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Highways and firms' exports: Evidence from China

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Abstract

This article investigates the impact of highway networks on Chinese firms' exports. We construct firm-level measures of highway access using GIS information on firm locations and highway routes and adopt an instrumental variable approach to deal with the endogeneity issue. The analysis finds that improvements in highway access significantly promote firms' exports, after controlling for firm characteristics and unobservable city and industry time-varying factors. Highway access helps firms to expand the scope of their exports and imports as well. More interestingly, the positive effects of highway access on exports are stronger for less productive firms. With greater highway access, less productive firms lower their markups while more productive firms experience an increase in average markups.

KEYWORDS

exports, GIS, highways, markup, product scope

JEL CLASSIFICATION

F14, H54, L25, L92

1 | INTRODUCTION

Transportation infrastructure plays a key role in economic growth. The poor transportation network in less developed countries has been a major barrier to trade expansion and economic development (Hummels, 2007). By contrast, it is believed that the massive investment in transportation and dramatic improvement in highways and railways have promoted international trade significantly for export-oriented countries, especially Asian economies such as Japan, Korea, Taiwan, and China, during the stage of economic take-off and industrialization. Business leaders, policymakers, and academic scholars all consider transportation infrastructure as a critical stimulus for firm growth and economic development. However, much less is known about how transportation networks affect firms' performance in the global market. Do highway and railway construction help firms to export? If so, how does transportation infrastructure increase firms' exports? And which types of firms benefit more?

This article aims to address these questions and provide new firm-level evidence on how highways promote firms' exports, drawing experience from a fast-growing economy, China, during the episode of rapid trade expansion and dramatic improvement of transportation infrastructure in the country. The article's main empirical innovation is to construct a measure of highway access at the firm level, by using the geographic information system (GIS) on firms' addresses and access to highways during 2000–2006 in China, measured as the highway density in the area centered at each firm with a certain radius, with the baseline radius of 20 km. Most of the existing measures of transportation infrastructure are based on administrative boundaries, and thus may not accurately capture the local highway network access for each firm, as all firms located in the same administrative area by definition share the same measure of the highway network, which ignores significant variations at the firm level and masks the heterogeneity of highway access of firms within administrative areas. Moreover, using the firm-level variation in highway access allows us to control for the unobserved region- and industry-time varying factors such as public amenities, local labor market environment, and government policies, and thus our study is less likely to suffer the criticism of omitted variable bias as the region-level analysis.

We first develop a simple model based on Melitz (2003) by incorporating domestic trade costs and then derive the relationship between firm exports and domestic trade costs (see Appendix B). The model does not intend to generate predictions on all the possible effects and mechanisms of highway access on firms' exports but rather remains parsimonious to guide our empirical analysis. The model implies that lower domestic trade costs can affect firm exports through three channels: direct savings in transportation costs, better access to suppliers, and tougher competition. The first two effects facilitate firms' exports, but the last may impede exporting. Thus, the overall effect is positive if the competition effect is controlled for at the local level.

Consistent with the theoretical predictions from the model, we find that improvement in highway access can significantly promote firms' exports after controlling for city-year and industry-year fixed effects. Having access to highways also helps firms to expand the scope of their exports and imports. More interestingly, we find that less productive firms benefit more in promoting exports from having access to highways than do more productive firms. One possible explanation, suggested by further evidence, is that more productive firms increase their markup while less productive firms reduce their markup in response to improvements in the highway network. Finally, our results also demonstrate heterogeneous impacts of highways across regions and cities. Firms in the inland regions or non-port cities benefit more from access to highways than firms in other places that are less dependent on highway transportation.

Our results are robust to an array of sensitivity checks. First, we use alternative measures of highway access at the firm level, including highway density in the area around each firm within a radius of 30 km and the distance to the nearest highway. Second, the endogeneity issue of transportation infrastructure challenges the empirical assessment of the impact of highway networks on regional development. Our study relies on the variation in highway access at the firm level, and unobservable region-time varying factors can be controlled and thus less likely to be subject to omitted variable bias. To mitigate further the concern that highway access might be correlated with unobserved firm characteristics, we construct a time-varying instrumental variable (IV) based on the average geographic slope of the area centered at each firm within a certain radius and the predicted length of highways at the province level. We find that our OLS estimation results continue to hold using the IV estimation method. Third, we address the potential concerns about the possibility that firms may choose to locate their plants close to highways. The positive effect of highways on firms' exports remains significant when using a balanced sample of firms that do not change their location during the sample period. Finally, we examine the estimates from the regressions using long differences as well, which capture the cumulative impacts of better highway access.

This study contributes to the literature on the impact of transportation infrastructure on trade and economic development. The importance of transportation has been long recognized in the literature, at least back to Fogel (1964) early work on evaluating the contribution of railroads to economic growth in the United States. Recently this topic has emerged as the focus of the spatial economics literature, due to the breakthrough in quantitative trade models (Eaton & Kortum, 2002) and the availability of geographic information on transportation infrastructure (Donaldson & Hornbeck, 2016). By combining quantitative trade models with rich GIS data on highway and railway systems, this so-called "market access" approach marks a methodological breakthrough and generates novel insights into the spatial distribution of economic activities and aggregate welfare gain from the transportation network.[1] However, this approach mainly focuses on aggregate implications at the regional level, such as the price index, real wage, and land rent, while remaining silent on the heterogeneous effects of the transportation network on firms' behavior. Our study complements this approach by analyzing the heterogeneous responses of firms to improvement in highway access in a large developing country, China, which has experienced massive infrastructure investment and explosive growth in international trade.

This article also contributes to the literature on the economic impacts of transportation in developing countries, which is unfortunately quite limited relative to its policy importance. Poor infrastructure has been shown to be the key factor causing high trade costs and low trade volume in less developed countries, and the improvement in transportation infrastructure helps to promote regions' exports and specialization (Cosar & Demir, 2016; Duranton et al., 2013; Limao & Venables, 2001). Martincus and Blyde (2013) find that the destruction of key infrastructure due to earthquakes has a significant negative impact on firm exports in Chile. Ghani et al. (2015) find that a major national highway improvement program in India promotes the growth of manufacturing plants along with the highway network. However, previous county-level studies on highways in China find mixed evidence on the economic effects for non-targeted counties in the highway network.[2] Fan et al. (2021) show that expressways construction in China has significantly promoted both international and domestic trade at the aggregate level. Our study employs plant-level data and provides new insights into the impact of highway access on firm exporting behaviors in China. To the best of our knowledge, this project is the first to bring the plant-level data into the study of the impact of highway access on firms' exports in China.

The remainder of this article is organized as follows. Section 2 discusses the development of the highway network in China and the data we employ for empirical analysis. Section 3 explains the empirical specifications, identification strategies, and main findings. Section 4 discusses the potential mechanisms and Section 5 concludes.

2 | BACKGROUND AND DATA

2.1 | China's highway development

Since the construction of the first highway in mainland China in 1988, the growth of highways in China has been explosive. As shown in Figures 1 and 2, not only the total length of highways has increased dramatically, but also the net increase has grown since 1992. By 2015, the total length of highways across the country reached 125,000 km.[3] The early development can be roughly divided into three phases (World Bank, 2007b). From 1988 to 1992 was the "kick-off" phase. More highways were constructed, but the speed of increase was relatively slow, with 50–250 km of new highways each year. From 1993 to 1997 was the first wave of "rapid development." In 1992, the Chinese State Council launched the National Trunk Highway Development Program, which constructed a "7-5" network, with seven horizontal and five vertical

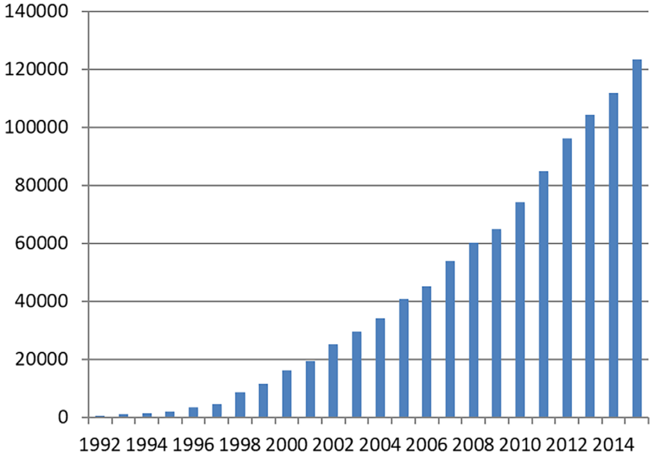

FIGURE 1 Length of highways in China, 1992 to 2015 (km). *Source*: China Statistical Yearbook 1993–2016 [Colour figure can be viewed at wileyonlinelibrary.com]

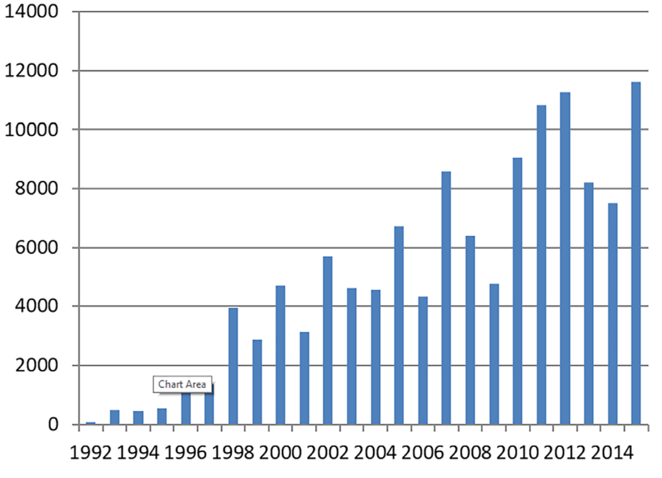

FIGURE 2 Increase in the length of highways in China, 1992 to 2015 (km). *Source*: China Statistical Yearbook 1993–2016 [Colour figure can be viewed at wileyonlinelibrary.com]

routes across China. After that, highway construction accelerated and the length of new highways increased to 450–1400 km each year until 1997. Since 1998, the pace of highway construction has been even faster, with financial support from the central and local governments. The annual increase in the length of highways ranges between 3000 and 5000 km. The reason for this acceleration in highway development is that it became part of the government's stimulus spending after the Asian financial crisis. Since 2008 the annual growth of highways has been around 10,000 km.

The spatial distribution of highways has been uneven across provinces. Figure 3 shows that highway density, measured by the length of highways divided by the total area, was highest in the eastern coastal provinces on average, followed by the middle and then the west. In 2000 and 2005, Beijing, Tianjin, Shanghai, Jiangsu, and Shandong were among the top five provinces with the highest highway density. Their neighboring provinces, Guangdong and Hainan, were among those on the next ladder. The highway densities for the middle and western provinces are among the lowest. This is related to the objective of highway construction to connect big cities, most of which are located in the coastal provinces.

