addition to residences (Baum-Snow et al., 2014; Baum-Snow, 2014). This decentralization may ensue in tandem with urban growth for various reasons. Providing firms the flexibility to decentralize reduces the cost of central city space for the types of industries that benefit most from agglomeration economies while at the same time lowering land and labor costs for decentralizing firms that do not benefit as much from such spillovers. Moreover, improved internal transport infrastructure may enhance the magnitude of metropolitan area wide agglomeration spillovers by facilitating lower cost shipping of intermediate inputs, more convenient interactions between workers across firms and better labor market integration.

Given the importance of decentralizing production in the process of urban maturation, any empirically relevant formal treatment of the important forces at play would require a model that allows for employment to be decentralized. But such theory that has been developed, as in Fujita & Ogawa (1982) and Lucas & Rossi-Hansberg (2001), yields multiple equilibria and no clear comparative statics of the effects of transport improvements on urban structure and productivity.[4] Because our primary focus is the growth effects of market integration, we prefer to focus our modeling there while at the same time recovering treatment effects of transport internal to cities on GDP and population. All existing evidence indicates that there is little to be learned for improving empirical inquiry by developing a formal model that captures the processes through which transport improvements may lead to urban growth.

4 Empirical Strategy

We begin with an estimation equation with three main explanatory variables of interest: transport infrastructure that is internal to the city R, a measure of access to nearby markets A and a measure of access to external markets E. The outcome variables on which we focus are log GDP and log population at the 2010 definition prefecture city or the 2005 definition prefecture levels of geography, denoted by y. Because China was still largely under a planning regime in 1990, we want to think about there being different coefficients on outcomes of interest in 1990 and subsequent years for which we have data t.

$$\begin{aligned} y_{i90} &= a_0 + \alpha_0 + \left(\alpha_1 - \alpha_1^{90}\right) R_{i90} + \left(\beta_1 - \beta_1^{90}\right) A_{i90} + \left(\beta_2 - \beta_2^{90}\right) E_{i90} + \varepsilon_i + u_{i90} \\ y_{it} &= a_0 + \alpha_1 R_{it} + \beta_1 A_{it} + \beta_2 E_{it} + \varepsilon_i + u_{it} \end{aligned}$$

Differencing these two equations, which eliminates fixed factors like natural advantages that may influence GDP or population, yields the following long-run growth equation.

$$\Delta_t y_i = \alpha_o + \alpha_1 \Delta_t R_i + \alpha_1^{90} R_{i90} + b_1 \Delta_t A_i + b_2 \Delta_t E_i + CX_i + v_{it} \tag{10}$$

[4] Duranton & Turner (2012) and Baum-Snow (2014) propose two empirically applicable theories that specify mechanisms through which internal city transport improvements can facilitate urban growth. Duranton & Turner (2012) emphasize enhanced agglomeration economies through the transport's attraction of additional residents. Baum-Snow (2014) considers influences on the spatial organization of economic activity and enhancement of citywide agglomeration economies conditional on city scale using a core-periphery style model.

In (10), Δ_t indicates the difference between year t and 1990. We add a vector of controls X_i that, when chosen appropriately as explained below, will account for omitted variables that are potentially correlated with instruments. This equation is similar to that examined in Baum-Snow et al. (2014) to understand the effects of transport infrastructure on urban decentralization in Chinese cities.

Equation (10) suggests regressing prefecture GDP or population growth on changes in cost of accessing markets, measured either by changes in extent of market coverage within a 6 hour drive and changes in time to the coast or by changes in the more theoretically founded measures of market access. The difficulty with this approach is that in 1990 all goods moving intermediate or long distances went by rail, not by road. Road market access to the rest of the country and to the coast was not a viable option, and thus 1990 variables describing road access to national or international markets are not relevant measures as their true values must be approximately zero. Moreover, there was very little international trade from China in 1990. Thus we think of the experiment as introducing a new mode of transporting long distance freight, relative to rail, and treating market and coastal access by rail as little changed between 1990 and 2010. In our primary specifications we thus treat changes in cost of accessing markets by road as just the 2010 level measures.

When it comes to transportation infrastructure that is internal to cities, we adopt the approach used in Baum-Snow et al. (2014). We treat 1990 radial highways serving cities as 0 since no highways existed at that time. While much of the railroad network did exist in 1990, we think of the internal structure of cities as conforming to central planning and thus not responding to market incentives for reorganization that might come from the local configurations of railroad networks until after 1990. That is, we assume the effects of railroads on 1990 city or prefecture GDP conditional on controls to be 0. Because this way of treating railroads is probably only partially accurate, we separate out estimates of the effects of railroads from that of other infrastructure in the empirical work, so as to quarantine any potential related endogeneity problems. This depends on being able to independently instrument for railroads, roads and market potential or market access, which we show below to be possible.

Given this discussion, most of our empirical work involves recovering coefficient estimates from regression equations that resemble

$$\Delta_t y_i = a_o + a_1 R_{it} + b_1 A_{it} + b_2 E_{it} + C X_i + v_{it}. \tag{11}$$

It is true that in 1990, certain types of freight was trucked locally, although a surprising amount of short haul freight was by rail with factories having their own sidings (World Bank, 1982). We might thus consider local market access in the region of the prefecture. To account for this local extent of market access, we adjust the dependent variable in this growth on levels specification to incorporate autarkic market access in 1990 using (8) inserted for 1990 into (4) and (5). That is, the dependent variable in GDP growth regressions examining effects of market access is

$$\Delta_t y_i + \frac{1+\gamma}{1+\alpha\theta}\frac{1}{2}\ln y_{i1990}, \tag{12}$$

and the dependent variable in population growth regressions examining effects of market access is

$$\Delta_t y_i + \left(\frac{1+\gamma}{1+\alpha\theta} + \frac{1}{\theta}\right)\frac{\theta}{1+2\theta}\ln y_{i1990},$$

where γ and α are calibrated to 0.7 and 0.2 respectively. Because market potential is calculated using data from outside of own prefecture i only, the same result is achieved by using 2010 levels in regressions examining effects of market potential.

Finally there is the issue that even today for many products long distance freight is by rail, especially from the interior to the coast. We thus might expect somewhat differential effects of improved access by road to regional markets, compared to international (coastal) markets. The specification with local coverage within 6 hours and time to the coast will help us explore this issue.

Clear identification challenges present themselves in the estimation of (11). First, internal transport infrastructure R may be built to serve growing cities, not vice-versa. Second, there is a mechanical relationship between market access and own prefecture GDP and population that must be accounted for. Third, regions that are growing for unobserved reasons that are not in X may also have growing market access for these reasons. That is, there are likely to be unobservables in the error term ν correlated with each of the explanatory variables of interest that predict the outcome.

Our solution to these identification challenges is to employ instrumental variables to isolate variation in R, A and E that is not correlated with unobservables that may predict $\Delta_t y_i$. We use highway and railroad networks from 1962 to achieve exogenous variation in all three explanatory variables of interest. In assessing instruments, we think it important to consider all three explanatory variables of interest R_i, A_i, and E_i simultaneously because they are potentially mutually correlated through the fact that the same road and rail networks contribute to calculating all of them.

We think of different elements of the 1962 road network as the primary source of identifying variation for all three endogenous variables of interest. As is discussed in more detail in Baum-Snow et al. (2014), cities with greater internal highway network capacity in 2010 received more highway upgrades between 1990 and 2010, thereby enhancing radial and ring road capacity. Cities that were better connected with local unpaved roads in 1962 were more likely to be better connected with highways in 2010, which means that market access and market potential increased. The idea is that because highways are built at lower cost along existing rights of way, modern highways were more likely to be built in areas with more roads as of 1962. However, since 1962 roads were primarily used for the transport of agricultural products within prefectures rather than interregional travel, they are plausibly exogenous conditional on a few carefully chosen control variables.

Clean identification requires controlling for all variables that are correlated with agricultural economic activity from this era and may have promoted 1990-2010 urban growth. We want to measure these controls before 1990 in order to eliminate any mechanical reverse causality problems for them. We use prefecture level controls so that within prefecture decentralization is not a concern and to maintain consistent specifications across city and prefecture level outcomes. As such, as a baseline specification we include 1982 fraction with a high school diploma, 1982 fraction working in manufacturing, 1982 total prefecture population and log distance to the coast. In robustness checks, we additionally control for various geographic and weather variables, including elevation, slope and precipitation.

