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A Comprehensive GIS Database for China's Surface Transport Network with Implications for Transport and Socioeconomics Research[*]

Steven Davis,[†] Meijun Qian,[‡] and Wen Zeng[§]

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HOOVER INSTITUTION
434 GALVEZ MALL
STANFORD UNIVERSITY
STANFORD, CA 94305-6010
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We build a granular GIS database that covers China's national highways, modern motorways, traditional railways, high-speed railways, and waterways at an annual frequency from 1993 to 2020. Overall network length more than tripled after 1993, with half the increase accounted for by modern motorways and high-speed railways. Mean distance from zip-code centroids in China to nearest motorway access point fell from 302 km in 1993 to 15 km in 2020. Average within-county connectivity to the transport network rose sharply. We also show that discrepancies between distance to nearest motorway access point and straight-line distance to motorway routes are often large, and they correlate with calendar time, terrain features, and economic development. This finding raises concerns about the use of straight-line distance when estimating the causal effects of transport improvements. Our GIS database is freely available on an open-access basis, creating an empirical laboratory for new research in multiple directions.

Keywords: Transport network, GIS database, China, Infrastructure investments, Transport access, Socioeconomic development
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[†] Steven Davis is a Senior Fellow at the Hoover Institution and at the Stanford Institute for Economic Policy Research. *Email*: StevenD5@Stanford.edu

[‡] Meijun Qian is a Chief Fellow in the Research Institute at People's Bank of China and Distinguished Visiting Professor, School of Public Policy and Management at Tsinghua University. *Email*: meijunqian@gmail.com

[§] Wen Zeng is a postdoctoral research fellow at Australia National Univ. *Email*: Wen.Zeng.001@gmail.com

I. Introduction

Transport networks shape the spatial distribution of economic activity and influence productivity, trade flows, prices, urbanization, geographic mobility, and more.[1] China's surface transport network has grown tremendously in scale and quality in recent decades. To track this development, we build a granular Geographic Information System (GIS) database that covers China's modern motorways, regular railways, high-speed railways, highways, and waterways at an annual frequency from 1993 to 2020.

Partial snapshots of China's transport network in previous studies show its growing scale and complexity over the past century (Wang et al., 2009; Jiao et al., 2014; Hu et al., 2015; Jin et al., 2019). While less relevant for freight and low-wage workers, high-speed railways and air travel growth in recent decades have greatly improved connectivity between Chinese cities (Lao et al., 2016; Jiao et al., 2017). Relative to earlier work, our GIS database is more granular, more comprehensive in its coverage of surface transport modes, more attentive to route access locations, and better suited for tracking year-to-year changes in motorway, railway, and highway transports over a long time span. We also incorporate travel speed estimates by travel modes and route segments.[2]

After describing the construction of our database, we characterize China's surface transport network and quantify its development in multiple aspects. Overall network length rose from 184,000 km in 1993 to 563,000 km in 2020. Half the increase took the form of modern motorways and high-speed railways. Mean distance from zip-code centroids in China to nearest motorway access point fell from 302 km in 1993 to 15 km in 2020, while the average county-level connectivity nearly doubled. Route density rose tremendously, as did other transport quality indicators.

We also show that straight-line distances from zip code centroids to the nearest motorway route deviate considerably from distances to nearest motorway access point. Moroever, these distance discrepancies correlate with calendar time, terrain features, and

[1] Studies on how transport networks affect trade, productivity, worker mobility, income, and economic growth include Eaton and Kortum (2002), Redding and Venables (2004), Faber (2014), Allen and Arkolakis (2014), Donaldson and Hornbeck (2016), Donaldson (2018), and Banerjee et al. (2020). The World Bank (2000, 2005), Sachs (2005), and Smith (2005) devote particular attention to market access and poverty alleviation. Studies that focus on land use, resource access, ecosystems, biodiversity, and environmental degradation include Kahn et al. (2007), Chapman (2007), Weinhold and Reis (2008), Benítez-López et al. (2010), Laurance (2013, 2014), and Ibisch et al. (2016). See Baum-Snow (2007), Duranton and Turner (2012), Zheng & Kahn (2013), Egger et al. (2023) and Ma and Tang (2024) for effects on urban development and regional integration. See Woodcock et al. (2009), Hystad et al. (2013), and Jiang et al. (2017) for public health effects. See Litman (2002), Lucas (2012), and Grieco and Urry (2016) on social equality and inclusiveness.

[2] We recently became aware of independent work by Egger et al. (2023), who measure the expansion in China's roads, highways, and railways from 2000 to 2013.

economic development. In light of this finding, using straight-line distances to routes as a proxy for actual travel distances to transport access points can lead to biases in the estimated causal effects of transport improvements.

Many studies investigate the effects of transport improvements on socioeconomic outcomes in China. Zheng and Khan (2013), Qin (2017), and Lin (2017) find that high-speed railways facilitate market integration and urban employment, raise house prices near passenger stations, and reduce output along upgraded railway routes. Faber (2014) finds that China's national trunk highways affect the concentration of economic activity and reduce growth in non-targeted peripheral counties. Zhang and Ji (2019) conclude that the development of railways and roads could raise or lower local GDP, depending on how new transports alter local competition with nearby areas. Banerjee et al. (2020) find that proximity to railways and waterways has modest positive effects on local GDP per capita but not on its growth rate. Baum-Snow et al. (2020) conclude that better access to national highways raises output and population in regional urban centers at the expense of hinterland areas. Our own work (Davis and Qian, 2021) suggests that better access to high-quality transport raises the average productivity of China's manufacturing plants while lowering productivity dispersion across plants.

There is much scope for further research into the effects of China's transport network on supply chains, productivity, geographic mobility, poverty, environmental outcomes, and the spatial distribution of production. Our database covers multiple transport modes with high geospatial granularity over 28 years, making it well-suited for long-span longitudinal studies. As an example, the tremendous build-out of China's transport network presumably led to greater internal integration and closer linkages to the world economy. In this respect, our database opens the door to quantitative analyses of how internal and external integration affects economic development, as in Fajgelbaum and Redding's (2022) analysis of the Argentine experience. Given the large size of its economy, transport in China also influences global trade patterns. Our open-access database can also be integrated with other GIS data sources for local streets and facilities, as in Davis and Qian (2021).

Section II defines transport modes, describes data sources, and explains the digitization of spatial information. Section III characterizes the evolution of China's surface transport network, graphically and statistically. Section IV stresses the distinction between transport routes and access points and documents the growth of "pass-through" counties with motorway and high-speed railway routes but no access points. Section V sketches possible applications of our database in future research, and Section VI concludes.

II. The Database: Definitions and Construction

Table 1 summarizes the main elements of our database. All shapefiles can be layered onto each other in the GIS and used for analysis.

II.1 Transport Modes and Coverage

(1) Motorways

A motorway in our database refers to a high-speed and access-controlled roadway with at least two traffic lanes in each direction and speed limits ranging from 80 to 120 km/h.[3] Some documents refer to motorways as expressways or freeways, and they are often regarded as parts of a national and provincial highway system from an administrative perspective.[4] Our GIS database records all operational motorways over 1993-2020. The shapefiles contain information on motorway routes, their maximum speeds, and entry and exit ramp locations. The first operating motorway opened in 1988 in China, from Shanghai to Jiading, and other major motorway projects began in the mid-1990s.[5] By the end of 2020, the total length of motorway transport reached 161,000 km in China, making it the longest national motorway network in the world (Ministry of Transport, 2020).

(2) Highways

Highways are a mix of primary, secondary, and tertiary roads that fill out the national highway system in China, including provincial and county roadways. Most highways in the Eastern region have 2-by-2 or 3-by-3 lanes with a speed limit of 60-80 km/h. In the Central and Western regions, highways are 2-by-2 or even 1-by-1 lanes, with a speed limit as low as 20 km/h. Highways usually connect smaller towns and are freely accessible, whereas motorways connect larger prefectural cities and ports and typically require tolls. Our GIS database digitizes all operational highways and manually collects speed limits for highway segments from 1993 to 2020. Since additions to highways primarily occurred after 2012, we adopt a GIS map in 1993 to represent the highway networks over 1993-2012, combined with year-to-year changes over 2013-2020. Our database suggests that motorways and

[3] Some motorway segments fall short of meeting these technical requirements in regions with a less developed road system. Typically, these segments involve a short primary road that completes a portion of the motorway network. These instances are infrequent.

[4] Regarding administration, roads in China are divided into national, provincial, and county highways. From the technical aspect, roads include motorways, primary, secondary, tertiary, and fourth roads. Thus, the administrative categorization of roads may only partially align with their technical and functional characteristics. *OpenStreetMap* also refers to roads as “trunk-ways”, which are primarily primary and secondary roads, as well as some tertiary roads in the Western region.

[5] For instance, the "7918" network project launched in 2004, and the "71118" project commenced in 2013 (Zhang et al., 2023).

highways have a total linear distance of 346,062 km in 2020[6] and that the proportion of counties covered by motorway or highway segments increased from 70% in 1993 to 96% in 2020 in China.

(3) Regular (Standard and Fast) Railways

Railways in China include regular (standard and fast) and high-speed railways. A standard railway has a maximum speed of 160 km/h, while a fast railway has a speed from 160 to 250 km/h, covering both passenger and freight routes.[7] We digitize routes of all operational standard and fast railways over 1995-2020 in one shapefile and information on stations in another. Speed limits for each route are also included in data attributes and categorized into six levels of stations for passenger and freight lines. Large-scale railway constructions began in the 1980s after economic reforms. After that, there were six "speed-up" campaigns in China from 1997 to 2007. In 2001, an "Eight Vertical and Eight Horizontal" railway network was launched, substantially expanding railway transport. In addition, we manually collect data on new railway additions and speed improvements from official documents released by the National Railway Administration (NRA).

(4) High-Speed Railways

Unlike regular railways, high-speed railways serve passengers only and have a much higher maximum speed of 250-350 km/h on main lines and 200-250 km/h on regional segments in China.[8] The construction of high-speed railways was first launched in 2003, followed by a large expansion that built high-speed railway segments parallel to the "Eight Vertical and Eight Horizontal" network in 2016. By 2020, there were more than 38,000 km of high-speed railways in China, more than any other country. Our GIS database contains annual maps of all operating high-speed railways over 2003-2020. As with other transports, we digitize GIS information of routes, stations, and speed limits in shapefiles. Combining regular and high-speed railways, the total length of railway transports reached 146,000 km in 2021, secondary only to the United States.[9] However, the extent of the railway network is less impressive in China if its geographic area or population size scales it. For instance, 84 countries have a per-capita railway length that exceeds China.

[6] The number computed by our database is very close to a linear distance of 370,700 km reported by the Statistical Bulletin on the Development of the Transport Industry in 2020 based on an administrative classification of roadways. See: http://wap.china-railway.com.cn/ (Last accessed on 2024/06/29)

[7] We manually collect railway speed information from official documents and high-speed railway launch announcements posted by the National Railway Administration (NRA). See: http://www.nra.gov.cn/

[8] China has tested higher speeds since 2014. For instance, the world's fastest maglev train, with a speed of up to 600 km/h, rolled off the assembly line in Qingdao, China, in 2021 but has yet to be placed in operation.

[9] https://en.wikipedia.org/wiki/List_of_countries_by_rail_transport_network_size

(5) Waterways

In China, navigable waterway routes have expanded modestly over the past three decades.[10] Using waterway maps from 1994 that include all inland and coastal routes navigable by ships, we identify six tonnage capacity levels as grade criteria: over 10,000 tons, 1,000-10,000 tons, 500-1,000 tons, 300-500 tons, 100-300 tons, and 50-100 tons. Our database contains one shapefile for waterway routes and another for capacity grades along each route.[11]

(6) Earlier Data on Roadways and Railways

Baum-Snow et al. (2017) study how the growth of roads and railways influenced the urban form of Chinese cities since the early 1990s using data on roadways and railways in 1962 to implement their identification strategy. They generously gave us permission to incorporate their data in 1962 into our database. As of 1962, roadways that formed highway networks typically had two lanes in each direction and operated in an open-access manner in China. Many roadways were designed for only some weather conditions or even paved (Lyons, 1985), and one of their main functions was to move agricultural goods to local markets back then. More than two-thirds of railways in 1962 were built before 1949 and were upgraded with engineering support from the Soviet Union from 1949 to 1962. During this period, the resource-rich Western region was connected with Eastern manufacturing centers, which shipped raw materials and manufactured goods between large urban cities (Baum-Snow et al., 2017). According to China Statistical Yearbooks, China had a total length of 34,600 km in railways and 143,442 km in roadways in 1962.[12]

II.2 Other Elements in the Database

In addition to transport modes, our database also includes information on terrain features, county boundaries, city locations, and postal areas as follows:

Terrain Features: We obtain data on county-level terrain features from the National Geographic Information database managed by the Ministry of Natural Resources in China.[13]

[10] The inland waterway system consists of two horizontal trunk waterways (Yangtze River and Xijiang River), one vertical trunk waterway (Beijing-Hangzhou Grand Canal), two high-grade waterway networks (Yangtze River Delta and Pearl River Delta), and 18 high-grade mainstreams and tributary waterways. The south-north coastal line covers major cities on the east coast between Beihai in Guangxi province in the Southern region and Dangdong in Liaoning province in the Northern region. The total waterway length was 110,200 km in 1993, 127,000 km in 2015, and 127,300 km in 2019 in China.