There are two national programs for highway construction in China so far. The first one is the National Trunk Highway Development Program, which was approved in 1992. It consists of seven horizontal and five vertical routes across the country, with a total length of 35,000 km. It connects all the provincial capitals and cities with an urban registered population above 500,000 on a single expressway network, and constructed routes between targeted centers in border provinces as part of the Asian Highway Network. The National Trunk Highway System (NTHS) was completed in 2007, much earlier than the original deadline of 2020. The second national program for highway construction was approved in 2004 by the State Council. This blueprint for highway construction, which is called the "7-9-18" system, consists of seven routes from Beijing to local cities, and nine vertical and 18 horizontal axes, with a total length of 85,000 km. Its objective is to connect all cities with an urban registered population of more than 200,000. This system is to be completed by 2020.[4]

Highway construction was mainly financed through domestic bank loans and other forms of debt. The central government contributed around 15% of the total spending on highway construction. In 2005, the contribution from the central government accounted for 0.5% of total gross domestic product (World Bank, 2007a, 2007b). Local governments were responsible for about 70%–80%, which would be paid through future toll revenues. Private investment from domestic and foreign investors could be up to 15% of financing.

In this article, "highway" is defined in technical terms. Most of the highway routes are four-lane or six-lane high-speed limited access tollways, with a minimum width of 28 m. Almost all the highways are technically designed for a driving speed limit up to 120 km per hour (kph). The actual speed limits range from 100 to 120 kph, depending on the local natural conditions. Generally speaking, the speed limits are 120 and 100 kph for national highways and provincial highways, respectively.

2.2 | Data

This section describes the data and variables used in our analysis. More detailed information on the sources of the data is provided in Appendix A.

Three data sets are combined in this article: firm-level information, customs transaction-level data on exporters, and GIS highway routes. The period covered is from 2000 to 2006. The firm-level

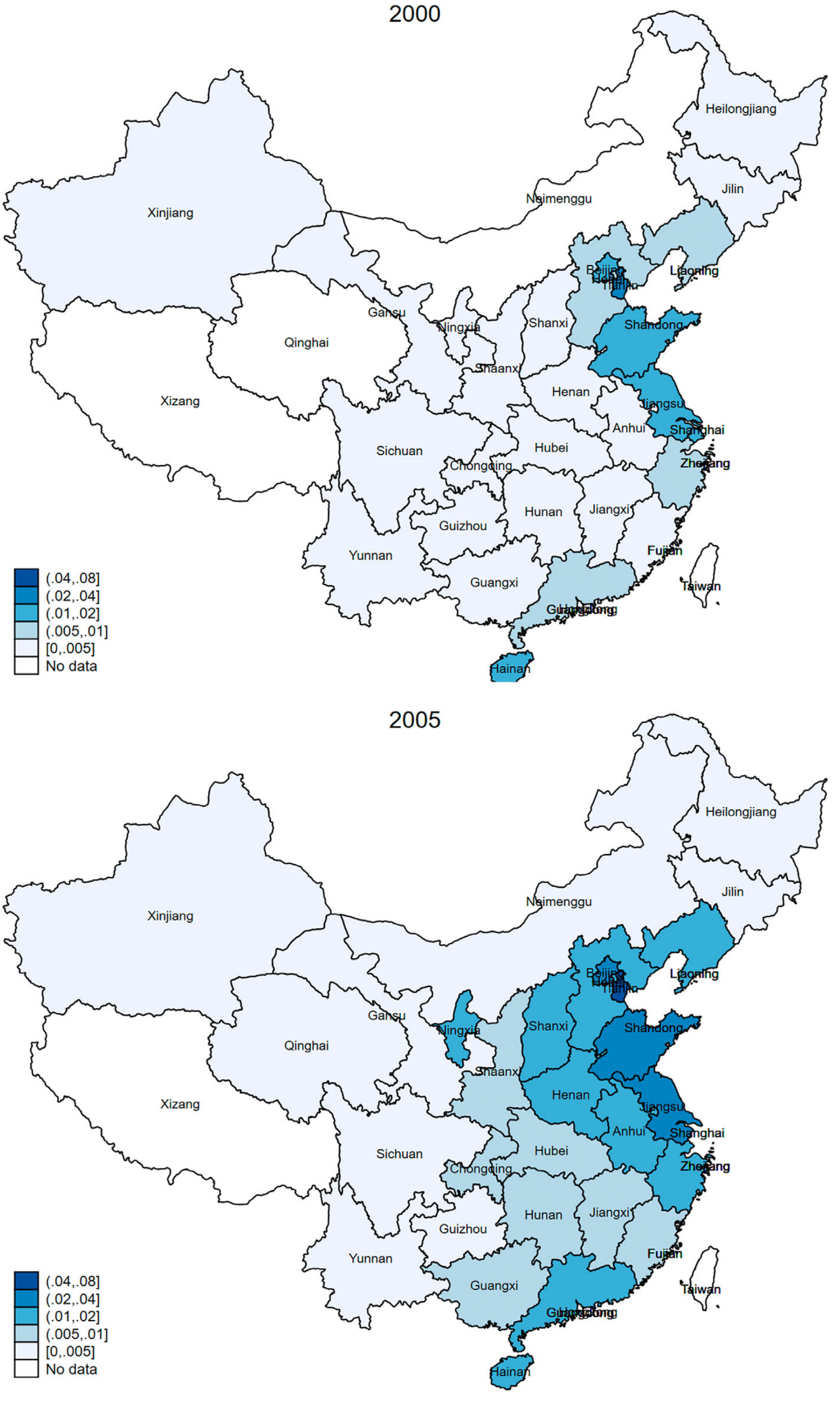

FIGURE 3 Province-level density of highways (km/squared km) in China, 2000 and 2005. Data are from the 60 years of the China Statistical Yearbook for 2000 and 2005. Ningxia and Xizang are excluded due to data issues. [Colour figure can be viewed at wileyonlinelibrary.com]

information was taken from the Annual Surveys of Manufacturing Enterprises (ASME), which are collected and maintained by China's National Bureau of Statistics. The data set covers between 162,885 firms (in 2000) and 301,961 firms (in 2006). All state-owned enterprises (SOEs) and non-SOEs with annual sales above RMB 5 million (about $770,000) are included in the surveys. The data set contains detailed information on firms' three major accounting statements (i.e. balance sheet, profit and loss account, and cash flow statement). It also provides firm location information, including province, city, postal code, and detailed street information, which is used to find firms' geographic location.

We first clean the data following the standard procedures in the literature. Observations with missing financial variables or fewer than eight workers were excluded from the sample, following Cai and Liu (2009) and Yu (2015). Firms with reported information against the Generally Accepted Accounting Principles were also deleted, as in Feenstra et al. (2014). In addition, we excluded firms with export values below the 1st percentile or above the 99th percentile in some specifications, to minimize the potential influence of noisy observations.[5]

In our mechanism analysis, the survey data are further matched with disaggregated transaction-level trade data obtained from China's General Administration of Customs, which provides each exporting firm's product list, including trading price, quantity, and value at the Harmonized System eight-digit level. The matching procedures and criteria follow Yu (2015), leading to a matching rate that is highly comparable to other literature using the same data sets, such as Ma et al. (2014). As discussed in detail in Yu (2015), the merged sample is skewed toward large firms. Therefore, our discussion on mechanisms may be valid only for large manufacturing trading firms that are engaged in international markets.

Table 1a reports the summary statistics for firm exporting participation and export values by year. As expected, the average magnitude of firm exports increased over the sample years by about 75%. The number of firms increased by about three times. This implies that there was a significant amount of entry each year.[6] In our later discussion, we will deal with the endogenous firm location choice by constructing a balanced sample. Table 2 shows the summary statistics for the main variables. They are all in line with those reported in the literature.

Geo-referenced firm locations are digitized based on firm addresses and the digital Baidu map of China in 2016 when the data were constructed.[7] For each year, we search for the latitude and longitude of each firm with firm address information in that year on the digital map of China. Fortunately, there was no big administrative adjustment during the sample period. Cities expanded over time, but the old street names were mostly kept.[8] This process leaves us 44,287 firms with

TABLE 1a Firm-level exports by year

		Exporting indicator		Export value (RMB 1000)	
Year	**Obs.**	**Mean**	**SD**	**Mean**	**SD**
2000	44,287	0.33	0.47	41,700	174,979
2001	49,452	0.31	0.46	41,459	244,256
2002	49,452	0.31	0.46	41,672	179,363
2003	100,713	0.31	0.46	49,999	444,187
2004	150,402	0.31	0.46	47,405	450,801
2005	167,131	0.30	0.46	56,669	390,635
2006	190,435	0.29	0.45	70,066	828,323

TABLE 1b Firm-level highway access

	Highway density (km/km^2)					
	20 km radius		30 km radius		Distance to highway (km)	
Year	Mean	SD	Mean	SD	Mean	SD
2000	0.023	0.024	0.019	0.019	2.415	1.435
2001	0.022	0.024	0.018	0.019	2.525	1.475
2002	0.026	0.027	0.021	0.019	2.379	1.479
2003	0.025	0.025	0.021	0.019	2.387	1.512
2004	0.027	0.025	0.023	0.019	2.276	1.491
2005	0.041	0.039	0.035	0.03	1.853	1.397
2006	0.039	0.038	0.034	0.03	1.881	1.412

Note: Highway density is calculated as the total length of highways within a 20 or 30 km radius centered by the firm divided by the area of the circle. Distance to highway is the shortest distance from the firm to the highway system.

TABLE 2 Summary statistics, 2000–2006

Variables	Mean	SD
TFP^{op}	1.09	0.43
TFP^{lp}	6.27	1.16
TFP^{acf}	3.02	1.21
SOEs indicator	0.01	0.11
Foreign invested indicator	0.42	0.5
Log of labor	4.8	1.09
Export scope	6.92	7.81
Import scope	13.29	22.92
Markup_GO1	1.31	0.25
Markup_GO2	1.26	0.31

Note: TFP^{op} is measured using the Olley–Pakes method; TFP^{lp} is estimated following Levinsohn and Petrin (2003); TFP^{acf} is based on the method developed by Ackerberg et al. (2015); "Export" scope is the firm's number of export varieties (at HS-8 level); "Import scope" is the firm's number of import varieties (at HS-8 level); "Markup_GO1" and "Markup_GO2" are estimated following the approach developed by De Loecker and Warzynski (2012) with Cobb–Douglas production function relying on material input share and labor input share, respectively.

geo-information available in 2000 and 190,435 firms in 2006 due to missing or incomplete address information.