Table 3 presents first stage regressions. Each column presents results of regressing a different endogenous explanatory variable used in a second stage specification on various instruments and the standard set of controls discussed above. Each regression has both 2010 radial highways and railroads to measure R and either market potential or market access measures of A and E from (11). We include measures of all three classes of endogenous variables simultaneously in each regression in order to establish that instruments can isolate independent variation in each of them.

Results in the first two columns of Table 3 apply to market potential measures within 6 hours travel time. Conditional on exogenous components of radial roads and railroads, 2010 market potential is strongly predicted by its counterpart calculated using roads data from 1962 (but at highway speed) and employment data from 1982. We use GDP and population within six hours drive because of all market potential variables built, we find that these provide the most identifying variation across prefectures. Both versions of market potential exhibit first stage elasticities of about 0.7. As seen in the third column, log road travel time to the nearest port over the 1962 network at highway speed is a strong predictor of its 2010 counterpart, with a first stage elasticity of 0.83. Results also indicate that larger, more educated and more manufacturing oriented prefectures had higher 2010 market potential.

The next six columns of Table 3 present first stage regressions for GDP based market access, population based market access and their components. Because of the better fit, we use the 1962 network at 25 kph (rather than 90 kph as in the market potential instruments) to construct instruments for market access. The recursive nature of market access means that imposing a fast road network results in little variation across prefectures. The instrument for GDP market access also uses a measure of consumer expenditure in 1982 constructed using data on employment by industry. Actual Chinese exports in 1990 is an additional input into building traded market access. Each of the market access instruments is strong, with exogenous variation in domestic and traded components successfully separately isolated.

Results in the final two columns show that each 1962 radial road predicts 0.35 radial highways in 2010 and each 1962 radial railroad predicts 0.33 radial railroads in 2010. These effects are strongly significant conditional on other exogenous variables. However, we see that conditional on 1962 radial roads, many other variables also predict the allocation of more highways to cities by 2010. Larger cities, less manufacturing oriented cities, provincial capitals, cities with better coastal access and cities with more railroads all ultimately received more highways by 2010. The fact that there is selection on these observables into highway and railroad treatments gives rise to the potential concern that there may be selection on unobservables as well that drive outcomes of interest. It is for this reason that we find it important to instrument for highways and railroads.

5 Main Results

The main treatment effect estimates are presented in Tables 4-6. Table 4 jointly examines the effects of market potential and access to international ports. Table 5 examines the effects of market access and Table 6 examines the effects of transport infrastructure that is internal to cities. Each table jointly examines prefecture GDP and population growth rates. Because radial highways and railroads serving prefecture cities generally have small treatment effects and are only weakly correlated with measures of market integration, we consider them separately from market access and market potential measures. We find it important to jointly consider effects of improved access to domestic and international markets because they are highly mutually correlated.

5.1 Market Potential

Columns 1-4 of Table 4 examine the effects of GDP and population based market potential and international port access on prefecture GDP and population growth. We find evidence of strong impacts of proximity to nearby markets on prefecture GDP, with estimated elasticities of 0.14 for GDP market potential and 0.16 for population market potential. However, we do not find that people disproportionately moved to prefectures that were better connected to markets. Therefore, GDP per capita increased more rapidly in prefectures that became better integrated domestically. However, we cannot say whether this is because of redistribution away from less connected prefectures to better connected prefectures or more rapid economic growth in better connected prefectures. The second row of results in Columns 1-4 indicates that prefectures with better connections to international ports experienced more rapid population growth but not more rapid GDP growth. In particular, increasing travel time to a port by 10 percent reduced population growth by 0.6 percent.

These results are consistent with two elements of the Chinese institutional environment. First, even though improved market potential promotes GDP growth, hukou migration restrictions allow the resulting real income differences across space to persist. Second, the Chinese promotion of foreign investment in special economic zones with good port access has gone along with lax hukou restrictions in these locations. This has allowed the population of many export-oriented prefectures to grow in recent decades, reducing real income differences between these locations and more interior migrant origin prefectures.

The model in Section 3 emphasizes two countervailing forces that may be at work. While greater market potential represents greater demand, it also represents greater competition, which pushes toward lower economic growth. While the market access measures we construct accommodate both effects, we first attempt to isolate these two forces in a reduced form way. In particular, we examine heterogeneity of treatment effects of market potential as a function of prefecture importance in the region. We define Rank=1 as those prefectures with the greatest 1982 population within a 6 hour drive on the 1962 road network at highway speed. We think of rank 1 prefectures as being less exposed to competition from greater market potential than prefectures further down regional hierarchies.

Results in the final four columns of Table 4 include Rank=1 interactions and consistently show that prefectures at the top of the regional hierarchy grew significantly faster in both population and GDP when treated with greater market potential. In a context of much more rapid national GDP growth than population growth, rank 1 prefectures with 10 percent more market potential experienced GDP growth that was approximately twice as rapid as prefectures further down regional hierarchies. Such rank 1 prefectures also experienced significantly more rapid population growth with increased market potential such that small prefectures that became better connected to markets actually lost population. This result is consistent with results in Faber (2014). Unfortunately, we do not have the power to additionally interact prefecture rank with time to the nearest international port.

5.2 Market Access

The role of the theory in Section 3 is to develop measures of market integration that simultaneously incorporate demand and competition effects. Table 5 examines causal effects of the resulting unified market access measures on prefecture GDP and population growth. Dependent variables in these regressions are adjusted to incorporate autarkic 1990 market access. As is discussed in Section 3, market access measures used in regressions impose a very low travel speed in order to generate more variation across prefectures. However, since correlations across market access measures built using different parameters is so high, as seen in Table 2, the choice of market access parameters almost entirely influences the size rather than the significance of coefficient estimates. Coefficient magnitudes are very sensitive to choices of θ and ρ. It is also useful to keep in mind that the theory tells us that coefficients on GDP and population versions of market access should be identical.

Market access results are broadly in line with those for market potential discussed in the previous sub-section. Results in Table 5 Columns 1, 3, 5 and 7 indicate that higher market access caused prefecture GDP growth but not prefecture population growth on average. These smaller estimated effects on prefecture population are inconsistent with the theory assuming free mobility, which is further evidence that hukou migration restrictions may be important for rationalizing results. Based on (4), the coefficient on market access in the structural equation describing GDP growth is $\frac{1+\gamma}{1+\alpha\theta}$, which equals about 0.85 when calibrated. Estimated elasticities of prefecture GDP with respect to market access are instead about 1.6. As we refine parameter values used to calculate market access, we intend to better determine why estimated coefficients diverge from theoretical predictions.

Table 5 Columns 2, 4, 6 and 8 examine the effects of domestic and external components of market access separately. While the theory indicates that coefficients on these two components should be the same, they are in fact somewhat different. In particular, estimated elasticities of GDP with respect to domestic market access are about 0.8 (in line with the theory) whereas those with respect to external market access are about 1.25. We also find that external market access positively affects prefecture population growth, with an estimated elasticity of about 0.5. This positive estimated effect of external market access on GDP is the only result in Table 5 at odds with the market potential results in Table 4. The gap may be explained by the more restrictive functional form imposed in Table 4.

The model in Section 3 incorporates prefectures' place in regional hierarchies to reduce market access for locations that experience a lot of local competition. Results in the final four columns of Table 5 indicate that this model based adjustment does not fully homogenize treatment effects as a function of prefecture rank. Rank 1 prefectures exhibit significantly larger effects of market access on prefecture GDP and population. These additional effects come in addition to base elasticities of about 1.4 for prefecture GDP and about 0.1 for prefecture population. These results indicate that the model does not fully incorporate the importance of the urban hierarchy in its market access measures. Unfortunately we do not have the statistical power to break out rank interactions by market access components.

5.3 Internal City Infrastructure

Table 6 examines effects of radial highways and railroads on prefecture and prefecture city GDP and population growth. Most estimates are imprecise. Point estimates indicate that each radial highway caused about 6% more rapid GDP growth in prefectures and prefecture cities but had little to no effect on population. However, each radial railroad is estimated to cause about 6% more rapid growth in both prefecture and prefecture city populations, with inconsistently estimated effects on GDP. Given evidence in Baum-Snow et al. (2014) that railroads promoted decentralization of manufacturing activity toward peripheral areas of prefecture cities, this result indicates that railroads may also have facilitated growth in manufacturing.