[11] Since 1994, there have been improvements in navigability and cargo-handling capabilities of ports on the Yangtze River, Xijiang River, and Beijing-Hangzhou Grand Canal (Ministry of Transport, 2020).

[12] The statistics come from China Statistical Yearbooks by the National Bureau of Statistics (NBS). See: http://www.stats.gov.cn/tjsj/ndsj/

[13] The Ministry of Natural Resources is an executive department of the State Council in China, which is responsible for the country's natural resources. See: http://www.mnr.gov.cn/ (Last accessed on 2024/06/19)

Satellite images yield data on terrain elevation for each raster (grid square) in a given county. For each county, we record the number of grid squares and the cross-raster mean, median, standard deviation, minimum, and maximum elevations. We also measure the count of unique elevation values as elevation variety in a given county.

Boundaries: Our database includes a shapefile that records 2,869 counties, 341 prefecture-level cities, and 31 provinces in China, along with their boundaries based on China's public administration structure in 2020. This file can be used to construct maps that exhibit how socioeconomic statistics in different administrative units vary with local transport measures and other data sources.

Geolocations: Our database includes geographical coordinates for 341 prefecture-level cities and provincial capitals in China. We record longitude and latitude information on the geographical centroids of city-level administrative units. Combined with our GIS data on transport modes, these data enable us to compute city-level transport quality measures, such as density, connectivity, as well as travel time and distances between cities.

Distances and Areas: We use the *GCS_WGS_1984* geographical coordinate system to define locations by longitude and latitude. This coordinate system is in wide use, including by *OpenStreetMap*. We then calculate distances between two points and straight-line distances between points and transport routes using *PointDistance* function in ArcGIS. We measure area sizes using the *Krasovsky_1940_Albers* projection.

Postal Areas: China partitions its area into 35,798 postal areas, analogous to zip codes in the United States. For each "zip code" with one or more operational manufacturing plants over 1998-2013, we incorporate longitude and latitude values for the area's centroid from Davis and Qian (2021) into our database and provide geolocation data for about 97.5% of all postal areas.[14]. We calculate travel time and distance between each postal area and their nearest motorway access points, railway stations, highway routes, and navigable waterways.

[Table 1. An overview of the GIS database of surface transports in China]

II.3 An Overview of Database Construction

We summarize the main steps to construct a reliable and ready-to-use GIS database for all surface transports in China:[15]

[14] The missing areas have little commerce in the Western region, which is less important for our analysis.

[15] The online technical manual "ReadMe" file describes additional details of our database for all surface transports in China over 1993-2020 (Davis and Qian, 2024). The file named "Technical Details of Digitization and Rectification" introduces in more detail the database construction process.

1) Obtain raw GIS data from *OpenStreetMap* in 2013 and 2020 that cover all transport modes and include information on land features;
2) Collect physical maps for transport modes over 1993-2020 from the China Road Atlas published by China Communications Press, online bookstores, such as Kongfuzi and Jiushujie, and second-hand book vendors on E-commerce platform, such as Taobao;[16]
3) Scan each physical map and incorporate spatial information into ArcGIS interface using the *GCS_WGS_1984* coordinate system compatible with *OpenStreetMap*;
4) Merge the digital representations of physical maps in 2013 with *OpenStreetMap* to build shapefiles for transport routes and identify motorway access points and railway stations as "nodes":
    a. Include certain primary and secondary roads as part of the national highway system, following *OpenStreetMaps*;
    b. Exclude subway lines, light rail lines, and tram networks in metropolitan cities from our designation of standard and fast railways;
    c. Designate each motorway access point by the centroid of a rampway, which is a curve or butterfly shape;
    d. Delete false intersections in *OpenStreetMap* when one highway passes over another;
    e. Draw on official sources to correct missing and wrongly located railway stations;[17]
    f. Identify false dangles in *OpenStreetMap* using satellite data, correct these false dangles to indicate the presence of a throughway, and fix the errors for motorways, highways, and railways;
5) Repeat Step 4 for the data in 2020;
6) Create shapefiles of transport modes from 2012 back to 1993 using the *OpenStreetMap* in 2013 and new additions of transports obtained by digital representations of physical maps year-by-year over 1993-2012;[18]

[16] Kongfuzi: www.kongfz.com; Jiushujie: www.jiushujie.com; Taobao: www.taobao.com
[17] We obtain the official information on railway stations from the National Railway Administration (NRA) (http://www.nra.gov.cn/) and 12306 China Railway (https://www.12306.cn/mormhweb/kyyyz/).
[18] Since GIS transport data has the most extensive coverage in 2013 over the period of 1993-2013, it is easier to delete transport additions from the map of 2013 backward than to draw new sections forwards. For instance, we match the digital representations of physical map data in 2012 with *OpenStreetMap* in 2013 and delete the relevant parts to attain the GIS data in 2012 to create the shapefile of transport modes in 2012. Similarly, the creation of shapefiles of transport modes from 2019 back to 2014 is finished using *OpenStreetMap* in 2020 in the same way.

7) Create shapefiles of transport modes from 2019 back to 2014 using the *OpenStreetMap* in 2020 and verify with the approach by adding new routes from 2013 onwards to obtain digital representations of physical maps over 2014-2019.
8) Add speed attributes for motorways and highways using the legal maximum speeds by route *OpenStreetMap* in 2020;
9) Adjust the speed attributes for other years based on data from the six railway speed-up campaigns;[19]
10) Add data on types of railway stations and grades of railway routes.

II.4 What Measures Does Our Database Deliver?

Table 2 lists location-specific, pairwise, and network-level transport statistics included as part of our database. Here, a "location" can refer to a county centroid, motorway access point, railway station, or port. We first calculate distances between county centroids and the nearest motorway access point, railway station, port, highway route, and waterway route. Our database delivers centrality measures for each location, as well as travel distances and times between locations. It also delivers route and node density measures and statistics on centrality and connectivity at national, regional, provincial, and user-defined levels.

[Table 2. Definition of transport measures in the database]

These measures are widely used in studies of transport networks. See Wasserman and Faust (1994) and Jackson (2010), among others, for broad treatments and many applications. See Kansky (1963), Taafee et al. (1996), and Rodrigue (2020) for a focus on transport networks. In previous work on China, Wang et al. (2009) measure the centrality and connectivity of city centroids based on railways only in various years from 1906 to 2000. Jin et al. (2010) quantify network attributes in 2006 based on data for railways, highways, ports, and airports.

III. The Evolution of Surface Transports

III.1 Visual Depictions of China's Transport System and Terrain Features

Figure 1 portrays China's development of motorway transports from 1993 to 2020. The extraordinary expansion of the motorway network is highly concentrated in the eastern part

[19] Due to the "Eight Vertical and Eight Horizontal" launched by the Chinese government in 2001, there were six "speed-up" campaigns in the railway network from 1997 to 2007. The National Railway Administration posted the specific date, railway section, and new speed of all speed improvements. We manually collect data on them and draw six separate shapefiles based on these official documents (http://www.nra.gov.cn/).

of China. Figure 2 presents a closer view of the motorway network in 1993, 2003, 2013, and 2020. Most new motorway routes were constructed after the early 2000s.

[Figure 1. The expansion of motorway transports over 1993-2020]

[Figure 2. Motorway transports in 1993, 2003, 2013, and 2020]

Figure 3 show high-speed railway routes in 2003, 2010, 2015, and 2020. We see an extraordinary expansion after 2003. Figure 4 shows the evolution of standard railways, indicating that China already had an extensive network of these railways in place by 1995. However, we find remarkable further expansions and upgrades after 1995, and especially after 2003. As of 1995, every major segment of the regular railway system had average speeds of only 50 km/h. By 2013, every major segment of the system was designd for maximum speeds of at least 120 km/h and up to 200 km/h along some routes.

[Figure 3. High-speed railways in 2003, 2010, 2015, and 2020]

[Figure 4. Regular railways in 1993, 2003, 2013, and 2020]

Figure 5 portrays national highway routes in 1993, 2003, 2013, and 2020. Despite already having a large national highway system in place by 1993, China still saw tremendous expansion in its national highways from 1993 through 2020.

Figure 6 depicts navigable waterways as of 1993. We distinguish waterways by six capacity levels and omit waterways with a capacity of less than 50 tons. China's inland waterway length from only modestly from 110,200 km in 1993 to 127,700 km in 2020.

[Figure 5. National highways in 1993, 2003, 2013, and 2020]

[Figure 6. Figure 6. Navigable waterways in 1993]

Figure 7 shows elevation mean and variability at the county level in China. Panel (a) shows shows how mean elevation levels rise in moving from East to West. Mean elevation is typically less than 300 meters in the East but exceeds 3,000 meters in much of the West. Not surprisingly, surface transport is much more highly developed in the low-lying Eastern counties. Panel (b) shows county-level ruggedness, measured as the standard deviation of within-county elevations. Eastern counties tend to have less rugged terrain. The Xinjiang and Southwest border of Yunnan Province feature the most rugged terrain.

[Figure 7. Mean and variability of terrain elevations by county]

III.2 Network Length, Access, and Coverage Statistics

Table 3 reports surface transport lengths based on our GIS database in Panel A and official statistics in Panel B. According to Panel A, motorway transport length grew from 6,300 km in 1993 to 153,400 km in 2020. High-speed railway length grew from a mere 400 km in

2003 to 13,600 km in 2013 and 39,000 km in 2020. Highway system length increased more than eighty percent from 1993 to 2020.

The official statistics in Panel B tell a similar story. Our database yields slightly greater railway lengths in the early years, because we include some routes that do not meet the grade requirements of the official statistics in the China Statistical Yearbooks. The total length for high-speed railways reported in our GIS database is higher than official statistics because we include route segments of regular tracks on which high-speed trains travel occasionally. The total length of highways from official sources are also very close to what we calculate in our GIS database.[20] Though not reported in Table 3, the total lengths of navigable waterways obtained from our GIS database are similar to official statistics.[21]

[Table 3. Total length of surface transports]

Figure 8 presents the number of access points for motorways, regular railways, and high-speed railways by year from 1993 to 2020. Regular railway stations rose in number from 6,684 in 1995 to 8,781 in 2020. High-speed railway stations rose from a mere 10 in 2003 to 1,069 in 2020. Motorway access points rose from 796 in 1993 to 9,972 in 2020.

[Figure 8. Number of access points to transports over 1993-2020]

Figure 9 shows coverage rates by transport type among all 2,819 counties in China. Panel (a) reports the proportion of counties through which a transport route passes, showing remarkable increases from 1993 to 2020. Motorways route coverage rose from 6.7% of counties in 1993 to 84.2% in 2020, and high-speed railway coverage rose from 0 in 2002 to 44.1% in 2020. The coverage of regular highways rose from 58.3% in 1993 to 72.4% in 2020. In addition, 70.5% of counties in 1993 had at least one highway route, rising to 92.7% in 2020. Panel (b) plots the fraction of counties with access points for various transport types. Only 0.3% (eight) counties had high-speed railway stations in 2003, rising to 29.1% in 2020. The coverage rate of regular railway stations rose from 53.4% in 1993 to 65.1% in 2020, and the coverage rate of motorway access points from 5.9% to 80.0% over the same period.

[Figure 9. Transport coverage at the county level over 1993-2020]

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[20] The China Statistical Yearbooks originally post the total lengths of national roadways, including highways and motorways, as defined in our GIS database. We subtract the total lengths of national roadways from motorways to attain the total lengths of highways in Panel B of Table 3.

[21] Our GIS database yields 64,000 km of navigable inland waterways in 1994 after dropping routes with graded capacity of less than 50 tons, nearly matching the length of 68,000 km in official sources.

III.3 Distance to Transport, Density, and Connectivity

Figure 10 presents information on the evolution of "average" distance to transports in China. It shows tremendous improvements in acess to motorways and high-speed railways and notable improvements for regular railways as well. For example, the average distance from zip-code centroids to the nearest motorway access point fell from 302 km in 1993 to 15 km in 2020. The average distance to the nearest high-speed railway station fell from 1,254 km in 2003 to 59 km in 2020.

[Figure 10. Average distance to the nearest transports]

Figure 11 preents several measures of transport density in China. Length density equals transport length per squared km of area, and node density equals the number of access points per squared km. Panel A shows that both density measures more than doubled from 1993 to 2020 at the national level. In panel B, we first compute the density measures at the county level and then compute the simple mean density over counties. This approach yields somewhat smaller gains in transport density. It's also clear from the figure that national density measures are smaller than average county-level density measures. This pattern arises because many counties in China have small areas but high transport densities, while a few counties have large areas and low transport densities. This heterogeneity yields right-skewed distributions of county-level transport densities.

[Figure 11. Transport density measures from 1993 to 2020]

Figure 12 presents county-level *connectivity* of all transport modes in 1993, 2000, 2010, and 2020. We use the Beta index measure of connectivity, defined as the average number of links per node in a network. Connectivity grew fastest in the Central region (Henan, Hebei, Shanxi, and Anhui provinces), reaching an average of 2.45 in 2020. It grew more slowly in the Western region (Xizang, Xinjiang, and Yunnan provinces), reach an average value of 2.02 in 2020.