Geo-referenced highway routes were obtained from the ACASIAN Data Center at Griffith University in Brisbane, Australia. Highway routes were digitized on the basis of a collection of high-resolution road atlas sources published between 1998 and 2007. These atlas sources make it possible to identify highway segments that were open to traffic in each year for the period studied. The sources also provide information on whether the segment is part of the NTHS, 90% of which was constructed between mid-1997 and 2007.[9] Faber (2014) uses the same data source but focuses on NTHS only. We include all the highways in our analysis. A list of the atlas publications as well as a more detailed description of the data processing classifications are given in the Appendix.

Figure 4 shows the highway routes and firm locations in 2000 and 2005. The red lines represent the highway routes constructed by the end of the year. The yellow dots are firms with geo-information. As can be seen clearly from the maps, the number of highway routes and firms increased significantly in this period. Firm density in the east and coastal provinces is much higher than in the middle or the west. Highway construction seems to have started around large cities and then spread further to connect with other cities. In our empirical analysis, we will take this correlation between firm location and highway construction into consideration by controlling for city-year specific fixed effects and constructing a balanced sample.

By combining the highway route GIS information with firm location geo-references, we construct two firm-level measures of highways access: one is the shortest distance from each firm to the highway system, and the other is highway density around each firm. Distance is a natural measure of highway accessibility, which is also used in Faber (2014). Highway density is measured as the total length of highways within a certain radius (20 or 30 km) around each firm divided by the area.[10] Table 1b reports the means and standard deviations of highway access for each year. The three measures show a consistent picture that firms get better highway access over time, as the highway density within a 20 km (30 km) radius increased by about 70% (80%) and the distance to the highway network dropped by 23% over the sample period. The standard deviations are around the same magnitude as the means, indicating significant variation in highway access across firms.

The density measure and the distance measure of highway access are complements of each other. On the one hand, the density measure captures certain variations better than the distance measure. For example, if two firms share the same distance to the nearest highway, and one firm can only access one highway and the other two highways, the latter firm should be considered as having better access to highways. On the other hand, if highways are all well connected and the cost of transporting on highways is much less (cheaper or faster) than on other roads, distance to highways becomes a more reasonable measure. For the baseline results, we use highway density in a 20 km radius as our measure of highway access, with the other two measures as robustness checks. In general, the three measures lead to quite similar results.

In addition, the slope data, which we use to construct the instrumental variable, is provided by the International Scientific & Technical Data Mirror Site, Computer Network Information Center, Chinese Academy of Sciences (http://datamirror.csdb.cn). The data are processed based on the first version of ASTER GDEM data released in 2009.[11] The ASTER GDEM is in GeoTIFF format with geographic latitude/longitude coordinates and a 1 arcs (30 m) grid of elevation postings. These data are processed by calculating the slope for each grid using ArcGIS tools for surface analysis.[12] When constructing the average slope of the land surface around each firm, we take the average over all grids that cross the area considered.

3 | EMPIRICAL SPECIFICATION AND IDENTIFICATION STRATEGY

3.1 | Empirical specification

Our empirical model is motivated by a simple theoretic framework of heterogeneous firms in Appendix B, and specified as follows:

$$\ln(\text{export}_{it}^{c,n}) = \alpha_0 + \alpha_{hw} \text{ highway access}_{it} + \alpha_{tfp}\, tfp_{it} + A_{\text{other}} X_{it} + \mu_{ct} + \mu_{nt} + \varepsilon_{it},$$

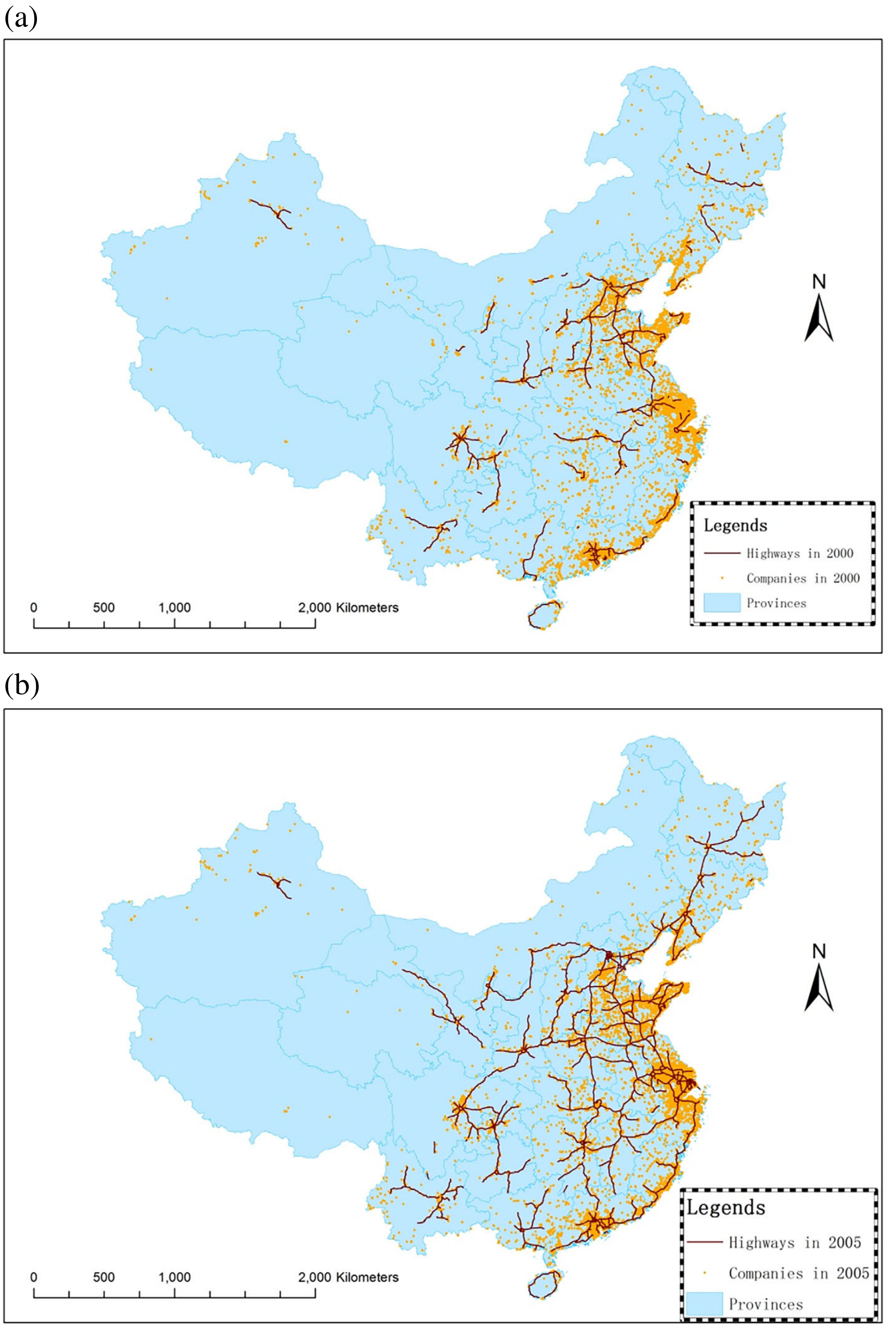

FIGURE 4 Highway System in mainland China, 2000 and 2005. Geo-referenced highway routes were obtained from the ACASIAN Data Center at Griffith University in Brisbane, Australia. Firms indicated on the graph are those with address information available and found on the current Baidu map. Taiwan province is not included due to data limitations. [Colour figure can be viewed at wileyonlinelibrary.com]

where $export_{it}^{c,n}$ is the value of exports by firm i in year t.[13] c represents the city where firm i is located and n represents the industry it belongs to. *highway access* is a measure of the firm's access to the highway system. *tfp* is firm productivity.[14] X is a collection of the firm's other characteristics that can affect firm exports, such as labor size and ownership.[15] μ_{ct} and μ_{nt} are city-year fixed effects and industry-year fixed effects, respectively. μ_{ct} controls for city-level time-variant characteristics that can affect all firms' exports, such as local competition (i.e. $\ln(P_r)$ in the model), institutions, resources, and input prices. More importantly, μ_{ct} could also control for all other types of infrastructure at the city level, such as railroads, waterways, and airports. This helps us to identify the impact of highways only. μ_{nt} controls for industry-level characteristics, such as technology development, foreign aggregate demand, and the level of competition in the foreign market (i.e. the term $\ln\{E_F(P_F)^{\sigma-1}\}$ in Appendix B). Moreover, it also controls for the Chinese import tariffs and foreign tariffs in the destination markets, which are particularly important as China has experienced fast trade liberalization during the sample period.[16]

The challenge in identifying the causal impacts of highways is the endogeneity issue. There are two main potential sources of endogeneity: highway location and firm location choice. First, factors, such as geographic characteristics and government expenditures, that affect the speed of highway construction can also influence firm exports. The central government initiated highway construction to promote development. The most important goal of highway construction was to connect all the big cities. This is determined by central government planning. However, which cities would be connected by highways earlier than others depended on local governments' ability to finance highway construction, which is highly correlated with local development. Rich provinces or cities tend to be connected sooner rather than later. At the same time, eastern regions were more developed and closer to the coast where firms were more likely to export. In addition, for those places where highways were constructed faster, railways could be developed more quickly too. We believe that these city-level missing variable issues are all well taken care of by the city-year fixed effects, which cover all the city-level time-variant or invariant factors.

The second source of endogeneity is from firms' location or relocation choice. More productive firms are more likely to be able to afford to locate closer to a highway and at the same time, they tend to be exporters. We first check the relocation issue in the data. According to the *Regulation of the People's Republic of China on the Administration of Company Registration, 2005*, firms are supposed to produce at the location where they registered. If a firm changes its production address, it must apply officially. In our data, there are only a few firms (<100) over this period that have changed their locations. This could be because the cost of relocation can be extremely high, which makes firms very unlikely to move to another place within a few years. However, as shown in Table 1a, many new firms entered the sample each year, and they may be affected by highway expansion. To deal with this, we use the fixed-effect model and explore within-firm variation to control for any time-invariant unobservable characteristics that could affect highway access and firm exports at the same time, such as ties to the government and social networks abroad. Furthermore, we construct a balanced sample that includes only firms existing in all years as a robustness check.