5.4 Implications and Interpretation

It is important to interpret the results in Table 4-6 recognizing that they likely reflect some combination of aggregate growth and redistribution. In part because of the One Child Policy, redistribution across prefectures must be especially important when considering the prefecture population results. Indeed, if estimates fully reflect population redistribution, they indicate that new highways linking prefectures with better port access gained population at the expense of more interior prefectures. Therefore, while it is straightforward to draw conclusions about the implied relative importance of various mechanisms through which highways influence the distribution of economic activity across prefectures, to this point we have not developed sufficient architecture to draw conclusions about aggregate growth.

To put our estimates in perspective, we consider how counterfactual road networks would influence prefecture GDP and population growth. Road construction in China between 1990 and 2010 increased population market potential by 1.77 log points on average.[5] Thus, estimates imply that this increased market potential led to GDP growth of 0.28 log points in the average prefecture. We find no reduced form evidence that access to international ports influenced prefecture GDP. While imprecise point estimates cannot rule out no GDP effects of new internal highway and railroad rays serving cities, they are consistent with effects that when added together are about the same magnitude as the influence of expanded market potential between 1990 and 2010. 3.78 additional radial highways and 0.3 radial railroads multiplied by coefficients in the first two columns of Table 6 yield a point estimated effect of 0.23 log points of this new infrastructure on prefecture GDP.

To evaluate how important changes in market access can be for influencing the variation in GDP across prefectures, we consider the effects of imposing a speed adjustment to the 2010 road network such that it is 10 times faster than that used for the market access measures used in estimation.[6] This speed adjustment increases log GDP market access by 0.17 (0.16 for the domestic component and 0.19 for the external component) and log population market access by 0.14 (0.14 for the domestic component and 0.18 for the external component). When combined with coefficients in Table 5, this indicates that a 10 fold road

[5] This magnitude of population market potential growth is similar when applying the 1990 and 2010 road networks to population data from 2010.

[6] For the purpose of constructing market access, we have imposed a low speed so as to generate a lot of variation across prefectures for initial estimation. As we refine parameter values used to calculate market access measures, we will calculate more empirically relevant counterfactuals.

speed increase would increase prefecture GDP by 0.29 using GDP market access and 0.22 using population market access. Our market access estimates indicate that most of this effect is through improving access to external markets, though improving access to domestic markets is also important. Because neither market potential nor domestic market access influence population, the conclusions for those effects also apply to GDP per capita.[7]

The context of severe migration restrictions in many cities and policies promoting foreign investment in other cities is important for reconciling the fact that new highways promoted population growth in prefectures with good port access but GDP growth in prefectures with good access to domestic markets. In the early 1990s, China embarked on a national plan to promote foreign investment by permitting foreign companies to establish production plants primarily oriented toward exports in certain special economic zones that typically had good port access. Such zones drew in many workers from elsewhere and may be an important driver of the population effects that we find. Otherwise, hukou migration restrictions have made rural-urban migration very costly. The larger effects of domestic trade integration on GDP than population growth are consistent with institutional migration restrictions. This may reflect labor segmentation in Chinese markets, where migrants have limited ability to access traditional employment occupied by local hukou holders and instead focus heavily on the export sector where they work on contract.

This unique context presents an opportunity to distinguish relocation effects of transport investment from growth effects. The usual challenge is that with perfect labor mobility much of differential market access effects could involve a reshuffling of resources from worse to better treated areas. As in Alder (2014), with limited labor mobility, improved market access can induce growth in per capita incomes not mitigated by migration. Take the result in Table 4 that a 10 percent increase in employment market potential increased prefecture GDP by 1.6 percent but did not influence prefecture population. Now take the other result that the elasticity of prefecture population with respect to travel time to an international port is -0.06 whereas the elasticity of prefecture GDP with respect to port access is 0. This actually implies a negative elasticity of GDP per capita with respect to port access, which

[7] To get a sense of how much of the effects we find is about redistribution within verses between prefectures, we also estimate all regressions using prefecture city as the unit of analysis. Market potential results, reported in Table A4, are similar as those for full prefectures, except that they show little effect on GDP. This implies that much of the prefecture GDP gains from improved market integration have occurred in less urban areas, which is consistent with evidence in Baum-Snow et al. (2014). However, market access results, reported in Table A5, exhibit stronger GDP effects. As we are still refining market access measures for prefecture cities, we prefer to focus on the market potential results for prefecture cities.

likely only comes because of initial large gaps in GDP per capita between port accessible areas and more internal regions. Had population not been allowed to increase in areas in which highways promoted improved port access, per-capita GDP growth may have ensued instead.

6 Conclusions

This paper uses the rapid construction of limited access highways between 1990 and 2010 in China to investigate various mechanisms through which transport infrastructure has caused urban and regional growth. We find strong evidence that improved access to domestic markets has promoted regional GDP and income growth whereas improved access to international markets has promoted population growth. While our evidence on the effects on GDP growth of railroads and highway infrastructure serving travel within prefecture cities is inconclusive, we do find that cities with more railroads accommodated greater populations. These findings come in an environment with costly internal migration and thus their magnitudes may not apply well to other developing country contexts with free labor mobility.

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Table 1: Empirical Patterns and Summary Statistics

Means with Standard Deviations in Parentheses

	1962/1982	1990	2010	Change 1990-2010
Panel A: Prefecture Level Outcomes				
log GDP		3.78	6.82	3.04
		(0.77)	(0.94)	(0.44)
log Population	14.82	14.95	15.09	0.14
	(0.68)	(0.65)	(0.66)	(0.22)
Per-Capita GDP ('000)		0.017	0.303	0.287
		(0.013)	(0.190)	(0.182)
Panel B: 2010 Definition Prefecture City Outcomes				
log GDP		2.67	5.88	3.21
		(1.14)	(1.19)	(0.58)
log Population	13.37	13.52	13.88	0.36
	(0.84)	(0.81)	(0.85)	(0.28)
Per-Capita GDP ('000)		0.024	0.392	0.368
		(0.016)	(0.230)	(0.218)
Panel C: Explanatory Variables and Instruments for Both Geographies				
log Population Within 6 hrs	14.57*	15.53	17.33	1.77
	(1.54)	(0.94)	(1.14)	(0.64)
log GDP Within 6 hrs	16.36[I]	4.18	8.94	4.75
	(1.17)	(0.92)	(1.40)	(0.85)
log Road Time to Nearest Port	6.06	7.15	5.86	-1.29
	(1.42)	(1.50)	(1.31)	(0.36)
log Total Market Access (GDP)	12.54	4.42	6.44	2.02
	(0.26)	(0.24)	(0.09)	(0.16)
log Domestic Market Access (GDP)	12.54	4.24	6.15	1.92
	(0.26)	(0.24)	(0.09)	(0.16)
log External Market Access (GDP)	-5.93	2.56	5.04	2.48
	(0.50)	(0.40)	(0.12)	(0.29)
log Total Market Access (Population)	8.83	8.96	9.36	0.40
	(0.27)	(0.24)	(0.09)	(0.16)
log Domestic Market Access (Population)	8.83	8.96	9.36	0.40
	(0.27)	(0.24)	(0.09)	(0.16)
log External Market Access (Population)	-2.17	-2.09	1.86	3.95
	(0.50)	(0.40)	(0.12)	(0.29)
Road Rays	2.01	2.87	3.78	3.78
	(1.38)	(1.38)	(1.97)	(1.97)
Rail Rays	1.09	1.48	1.78	0.30
	(1.24)	(1.28)	(1.27)	(1.12)

Notes: Means and standard deviations are reported for the 282 prefectures in our data that are comprised of more than one unit of geography. All market access variables are calculated using θ=5 and ρ=0.2. In the 1962/1982 column, market potential and port access measures are calculated using the 1962 network at highway speed. Market access measures are calculated using the 1962 network at local travel speed. *These statistics instead describe log 1982 employment within 6 hours over the 1962 road network at 1990 road speed. [I]These statistics instead describe log 1982 employment within 6 hours over the 1962 road network at highway speed.