[Figure 12. County-level connectivity in 1993, 2000, 2010, and 2020]

IV. Transport Routes *versus* Transport Access

Many studies use transport routes that pass through a given county or other geographic unit as a measure of transport coverage. However, Figure 9 reveals material differences between route coverage and transport access. A strength of our GIS database is that it distinguishes between transport routes and transport access, as we illustrate in this section.

IV.1 "Passing-Through" Counties

New transports in China often pass through particular counties without providing within-county access to the transport. As of 2020, 1,243 counties (44%) had at least one high-speed railway line passing through without access, and 421 counties had no high-speed railway stations. Using straight-line distances to high-speed railway lines yields a problematic indicator of access to high-speed railway transport for these counties.

More broadly, Figure 13 shows the average county-level discrepancy between distance to nearest access point and shortest distance to the transport route. In computing this average, we weight counties equally in Panel (a) and by GDP in Panel (b). The average distance discrepancies vary over time, especially for high-speed railways. Average motorway distance dicrepaencies fluctuate and drift downward over time. These patterns raise concerns about studies that use distance to route to proxy for distance to access. Faber's (2004) study reinforces this concern, given his finding that new motorways can lead to reduced economic activity in passing-through counties.

[Figure 13. Distance discrepancy between access point and route to county centroid]

IV.2 Correlates of Distance Discrepancies

We now consider how discrepancies between route "proximity" and distance to transport access correlate with geographic and socioeconomic characteristics. As before, we compute the distance discrepancy as shortest distance from county-level centroid to the transport route minus the distance from the county-level centroid to the nearest transport access point.

Table 4 correlates these county-level discrepancies with distance to access points and to routes for three transport types. We pool over years before computing these correlations. Since differences in geography may influence transport placement and access, we show results for four main regions in China. For motorways, the discrepancies correlate positively with distance to access and distance to route, with correlations as great as 0.24 in the Central region. The pattern is more complicated for high-speed railways, with correlations around -0.28 in the Central region (and -0.20 to -0.23 in the Eastern and Westenr regions) but around 0.68 in the Northeastern region. Taken together with Figure 13, these results say that using distance to route to proxy for distance to access ponts introduces measurement errors that vary over time, by transport type, by region, and differently so across region and transport type.

[Table 4. Correlation of distance discrepancies with distance measures]

Table 5 relates distance descrepancies at the county and city levels to local economic performance using panel regressions. All specifications include controls for local log population, annual government revenue and spending, household savings, loans, consumption, industrial companies, primary school students, hospital beds, and county and year fixed effects. The county-level and city-level regressions tell similar stories: Motorway distance discrepancies are smaller for counties and cities with higher log GDP, which reflects greater density of motorway access in more developed areas. Regular railways, and especially high-speed railways, show the opposite pattern – larger distance discrepancies for more developed areas. This pattern may reflect the government's strategy for the placement of high-speed railway lines and stations, which aims to help balance economic development across regions in China.

[Table 5. How distance discrepancies relate to local economic outcomes]

These results underscore two points. First, the endogenous response of transport improvements to local economic conditions differs between motorways and railways in China. Put differently, long-term development goals appear to receive greater weight in the placement of high-speed railway lines and stations than in the placement of motorway routes and access points. Second, the measurement errors introduced by using distance to route to proxy for distance to access covary with local economic conditions differently for motorways and railways.

V. Advantages of Our GIS Database

Appendix Table B1 lists sixteen datasets used in other research on various aspects of China's surface transport system and its socioeconomic consequences. For each data source, we describe the transport modes, time spans, and transport measures covered by the dataset. We also list studies that use each data source. Compared with these existing databases, our GIS database offers four advantages.

First, our panel database is more comprehensive in covering multiple transport modes over a long time span and at an annual frequency, as summarized in Table 1. Our long panel dimenion allows for the examination of transport development and its dynamic relationship to socioeconomic development. Our year-by-year coverage allows for sharper causal inferences about the determinants and effects of changes to the transport system over time. Our multi-mode coverage allows for fuller controls of alternative transport modes when studying the (marginal) effects of a particular types of transport expansion or improvement. It also opens the door to studies of system-wide resilience in the face of shocks or developments that affect some transport modes more than others. Beyond that, covering all surface transport modes yields a more accurate estimation of shortest-distance and shortest-time movements of goods or people.

Second, our GIS database contains geospatial information on motorway access points and railway stations, which helps differentiate route-passing from transport access points. Figure B1 illustrates the level of detail that our GIS databse provides with respect to routes and access points for motorways and railways. As we showed in Section IV, using distance to route to proxy for distance to transport access introduces non-classical forms of measurement error that differ by time, region, and mode and that correlate with local economic performance in complex ways. Moreover, the absence of data on railway stations and motorway access points leads to innacurate measures of connectivity and centrality for counties, cities and local areas within the overall transport network.

Third, our GIS database significantly improves the accuracy of geographic information by building on *OpenStreetMap*, which has several advantages over digitized physical maps. Digitizing physical maps requires rectifying the scanned paper maps with known geographical coordinates. However, without a coordination benchmark for rectification, we cannot achieve the best match between scanned transport lines, open street road lines, and fitting coordinators. The original GIS data in *OpenStreetMap* has geographical information on locations and directions of transport routes, local streets, firms, and city and county boundaries. Furthermore, it is easy to keep updating and improving our GIS database in a consistent manner, drawing on joint efforts by the GIS community and *OpenStreetMap*.

Finally, using our GIS database, other researchers can directly calculate travel distance, travel times, and other transport quality measures. We executed many topology verifications and rectifications in the GIS and put much effort into matching speed information for transport routes and modes in *OpenStreetMap*. In contrast, some other studies assume constant speed on all roads and consider the same speed for the same type of transport mode to construct efficiency kilometers. Our GIS database includes route-specific attributes of speed limitations for different transport modes, yielding a more accurate estimation of travel time between two locations.

VI. Potential Applications of Our GIS Database

This section sketches a few potential applications of our GIS database for research, commercial decisions, and policymaking.

(I) **Transport system productivity:** The (marginal) productivity of transport system expansions is an important issue. Figure 10 suggests that motorway and high-speed railway expansisons in the 1990s had much greater effects per km in reducing distance to transport access points than did the later expansions. Shorter distances translate into shorter travel times. In this sense, the marginal productivity of motorway and high-speed railway expansions fell sharply during our sample period. Whether the later expansions were warranted by the growth (actual and anticipated) of China's economy is an interesting question that our database can help answer. Our database also provides the grist for studies of substitutability and complementarity across surface transport modes.

(II) **Transport system determinants:** The marginal productivity of the transport system (at various locations) influences the future development of the transport system. How and to what extent are interesting questions. Other forces also play a role. For example, it's natural to ask how China's motorways and high-speed railways were and are influenced by political forces. Another natural question is how the observed network compares to theoretically optimal networks, as in Fajgelbaum and Schaal (2020), or how observed network expansions relate to algorithmic predictions, as in Faber (2014).

(III) **Economic effects:** Better and more extensive transports reduce the cost of moving goods and people, broaden market access, facilitate regional integration, and more closely link interior cities and regions to the world economy. There is at least the potential for transport network expansions and improvements to promote internal and external trade, raise productivity and real wages, and encourage business investment. For these questions and many others, the key question is how much? Our database can help answer specific versions of this question. Most spatial equilibrium models imply that the economic effects of transport improvements depend on network structure. Our database can be used to test theory-based implications for the heterogeneous effects of transport improvements.

(IV) **Industry and spatial development:** Transport networks influence the geography of development and the nature and intensity of spatial competition. By lowering transportation costs, transport improvements reduce trade costs and thereby enable locations to more fully specialize according to their respective comparative advantages. China now has the world's largest and most comprehensive manufacturing sector. Yet the extent to which the tremendous expansion of its transport system facilitated that development remains unclear.

(V) **Agglomeration and urbanization**: Modern lifestyles often involve a spatial separation of production and residential consumption. By reducing the time costs of commuting, motorways and railways make possible the large-scale separation of workplaces and residence and allow for greater agglomeration benefits in each, as stressed by Heblich et al. (2020) for the case of London. Labor mobility also facilitates urbanization. Our GIS database encompasses all surface transport modes that supported domestic migration during China’s rapid urbanization. Hundreds of millions of persons moved from rural villages to large metropolitan areas and from agriculture to the manufacturing sector. Our GIS dataset offers opportunities to explore how infrastructure investment and better transport access contributed to urbanization.

(VI) **Social mobility and poverty reduction:** Building roads to get rich has become a widespread slogan in rural areas. Resource allocations, economic activities, and urbanization lead to socioeconomic changes, poverty reduction, and social mobility. The Chinese government has stressed transport improvements as a means to alleviate poverty. The impoverished population has decreased notably in rural China, even as the poverty criterion rose from an annual income of 2,300 CNY ($335) in 1995 to 4,000 CNY ($584) in 2020.[22] Our GIS database offers new opportunities to explore the role of transport system expansions and improvements in rural-to- urban migration, daily labor mobility, poverty reduction, and regional economic development.

(VII) **Environment**: Transport infrastructure facilitates mobility and technology diffusion, which supports income and economic development. However, it can also aggravate pollution emissions and lead to environmental degradation.[23] That raises questions about whether, and how, transport system expansions can achieve development gains while minimizing environmental harms.

(VIII) **Policymaking, education, and commercial use**: Our GIS database can help local governments visualize transport networks, their evolution over time, and their relation to local development. Moreover, our database is readily combined with other sources of data to provide useful inputs for site selection, capital investment, marketing, and other commercial decisions. In short, our database is useful for many commercial, governmental, and policymaking organizations.

[22] The data is from Xinhua News. See: http://www.xinhuanet.com/fortunepro/2021-02/25/c_1127137706.htm (Last accessed on 2024/07/10)

[23] For example, Laurance (2009) documents that over 95% of deforestation, fires, and atmospheric carbon emissions in the Brazilian Amazon occurred within 50 kilometers of a road.

VII. Concluding Remarks

We construct and introduce a new GIS database for China's surface transport sytem and use it to shed new light on measurement issues that pertain to the impact of transport networks on local economies. Our database covers motorways, national highways, regular railways, high-speed railways, and waterways from 1993 to 2020. We conduct extensive rectifications and verifications in the GIS database to ensure accuracy and reliability. The statistics on transport lengths derived from our database match well with those in official documents. Our database has the most extensive coverage among currently available GIS databases and digital maps for China's transport network. It also contains data items often missing in other datasets such as geocoded motorway access points and railway stations, lane directions, railway tracks, and speed limitations. These key attributes yield more accurate transport quality measures such as node density, connectivity, and travel times.

Using our GIS database, we find sizable discrepancies between distance to transport access points and distance to transport routes. Our evidence underscores the dangers in using the latter to proxy for the former when seeking to estimate causal effects of transport improvements. Our data facilitate attention to the effects of China's transport expansion on peripheral regions, including "passing-through" regions. The data also create new opportunities for long-span longitudinal analyses, better controls for alternative transport modes, and better identification of transport effects in studies of trade, productivity, income distributions, labor and population mobility, land usage, and environmental quality.

Finally, we use our database to quantify several aspects of transport scale, scope, access, density, and connectivity. Our data let us calculate these and other measures at the zip code, county, city, provincial, regional, and national levels. Our summary statistics and graphical presentations show large variations in transport access over time and across regions in China. We use the data to explore the relationship between transport access and economic development in Davis et al. (2021, 2024). We hope other researchers will find value in applying these data to a wide-ranging collection of important questions.