3.2 | Benchmark results

Table 3 reports the benchmark results from OLS regressions. Industry-year and city-year fixed effects are controlled for in all regressions. The first two columns use highway density within a 20 km radius as the measure of highway access. Columns 3 and 4 use highway density within a

TABLE 3 Firm exports and highway access: Benchmark, OLS

Regressand: ln(export)	(1)	(2)	(3)	(4)	(5)
Highway density (20 km)	2.991***	0.675***			0.199*
	[0.183]	[0.162]			[0.119]
Highway density (30 km)			0.994***		
			[0.224]		
Inversed dist. to highway				0.011***	
				[0.003]	
TFP^{op}	0.455***	0.319***	0.319***	0.319***	0.132***
	[0.018]	[0.015]	[0.015]	[0.015]	[0.013]
State owned indicator		0.666***	0.666***	0.667***	0.1
		[0.097]	[0.097]	[0.097]	[0.087]
Foreign invested indicator		2.840***	2.840***	2.840***	0.399***
		[0.021]	[0.021]	[0.021]	[0.054]
Ln(labor)		1.157***	1.157***	1.157***	0.490***
		[0.008]	[0.008]	[0.008]	[0.012]
Industry*year FE	Yes	Yes	Yes	Yes	Yes
City*year FE	Yes	Yes	Yes	Yes	Yes
Firm FE	No	No	No	No	Yes
R^2	0.27	0.41	0.41	0.41	0.87
N	738,763	738,763	738,763	738,763	648,281

Note: The dependent variable is the log of export value measured in 1000 RMB; highway density is calculated as the total length of highways within a 20 or 30 km radius centered by the firm divided by the area of the circle; "inversed dist. to highway" is the inverse of the shortest distance from the firm to the highway network. TFP^{op} is measured using the Olley–Pakes method; industries are at the SITC four-digit level; cities are at the prefecture level; standard errors are all clustered at the firm level and reported in brackets; *$p < .1$, **$p < .05$, ***$p < .01$.

30 km radius and shortest distance to the highway system, respectively, as alternative measures. Firm fixed effects are further controlled for in the last column. The specification in column 1 follows closely the implications of the model. It can be seen that firms with better highway access export significantly more, and more productive firms export more. This is highly consistent with the model's predictions.

One concern with the specification in column 1 is that it cannot deal with the potential endogeneity issue caused by measurement errors or missing variables. For example, it is well documented that foreign-invested firms are more likely to export more, and they tend to locate in special economic zones with better infrastructure provided by the local government to attract foreign investment. To deal with this issue, the specification in column 2 further controls for firm size and ownership type. The results show that SOEs and foreign-invested firms tend to export more, and larger firms export more too. The coefficient on highway access decreases by a fourth but is still positive and significant. Columns 3 and 4 show consistent results using alternative measures of highway access. Moreover, the coefficients on the control variables barely change, which implies that the distance measure and the density measures are highly consistent. In our later regressions, we will only show the results using the density measures. When firm fixed effects are further controlled for, as shown in the last column, the coefficient on highway access decreases by about 72% but is significant at the 10% level.[17]

Overall, our benchmark analysis shows consistent results that improvement in highway access is positively associated with firm exports after controlling for potential impacts at the city and industry levels. This result is robust to various measures of highway access and model specifications. We will further deal with the potential endogeneity issues caused by selection into exporting and missing variables.

3.3 | Instrumental variable approach

Although highway development is planned by the central government and conducted by the local governments, it is not completely impossible for some firms to have a certain amount of influence on some local routes and the entrances or exits, to get better access to highways. At the same time, these firms can become exporters due to technological improvement but not highways. Therefore, we adopt an instrumental variable approach to address the endogeneity issue caused by missing variables at the firm level.

Our instrumental variable is constructed based on the monotonic relationship between highway construction cost and the steepness of the surface. According to the *Technical Standard on Highway Engineering* (2005) published by the Ministry of Transportation of the People's Republic of China, the maximum gradient is 4% for highways with a speed limit 100 kph or higher. This is mainly for safety considerations since a higher gradient increases the risk of traffic accidents dramatically. Nicolls (1897) also points out that the hauling capacity of the railway decreases quickly with the gradient of the surface, which implies that the cost increases with the gradient for railroads. We use the digital elevation map to calculate the average gradients of the surface within a 20 or 30 km radius centered by firm location. Then, we use this average to explore the variation in highway access across firms.

Inspired by Duflo and Pande (2007), we construct our instrumental variable by running the following regression:

$$\text{highway access}_{it}^{p} = \beta_0 + \beta_1(\text{slope}_i * \overline{hw}_{pt}) + \beta_2(\text{slope}_i * l_t) + \delta_i + \delta_{pt} + \omega_{it}.$$

$\overline{hw}_{pt}$ is the measured length of highways in province p in year t, which captures the province-level variation. $\overline{hw}_{pt}$ is calculated as the total length of highways in year t times the share of highways in province c in 1999, which is before the sample period. The purpose of this term is to capture the cross-province variation in the effect of the slope on highway construction due to factors such as climate. By using the predicted length of highways rather than the actual highway length, we can make sure it is exogenous with respect to highway access at the firm level. l_t is the year dummy and captures the over-time variation. δ_i is firm fixed effects and δ_{pt} is province-year fixed effect. We use the predicted firm highway access estimated from the above regression as the instrumental variable for actual firm highway access.

Table 4 shows the two-stage least squares (2SLS) estimates using the instrumental variable approach.[18] City-year and industry-year fixed effects are controlled for in each specification. Firm-level control variables, including productivity, firm size, and ownership type, are all controlled for in the last four columns. The first two columns repeat the analysis in the first two columns in Table 3. It can be seen that highway access has a significant and

TABLE 4 Firm exports and highway access: IV estimates

	(1)	(2)	(3)	(4) Balanced sample	(5)	(6)
Highway density (20 km)	6.475*** [0.344]	1.269*** [0.299]	3.400*** [0.458]	3.162* [1.884]		0.29 [0.402]
Highway density (30 km)					1.853*** [0.391]	
Highway density $(20\ \text{km})^2$			−17.343*** [3.503]			
TFP^{op}	0.461*** [0.018]	0.328*** [0.016]	0.331*** [0.013]	0.403*** [0.062]	0.328*** [0.016]	0.132*** [0.013]
Other control variables	No	Yes	Yes	Yes	Yes	Yes
Industry*year FE	Yes	Yes	Yes	Yes	Yes	Yes
City*year FE	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	No	No	No	No	No	Yes
R^2	0.25	0.39	0.19	0.44	0.39	0.87
N	738,769	738,769	738,763	90,331	738,769	648,281
First-stage regressions						
Predicted highway density (20 or 30 km)	0.937*** [0.001]	0.937*** [0.001]	0.859*** [0.002]	0.970*** [0.004]	0.923*** [0.001]	0.898*** [0.005]
Predicted highway density^2			0.820*** [0.0284]			
K-P rk LM χ^2 statistic	5.70E+04	5.60E+04	6.73E+03	3.46E+03	6.10E+04	1.80E+04
K-P rk Wald F statistic	1.30E+06	1.30E+06	2.36E+04	6.90E+04	1.10E+06	3.20E+04

Note: The dependent variable is the log of export value measured in 1000 RMB; highway density is calculated as the total length of highways within a 20 or 30 km radius centered by the firm divided by the area of the circle; TFP is measured using the Olley–Pakes method; industries are at the SITC four-digit level; cities are at the prefecture level; standard errors are reported in brackets and all clustered at the firm level; *$p < .1$, **$p < .05$, ***$p < .01$.

positive impact on firm exports. The magnitude of the effect is greater using the 2SLS estimator than the OLS estimator, which implies that the OLS estimator may underestimate the impact.

One may be wondering that the highway access may have nonlinear effects on firms' exports. Thus, we include a quadratic term of highway intensity in the baseline regression. As shown in column 3, we find the estimate of highway intensity itself remains positively significant while the estimate of the quadratic term of highway intensity is significantly negative, indicating the declining marginal return to highway access. However, the quantitative effect of the quadratic term of highway intensity seems to be very small, as the average of highway density with a radius of 20 km is 0.029 during the sample period, and thus the average of the quadratic term is only 0.000841. Thus, in the remaining analysis, we only include highway intensity in regressions as we focus on the average effect of highway access on firm exports.

Furthermore, to deal with endogenous firm entry, we construct a balanced panel and report the results in column 4. The results show a similar sign and significance pattern, but with a much larger estimate on highway access. Although the results provide reassurance of the positive impact of highway access on firm exports, they also indicate that the IV estimates are much noisier, with larger standard errors than the OLS estimates. Column 5 presents the results using the alternative measure of highway intensity with a radius of 30 km and the results are similar to column 2. The specification in the last column further controls for firm fixed effects. The coefficient is positive and bigger than the OLS estimate in Table 3, but less significant due to the large standard error of the IV estimate. Note this sample includes non-exporters as well, later we will show that the estimate of highway access remains significantly positive with firm fixed effects, once we properly control for the exporting selection issue.

The test results show that the instrument we constructed is qualified. First, the Kleibergen–Paap LM chi-squared statistic from the test of the null hypothesis that the model is under-identified is rejected at the 1% significance level. Moreover, the Kleibergen–Paap rk Wald F-statistic provides strong evidence for rejecting the null hypothesis that the first stage is weakly identified at a highly significant level. Finally, the first-stage estimates reported in the lower module of Table 4 further offer strong evidence to justify the instrument. In particular, all the t-values of the instruments are significant with standard errors clustered at the firm level.[19]

3.4 | Heckman two steps

Another issue with the above specifications is that the control variables, such as productivity and labor size, are endogenous. Exporters are on average more productive and larger, as shown in the literature (Bernard & Jensen, 1999; Bernard et al., 1995). More productive firms are more likely to self-select into exporting. To control for selection bias, we adopt a type-2 Tobit model, as in Yu (2015). The first step is to estimate an exporting participation equation:

$$\text{Exporting}_{it} = \begin{cases} 0, & \text{if } V_{it} < 0, \\ 1, & \text{if } V_{it} \leq 0, \end{cases}$$

where V_{it} is the latent variable for firm i in year t. Specifically, we estimate the following probit model:

$$\begin{aligned} P_r(\text{Exporting}_{it} = 1) &= P_r(V_{it} \geq 0) \\ &= \phi(\gamma_0 + \gamma_{hw}\text{highway access}_{it} + \gamma_1\text{TFP}_{it} + \gamma_2\text{SOE}_{it} + \gamma_3\text{FIE}_{it} \\ &\quad + \gamma_4 \ln(\text{Labor}_{it}) + \gamma_5\text{Tenure}_{it} + \varsigma_c + \varsigma_{nt}), \end{aligned}$$

where $\phi(\cdot)$ is the cumulative distribution function of normal distribution. Here, in addition to highway access, productivity, and size, firm ownership types (SOE, FIE), and firm's age (Tenure_{it}) are also controlled for, since they are well documented to be relevant to the firm's exporting status (Feenstra et al., 2014). Firm's age is used as the excluded variable since older firms are more likely to export (Amiti & Davis, 2012), and the correlation between export value and firm's age is almost

TABLE 5 Firm exports and highway access: Heckman two steps

	First step	Second step		
	(1) Probit	(2) OLS	(3) OLS	(4) IV
	Exporter indicator	Ln(Export)	Ln(Export)	Ln(Export)
Highway density (20 km)	0.182***	0.207***	0.161**	0.429*
	[0.061]	[0.090]	[0.075]	[0.254]
TFP^{op}	0.056***	0.564***	0.230***	0.223***
	[0.004]	[0.016]	[0.012]	[0.012]
State owned indicator	0.137***	−0.102**	0.149***	0.151***
	[0.021]	[0.048]	[0.056]	[0.056]
Foreign invested indicator	1.017***	0.960***	0.265***	0.291***
	[0.004]	[0.028]	[0.057]	[0.058]
Log(labor)	0.396***	0.826***	0.537***	0.547***
	[0.002]	[0.010]	[0.023]	[0.023]
Tenure	0.000**			
	[0.000]			
Inverse Mills ratio		0.989***	0.355***	0.402***
		[0.042]	[0.091]	[0.091]
Industry*year FE	Yes	Yes	Yes	Yes
City*year FE	Yes	Yes	Yes	Yes
Firm FE	No	No	Yes	Yes
N	714,599	204,233	185,652	185,788
R^2		0.42	0.86	0.86

Note: "Exporter indicator" is equal to 1 if firm exports are positive in the current year, otherwise 0; "ln(Export)" is the log of export value measured in 1000 RMB; highway density is calculated as the total length of highways within a 20 km radius centered by the firm divided by the area of the circle; TFP^{op} is measured using the Olley–Pakes method; industries are at the SITC four-digit level; cities are at the prefecture level; standard errors are reported in brackets and all clustered at the firm level; $^{*}p < .1$, $^{**}p < .05$, $^{***}p < .01$.

zero (0.01). City-year and industry-year fixed effects are also included to control for city-level and industry-level unobserved factors that may affect a firm's exporting status.