Table 2: Correlations Between Market Potential and Market Access Measures

All Measures are in Levels

	Market Potential		GDP Market Access			Pop Market Access		
	GDP	Pop/Emp	$\theta = 1.5$ $\rho = 0.2$	$\theta = 1.5$ $\rho = 0.02$	$\theta = 5$ $\rho = 0.02$	$\theta = 1.5$ $\rho = 0.2$	$\theta = 1.5$ $\rho = 0.02$	$\theta = 5$ $\rho = 0.02$
Panel A: 1962/1982								
Market Potential, Employment		1.00	0.71	0.66	0.67	0.71	0.66	0.67
Exp Market Access, θ=5, ρ=0.2		0.75	0.99	0.96	0.97	0.98	0.95	0.96
Pop Market Access, θ=5, ρ=0.2		0.77	0.99	0.96	0.97	0.99	0.96	0.97
Panel B: 1990								
Market Potential, GDP	1.00	0.87	0.59		0.57	0.52	0.49	0.50
Market Potential, Population	0.87	1.00	0.61		0.59	0.62	0.58	0.59
GDP Market Access, θ=5, ρ=0.2	0.62	0.63	0.99		0.98	0.91	0.89	0.89
Pop Market Access, θ=5, ρ=0.2	0.54	0.66	0.93		0.93	0.99	0.97	0.97
Panel C: 2010								
Market Potential, GDP	1.00	0.93	0.76	0.75	0.75	0.68	0.67	0.67
Market Potential, Population	0.92	1.00	0.77	0.76	0.76	0.76	0.75	0.75
GDP Market Access, θ=5, ρ=0.2	0.78	0.77	1.00	1.00	1.00	0.92	0.91	0.91
Pop Market Access, θ=5, ρ=0.2	0.69	0.76	0.92	0.93	0.93	1.00	1.00	1.00

Table 3: First Stage Regressions

	log 2010 GDP Within 6 Hours	log 2010 Pop Within 6 Hours	log 2010 Time to Nearest Port	log 2010 GDP Market Access	log 2010 GDP Dom. Market Access	log 2010 GDP Trade Market Access	log 2010 Pop Market Access	log 2010 Pop Dom. Market Access	log 2010 Pop Trade Market Access	Road Rays	Rail Rays
Instruments											
log 1962/1982 Emp.	0.77***	0.68***	0.16***							-0.12	-0.00
Market Potential	(0.09)	(0.07)	(0.05)							(0.11)	(0.09)
log 1962 Time to	-0.00	0.01	0.83***							-0.19*	-0.09*
Nearest Port	(0.06)	(0.04)	(0.04)							(0.11)	(0.05)
1962/1982 log Full				0.21***			0.23***				
Market Access				(0.03)			(0.03)				
1962/1982 log Dom.					0.20***	-0.10***		0.23***	-0.08***		
Market Access					(0.03)	(0.03)		(0.03)	(0.03)		
1962/1982 log Trade					0.03**	0.22***		0.01	0.21***		
Market Access					(0.01)	(0.01)		(0.01)	(0.01)		
1962 Road Rays	-0.15***	-0.14***	0.02	-0.01**	-0.01***	-0.01**	-0.01***	-0.01***	-0.01**	0.35***	-0.01
	(0.04)	(0.03)	(0.02)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.08)	(0.05)
1962 Rail Rays	0.10**	0.08**	-0.06**	0.01	0.00	0.01**	0.00	0.00	0.01**	0.12	0.34***
	(0.05)	(0.04)	(0.03)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.09)	(0.07)
Controls											
Provincial	-0.90***	-0.47***	0.03	-0.04***	-0.02	-0.00	-0.02	-0.02	-0.00	1.68***	0.05
Capital	(0.22)	(0.18)	(0.10)	(0.02)	(0.02)	(0.01)	(0.01)	(0.02)	(0.01)	(0.50)	(0.27)
log 1982 Prefecture	0.42***	0.35***	-0.17***	0.03***	0.03***	0.02***	0.03***	0.03***	0.02***	0.71***	0.36***
Population	(0.11)	(0.10)	(0.06)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.17)	(0.12)
1982 Fraction	3.75**	3.00**	0.02	0.25**	0.04	0.15	0.03	0.01	0.16*	3.97	4.63**
HS Graduate	(1.69)	(1.41)	(0.86)	(0.11)	(0.12)	(0.10)	(0.11)	(0.11)	(0.10)	(2.78)	(1.92)
1982 Fraction	3.30***	1.14*	0.15	0.09	0.01	-0.10**	0.00	-0.01	-0.10**	-3.50**	-1.02
Manufacturing	(0.69)	(0.62)	(0.59)	(0.05)	(0.05)	(0.04)	(0.05)	(0.05)	(0.04)	(1.60)	(0.91)
log km to Coast	-0.10**	-0.05*	0.06***	-0.01***	-0.00	-0.01***	-0.00*	-0.00	-0.01***	0.18***	0.11***
	(0.04)	(0.03)	(0.02)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.07)	(0.04)
Constant	-9.93***	0.98	0.39	3.35***	3.37***	7.31***	6.95***	7.02***	2.79***	-5.64*	-4.24**
	(2.10)	(1.59)	(1.04)	(0.32)	(0.46)	(0.40)	(0.24)	(0.29)	(0.26)	(2.99)	(1.98)
R-squared	0.58	0.57	0.89	0.56	0.55	0.81	0.56	0.56	0.80	0.31	0.25

Notes: Each column is a separate first stage regression for IV results reported in Tables 4-6. Each regression has 282 observations.

Table 4: Prefecture Growth IV Regressions - Market Potential

Outcome:	Δ log Prefecture GDP		Δ log Prefecture Population		Δ log Prefecture GDP		Δ log Prefecture Population	
Market Potential Measure:	GDP	Population	GDP	Population	GDP	Population	GDP	Population
log 2010 Market	0.14***	0.16***	-0.0065	-0.0075	0.12**	0.13**	-0.031*	-0.034*
Potential	(0.040)	(0.049)	(0.015)	(0.018)	(0.046)	(0.052)	(0.017)	(0.019)
log 2010 Time to	-0.0095	-0.012	-0.061**	-0.060**	-0.017	-0.019	-0.066**	-0.065**
Coast	(0.026)	(0.026)	(0.027)	(0.027)	(0.026)	(0.026)	(0.027)	(0.027)
log 2010 Market					0.094*	0.13**	0.064***	0.076***
Potential X Rank = 1					(0.051)	(0.063)	(0.018)	(0.021)
Rank = 1					-0.75	-2.13*	-0.56***	-1.31***
					(0.48)	(1.11)	(0.16)	(0.35)
Provincial	0.35***	0.30***	0.27***	0.27***	0.34***	0.29***	0.26***	0.27***
Capital	(0.079)	(0.076)	(0.042)	(0.040)	(0.080)	(0.078)	(0.043)	(0.041)
log 1982 Prefecture	-0.15***	-0.15***	-0.12***	-0.12***	-0.16***	-0.16***	-0.11***	-0.12***
Population	(0.046)	(0.045)	(0.036)	(0.036)	(0.051)	(0.050)	(0.039)	(0.040)
1982 Fraction	-0.24	-0.20	-0.47	-0.47	-0.29	-0.25	-0.45	-0.47
HS Graduate	(0.64)	(0.63)	(0.29)	(0.30)	(0.65)	(0.65)	(0.29)	(0.29)
1982 Fraction	0.22	0.50	0.23	0.22	0.24	0.52*	0.29	0.25
Manufacturing	(0.34)	(0.32)	(0.23)	(0.22)	(0.34)	(0.31)	(0.23)	(0.22)
log km to Coast	-0.058***	-0.063***	-0.018*	-0.018*	-0.055***	-0.059***	-0.017*	-0.016*
	(0.017)	(0.018)	(0.0094)	(0.0094)	(0.017)	(0.018)	(0.0094)	(0.0093)
Constant	4.32***	2.74***	2.40***	2.47***	4.77***	3.49***	2.59***	2.91***
	(0.66)	(0.84)	(0.62)	(0.62)	(0.69)	(0.84)	(0.64)	(0.63)
First Stage F	33.5	42.4	33.5	42.4	23.8	24.1	23.8	24.1

Notes: Each column is a separate regression of the change in log prefecture GDP or population between 1990 and 2010 on the variables listed at left. All variables above "Rank = 1" are treated as endogenous, with first stage results in Table 3. Rank 1 prefectures have the largest 1982 population within a 6 hour drive on the 1962 road network at highway speeds. Market potential variables are measured using either GDP or population, as is indicated in column headers. Each regression has 282 observations. Analogous OLS results are in Table A1. Analogous regressions for prefecture cities are in Table A4.