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Figures and Tables

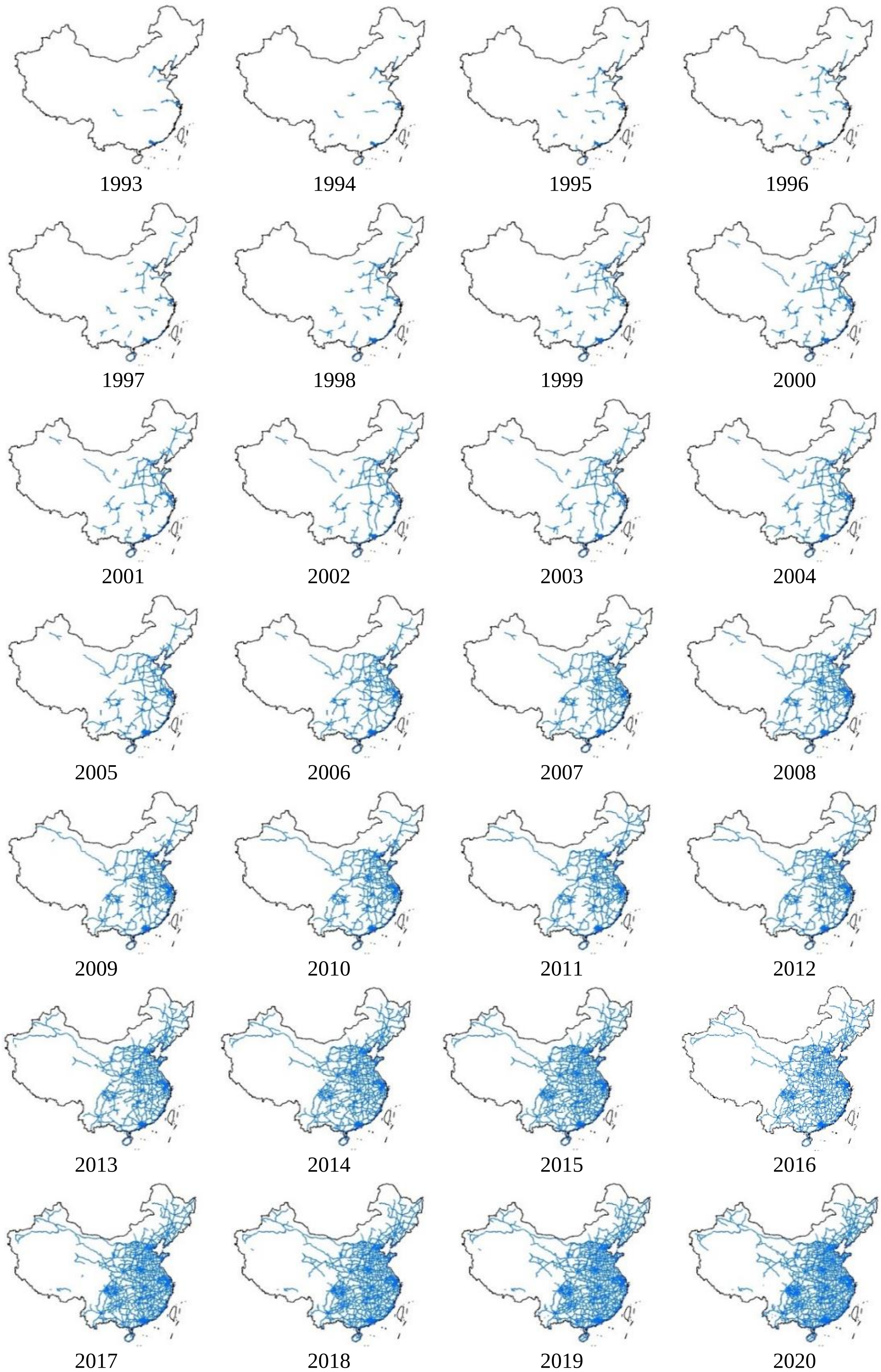
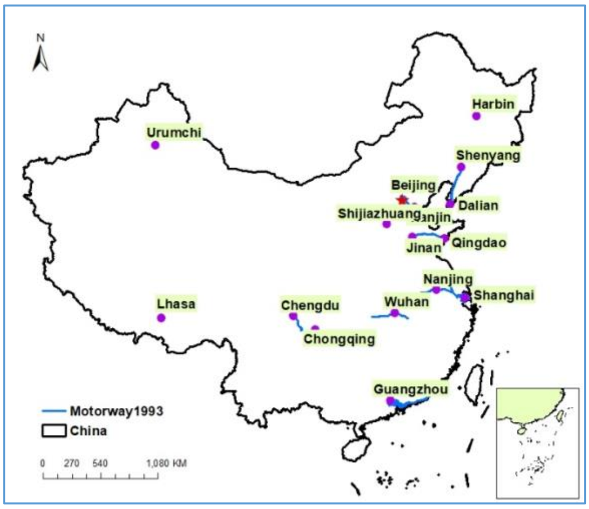
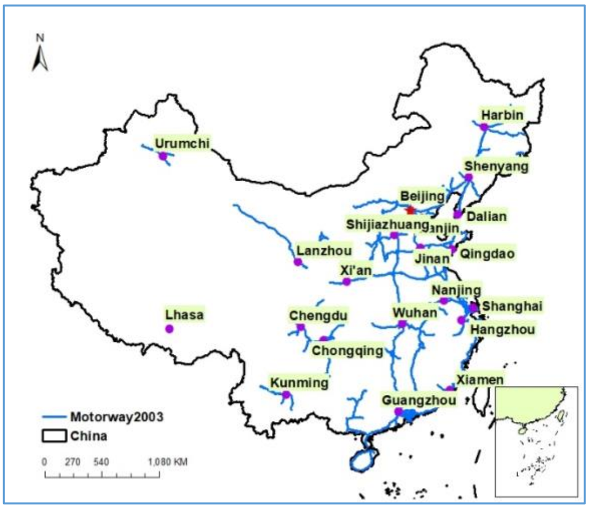


Figure 1. The expansion of motorway transports over 1993-2020

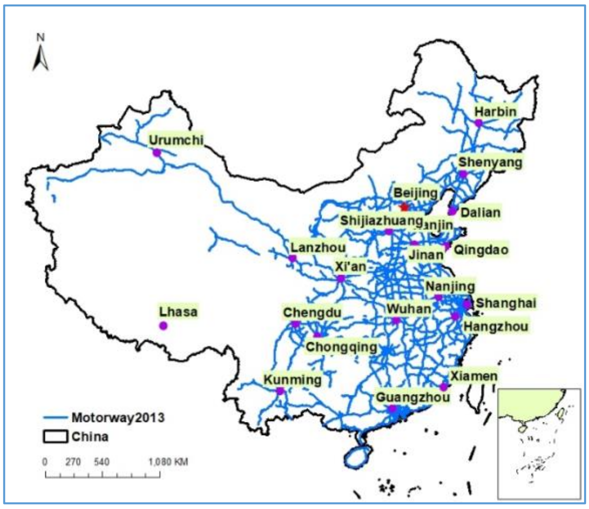
Note: The panels show the temporal evolution of motorway transports in China. *Data source*: GIS database



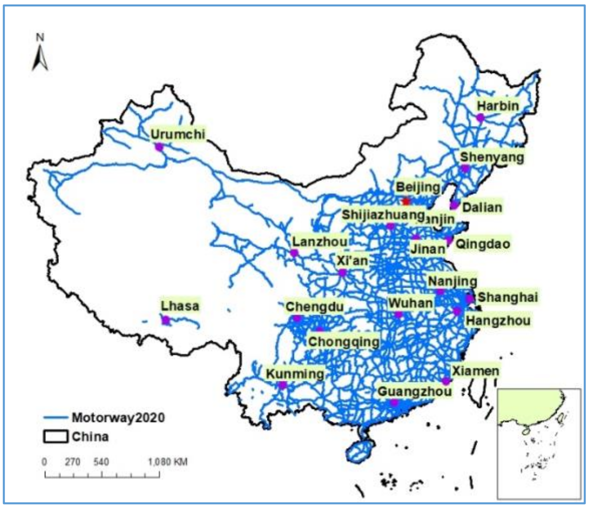
(a) 1993



(b) 2003



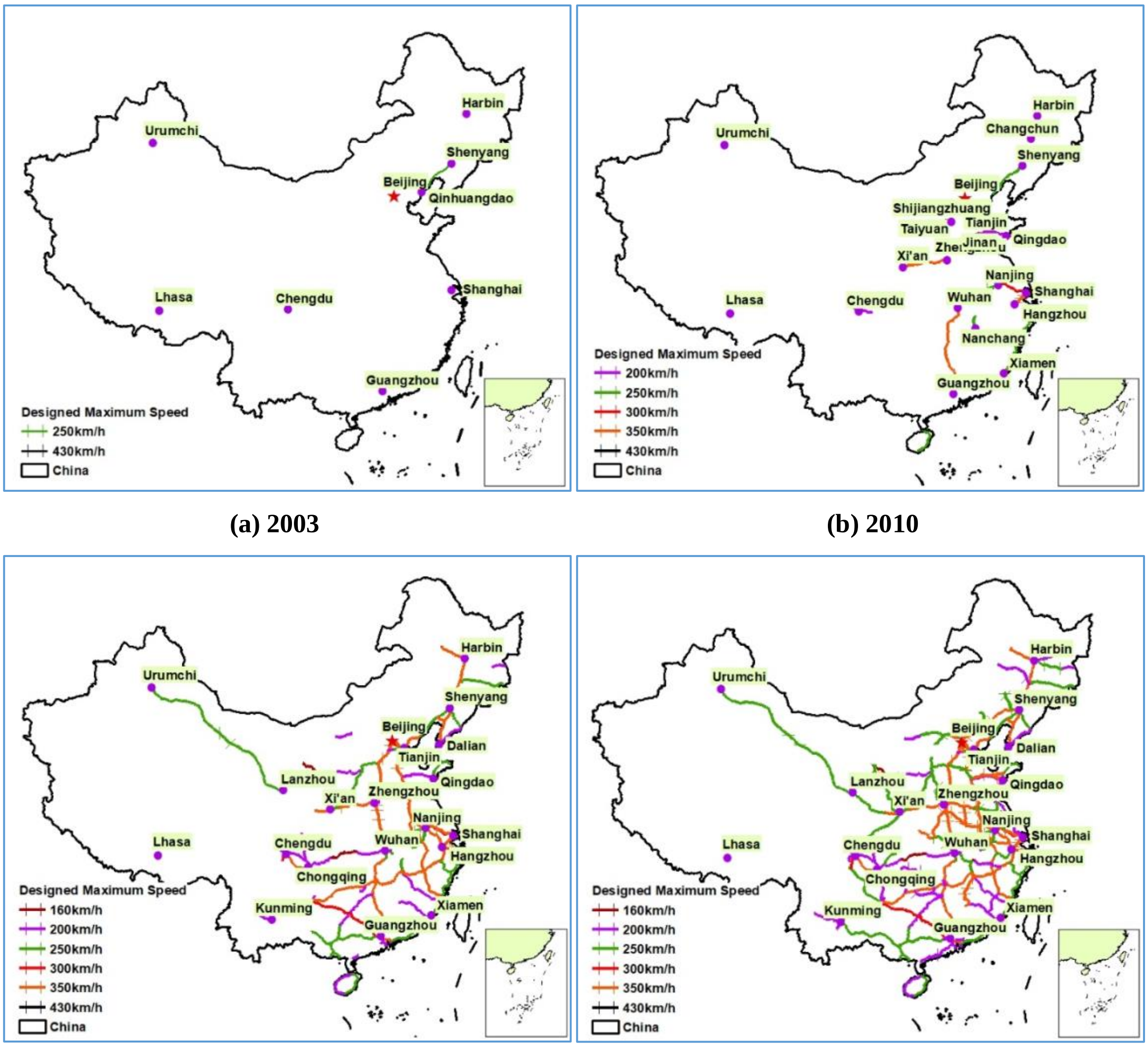
(c) 2013



(d) 2020

Figure 2. Motorway transports in 1993, 2003, 2013, and 2020

Note: The panels show the temporal evolution of motorway transports in China. *Data source*: GIS database

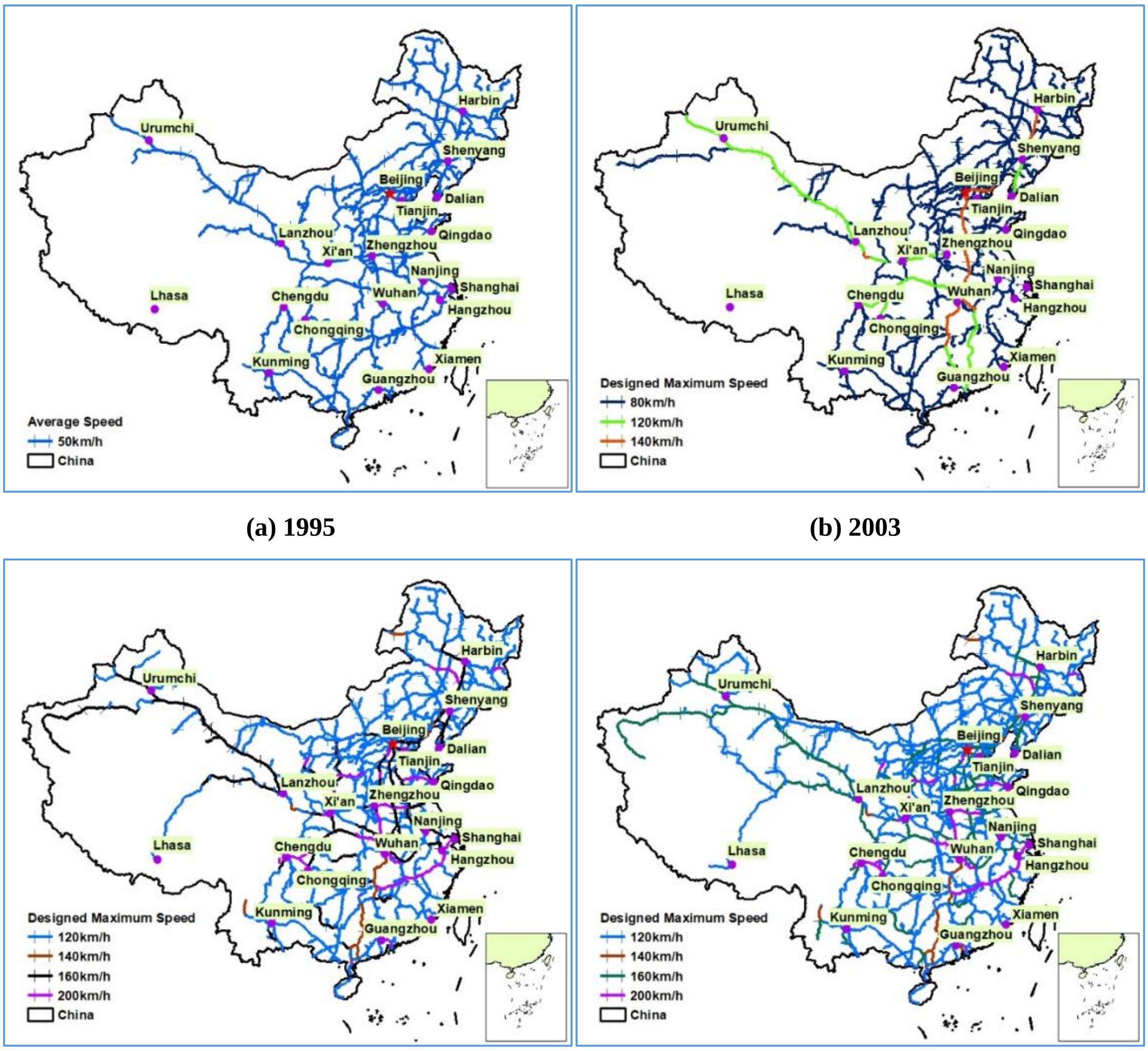


(a) 2003 **(b) 2010**

(c) 2015 **(d) 2020**

Figure 3. High-speed railways in 2003, 2010, 2015, and 2020

Note: The panels show high-speed railways in 2003, 2010, 2015, and 2020, respectively, including some lines with speed limits below 200 km/h. This is because some connections along high-speed rail lines have lower speed limits, and some lines are shared between high-speed and slower regular trains. For instance, part of the high-speed rail lines between Yichang and Enshi in Hubei province were designed as fast railways. Since high-speed trains also travel along this line, they reduce their speed in line with the lower maximum speed limit on these lines. *Data source*: GIS database