Table 5 reports the estimation results for the above Tobit-2 selection model. From the first-step probit estimates (column 1), it can be seen that firms with better highway access are more likely to export. And more productive and larger firms are more likely to export. In addition, state-owned and foreign firms are more likely to export than other private firms. Consistent with the findings in the literature, older firms are more likely to engage in exporting. We then include the computed inverse Mills ratio obtained in the first-step probit estimates in the second-step Heckman estimation. Columns 2 and 3 show the results without and with controlling for firm fixed effects, respectively. The results show that, after correcting the selection bias, highway access is still positively associated with firm exports. The last column shows the instrumental variable estimates with firm fixed effects are significant, suggesting that the correction of selection bias may improve the estimation efficiency. The inverse Mills ratio is significant in the second-step regressions, which indicates that the selection issue may indeed have caused upward bias in the earlier estimates.

So far, the empirical evidence supports the prediction from the model that improved highway access can promote firm exports. Regarding the magnitude of the impact, the instrumental variable estimates show that the marginal effect of highway access, measured by highway density in a 20 km radius, is 1.27 (column 2 in Table 4). The summary statistics in Table 1b show that highway density increased by 0.016 km/km^2 (about two-thirds of the standard deviation in highway density) over the sample period. This implies that the overall impact of highway construction from 2000 to 2006 increased exports by approximately 2%. This finding is in line with the recent findings by Campante and Chor (2017) on the impacts of culture. They find that the effect of the median change in the degree of obedience in a country's culture is associated with a 0.7% change in exports for an industry that is one standard deviation more cognitively routine. The corresponding effects of the median changes in a country's physical capital stock and human capital stock are 3.0% and 4.6%, respectively. Furthermore, it should be noted that our estimates exclude the aggregate potential impact of highways at the city or industry level.

3.5 | Heterogeneous impacts depending on productivity

One of the key implications of the Melitz framework with heterogeneous firms is that trade has a redistribution effect, from less productive firms to more productive firms. In this subsection, we investigate whether improvement in highway access also has similar redistribution effects. An interaction term between highway access and total factor productivity (TFP) is added to the above specification. The coefficient of this interaction term captures how the impact of highway access can vary with firm productivity. If it is positive, it means that more productive firms benefit more from the same improvement in highway access. The opposite holds if otherwise.

Table 6 reports the results. The first column shows the OLS estimates, and the second column shows the IV estimates. Industry-year, city-year, and firm-specific fixed effects are all controlled for. The estimates show that the coefficients on the interaction term are negative and significant. Interestingly, this indicates that low-productivity firms benefit more from improvement in highway access than high-productivity firms in terms of exports. This finding is the opposite of the redistribution effects of lowering international trade costs predicted by the models with heterogeneous firms and variable markups, pioneered by Melitz and Ottaviano (2008). In these frameworks, resources should be redistributed from low-productivity firms to high-productivity firms when trade liberalization is symmetric.

There can be at least two potential explanations for our results. First, high-productivity firms already have better access to highways compared with low-productivity firms. The average highway density for firms in the highest productivity quantile is about 15% higher than for those in the lowest quantile. The marginal effect of highway improvement may decrease after it reaches a certain level. Second, high-productivity firms on average may have better access to ports and tend to be less dependent on highway transportation. Thus, the marginal effect of highway improvement may be smaller for more productive firms than that for less productive firms. In addition, as we discuss later in Section 4.3, highway construction decreases markups for low-productivity firms. This implies that these firms may react to tougher competition by lowering their markup and increasing the quantity produced. Overall, the above analysis indicates that infrastructure improvements have heterogeneous impacts on firms, depending on firm

TABLE 6 Firm exports and highway access: Heterogeneous effects

Regressand: ln(Export)	TFP^{op} (1) OLS	TFP^{op} (2) IV	TFP^{lp} (3) IV	TFP^{lp} (4) IV	TFP^{acf} (5) IV	TFP^{acf} (6) IV
Highway density (20 km)	0.696***	2.435***	1.091*	7.563***	1.138*	3.197***
	[0.214]	[0.478]	[0.630]	[2.073]	[0.631]	[1.147]
Highway density (20 km) * TFP^{op}	−0.498***	−2.035***				
	[0.180]	[0.366]				
TFP^{op}	0.237***	0.295***				
	[0.014]	[0.019]				
TFP^{lp}			0.382***	0.422***		
			[0.012]	[0.017]		
Highway density (20 km) *TFP^{lp}				−1.023***		
				[0.300]		
TFP^{acf}					0.288***	0.315***
					[0.011]	[0.016]
Highway density (20 km) * TFP^{acf}						−0.677**
						[0.300]
Other control variables	Yes	Yes	Yes	Yes	Yes	Yes
Industry*year FE	Yes	Yes	Yes	Yes	Yes	Yes
City*year FE	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
R^2	0.86	0.86	0.89	0.89	0.89	0.89
N	188,654	188,654	33,421	33,421	33,964	33,964

Note: "ln(Export)" is the log of export value measured in 1000 RMB; highway density is calculated as the total length of highways within a 20 km radius centered by the firm divided by the area of the circle; TFP^{op} is measured using the Olley–Pakes method; TFP^{lp} is estimated following Levinsohn and Petrin (2003); TFP^{acf} is based on the method developed by Ackerberg et al. (2015); industries are at the SITC four-digit level; cities are at the prefecture level; standard errors are reported in brackets and all clustered at the firm level; *$p < .1$, **$p < .05$, ***$p < .01$.

productivity. It is necessary to take this into consideration when discussing the effects at the aggregate level.

3.6 | Additional robustness checks with alternative TFP measures

As shown in the model, the most important determinant of firm exports is productivity. To capture the exact effect of highway improvement, we control for firm productivity in all the above specifications. In the literature, there are multiple ways to measure firm productivity. In this subsection, we provide the results using alternative measures of productivity, to show that our results are robust. Here, we adopt two alternative measures developed by Levinsohn and Petrin (2003) and Ackerberg et al. (2015), TFP^{lp} and TFP^{acf}, respectively. As suggested by Feenstra and Hanson (2005) and further shown by Yu (2015), firms conducting processing trade should be considered separately from ordinary firms, since the former relies heavily on imported inputs and their production process is significantly different from other firms. Therefore, we further merge the AMSE data with the Chinese customs trade data to obtain detailed information on imported inputs. Note this leads to a significant drop in sample size. The results are shown in the last four columns in Table 6. Columns 3 and 5 repeat the regressions in column 2 in Table 4 using TFP^{lp} and TFP^{acf} as the alternative measure of productivity, respectively. Consistent with the earlier findings, highway access still has a positive and significant impact on firm exports, and productivity is positively associated with exports on average. Columns 4 and 6 examine the heterogeneous effects. The results also show that less productive firms benefit more from better highway access in terms of exports.[20]

We conduct four additional robustness checks. First, Silva and Tenreyro (2006) suggest that log-linear models can lead to significant bias in the estimates of elasticities when heteroscedasticity or selection in zeros exists. We thus use the Poisson pseudo-maximum likelihood model as our robustness check (column 1 in Table C1). Second, since highways were planned to target big cities, we exclude firms in big cities with a total population of more than eight million, to alleviate potential bias (column 2 in Table C1). Moreover, it is possible that firms register their headquarters in big cities such as Beijing and Shanghai, but set up factories for production elsewhere. Excluding firms in big cities helps to mediate the within-firm reallocation problem. Third, it may be impossible to construct highways in mountainous regions. To deal with this, we exclude firms with an average slope within a 20 km radius that is greater than 10° (column 3 in Table C1). Fourth, some firms may have established special ties to the government over time, which can affect their highway access and exports at the same time. Thus, we exclude all SOEs and FIEs and focus on other private firms only (column 4 in Table C1). The detailed results of these robustness checks are included in the Appendix. As you can see from Table C1, none of these additional checks lead to dramatically different results.

Finally, we examine the cumulative impact of highway access. Once a firm gets better access to highways, the impact may not immediately show in the current or next year but may take a longer time to be visible. Thus, we further conduct an analysis of the long differences. The results are reported in Table C2. Two measures of highway access change are considered: change in highway density (highway density change) and an indicator equal to one if highway density is higher (highway density improved). Overall, the results from long differences support our baseline finding that highway construction in China indeed helps firms integrate into the international market.[21]

4 | DISCUSSIONS ON MECHANISMS

As shown from the model in Appendix B, lower domestic transportation costs can affect firm exports through various channels: direct savings in transportation costs, cheaper domestic and international inputs, and tougher competition. In this section, based on the merged data of the AMSE and Chinese firm-product customs data, we first decompose total exports into the extensive margin (number of varieties exported) and the intensive margin (average value of exports for each variety), and investigate whether highways help firms expand the scope of exports, and intensity of each variety, or both. Next, we examine the margins of firm imports, which can promote firm exports, as shown by Feng et al. (2016). We then provide some evidence on the connection between highway access and firm markup, which can be considered as a measure of the competition faced by firms. Finally, by comparing the impacts between the east and the west, and between port cities and non-port cities, we shed some light on how highways may have integrated firms into the domestic market.