Table 5: Prefecture Growth IV Regressions - Market Access

Outcome:	Δ log Adjusted Prefecture GDP				Δ log Adjusted Prefecture Population				Δ log Adj Pref GDP		Δ log Adj Pref Pop	
Market Access Measure:	GDP		Population		GDP		Population		GDP	Pop	GDP	Pop
log Total Market	1.71***		1.55***		0.26		0.26		1.48***	1.31***	0.11	0.12
Access	(0.34)		(0.32)		(0.19)		(0.18)		(0.43)	(0.40)	(0.21)	(0.20)
log Domestic		0.80*		0.78*		-0.13		-0.042				
Market Access		(0.44)		(0.40)		(0.26)		(0.23)				
log External		1.19**		1.28***		0.57*		0.50*				
Market Access		(0.48)		(0.44)		(0.32)		(0.29)				
log 2010 Market									1.22*	1.29**	1.14***	1.07***
Access X Rank = 1									(0.65)	(0.60)	(0.38)	(0.36)
Rank = 1									-7.84*	-12.0**	-7.29***	-9.99***
									(4.14)	(5.57)	(2.42)	(3.34)
Provincial	0.43***	0.48***	0.37***	0.47***	0.31***	0.34***	0.30***	0.34***	0.42***	0.37***	0.30***	0.30***
Capital	(0.085)	(0.087)	(0.085)	(0.087)	(0.046)	(0.053)	(0.043)	(0.053)	(0.086)	(0.086)	(0.045)	(0.042)
log 1982 Prefecture	0.21***	0.20***	0.23***	0.20***	0.33***	0.32***	0.33***	0.32***	0.20***	0.22***	0.31***	0.31***
Population	(0.050)	(0.051)	(0.050)	(0.051)	(0.045)	(0.047)	(0.044)	(0.047)	(0.055)	(0.054)	(0.050)	(0.049)
1982 Fraction	0.32	-0.19	0.78	-0.16	-0.23	-0.56	-0.16	-0.52	0.36	0.77	-0.23	-0.18
HS Graduate	(0.65)	(0.75)	(0.67)	(0.74)	(0.35)	(0.47)	(0.37)	(0.47)	(0.66)	(0.68)	(0.33)	(0.35)
1982 Fraction	1.69***	1.55***	1.91***	1.60***	0.29	0.20	0.32	0.20	1.73***	1.95***	0.31	0.36
Manufacturing	(0.36)	(0.35)	(0.37)	(0.35)	(0.22)	(0.20)	(0.22)	(0.20)	(0.37)	(0.38)	(0.23)	(0.22)
log km to Coast	-0.082***	-0.058**	-0.099***	-0.056**	-0.042***	-0.026*	-0.045***	-0.028**	-0.081***	-0.096***	-0.041***	-0.042***
	(0.018)	(0.023)	(0.020)	(0.023)	(0.013)	(0.014)	(0.013)	(0.014)	(0.018)	(0.019)	(0.012)	(0.013)
Constant	-9.36***	-9.05***	-13.0***	-7.89**	0.93	0.65	0.19	2.20	-7.74***	-10.6***	2.13**	1.70
	(2.04)	(1.86)	(2.78)	(3.29)	(0.92)	(0.80)	(1.30)	(1.83)	(2.53)	(3.51)	(1.01)	(1.48)
First stage F	55.4	27.1	57.7	28.2	55.4	27.1	57.7	28.2	16.4	15.5	16.4	15.5

Notes: Each column is a separate regression of the change in log prefecture GDP or population between 1990 and 2010, adjusted to account for 1990 market access assuming autarky in the prefecture, on the variables listed at left. Adjustments for 1990 market access use results in Equations (4), (5) and (8) in the text, assuming γ=0.7, α=0.2 and θ=5. All variables above "Rank = 1" are treated as endogenous, with first stage results in Table 3. Market access variables are measured using either GDP or population, as is indicated in column headers. Each regression has 282 observations. Analogous OLS results are in Table A2. Analogous results for prefecture cities are in Table A5.

Table 6: Effects of City Transport Networks - IV Regressions

Unit of Analysis:	Prefecture		City		Prefecture		City	
Outcome:	Δ log GDP				Δ log Population			
Highway Rays	0.058		0.066		-0.0070		0.027	
	(0.049)		(0.060)		(0.025)		(0.032)	
Rail Rays		0.048		-0.071		0.058*		0.066
		(0.061)		(0.083)		(0.032)		(0.042)
Provincial	0.15	0.25***	0.36**	0.49***	0.27***	0.25***	0.19**	0.23***
Capital	(0.13)	(0.083)	(0.18)	(0.13)	(0.050)	(0.040)	(0.079)	(0.054)
log 1982 Prefecture	-0.059	-0.030	-0.19**	-0.090	-0.097**	-0.13***	-0.043	-0.053
Population	(0.063)	(0.060)	(0.081)	(0.084)	(0.042)	(0.039)	(0.046)	(0.041)
1982 Fraction	-0.47	-0.55	-1.71	-0.84	-0.26	-0.73**	-0.56	-0.93*
HS Graduate	(0.73)	(0.89)	(1.06)	(1.15)	(0.29)	(0.37)	(0.41)	(0.49)
1982 Fraction	0.83**	0.67*	-0.52	-0.67	0.41**	0.41**	0.31	0.22
Manufacturing	(0.36)	(0.35)	(0.76)	(0.72)	(0.19)	(0.20)	(0.25)	(0.25)
log km to Coast	-0.091***	-0.087***	-0.13***	-0.12***	-0.039***	-0.046***	-0.056***	-0.060***
	(0.019)	(0.020)	(0.040)	(0.041)	(0.013)	(0.013)	(0.016)	(0.016)
Constant	4.12***	3.83***	6.68***	5.42***	1.77***	2.29***	1.20*	1.40**
	(0.89)	(0.91)	(1.27)	(1.38)	(0.63)	(0.63)	(0.66)	(0.65)
First stage F	19.8	27.2	19.8	27.2	19.8	27.2	19.8	27.2

Notes: Each column is a separate IV regression of the outcome listed at top between 1990 and 2010 in the unit of analysis listed at top on the variables listed at left. Road rays and rail rays treated as endogenous, with first stage results in Table 3. Each regression has 282 observations. Analogous OLS results are in Table A3.

Table A1: Prefecture Growth OLS Regressions - Market Potential

Outcome:	Δ log Prefecture GDP		Δ log Prefecture Population		Δ log Prefecture GDP		Δ log Prefecture Population	
Market Potential Measure:	GDP	Population	GDP	Population	GDP	Population	GDP	Population
log 2010 Market	0.14***	0.16***	-0.0044	0.0059	0.13***	0.14***	-0.012	-0.0011
Potential	(0.024)	(0.032)	(0.0086)	(0.0093)	(0.021)	(0.028)	(0.0077)	(0.0089)
log 2010 Time to	-0.017	-0.019	-0.062**	-0.059**	-0.017	-0.019	-0.063**	-0.060**
Coast	(0.024)	(0.023)	(0.026)	(0.025)	(0.024)	(0.023)	(0.026)	(0.025)
log 2010 Market					-0.55	-1.96*	-0.34***	-0.77***
Potential X Rank = 1					(0.41)	(1.01)	(0.079)	(0.18)
Rank = 1					0.072	0.12**	0.040***	0.046***
					(0.045)	(0.058)	(0.010)	(0.011)
Provincial	0.35***	0.30***	0.27***	0.28***	0.35***	0.29***	0.27***	0.28***
Capital	(0.076)	(0.077)	(0.039)	(0.038)	(0.076)	(0.078)	(0.038)	(0.038)
log 1982 Prefecture	-0.15***	-0.15***	-0.12***	-0.13***	-0.17***	-0.17***	-0.13***	-0.14***
Population	(0.039)	(0.039)	(0.032)	(0.033)	(0.042)	(0.042)	(0.033)	(0.035)
1982 Fraction	-0.26	-0.22	-0.48	-0.47	-0.31	-0.26	-0.47	-0.48
HS Graduate	(0.65)	(0.65)	(0.30)	(0.30)	(0.66)	(0.66)	(0.30)	(0.30)
1982 Fraction	0.18	0.48	0.22	0.21	0.20	0.51	0.24	0.23
Manufacturing	(0.33)	(0.32)	(0.21)	(0.21)	(0.31)	(0.31)	(0.21)	(0.21)
log km to Coast	-0.054***	-0.061***	-0.017*	-0.017*	-0.053***	-0.058***	-0.017*	-0.016*
	(0.016)	(0.017)	(0.0092)	(0.0092)	(0.017)	(0.018)	(0.0092)	(0.0092)
Constant	4.41***	2.81***	2.43***	2.40***	4.77***	3.40***	2.57***	2.61***
	(0.66)	(0.78)	(0.60)	(0.60)	(0.69)	(0.76)	(0.62)	(0.61)
R-Squared	0.35	0.34	0.39	0.39	0.36	0.36	0.40	0.40

Notes: Each column is a separate OLS regression of the change in log prefecture GDP or population between 1990 and 2010 on the variables listed at left. Market potential variables are measured using either GDP or population, as is indicated in column headers. Each regression has 282 observations.