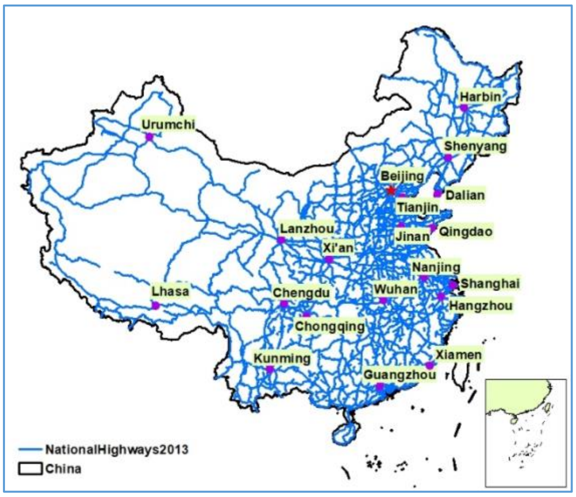
(a) 1995 **(b) 2003**

(c) 2013 **(d) 2020**

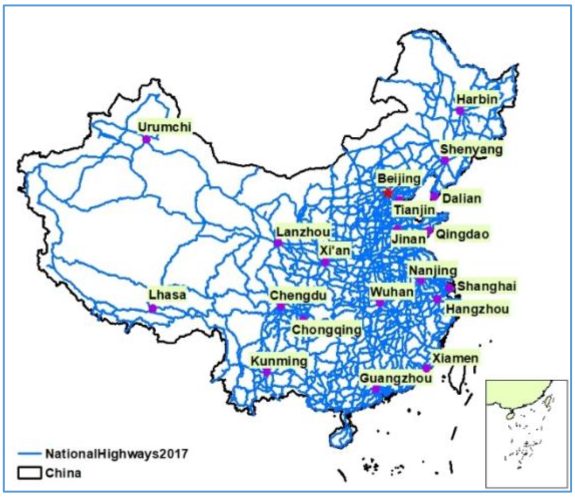
Figure 4. Regular railways in 1995, 2003, 2013, and 2020

Note: The panels show the temporal evolutions of regular railways in 1995, 2003, 2013, and 2020 in China. Regular railways include standard and fast railways. *Data source*: GIS database

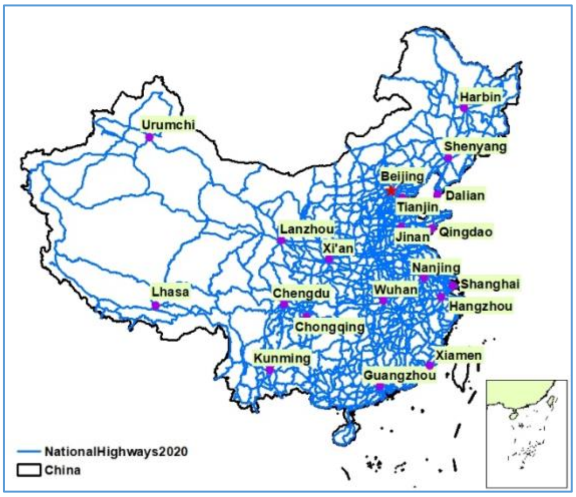
(a) 1993



(b) 2013



(c) 2017



(d) 2020

Figure 5. National highways in 1993, 2003, 2013, and 2020

Note: The panels show the temporal evolutions of national highways in 1993, 2003, 2013, and 2020 in China.
Data source: GIS database

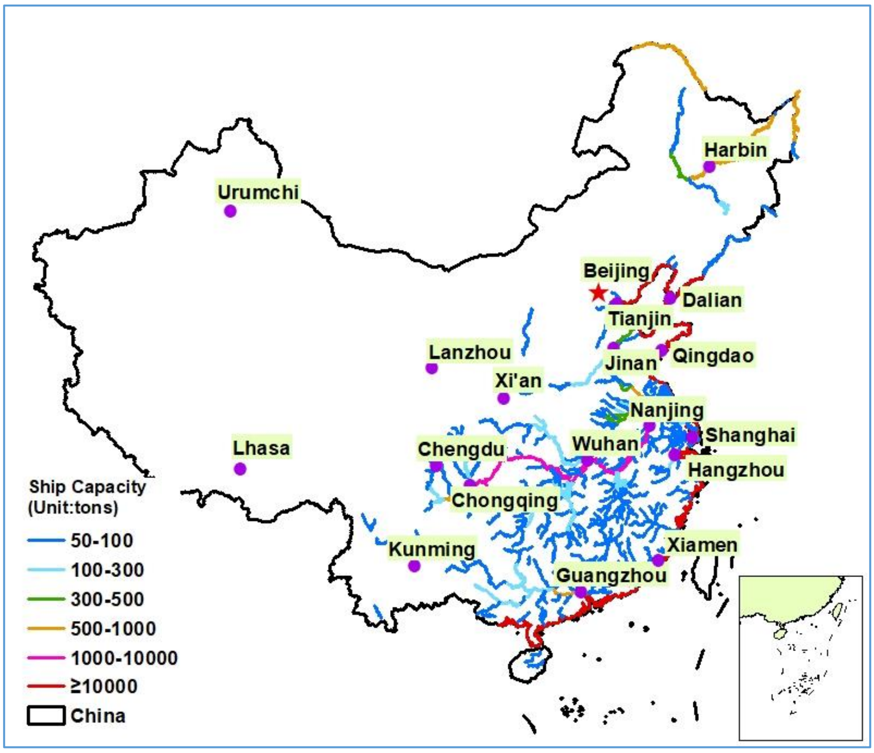
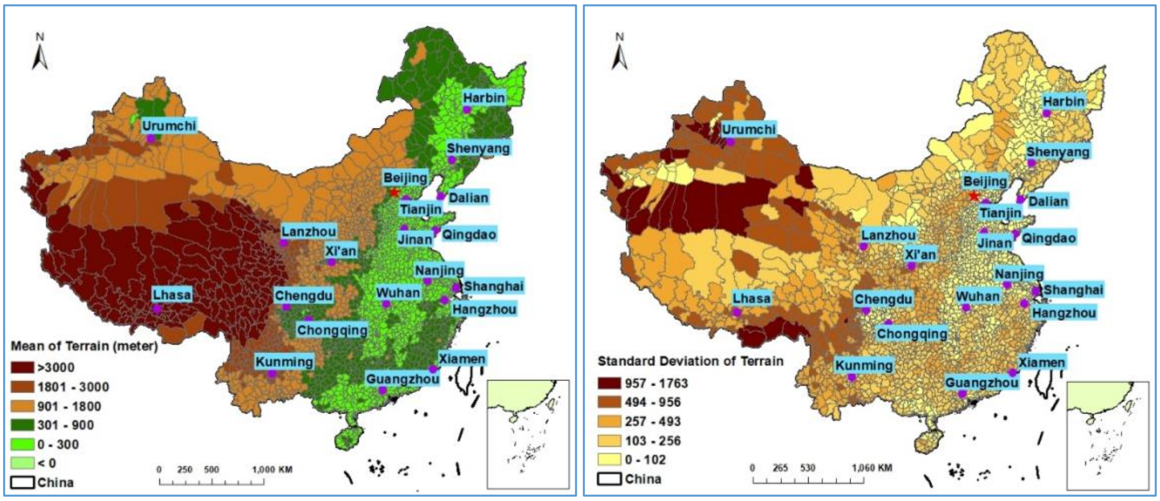


Figure 6. Navigable waterways in 1993

Note: The panels show the geographical distributions of navigable waterways in 1993 in China, with six grades of transporting capacities. Since there exists only a small increase of 15.8% in total inland waterway length over the past decades, from 110,200 km in 1993 to 127,700 km in 2020, we plot the navigable waterways in one year. We drop the waterways with less than 50 tons of capacity since they cannot be navigable channels used to transport goods, materials, or other movable objects. *Data source*: GIS database



(a) Mean elevation above sea level (b) Variability of elevation

Figure 7. Mean and variability of terrain elevations by county

Note: The panels show China's county-level mean and variability terrain elevations. Panel (a) presents the average elevation (meter) above the sea-level. The darkest brown denotes the highest elevation, such as Tibet, which is greater than 3,000 meters above sea-level, while the darkest green represents the lowest areas in the Eastern region. Panel (b) presents county-level ruggedness measured as the standard deviation (variability) of within-county elevations. The darkest brown denotes the most rugged counties with a standard deviation of elevation over 957-1,750 meters, such as Xinjiang and the Southwest border of Yunnan Province. *Data source*: GIS database.