4.1 | Extensive margin versus intensive margin

We first conduct the following simple decomposition of firm exports:

$$\ln(\text{export}) = \ln(\text{number of varieties}) + \ln\left(\frac{\text{export}}{\text{number of varieties}}\right). \tag{1}$$

The first part is defined as the extensive margin of exports; the latter part is called the intensive margin. Amiti and Konings (2007) argue that tariff reductions could result in firms switching their scope from low- to high-productivity products. Yu (2015) further finds that lower tariffs can affect firm productivity through the positive impact on export scope. Highway construction is supposed to have a similar effect on the export scope as tariff reduction. Regarding the intensive margin, we expect that lower transportation costs may help firms export more of their high-productivity products, and thus lead to higher average export intensity, as shown by Bernard et al. (2010), who establishes theoretic models to explain within-firm switching in products toward more productive products after trade liberalization.

Table 7 reports the estimates using OLS and IV approaches. As can be seen from the first two columns, highway access can promote firm export scope after controlling for firm productivity, ownership type, size, and average impact at the city and industry levels. Since the export scope is not a continuous variable, we also use a negative binomial regression with the number of export varieties as the dependent variable and the same set of control variables. This regression leads to similar results, which are highly consistent with the findings in the literature. In addition, the results reported in the last two columns show that highway access is significantly and

TABLE 7 Mechanism I: Extensive margin versus intensive margin

	Ln(Export scope)		Export intensity	
	(1) OLS	(2) IV	(3) OLS	(4) IV
Highway density (20 km)	0.347***	0.704***	1.394***	2.687***
	[0.095]	[0.190]	[0.434]	[0.817]
TFP^{op}	0.097***	0.097***	−0.044	−0.044
	[0.010]	[0.010]	[0.042]	[0.042]
Other control variables	Yes	Yes	Yes	Yes
Industry*year FE	Yes	Yes	Yes	Yes
City*year FE	Yes	Yes	Yes	Yes
N	122,630	122,630	122,630	122,630
R^2	0.23	0.23	0.18	0.18

Note: "Export scope" is the number of export varieties; "export intensity" is the log of average exports of each variety; highway density is calculated as the total length of highways within a 20 km radius centered by the firm divided by the area of the circle; TFP^{op} is measured using the Olley–Pakes method; industries are at the SITC four-digit level; cities are at the prefecture level; standard errors are reported in brackets and all clustered at the firm level; $^*p < .1$, $^{**}p < .05$, $^{***}p < .01$.

TABLE 8 Mechanism II: Firm imports

	Ln(Import scope)		Import intensity	
	(1) OLS	(2) IV	(3) OLS	(4) IV
Highway density (20 km)	0.659***	1.686***	0.2	0.456
	[0.147]	[0.300]	[0.292]	[0.566]
TFP^{op}	0.210***	0.209***	0.408***	0.408***
	[0.017]	[0.017]	[0.029]	[0.029]
Other control variables	Yes	Yes	Yes	Yes
Industry*year FE	Yes	Yes	Yes	Yes
City*year FE	Yes	Yes	Yes	Yes
N	94,851	94,851	63,768	63,768
R^2	0.51	0.51	0.33	0.33

Note: "Import scope" is the total number of import varieties; "import intensity" is the log of the average imports of each variety; highway density is calculated as the total length of highways within a 20 or 30 km radius centered by the firm divided by the area of the circle; TFP^{op} is measured using the Olley–Pakes method; industries are at the SITC four-digit level; cities are at the prefecture level; standard errors are reported in brackets and all clustered at the firm level; $*p < .1$, $**p < .05$, $***p < .01$.

positively associated with average export intensity. This finding is consistent with the theoretic prediction from the model and the widely documented empirical finding that trade liberalization can increase the intensive margin of exports.

4.2 | Highways and firm imports: Extensive margin versus intensive margin

Here, we examine the relationship between highway access and firm imports. This is inspired by the recent finding in the literature of a strong and positive connection between imported intermediate inputs, firm productivity, and product scope (Feng et al., 2016; Goldberg et al., 2010a; Goldberg et al., 2010b). We first decompose firm imports into the intensive margin and extensive margin in a similar way as in Equation (1). Then, we explore whether highway access has a positive impact on firm import scope or intensity. The results are reported in Table 8. The first two columns show the OLS and IV regression results for import scope, respectively, and the last two columns are for import intensity. The results show that highway access increases firm import scope significantly but not import intensity. This is in line with the finding that lower trade costs enable firms to access new imported inputs, which can further promote firm exports (Goldberg et al., 2010b).

4.3 | Highways and markups

It has been debated in the literature whether lower trade costs promote competition. On the one hand, some researchers find that lower trade costs can change the markups charged by domestic producers, for example, Chen et al. (2009), De Loecker and Warzynski (2012), and De Loecker et al. (2016). On the other hand, some find that the pro-competition effect of trade is negligible,

TABLE 9 Mechanism III: Markup

	Markup_GO1			Markup_GO2
	(1) OLS	(2) OLS	(3) IV	(4) IV
Highway density (20 km)	−0.003	−0.288***	−0.470***	−0.479***
	[0.013]	[0.049]	[0.073]	[0.081]
TFP^{op}	0.044***	0.034***	0.027***	0.030***
	[0.003]	[0.004]	[0.004]	[0.005]
Highway density (20 km) * TFP^{op}		0.246***	0.412***	0.420***
		[0.043]	[0.064]	[0.071]
Other control variables	Yes	Yes	Yes	Yes
Industry*year FE	Yes	Yes	Yes	Yes
City*year FE	Yes	Yes	Yes	Yes
R^2	0.79	0.79	0.79	0.85
N	134,953	134,953	134,953	134,953

Note: "Markup_GO1" and "Markup_GO2" are estimated following the approach developed by De Loecker and Warzynski (2012) with gross output Cobb–Douglas production function relying on material input share and labor input share, respectively; highway density is calculated as the total length of highways within a 20 km radius centered by the firm divided by the area of the circle; TFP^{op} is measured using the Olley–Pakes method; industries are at the SITC four-digit level; cities are at the prefecture level; standard errors are reported in brackets and all clustered at the firm level; *$p < .1$, **$p < .05$, ***$p < .01$.

for example, Feenstra and Weinstein (2017) and Arkolakis et al. (2019). In this subsection, we investigate the relationship between highway access and firm markups.

We adopt two measures of firm markups, following the approach developed by De Loecker and Warzynski (2012) and De Loecker et al. (2016). De Loecker and Warzynski (2012) propose a method relying on physical output, the first-order conditions from cost minimization, and the cost-share of variable inputs. They compare markup measures obtained from various assumptions on the production function and show similar a picture for export status. Here, we adopt two measures of markups, as in De Loecker and Warzynski (2012), running a Cobb–Douglas gross output production function and relying on the material input share (Markup_GO1) and labor input share (Markup_GO2), respectively.[22]

Table 9 reports the OLS and IV estimates. The first three columns use Markup_GO1 as the measure of markup and the last column uses Markup_GO2. Industry-year and city-year fixed effects are controlled for in each specification. The results in the first column show that highway access is not significantly associated with markups after controlling for firm productivity, ownership type, and size. This is consistent with the findings in Arkolakis et al. (2019) and Feenstra and Weinstein (2017). Moreover, we add an interaction term of highway access and TFP in the regression to see if the effects are heterogeneous depending on firm productivity. The results in columns 2 and 3 show that highway access decreases the markups charged by low-productivity firms, but increases the markups charged by high-productivity firms. This result is robust to the alternative markup measure as shown in column 4. This suggests that highway construction may promote the degree of competition faced by less productive firms but ease the competition faced by more productive firms. These findings are consistent with the predictions from the line of research with heterogeneous markups pioneered by Melitz and Ottaviano (2008) and Atkeson and Burstein (2008), who show that trade liberalization can make the most productive firms charge higher markups. These results imply that high-productivity firms and low-productivity firms may expand their international market in different ways. High-productivity firms may switch to higher-markup products, while low-productivity firms seem to rely more on expanding export volumes by charging lower prices.

4.4 | Highways and domestic market integration

Highway construction not only reduces the cost to reach the international market but also integrates the domestic market, which means that it is cheaper for firms to sell to/buy from the domestic market. This implies that with lower domestic costs, firms may be able to get better access to domestic inputs and thus lower unit costs and promote exports. Ramondo et al. (2016) find that it is relevant to take domestic trade costs into consideration when examining international trade flows. This is especially important for China, as it is a large country with many regional markets spreading all over the country. To see how integration into the domestic market may matter, we compare across regions with heterogeneous levels of access to international markets. Intuitively, if only the international market matters, we would expect firms farther away from the coast to benefit more from highway access in terms of exporting. In particular, we compare the effect of highway access on exports for firms in the eastern regions with that of firms in the middle or west. We make a similar comparison between the port cities and non-port cities.

Table 10 reports the estimates using these subsamples. The results show that highway access has a positive and significant impact on exports only for firms located in the non-east regions, but no significant impact in the east. Similarly, the positive association between highway access and exports only exists for firms in non-port cities, but not those in port cities, which already have better access to the international market. These findings imply that highway construction in China seems to be effective in integrating firms that are relatively remote from international

TABLE 10 Firm exports and highway access: Heterogeneous effects by region

Regressand: ln(export)	East (1) IV	Non-east (2) IV	Ports (3) IV	Non-ports (4) IV
Highway density (20 km)	−0.234	0.754**	−0.349	0.488*
	[0.367]	[0.324]	[0.447]	[0.296]
TFP^{op}	0.374***	0.132***	0.235***	0.202***
	[0.022]	[0.013]	[0.017]	[0.015]
Other control variables	Yes	Yes	Yes	Yes
Industry*year FE	Yes	Yes	Yes	Yes
City*year FE	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes
R^2	0.86	0.88	0.87	0.87
N	110,450	78,140	80,919	107,672

Note: The dependent variable is the log of export value measured in 1000 RMB; highway density is calculated as the total length of highways within a 20 km radius centered by the firm divided by the area of the circle; TFP^{op} is measured using the Olley–Pakes method; industry is at the SITC four-digit level; city is at the prefecture level; standard errors are reported in brackets and all clustered at the firm level; *$p < .1$, **$p < .05$, ***$p < .01$.

markets into the global market. Although firms in the east or port cities may still benefit from highways in terms of better access to domestic inputs, their easier access to imported inputs and international markets makes them less dependent on domestic infrastructure.

5 | CONCLUSIONS

In the past three decades, China has experienced rapid growth in exports and infrastructure. How does infrastructure affect trade at the firm level? In this article, we investigate this issue by constructing firm-level highway access information and using an instrumental variable approach to deal with the endogeneity problem. We find that improvement in highway access can significantly promote firm exports, after controlling for aggregate effects at the city and industry levels. There is a redistribution effect of highways on exports, from high-productivity firms to low-productivity firms. In addition, highways help firms to expand their export and import scopes. We find no evidence that highways promote the competition on average, but low-productivity firms may face tougher competition. Moreover, the heterogeneous impacts of highways across regions/cities indicate that highways have effectively integrated inland firms into the international market.