Table A2: Prefecture Growth OLS Regressions - Market Access

Outcome:	Δ log Adjusted Prefecture GDP				Δ log Adjusted Prefecture Population				Δ log Adj Pref GDP		Δ log Adj Pref Pop	
Market Access Measure:	GDP		Population		GDP		Population		GDP	Pop	GDP	Pop
log Total Market	2.00***		1.84***		0.39***		0.39***		1.90***	1.70***	0.32**	0.31**
Access	(0.26)		(0.25)		(0.15)		(0.14)		(0.28)	(0.28)	(0.15)	(0.14)
log Domestic		1.28***		1.23***		0.011		0.16				
Market Access		(0.35)		(0.34)		(0.20)		(0.18)				
log External		0.74*		0.88**		0.42		0.32				
Market Access		(0.41)		(0.38)		(0.26)		(0.23)				
log 2010 Market									0.87*	0.99**	0.71***	0.67***
Access X Rank = 1									(0.49)	(0.47)	(0.24)	(0.22)
Rank = 1									-5.59*	-9.23**	-4.55***	-6.25***
									(3.13)	(4.34)	(1.50)	(2.04)
Provincial	0.43***	0.45***	0.37***	0.43***	0.31***	0.33***	0.30***	0.32***	0.43***	0.36***	0.31***	0.30***
Capital	(0.085)	(0.087)	(0.086)	(0.087)	(0.045)	(0.050)	(0.043)	(0.048)	(0.086)	(0.087)	(0.044)	(0.043)
log 1982 Prefecture	0.20***	0.20***	0.21***	0.20***	0.32***	0.32***	0.32***	0.32***	0.18***	0.20***	0.31***	0.31***
Population	(0.049)	(0.050)	(0.049)	(0.050)	(0.044)	(0.044)	(0.044)	(0.045)	(0.052)	(0.052)	(0.047)	(0.046)
1982 Fraction	0.31	0.13	0.84	0.18	-0.24	-0.46	-0.13	-0.37	0.30	0.82	-0.26	-0.16
HS Graduate	(0.66)	(0.74)	(0.66)	(0.74)	(0.35)	(0.44)	(0.36)	(0.44)	(0.67)	(0.67)	(0.35)	(0.35)
1982 Fraction	1.67***	1.63***	1.92***	1.70***	0.28	0.22	0.33	0.25	1.68***	1.95***	0.29	0.35
Manufacturing	(0.36)	(0.35)	(0.37)	(0.36)	(0.22)	(0.21)	(0.22)	(0.20)	(0.36)	(0.38)	(0.22)	(0.22)
log km to Coast	-0.077***	-0.070***	-0.097***	-0.068***	-0.040***	-0.031**	-0.044***	-0.033**	-0.076***	-0.095***	-0.039***	-0.043***
	(0.018)	(0.023)	(0.020)	(0.023)	(0.013)	(0.015)	(0.013)	(0.015)	(0.018)	(0.020)	(0.013)	(0.013)
Constant	-11.0***	-9.71***	-15.6***	-11.2***	0.22	0.56	-0.92	0.67	-10.1***	-14.1***	0.84	-0.0096
	(1.57)	(1.43)	(2.22)	(2.72)	(0.66)	(0.59)	(0.88)	(1.29)	(1.70)	(2.46)	(0.69)	(0.92)
R-Squared	0.61	0.61	0.60	0.61	0.67	0.67	0.67	0.67	0.61	0.61	0.68	0.68

Notes: Each column is a separate OLS regression of the change in log prefecture GDP or population between 1990 and 2010 on the variables listed at left. Market access variables are measured using either GDP or population, as is indicated in column headers. Each regression has 282 observations.

Table A3: Effects of City Transport Networks - OLS Regressions

Unit of Analysis:	Prefecture		City		Prefecture		City	
Outcome:	Δ log GDP				Δ log Population			
Road Rays	0.012		0.0059		0.020**		0.018*	
	(0.013)		(0.016)		(0.0079)		(0.0096)	
Rail Rays		0.017		0.022		0.0012		0.020
		(0.023)		(0.026)		(0.0088)		(0.013)
Provincial	0.23**	0.25***	0.47***	0.47***	0.22***	0.26***	0.20***	0.23***
Capital	(0.091)	(0.085)	(0.14)	(0.12)	(0.033)	(0.039)	(0.060)	(0.059)
log 1982 Prefecture	-0.016	-0.014	-0.13**	-0.14**	-0.12***	-0.10***	-0.034	-0.028
Population	(0.056)	(0.057)	(0.066)	(0.070)	(0.035)	(0.032)	(0.036)	(0.034)
1982 Fraction	-0.24	-0.31	-1.41	-1.55	-0.39	-0.30	-0.52	-0.58
HS Graduate	(0.70)	(0.72)	(0.99)	(1.01)	(0.32)	(0.31)	(0.42)	(0.42)
1982 Fraction	0.72**	0.68*	-0.68	-0.70	0.47**	0.42**	0.29	0.23
Manufacturing	(0.36)	(0.35)	(0.74)	(0.72)	(0.20)	(0.20)	(0.25)	(0.26)
log km to Coast	-0.084***	-0.084***	-0.12***	-0.13***	-0.043***	-0.040***	-0.055***	-0.054***
	(0.017)	(0.018)	(0.040)	(0.040)	(0.012)	(0.012)	(0.015)	(0.015)
Constant	3.61***	3.60***	6.01***	6.11***	2.07***	1.86***	1.10*	1.05*
	(0.85)	(0.88)	(1.15)	(1.21)	(0.55)	(0.52)	(0.57)	(0.56)
R-Squared	0.20	0.20	0.16	0.16	0.34	0.32	0.19	0.18

Notes: Each column is a separate OLS regression of the outcome listed at top between 1990 and 2010 in the unit of analysis listed at top on the variables listed at left. Each regression has 282 observations.

Table A4: Prefecture City Growth IV Regressions - Market Potential

Outcome:	Δ log Prefecture GDP		Δ log Prefecture Population		Δ log Prefecture GDP		Δ log Prefecture Population	
Market Potential Measure:	GDP	Population	GDP	Population	GDP	Population	GDP	Population
log 2010 Market	0.11	0.13	0.0028	0.0032	0.19**	0.20**	0.00060	0.00072
Potential	(0.075)	(0.084)	(0.019)	(0.022)	(0.075)	(0.081)	(0.025)	(0.027)
log 2010 Time to	-0.011	-0.016	-0.073***	-0.073***	0.0029	-0.0069	-0.074***	-0.074***
Coast	(0.055)	(0.053)	(0.026)	(0.026)	(0.054)	(0.052)	(0.026)	(0.026)
log 2010 Market					-0.072	-0.065	0.021	0.026
Potential X Rank = 1					(0.11)	(0.13)	(0.028)	(0.034)
Rank = 1					0.90	1.35	-0.17	-0.43
					(1.09)	(2.32)	(0.27)	(0.59)
Provincial	0.56***	0.53***	0.26***	0.26***	0.60***	0.54***	0.26***	0.26***
Capital	(0.13)	(0.12)	(0.064)	(0.062)	(0.13)	(0.12)	(0.066)	(0.064)
log 1982 Prefecture	-0.24***	-0.24***	-0.045	-0.045	-0.30***	-0.29***	-0.053	-0.053
Population	(0.085)	(0.084)	(0.039)	(0.039)	(0.10)	(0.099)	(0.042)	(0.042)
1982 Fraction	-1.57	-1.47	-0.65	-0.64	-1.91**	-1.72*	-0.68	-0.68
HS Graduate	(0.99)	(0.99)	(0.40)	(0.40)	(0.97)	(0.97)	(0.42)	(0.42)
1982 Fraction	-1.01	-0.88	-0.019	-0.016	-1.18*	-0.96	-0.022	-0.016
Manufacturing	(0.67)	(0.62)	(0.26)	(0.25)	(0.69)	(0.63)	(0.25)	(0.25)
log km to Coast	-0.097*	-0.10**	-0.025*	-0.025*	-0.092*	-0.10**	-0.024*	-0.024*
	(0.050)	(0.051)	(0.014)	(0.014)	(0.049)	(0.050)	(0.014)	(0.014)
Constant	6.44***	5.26***	1.61***	1.58***	6.55***	4.73***	1.75***	1.75***
	(1.06)	(1.31)	(0.59)	(0.57)	(1.11)	(1.12)	(0.61)	(0.61)
First Stage F	19.8	28.2	19.8	28.2	16.9	19.4	16.9	19.4