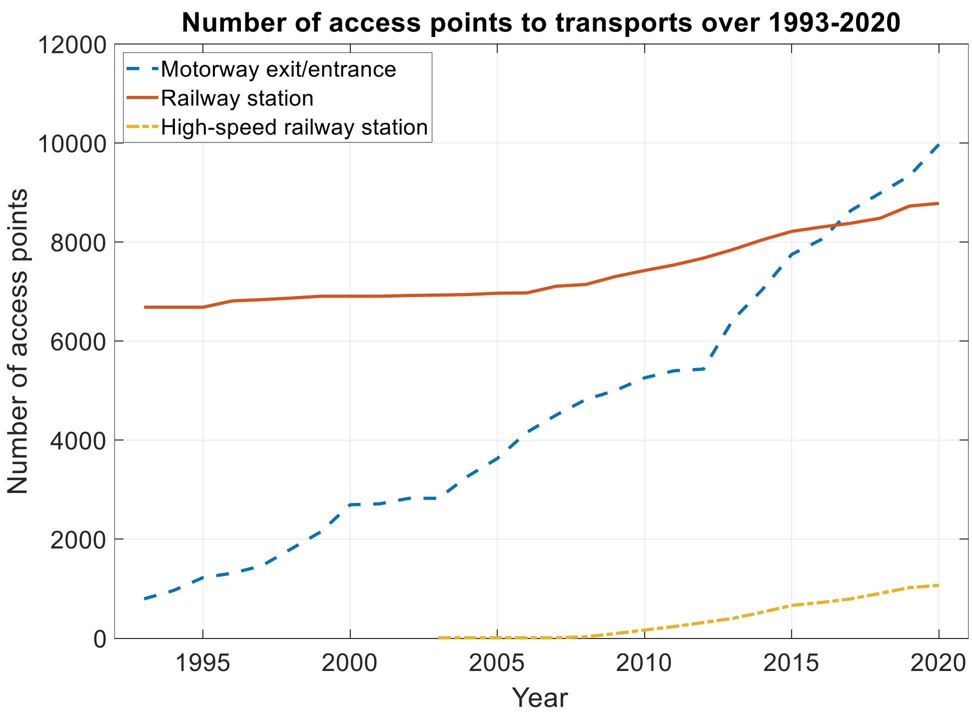
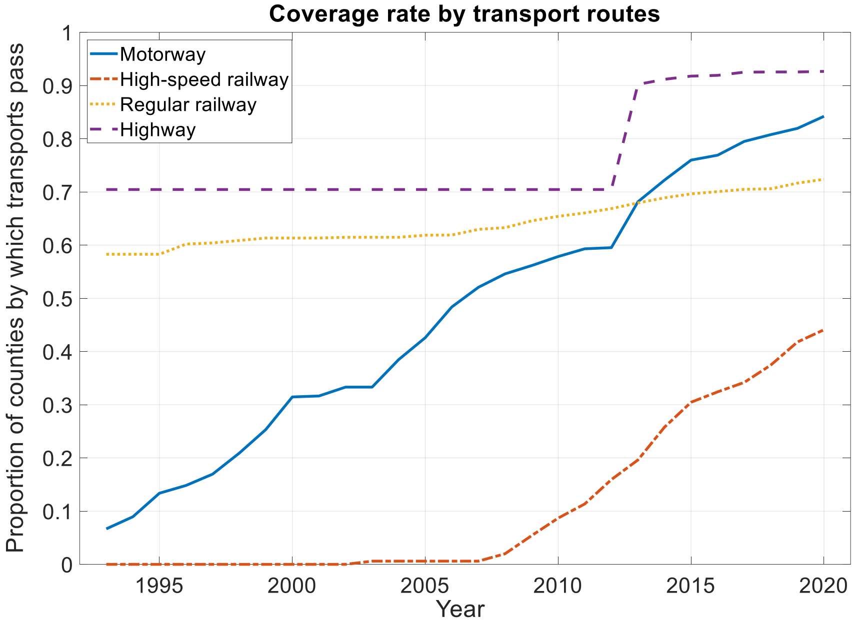
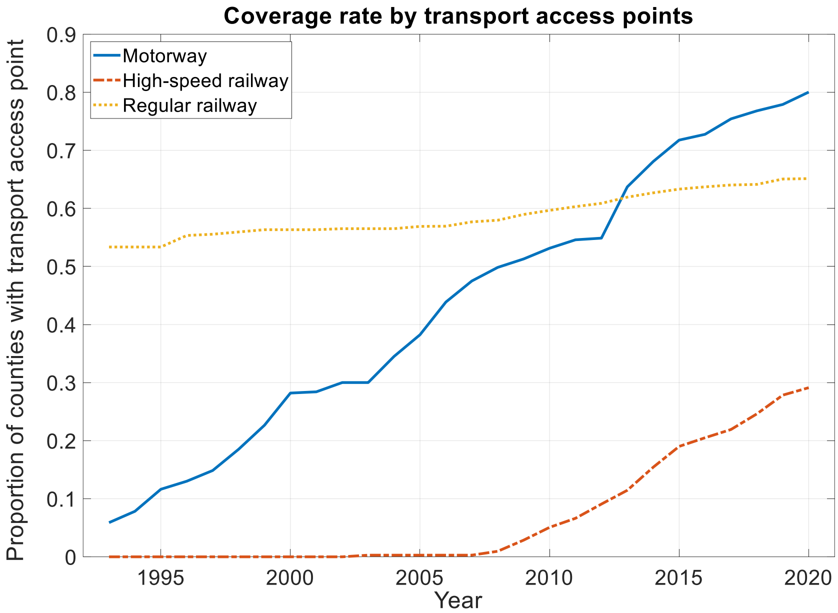


Figure 8. Number of access points to transports over 1993-2020

Note: This graph presents the number of access points to motorways, railways and high-speed railways from 1993 to 2020. The number of motorway exits/entrances increased by more than 12 times in the period, while the number of railway stations increased by 31%. High-speed railway stations initiated in 2003 and expanded to 1,069 in 2020. *Data source*: GIS database



(a) Coverage rate by transport routes



(b) Coverage rate by transport access points

Figure 9. Transport coverage at the county level over 1993-2020

Note: This graph presents the fraction of counties covered by transport networks from 1993 to 2020 in China. In Panel A, we define the counties as covered if transport routes pass through them, while we plot the fraction of counties with access to motorway entrances/exits, railway stations, or high-speed railway stations within its geographical boundary in Panel B. *Data source*: GIS database

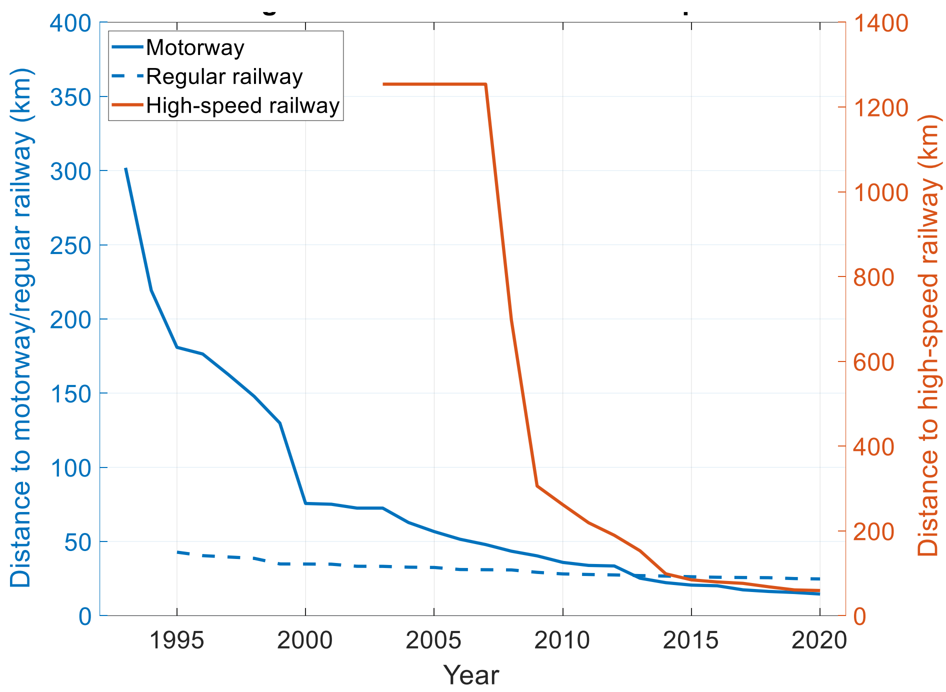
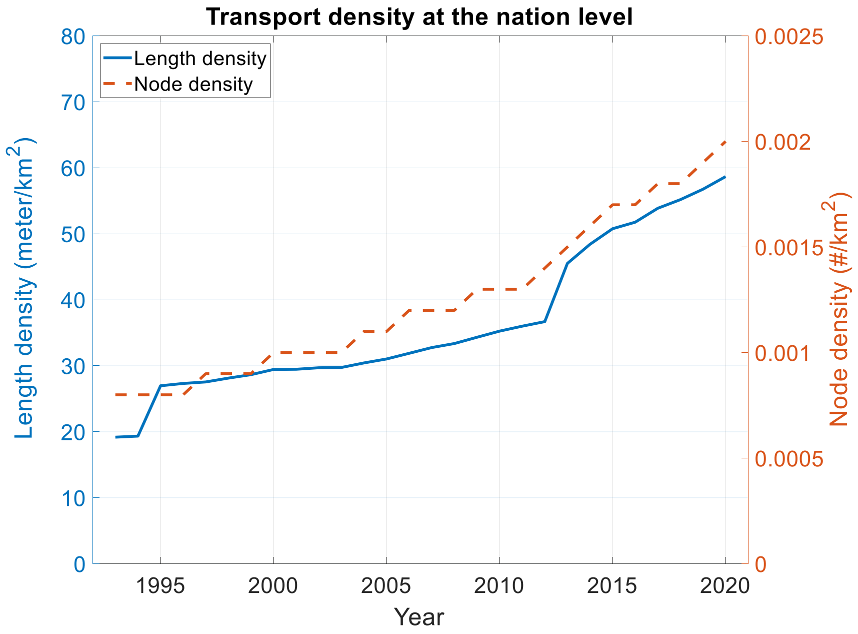
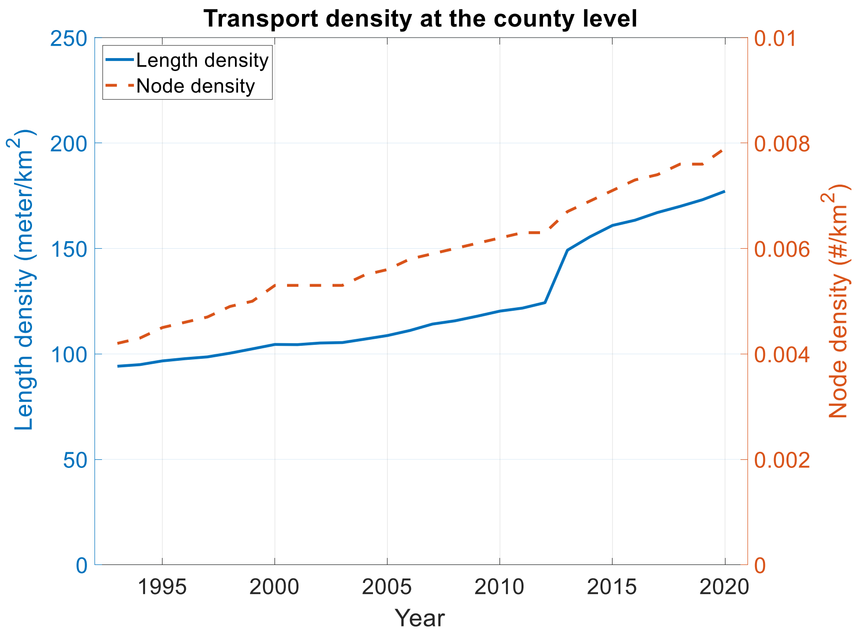


Figure 10. Average distance to the nearest transport access points

Note: This chart shows the mean distance in km from zip-code centroids to the nearest acces point for motorways, regular railways, and high-speed railways by year from 1993 to 2020. There are 34,889 zip codes.



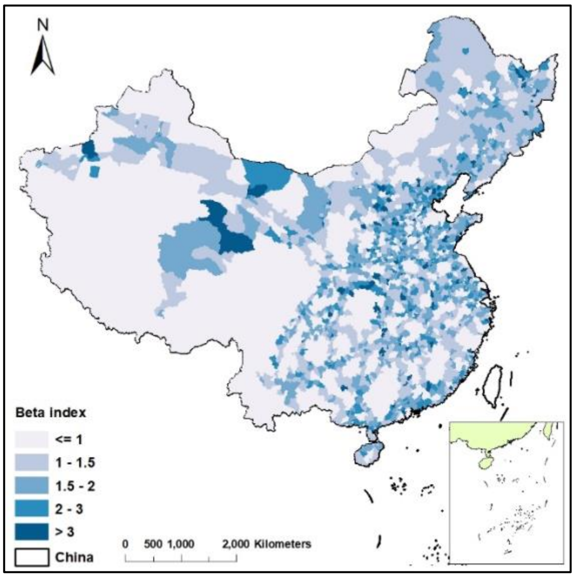
Panel (a): Transport density at the national level



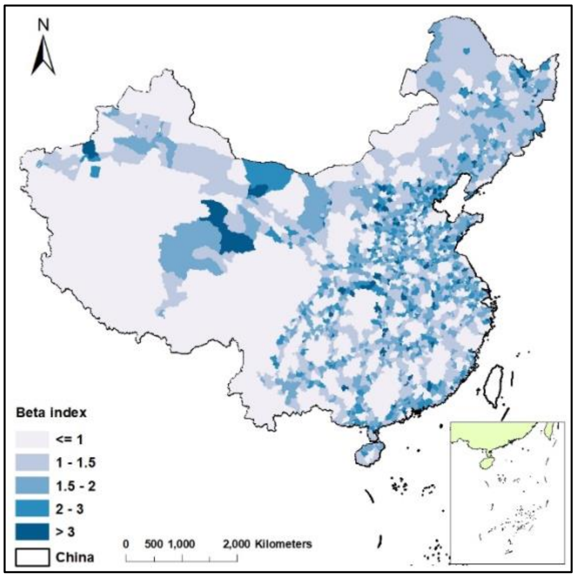
Panel (b): Transport density at the county level

Figure 11. Transport density measures from 1993 to 2020

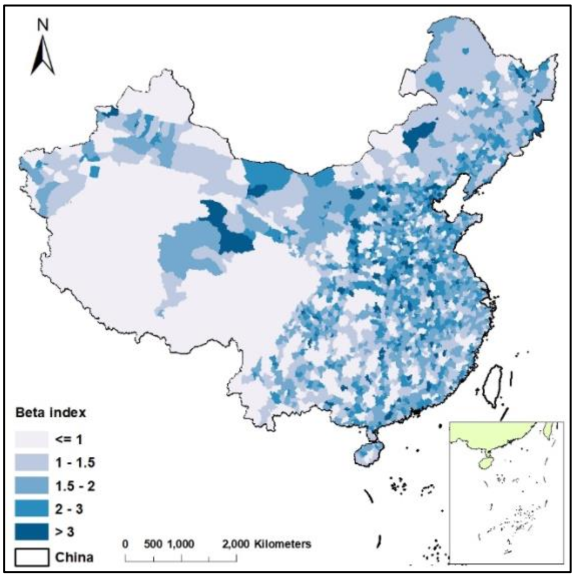
Note: The graphs present the transport density of length and access points in China from 1993 to 2020. Panel (a) shows the transport densities computed at the nation level, and Panel (b) exhibits the average densities at the county level. Length Density equals the ratio of total length of all transports to a county's area, including motorway, high-speed rail, regular rail, highway, and waterway, in units of meter/km^2, and Node Density is the ratio of number of access points to the area, for motorway exit/entrance and railway stations, in units of #/km^2.