In this article, we do not intend to evaluate the overall impact of highway construction on trade and welfare as in Duranton et al. (2013) and Asturias et al. (2019), which rely heavily on structural models. Instead, we focus on investigating the micro-foundations of how infrastructure affects firms and the potential redistribution effects between firms, which is extremely policy-relevant. In addition, we shed some light on how infrastructure affects firm exports and the potential role of highways in competition. Our findings are highly consistent with and complementary to the existing literature.

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DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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ENDNOTES

[1] Recently a number of studies have shown that railways and highways reshaped the spatial distribution of economic activities and improved aggregate welfare, including Donaldson (2018), Ahlfeldt et al. (2015), Duranton et al. (2013), Allen and Arkolakis (2014), Baumsnow et al. (2016), and Donaldson and Hornbeck (2016), among others. See Redding and Turner (2015) for a comprehensive review of recent developments in the literature on transportation infrastructure and spatial distribution of economic activities.

[2] Banerjee et al. (2012) find that proximity to transportation networks has a moderate positive effect on per capita gross domestic product (GDP) levels across sectors. By contrast, Faber (2014) finds that China's National Trunk Highway System led to a reduction in GDP growth among non-targeted peripheral counties through a significant reduction in industrial output growth. Recently, Baum-Snow et al. (2020) suggest that the different findings between the previous two studies might be due to the difference in sample coverage of cities.

[3] The data are from the National Bureau of Statistics of China. See http://data.stats.gov.cn/easyquery.htm?cn=C01.

[4] In 2013, the State Council of China approved a revised blueprint on road development until 2030, which was based on the earlier one but extended it significantly.

[5] However, our main results are not sensitive to the sample trimming.

[6] Firm "entry" here could be caused by small firms originally below the RMB 5 million threshold growing bigger or new firms entering. We cannot distinguish them due to the data limitation.

[7] Unfortunately, we do not have historical digital maps.

[8] According to the General Regulation of Location Names by the State Council of the People's Republic of China in 1996, it is required to go through strict procedures to rename an existing town, county, city, or even street. Therefore, it is reasonable for us to assume there was little change in existing location names over the sample period.

[9] The years with highway information are 2000, 2002, 2003, 2005, and 2007. For the years 2001, 2004, and 2006, we use the average accessibility to highways before and after the missing years as an approximation in some specifications.

[10] We also calculate highway densities using the 40 and 50 km radius. All the density measures are highly correlated and show similar pictures.

[11] There are some irregular values in the first version of the ASTER GDEM data, which were inherited in the processed data. Please refer to the validation report on the ASTER GDEM official website: http://www.jspacesystems.or.jp/ersdac/GDEM/E/1.html.

[12] Please refer to its official website for a detailed definition of the slope calculated by ArcGIS: http://resources.arcgis.com/en/help/main/10.1/index.html#//00q90000001r000000.

[13] For the baseline results, we include firms with zero exports by adding one. This can effectively include firms with only domestic sales in our analysis. Head and Mayer (2013) show that this approach could make the results sensitive to the unit of export values. Therefore, we also try Heckman's two-step and Poisson pseudo-maximum likelihood regression using the value of firm exports as the dependent variable to deal with the zero exports issue. The results are consistent.

[14] Without controlling for firm productivity, the estimates of highway impact tend to be bigger and more significant.

[15] Please refer to Table 2 for summary statistics of the main control variables.

[16] As the ASME firm-level data does not provide the specific products that are exported to different destinations, we cannot compute the firm-specific tariffs in this data set for the baseline regressions. We could compute the firm-specific tariffs by using the matched data with the transaction level customs data. However, the matched sample size will be significantly reduced during the matching progress. Moreover, the firm-specific tariffs suffer the critical endogeneity issue as firms choose particular products for certain destination markets. Thus, we choose to use industry-year fixed effects as a parsimonious approach to control for industry-specific tariffs.

[17] It should be noted that the city-year and industry-year fixed effects have taken away the aggregate impact of highways at the city- and industry-level. Thus, it's not surprising to see the estimate using within-firm variation only is small and less significant.

[18] We also tried the generalized method of moments (GMM) estimator and the results are very similar.

[19] In the literature with a similar type of instrumental variable, IV estimates tend to be larger than OLS estimates (Donaldson & Hornbeck, 2016; Duflo & Pande, 2007).

[20] Using these alternative measures of TFP makes the sample size drop dramatically, due to the additional information on intermediate inputs needed for the estimation of TFP. However, it can be shown that these subsamples are similar to the whole sample in terms of TFP distribution and exports.

[21] We also consider the distance measure of highway access. The results are consistent as shown in the last two columns of Table C2.

[22] For detailed information, please refer to the Appendix in Lim et al. (2017). We also check the results using other measures, such as running a translog value-added production function. The results are similar.

[23] The model can be easily extended into a multi-country framework as in Chaney (2008). Since we do not want to look into destination-specific exports, we aggregate the rest of the world as Foreign.

[24] We make this assumption for simplicity, but it is not necessary for our later analysis to hold.

[25] d_{rp_r} could be greater than 1 even for firms in port cities, because of transportation costs from the factory to the port, loading costs, and so on.

[26] This assumption can be relaxed, and the implications would not change.

REFERENCES

Ackerberg, D. A., Caves, K., & Garth, F. (2015). Structural identification of production functions. *Econometrica*, *83*(6), 2411–2451.

Ahlfeldt, G. M., Redding, S. J., Sturm, D. M., & Wolf, N. (2015). The economics of density: Evidence from the Berlin Wall. *Econometrica*, *83*(6), 2127–2189.

Allen, T., & Arkolakis, C. (2014). Trade and the topography of the spatial economy. *Quarterly Journal of Economics*, *129*(3), 1085–1140.

Amiti, M., & Davis, D. R. (2012). Trade, firms, and wages: Theory and evidence. *Review of Economic Studies*, *79*(1), 1–36.

Amiti, M., & Konings, J. (2007). Trade liberalization, intermediate inputs, and productivity: Evidence from Indonesia. *American Economic Review*, *97*(5), 1611–1638.

Arkolakis, C., Costinot, A., Donaldson, D., & Rodríguez-Clare, A. (2019). The elusive pro-competitive effects of trade. *The Review of Economic Studies*, *86*(1), 46–80.

Asturias, J., García-Santana, M., & Ramos, R. (2019). Competition and the welfare gains from transportation infrastructure: Evidence from the golden quadrilateral of India. *Journal of the European Economic Association*, *17*(6), 1881–1940.

Atkeson, A., & Burstein, A. (2008). Pricing-to-market, trade costs, and international relative prices. *American Economic Review*, *98*(5), 1998–2031.

Banerjee, A. V., Duflo, E., & Qian, N. (2012). On the road: Access to transportation infrastructure and economic growth in China. *Social Science Electronic Publishing*, *11*(1), 1–53.

Baum-Snow, N., Henderson, J. V., Turner, M. A., Zhang, Q., & Brandt, L. (2020). Does investment in national highways help or hurt hinterland city growth? *Journal of Urban Economics*, *115*, 103124.

Baumsnow, N., Loren Brandt, J., Henderson, V., Turner, M. A., & Zhang, Q. (2016). Highways, market access and urban growth in China. *Serc Discussion Papers*.

Bernard, A. B., & Jensen, J. B. (1999). Exceptional exporter performance: Cause, effect, or both? *Journal of international economics*, *47*(1), 1–25.

Bernard, A. B., Jensen, J. B., & Lawrence, R. Z. (1995). Exporters, jobs, and wages in U.S. manufacturing: 1976-1987. *Brookings Papers on Economic Activity Microeconomics*, *1995*, 67–119.

Bernard, A. B., Redding, S. J., & Schott, P. K. (2010). Multiple-product firms and product switching. *American Economic Review*, *100*(1), 70–97.

Cai, H., & Liu, Q. (2009). Competition and corporate tax avoidance: Evidence from Chinese industrial firms. *The Economic Journal*, *119*(537), 764–795.

Campante, F. R., & Chor, D. (2017). *Just do your job": Obedience, routine tasks, and the pattern of specialization* (Working Papers).

Chaney, T. (2008). Distorted gravity: The intensive and extensive margins of international trade. *American Economic Review*, *98*(4), 1707–1721.

Chen, N., Imbs, J., & Scott, A. (2009). The dynamics of trade and competition? *Journal of International Economics*, *77*(1), 50–62.

Cosar, A. K., & Demir, B. (2016). Domestic road infrastructure and international trade: Evidence from Turkey. *Journal of Development Economics*, *118*, 232–244.

De Loecker, J., Goldberg, P. K., Khandelwal, A. K., & Pavcnik, N. (2016). Prices, markups, and trade reform. *Econometrica*, *84*(2), 445–510.

De Loecker, J., & Warzynski, F. (2012). Markups and firm-level export status. *American Economic Review*, *102*(6), 2437–2471.

Donaldson, D. (2018). Railroads of the Raj: Estimating the impact of transportation infrastructure. *American Economic Review*, *108*(4-5), 899–934.

Donaldson, D., & Hornbeck, R. (2016). Railroads and American economic growth: A "market access" approach. *Quarterly Journal of Economics*, *131*, 799–858.

Duflo, E., & Pande, R. (2007). Dams. *The Quarterly Journal of Economics*, *122*(2), 601–646.

Duranton, G., Morrow, P. M., & Turner, M. A. (2013). Roads and trade: Evidence from the US. *Review of Economic Studies*, *81*(2), 681–724.

Eaton, J., & Kortum, S. (2002). Technology, geography, and trade. *Econometrica*, *70*(5), 1741–1779.

Faber, B. (2014). Trade integration, market size, and industrialization: Evidence from China's national trunk highway system. *Review of Economic Studies*, *81*(3), 1046–1070.

Fan, J., Yi, L., & Luo, W. (2021). Valuing domestic transport infrastructure: A view from the route choice of exporters. *The Review of Economics and Statistics*, 1–46.

Feenstra, R. C., & Hanson, G. H. (2005). Ownership and control in outsourcing to china: Estimating the property-rights theory of the firm. *Quarterly Journal of Economics*, *120*(2), 729–761.

Feenstra, R. C., Li, Z., & Miaojie, Y. (2014). Exports and credit constraints under incomplete information: Theory and evidence from China. *Review of Economics and Statistics*, *96*(4), 729–744.

Feenstra, R. C., & Weinstein, D. E. (2017). Globalization, markups, and US welfare. *Journal of Political Economy*, *125*(4), 1040–1074.

Feng, L., Li, Z., & Swenson, D. L. (2016). The connection between imported intermediate inputs and exports: Evidence from Chinese firms. *Journal of International Economics*, *101*, 86–101.