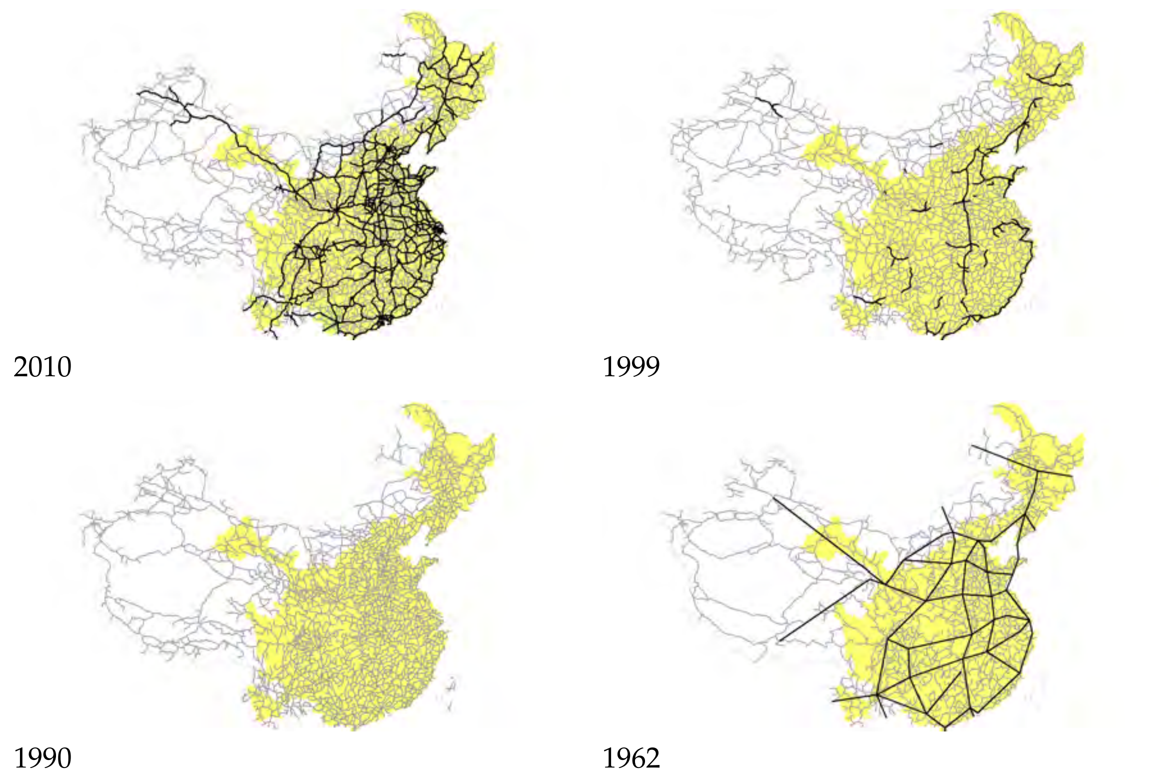
Notes: Each column is a separate regression of the change in log prefecture city GDP or population between 1990 and 2010 on the variables listed at left. All variables above "Rank = 1" are treated as endogenous. Market potential variables are measured using either GDP or population, as is indicated in column headers. Each regression has 282 observations.

Table A5: Prefecture City Growth IV Regressions - Market Access

Outcome:	Δ log Adjusted Prefecture GDP				Δ log Adjusted Prefecture Population				Δ log Adj Pref GDP		Δ log Adj Pref Pop	
Market Access Measure:	GDP		Population		GDP		Population		GDP	Pop	GDP	Pop
log Total Market	2.29***		2.10***		0.74**		0.72***		2.18***	2.00***	0.54*	0.55*
Access	(0.46)		(0.44)		(0.30)		(0.28)		(0.54)	(0.52)	(0.30)	(0.28)
log Domestic		1.65**		1.55**		0.44		0.50				
Market Access		(0.71)		(0.66)		(0.40)		(0.36)				
log External		0.68		0.91		0.36		0.37				
Market Access		(0.77)		(0.69)		(0.41)		(0.36)				
log 2010 Market									1.90*	1.80*	1.16	1.13*
Access X Rank = 1									(1.07)	(1.05)	(0.73)	(0.64)
Rank = 1									-12.1*	-16.7*	-7.45	-10.5*
									(6.93)	(9.84)	(4.66)	(6.01)
Provincial	0.88***	0.89***	0.80***	0.88***	0.68***	0.69***	0.66***	0.69***	0.88***	0.80***	0.68***	0.66***
Capital	(0.12)	(0.11)	(0.12)	(0.11)	(0.066)	(0.072)	(0.063)	(0.072)	(0.12)	(0.11)	(0.066)	(0.062)
log 1982 Prefecture	-0.037	-0.039	-0.018	-0.040	0.15***	0.15***	0.16***	0.15***	-0.074	-0.056	0.14**	0.14***
Population	(0.065)	(0.063)	(0.064)	(0.063)	(0.051)	(0.053)	(0.050)	(0.053)	(0.077)	(0.074)	(0.057)	(0.055)
1982 Fraction	-0.55	-0.63	0.061	-0.60	-0.33	-0.45	-0.13	-0.40	-0.63	-0.015	-0.31	-0.14
HS Graduate	(0.85)	(1.10)	(0.86)	(1.09)	(0.50)	(0.62)	(0.51)	(0.61)	(0.86)	(0.86)	(0.49)	(0.51)
1982 Fraction	1.63***	1.61***	1.91***	1.69***	1.36***	1.32***	1.45***	1.36***	1.65***	1.97***	1.39***	1.49***
Manufacturing	(0.53)	(0.47)	(0.53)	(0.47)	(0.29)	(0.28)	(0.29)	(0.28)	(0.54)	(0.53)	(0.30)	(0.29)
log km to Coast	-0.12***	-0.11**	-0.14***	-0.11**	-0.065***	-0.059***	-0.072***	-0.059***	-0.11***	-0.13***	-0.064***	-0.069***
	(0.028)	(0.045)	(0.029)	(0.044)	(0.015)	(0.017)	(0.015)	(0.017)	(0.028)	(0.029)	(0.015)	(0.015)
Constant	-9.44***	-8.24***	-14.6***	-10.9**	-0.036	0.23	-2.09	-0.60	-8.18***	-13.1***	1.36	-0.27
	(2.84)	(2.54)	(3.94)	(5.14)	(1.67)	(1.42)	(2.32)	(2.91)	(3.15)	(4.44)	(1.59)	(2.32)
First stage F	55.4	27.1	57.7	28.2	55.4	27.1	57.7	28.2	16.4	15.5	16.4	15.5