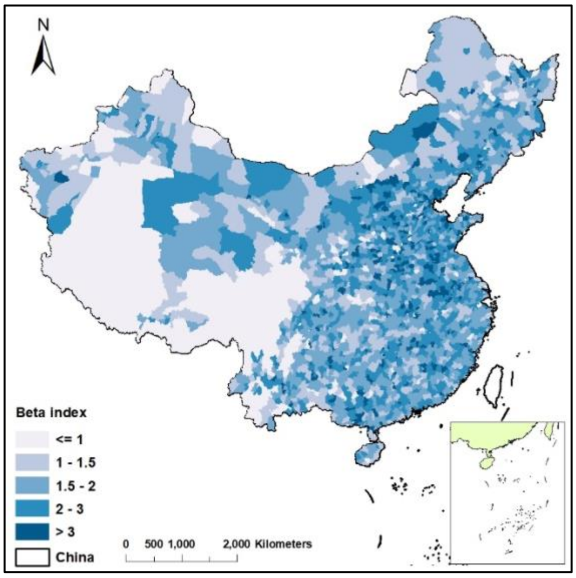
(a) 1993



(b) 2000



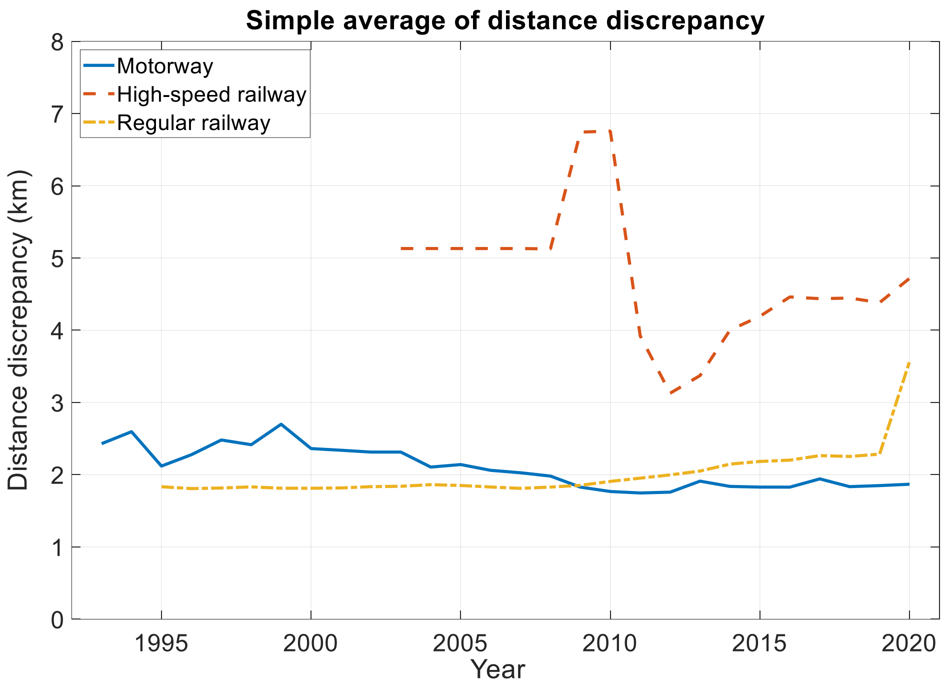
(c) 2010



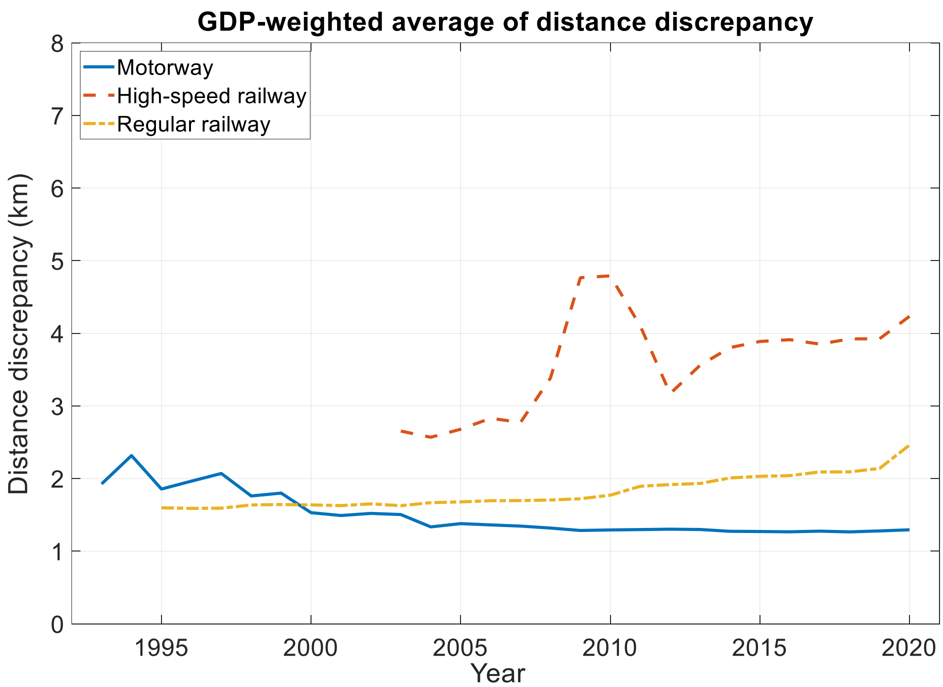
(d) 2020

Figure 12. County-level connectivity in 1993, 2000, 2010, and 2020

Note: The panels show county-level connectivity (Beta index) of all transport modes in 1993, 2000, 2010, and 2020.



Panel (a): Simple average of distance discrepancy across counties



Panel (b): GDP-weighted average of distance discrepancy across counties

Figure 13. Distance discrepancy between access point and route to county centroid

Note: The panels show the discrepancy between the shortest distance to transport access points and routes over 1993-2020. We first compute two distance measures between county centroid and motorways, railways, and high-speed railways at the county level and then take the differences between the two distances. Panel (a) exhibits the simple average of distance discrepancies across counties, while Panel (b) shows the GDP-weighted average of distance discrepancies across counties.

Table 1. An overview of the GIS database of surface transports in China

Transport Mode	File Organization	Year	Shapefile
Panel A: Surface Transport Modes			
Transport Mode	File Organization	Year	Shapefile
Motorways	Motorway network	1993-2020	Routes and max speed by route segment
	Motorway enter/exits	1993-2020	Motorway entry and exit points
Highways	Highway network	1993-2007, 2013-2020	Routes and max speed by route segment
Railways	Railway network	1995-2020	Routes and max speed by route segment
	Railway stations	1995-2020	Station locations and types
	Speed-up campaigns	1997, 1998, 2000, 2011, 2004, 2007	Railway additions and speed improvements
High-speed railways	High-speed railway network	2003-2020	Routes and max speed by route segments
	High-speed railway stations	2003-2020	Station locations
Waterways	Waterway network	1993	Waterways (inland and coastal) and tonnage grades
Panel B: Historical Data on Roadways and Railways			
Roadways	Road network	1962	Routes by route segment
Railways	Railway network	1962	Routes and stations
Panel C: Other Datasets			
Terrain features	Terrian	2002	Raster counts, mean, median, standard deviation, min, max, and the sum of elevations at the county level
Administrative boundaries	Boundary	2002	County and provincial boundaries
Cities and postal areas	Postal codes	2002	Coordinates of prefectural cities, provincial capitals, and postal areas

Note: This table summarizes the main elements of our database, including surface transport modes, historical data on roadways and railways, and some other datasets. All shapefiles can be layered onto each other in the GIS and used for analysis.

Table 2. Definition of transport quality measures in the database

Measure	Definition
Panel A: Location-specific measures	
Access indicator	Whether a location has access to transport within a distance
Access distance	The shortest distance to the nearest access point, i.e., motorway entrance/exit, railway station, or highway route
Centrality (Betweenness index)	Ratio of the number of links summed over all shortest paths in the network that pass through a county to the total number of links on the shortest paths summed over all node pairs in the network
Centrality (Degree index)	Ratio of the number of nodes connecting a county to the total number of nodes in the network
Centrality (Closeness)	Ratio of the total number of nodes in a network to the number of links along the shortest paths between a county and all other nodes
Panel B: Pairwise measures	
Travel Distance	Travel distance between locations via transport mode from one city to another or from a postal code centroid to a port
Travel Time	Shortest travel time between geolocations with a transport mode
Panel C: Network-level measures	
Centrality	Aggregations of location-specific centrality measures in a region
Route density	Transport length divided by its area in a region
Node density	Number of access points divided by its area in a region
Connectivity (Beta index)	Average number of links per node in a network (total number of links divided by total number of nodes
Connectivity (Gamma index)	Number of links in a network divided by the maximum feasible number

Note: This table defines location-specific, pairwise, and network-level transport measures in our database.

Table 3. Total length of surface transports

	(1) Railways	(2) High-speed rails	(3) Motorways	(4) Highways	(5) Railways	(6) High-speed rails	(7) Motorways	(8) Highways[1]
Year	Panel A: Statistics from our database				Panel B: Statistics from official documents			
1993	69.9		6.3	104.9	58.6		1.1	
1994	69.9		7.8	104.9	59.0		1.6	
1995	69.9		10.8	104.9	62.4		2.1	
1996	72.3		11.9	104.9	64.9		3.4	
1997	72.6		13.8	104.9	66.0		4.8	
1998	73.5		18.2	104.9	66.4		8.7	
1999	73.9		22.7	104.9	67.4		11.6	
2000	73.9		30.2	104.9	68.7		16.3	
2001	73.9		30.5	104.9	70.1		19.4	102.6
2002	74.4		32.2	104.9	71.9		25.1	99.9
2003	74.9	0.4	32.2	104.9	73.0		29.7	98.2
2004	75.0	0.4	38.6	104.9	74.4		34.3	95.5
2005	75.6	0.4	43.8	104.9	75.4		41.0	91.7
2006	75.8	0.4	51.8	104.9	77.1		45.3	88.1
2007	77.7	0.4	58.1	104.9	78.0		53.9	83.2
2008	79.2	1.0	62.4	104.9	79.7	0.7	60.3	95.0
2009	85.2	3.3	65.5	104.9	85.5	2.7	65.1	93.4
2010	89.3	5.0	70.2	104.9	91.2	5.1	74.1	89.9
2011	93.1	7.3	73.6	104.9	93.2	6.6	84.9	84.5
2012	99.0	10.5	74.2	104.9	97.6	9.4	96.2	77.2
2013	106.0	13.6	91.7	164.2	103.1	11.0	104.4	72.4
2014	114.0	19.6	102.3	173.2	111.8	16.5	111.9	67.3
2015	121.2	24.2	113.9	177.0	121.0	19.8	123.5	61.8
2016	123.8	26.3	118.6	179.1	124.0	23.0	131.0	223.8
2017	127.4	28.5	129.5	184.6	127.0	25.1	136.4	222.0
2018	131.4	32.3	136.0	186.6	131.7	29.9	142.6	220.4
2019	138.2	36.5	142.1	188.7	139.9	35.3	149.6	216.5
2020	143.2	39.0	153.4	190.7	146.0	38.0	161.0	209.7

Notes: This table lists and compares the total lengths of surface transports based on our database (Panel A) and those officially reported by China Statistical Yearbooks (Panel B). We treat all routes as single lines to compute lengths in our GIS database. [1]The China Statistical Yearbooks release total national roadways lengths that include highways and motorways defined in our GIS database. Thus, we subtract the total lengths of national roadways from motorways to attain the total lengths of highways. All lengths are measured in units of 1,000 kilometers. *Data source*: China Statistical Yearbooks and our GIS database, 1993-2020

Table 4. Correlation of distance discrepancies with distance measures

	Distance to access points	Shortest straight-line to routes
Distance discrepancy	Full sample	
Motorway	0.10***	0.09***
	(27.37)	(24.15)
High-speed railway	-0.10***	-0.11***
	(-21.69)	(-24.99)
Regular railway	0.08***	0.04***
	(21.55)	(11.62)
Distance discrepancy	Eastern region	
Motorway	0.16***	0.12***
	(23.55)	(18.39)
High-speed railway	-0.23***	-0.24***
	(-28.10)	(-29.33)
Regular railway	0.06***	-0.07***
	(8.98)	(-9.72)
Distance discrepancy	Central region	
Motorway	0.24***	0.20***
	(34.04)	(28.07)
High-speed railway	-0.28***	-0.29***
	(-32.60)	(-33.69)
Regular railway	0.06***	-0.08***
	(8.07)	(-10.30)
Distance discrepancy	Northeastern region	
Motorway	0.08***	0.05***
	(7.02)	(4.62)
High-speed railway	0.69***	0.64***
	(66.43)	(58.49)
Regular railway	0.13***	-0.07***
	(11.14)	(-6.37)
Distance discrepancy	Western region	
Motorway	0.07***	0.06***
	(11.87)	(10.38)
High-speed railway	-0.21***	-0.21***
	(-29.26)	(-30.24)
Regular railway	0.07***	0.04***
	(11.63)	(6.51)