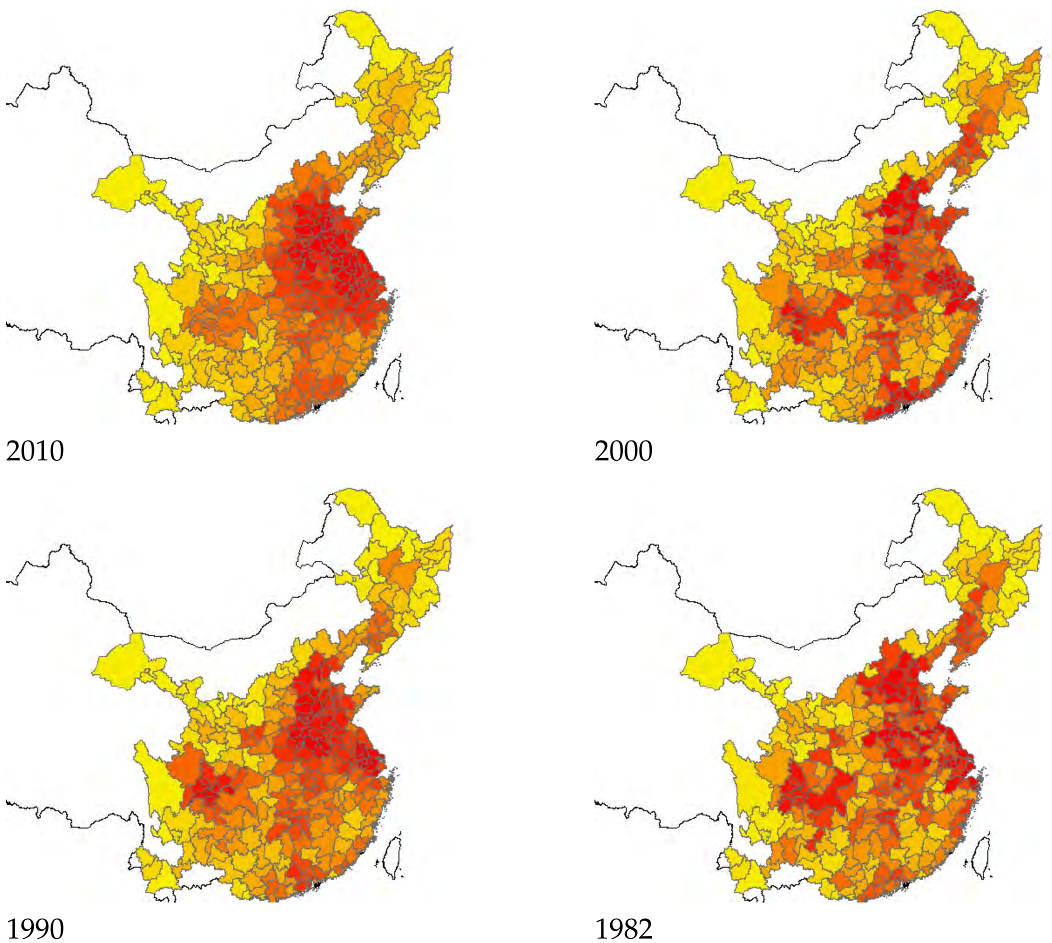
Notes: Each column is a separate regression of the change in log prefecture city GDP or population between 1990 and 2010 on the variables listed at left. All variables above "Rank = 1" are treated as endogenous. Market access variables are measured using either GDP or population, as is indicated in column headers. Each regression has 282 observations.

Figure 1: Road networks over time.



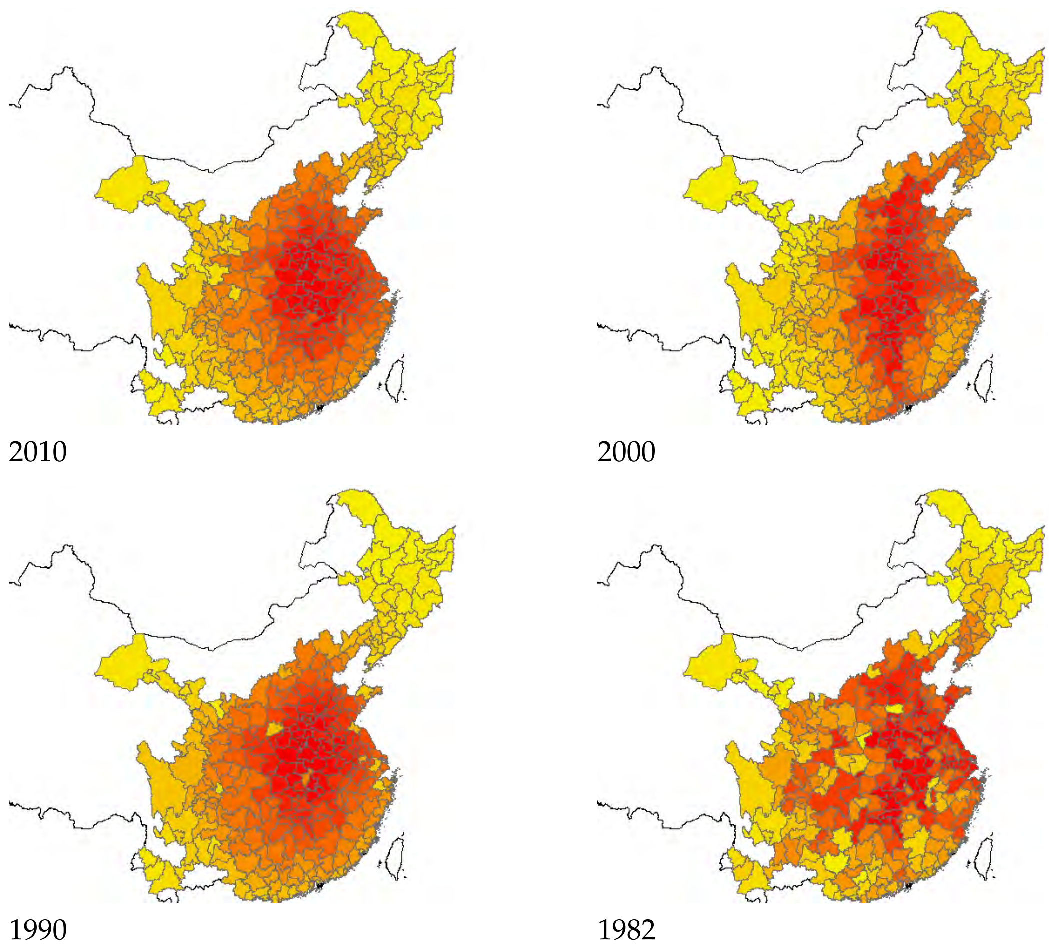
Note: Maps illustrate the road networks on which travel time and radial road calculations are based. In all years gray lines indicate minor highways and national roads. Black lines indicate limited access highway in all years except 1962. In 1962 black lines indicate our straight line approximation of the "5-7 plan" network. Our study area is highlighted in yellow. For the purposes of minimum network travel time calculations, in all years traffic moves at 90 kph on limited access highways, 25 kph on minor roads and 15 kph overland. Note that there are no limited access highways in 1990.

Figure 2: Employment based market potential measure over time.



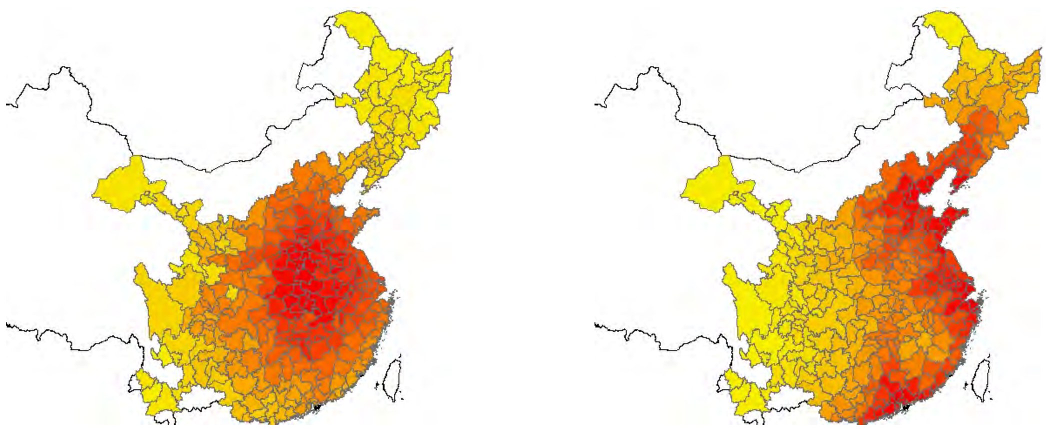
Note: Maps illustrate market potential ranking. Darker colors indicate prefectures with higher rankings and hence larger market potential values.

Figure 3: Population based market access measure over time for $\rho = 0.2$ and $\theta = 1.5$.



Note: Maps illustrate prefectural market access ranking. Darker colors indicate prefectures with higher rankings and hence larger market access values.

Figure 4: Domestic and international components of population based market access measure in 2010 when $\rho = 0.2$ and $\theta = 1.5$.



Domestic International

Note: Maps illustrate prefectural ranking based on domestic and international components of market access. Darker colors indicate prefectures with higher rankings and hence larger market access values.