*Note***:** This table presents the correlation analysis at the county-year level between distance discrepancy and two kinds of distance, i.e., the distance to the nearest transport access point and the shortest straight-line distance to transport, using the whole dataset. Access points are exits/entrances for motorways and stations for railways. We consider distance discrepancy the difference between the shortest distance to a transport access point and the shortest distance to the nearest transport route from a county's centroid. We also divide the 2,819 counties into four regions in China, i.e., Eastern (785), Central (688), Northeastern (277), and Western (1,069), to explore the regional heterogeneity. The *t* statistics are in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Table 5. How distance discrepancies relate to local economic outcomes

Panel A: Panel regression at the county level						
Distance discrepancy	Motorway		High-speed railway		Regular railway	
Log GDP	-0.37***	-0.40***	1.51***	1.16***	0.54***	0.61***
	(0.06)	(0.06)	(0.31)	(0.30)	(0.13)	(0.14)
GDP Growth (%)		-0.01		-0.14***		0.02*
		(0.01)		(0.03)		(0.01)
GDP per Capita	0.00	0.01	-0.00	0.02	0.07***	0.07***
	(0.01)	(0.01)	(0.04)	(0.04)	(0.02)	(0.02)
GDP per Capita		0.01		0.14***		-0.02**
Growth (%)		(0.01)		(0.03)		(0.01)
Controls	Y	Y	Y	Y	Y	Y
County FE	Y	Y	Y	Y	Y	Y
Year FE	Y	Y	Y	Y	Y	Y
N	37,653	37,365	32,598	32,425	37,653	37,365
R^2	0.490	0.490	0.517	0.512	0.492	0.491
Panel B: Panel regression at the city level						
Distance discrepancy	Motorway		High-speed railway		Regular railway	
Log GDP	-.30***	-.29***	4.26***	3.70***	0.11	0.21
	(0.09)	(0.09)	(0.79)	(0.81)	(0.19)	0(.22)
GDP Growth (%)		-0.00		-.05***		0.00
		(0.00)		(.01)		(0.00)
GDP per Capita	0.03*	0.01	0.25***	0.19**	0.08*	0.07*
	(0.02)	(0.02)	(0.07)	(0.09)	(0.04)	(0.04)
GDP per Capita		0.00*		0.07***		-0.01**
Growth (%)		(0.00)		(0.02)		(0.00)
Controls	Y	Y	Y	Y	Y	Y
County FE	Y	Y	Y	Y	Y	Y
Year FE	Y	Y	Y	Y	Y	Y
N	7,089	6,722	5,791	5,765	7,089	6,722
R^2	0.477	0.495	0.421	0.420	0.374	0.368

Note: This table presents the relationship between distance discrepancies and local socioeconomic factors through panel regressions. Panel A shows the results at the county level (excluding counties in the prefectural cities, while Panel B shows the results at the prefectural city level. Given the data availability, we conduct regressions for motorway and regular railways over 1999-2020 and high-speed railways over 2003-2020. The dependent variable is the distance discrepancy for the motorway, high-speed railway, and regular railway, measured in kilometers. The main explanatory variables include log GDP, GDP per capita, and GDP growth rate expressed as a percentage. We also include controls for commonly used local socioeconomic indicators, such as log population, annual government revenue and spending, aggregate household savings, loans, consumption, number of industrial companies, number of primary school students, and number of hospital beds. We hand collected these data from the Statistical Yearbooks of Counties and the Statistical Yearbooks of Cities. Year- and county-level fixed effects are also included as control variables. Local terrain characteristics, including elevation (average above sea level in the county/city), ruggedness (standard deviation of above sea level in the county/city), and other geographical factors, are excluded when incorporating county-level fixed effects. The robust standard errors are shown in the parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.1$

Appendix

A. Existing Transport Databases in Other Studies

We extensively searched existing databases on China's transportation, including GIS data, digital maps, and statistical data sources in other academic studies. These studies fall into either the strand on the impact of transportation on various socioeconomic activities or geospatial analyses of transports themselves. Table B1 in the Appendix summarizes the search results and introduces other studies' transport datasets.

Panel (a) first presents other GIS data sources. The Australian Consortium for the Asian Spatial Information and Analysis Network (ACASIAN) at Griffith University has been the most frequently used among all extant databases. The panel data covers a shorter period than ours and ends in 2011. Based on published atlases, the ACASIAN includes data on motorways over 1992-2011, national and provincial highways over 2007-2010, railways over 1997-2000, and waterways, but not on motorway exits/entrances and railway stations in China. The China Historical Geographic Information System (CHGIS) from Harvard University includes high-speed railways and stations in 2016 and road data that reflect 1990 conditions. The China in Time and Space (CITAS) database from the University of Washington includes roads, railroads, drainage systems, populated places, and urbanized areas and contours. It is historical data covering discrete periods from 1765 to 1994, with a large volume of local maps. It is also accessible through the Center for International Earth Science Information Network (CIESIN) at Columbia University. The National Fundamental Geographic Information System of China (NFGIS) from the Chinese Academy of Sciences has railway data in 2012.

We also introduce some studies on Chinese transport that build their own datasets in Panel (b). For example, Baum-Snow et al. (2016) obtained highway and railway data by digitalizing published maps from SinoMaps Press and Planet Maps Press. Jin et al. (2010) digitized transport lines using a remote sensing map. These studies cover some annual snapshots in a short timeframe and usually only one or two transport modes. In Panel (c), some other studies use statistics, rather than maps, of transports from Statistical Yearbooks at national, provincial, and regional levels. Others use the train timetable data in Panel (d).

In addition to those listed in Table B2, the China Transport Statistical Yearbooks have many statistics cited in many studies. The National Catalogue Service for Geographic Information (NCSG) data managed by the Ministry of Natural Resources of China includes accurate information on roads, e.g., motorways and high-speed railways, for 2015 in GIS.

Another is the Resource and Environment Science and Data Center (RESDC) data from the Chinese Academy of Sciences, which includes the road data in 1995 and GIS. However, to date, we have found no studies using these two data sources.

B. Additional Tables and Figures

Table B1. The summary of transport datasets in other studies

Data Source	Transport Mode	Time Span	Used in Studies	Transport Measure
Panel (a): Other GIS data sources				
(1) ACASIAN Data Center from Griffith University: https://acasian.com/price.html#china				
	Motorway	1992-2011	Faber (2014)	Whether a county is within 10 km of the route of the National trunk highway, 1998-2007
	Highway	2007-2010	Yang (2017)	Travel distance between cities by highway, railway, waterway, 1995-2005
	Railway	1997-2000	Liu et al. (2017)	Access to expressway and expressway density within the firm's radius, 2000-2006
	Waterway	1965-2010	Lin (2017)	Travel time to port through high-speed railway and highways, 2003-2014
			Huang and Xiong (2017)	Travel distance and time between prefecture-level cities by expressway, 1998-2007
			He, Xie, and Zhang (2020)	Whether any highway pass through the county, 1992-2010
			Fan (2019)	Travel time on roads used for market access, 1999, 2010
(2) CHGIS from Havard University: https://dataverse.harvard.edu/dataverse/chgis				
	Highway, railroad, and high-speed railway	1990	Banerjee et al. (2012)	The shortest distance to network route, straight-line, railroad, highway, and navigable waterways, 1990
	Waterway	2012		
(3) CITAS from University of Washington: https://citas.csde.washington.edu/				
	Road, railway, River, and lake	1765-1994, 2000, 2004	Emran and Hou (2013)	Access to transportation network through road, railway, navigable waterways, 1990, 2000, 2004
(4) NFGIS from Resource and Environment Science and Data Center (RESDC) from Chinese Academy of Sciences: https://www.resdc.cn/				
	Railway, road	2012	Jiao et al. (2014)	Travel time between cities via expressway, highway, and high-speed railway, 2012
Panel (b): Digital and GIS data collected by other authors				
(5)	Railway, motorway, national highway, port, airport	2006	Jin et al. (2010)	Density, proximity, accessibility, travel distance between cities, through railway, motorway, national highway, port, and airport, 2006
(6)	Railway and highway	1924, 1962, 1980, 1990, 1999, 2005, and 2010	Baum-Snow (2017)	Number of railroads and highway lines 5 and 10 km from CBD 1990, 2000, and 2010
			Baum-Snow (2020)	Travel time used for market access through highway and railway, 1990, 1999, 2005, and 2010
(7)	Railway, motorway, national highway	1911, 1935, 1953, 1981 and 2012	Hu et al. (2015)	Density, proximity, and accessibility of railway, motorway, and national highway, 1911, 1935, 1953, 1981 and 2012
(8)	Railway	11 discrete years from 1906 to 2000	Wang et al. (2009)	Connectivity, travel distance between cities through railway, 1906, 1911, 1925, 1937, 1949, 1957, 1965, 1974, 1981, 1988, and 2000

(9)	Motorway and national highway	2013, 2015	Liu (2019)	Compare planned and finished motorway and national highway, 2013, 2015
(10)	High-speed railway	2006-2010	Zheng and Kahn (2013)	Travel time and market access through high-speed railway, 2006-2010
		2004, 2007	Qin (2017)	Whether high-speed railway was upgraded, 2004, 2007
Panel (c): Data from China Statistical Yearbooks				
Transport mode: railway, high-speed railway, highway, navigable river, and port				
(11) China Statistical Yearbook from National Bureau of Statistics (NBS): http://www.stats.gov.cn/tjsj/ndsj/				
		1981-2020	Lean et al. (2014)	Length of railway, highway, number of deep-water berths, 1980-2009
			Tong and Yu (2018)	Freight transportation per capita, 2000-2015
(12) China City Statistical Yearbook from National Bureau of Statistics (NBS): https://data.cnki.net/Yearbook				
		1985-2020	Yu et al. (2016).	Density of motorway in each city, 2000-2010
			Yang et al. (2020)	Whether a city is connected to a high-speed railway, 1996-2017
(13) Regional Economic Statistical Yearbook from National Bureau of Statistics (NBS): https://data.cnki.net/Yearbook				
		2000-2014	Roberts et al. (2012)	Expenditure on national motorways, 2007
(14) China Provincial Statistical Yearbooks from National Bureau of Statistics (NBS): https://data.cnki.net/Yearbook				
		1983-2020	Deng et al. (2014)	Density of highway, 1987- 2010
Panel (d): Train Timetable Data				
(15) National railway passenger train schedules from National Railway Administration: http://www.nra.gov.cn/ and http://www.tielu.org				
	Regular railway and high-speed railway	1957-2016	Jiao et al. (2017)	Connectivity and centrality of high-speed railway, 2003-2014
			Diao (2018)	Travel time and accessibility through high-speed railway, 2009, 2010, 2012, 2013
(16) Train timetable data from official website: www.12306.cn				
	Railway, high-speed railway	Periodical	Huang and Zong (2020)	Connectivity and centrality of high-speed railway, 2016, 2019
			Wang et al. (2020)	Connectivity and centrality of high-speed railway, 2018

Note: The table presents the summary of transport datasets in other studies, including other GIS data sources, digital and GIS data collected by other authors, China Statistical Yearbooks, and timetable data. We outline the data sources, transport mode, time span, transport measures, and studies that use these data.

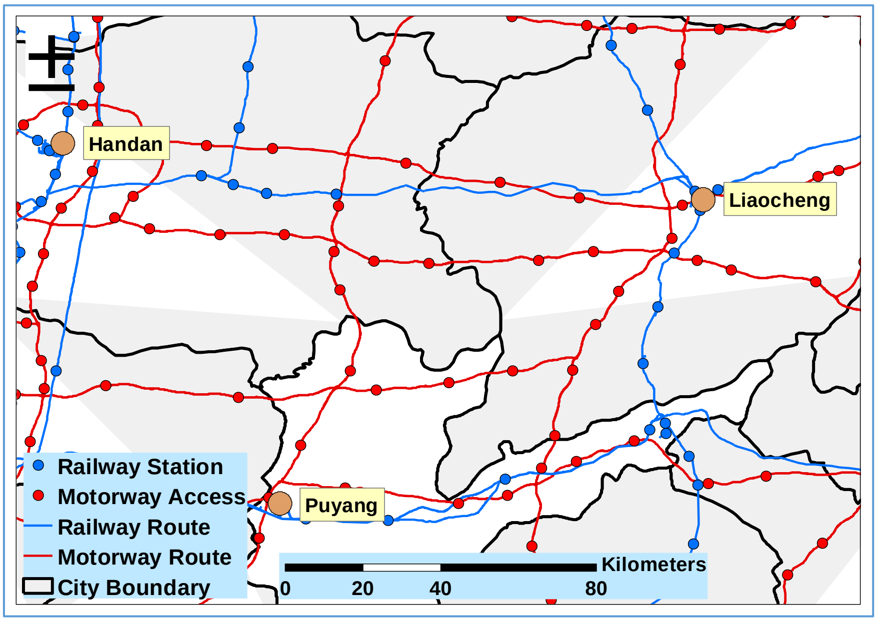


Figure B1. An example of motorways and railways in our GIS database

Note: The figure is a map scaled at 1:2,000,000. Blue lines are railways, and red lines are motorways. Points represent railway stations and entrances/exits. *Data source*: GIS database