Fogel, R. W. (1964). *Railroads and American economic growth: Essays in econometric history*. Johns Hopkins University Press.

Ghani, E., Goswami, A. G., & Kerr, W. R. (2015). Highway to success: The impact of the golden quadrilateral project for the location and performance of indian manufacturing. *Economic Journal*, *126*(591), 317–357.

Goldberg, P. K., Khandelwal, A. K., Pavcnik, N., & Topalova, P. (2010a). Multiproduct firms and product turnover in the developing world: Evidence from India. *Review of Economics Statistics*, *92*(4), 1042–1049.

Goldberg, P. K., Khandelwal, A. K., Pavcnik, N., & Topalova, P. (2010b). Imported intermediate inputs and domestic product growth: Evidence from India. *Quarterly Journal of Economics*, *125*(4), 1727–1767.

Helpman, E., Melitz, M. J., & Yeaple, S. R. (2004). Export versus FDI with heterogeneous firms. *American economic review*, *94*(1), 300–316.

Hummels, D. (2007). Correction: Transportation costs and international trade in the second era of globalization. *Journal of Economic Perspectives*, *21*(4), 237–238.

Levinsohn, J., & Petrin, A. (2003). Estimating production functions using inputs to control for unobservables. *Review of Economic Studies*, *70*(2), 317–341.

Lim, K., Trefler, D., & Miaojie, Y. 2017. *Escaping the competition: the impact of china's exports on Chinese and global innovation* (Working Paper), University of Toronto.

Limao, N., & Venables, A. J. (2001). Infrastructure, geographical disadvantage, transport costs, and trade. *The Bank Economic Review*, *15*(3), 451–479.

Ma, Y., Tang, H., & Zhang, Y. (2014). Factor Intensity, product switching, and productivity: Evidence from Chinese exporters. *Journal of International Economics*, *92*(2), 349–362.

Martincus, C. V., & Blyde, J. (2013). Shaky roads and trembling exports: Assessing the trade effects of domestic infrastructure using a natural experiment. *Journal of International Economics*, *90*(1), 148–161.

Melitz, M. J. (2003). The impact of trade on intra-industry reallocations and aggregate industry productivity. *Econometrica*, *71*(6), 1695–1725.

Melitz, M. J., & Ottaviano, G. I. P. (2008). Market size, trade, and productivity. *Review of Economic Studies*, *75*(1), 295–316.

Nicolls, W. J. (1897). *The railway builder: A handbook for estimating the cost of American railway construction and equipment* (5th ed.). J.B. Lippincott Company.
Ramondo, N., Rodríguez-Clare, A., & Saborío-Rodríguez, M. (2016). Trade, domestic frictions, and scale effects. *American Economic Review*, *106*(10), 3159–3184.
Redding, S. J., & Turner, M. A. (2015). Ch. 20. Transportation costs and the spatial organization of economic activity. *Handbook of Regional Urban Economics*, *5*(8), 1339–1398.
Silva, J. S., & Tenreyro, S. (2006). The log of gravity. *The Review of Economics and Statistics*, *88*(4), 641–658.
World Bank. (2007a). China study tour by new delhi transport office team. *World Bank Other Operational Studies*.
World Bank. (2007b). China's expressways: Connecting people and markets for equitable development. *World Bank Other Operational Studies*.
Yu, M. (2015). Processing trade, tariff reductions and firm productivity: Evidence from Chinese firms. *Economic Journal*, *125*(585), 943–988.

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APPENDIX A. GIS DATA

Geo-referenced highway routes were obtained from the ACASIAN Data Center at Griffith University in Brisbane, Australia. Highway routes were digitized based on the following high-resolution road atlas sources published between 1998 and 2007:

(1) China Newest Public Road Atlas (1998), Ha Na Bin Map Publishing Company
(2) China Road Atlas (2002), Shandong Map Publishing Company
(3) China Public Road Atlas (2002), Shandong Map Publishing Company
(4) China Expressway Atlas (2003), People's Transport Press
(5) China Transportation Network Atlas (2003), Guangdong Map Publishing Company
(6) China Road Atlas (2003), Xue Yuan Map Publishing Company
(7) China Automobile Map (2003), China World Map Publishing Company
(8) Chinese People's Road Atlas (2005), Globe Publishing Company
(9) China Road Atlas (2007), Shandong Map Publishing Company.

These atlas sources made it possible to identify highway segments that were open to traffic in each year available in the data. Information on highway segments that were under construction is also available. In particular, source (1) was used to digitize a baseline layer of highway routes that were in place by midyear in 1997, and source (9) was used to digitize a baseline layer of highway routes that were in place by the end of 2005. These baseline route maps were then cross-referenced with route information provided in the remaining listed atlas sources. In cases where the remaining atlas sources were at odds with the information from the baseline maps (i.e. routes present in 1997 but not in 2000 or thereafter, or routes present in 2003 but not thereafter), a decision was taken based on the majority of sources (for the 1997 layer), or after tracking down highway openings through press releases on highway opening ceremonies for a few cases where sources (8) and (9) were at odds.

Slope data were provided by the International Scientific & Technical Data Mirror Site, Computer Network Information Center, Chinese Academy of Sciences (http://datamirror.csdb.cn).

The data were processed based on the first version of ASTER GDEM data released in 2009. The preciseness of the data is 30 m. When constructing the average slope of the land surface around each firm, we take the average over all grids that cross the area considered. For a robustness check, we included only those grids with more than half the area falling into the range of area considered. The results are similar.

APPENDIX B. A SIMPLE MODEL

In this appendix, we set up a simple model with heterogeneous firms, following Melitz (2003) and Chaney (2008). We incorporate domestic trade costs as in Ramondo et al. (2016) into the model to illustrate how changes in domestic trade costs can affect exports at the firm level.

There are two countries in the world: Home and Foreign.[23] Home has R regions that trade with each other and with Foreign. There is a continuum of differentiated goods. Consumer utility is the standard constant elasticity of substitution form:

$$U = \left(\int_{\Omega} q(\omega)^{(\sigma-1)/\sigma} d\omega \right)^{[\sigma/(\sigma-1)]},$$

where Ω represents the set of varieties available, and $q(\omega)$ is the amount of variety ω consumed.

The production side is modeled as in Melitz (2003) with increasing returns to scale and heterogeneous firms. Each firm randomly draws a productivity φ from a distribution that is assumed to be a Pareto distribution as in Helpman et al. (2004) with distribution function $G(\varphi) = 1 - \varphi^{\gamma}, \varphi \in [1, +\infty)$. A firm with productivity φ produces with marginal cost equal to c_i/φ and pays the common fixed cost $c_i f$, where c_i is the marginal cost for the least productive firm and composed of intermediate input cost and labor cost, $(P_i)^{1-\alpha}(w_i)^{\alpha}, 0 < \alpha < 1$. $w_i, i = H, F$ represents wages in Home or Foreign. P_i is the price index with the formula, $P_i = \left(\int_{\Omega} p_i(\omega)^{(1-\sigma)} d\omega\right)^{1/(1-\sigma)}$. Firms produce slightly differentiated goods and face monopolistic competition.

There are iceberg trade costs $d_{r_1 r_2} > 1$ from region r_1 to r_2, but no trade cost within any region r with $d_{rr} = 1$ or within Foreign, $d_{FF} = 1$.[24] International trade requires goods to be transported to the nearest port first and then shipped abroad. Let $d_{rF} = d_{rp_r} * \tau > 1$, where d_{rp_r} is the domestic trade cost from region r to the nearest port p_r and $\tau > 1$ is the international iceberg trade cost.[25] For simplicity, domestic trade costs are assumed to be symmetric and the same: $d_{r_1 r_2} = \overline{d} > 1$.[26] International variable trade costs become $d_{Fr} = d_{rF} = (\overline{d}) * \tau$. And fixed cost f_x is required to export.

Given the demand and trade costs, the optimal price charged by a firm is $p_{ij}(\varphi) = \sigma/(\sigma - 1)(P_i)^{1-\alpha} w_i^{\alpha} d_{ij}/\varphi$. If $\varphi > \overline{\varphi}_{rF}^{x}$, where $\overline{\varphi}_{rF}^{x}$ is the productivity threshold to export. Firm-level exports can be written as:

$$x_{rF}(\varphi) = [p_{rF}(\varphi)]^{1-\sigma} E_F (P_F)^{\sigma-1} = \{\sigma/(\sigma-1)(P_r)^{1-\alpha} w_H^{\alpha} d_{rF}/\varphi\}^{1-\sigma} E_F (P_F)^{\sigma-1}, \tag{B1}$$

where E_F is the total expenditure of foreign, P_F and P_r are the price indices in foreign and region r in home, respectively. P_F captures the degree of competition in foreign faced by firms, and P_r captures the price of intermediate inputs in region r. The price indices can be expressed as follows:

$$P_r = \left\{ \sum_{m \in \{1 \ldots R, F\}} \int_{\overline{\varphi}_{mr}}^{+\infty} [\sigma/(\sigma-1)(P_m)^{1-\sigma} w_m^{\alpha} d_{mr}/\varphi]^{1-\alpha} dG(\varphi) \right\}^{1/(1-\sigma)},$$

where $d_{mr} = \overline{d} > 1$ if $m \neq r$ or F; $d_{rr} = 1$; and $d_{Fr} = \overline{d} * \tau$. $w_m = w_H$ if $m \neq F$. $\overline{\varphi}_{mr}$ is the productivity threshold for region m to sell in region r, and it can be shown that $\overline{\varphi}_{mr} \propto P_m^{1-\sigma} d_{mr}/p_r$. It can be proved that under perfect symmetry, that is, $P_r = P_m$ for r, the price index in each region or country satisfies

$$P_r'(\overline{d}) > 0 \text{ and } P_F'(\overline{d}) > 0.$$

This implies that P_r and P_F increase with $\overline{d}$. Intuitively, this means that lower domestic trade cost can increase the degree of competition and at the same time lower the price of intermediate inputs.

Next, taking logs to Equation (1), it follows that

$$\ln\{x_{rF}(\varphi)\} = \beta_0 + (1-\sigma)\ln(\overline{d} * \tau) + (\sigma - 1)\ln(\varphi) + (1-\sigma)[(1-\alpha)\ln P_r + \alpha \ln w_H] + \ln\{E_F(P_F)^{\sigma-1}\}. \quad \text{(B2)}$$

Our interest is to see how infrastructure improvement can affect firm exports. Undoubtedly, better infrastructure or more highways means lower domestic trade cost $\overline{d}$. It can be seen from Equation (B1) that $\overline{d}$ can affect firm exports through multiple channels. First, lower $\overline{d}$ directly increases exports, since it is less costly to ship goods abroad; second, lower $\overline{d}$ decreases the price of intermediate inputs P_r and thus leads to lower marginal cost and lower price, which makes firms more competitive in the foreign market; and third, if the whole transportation network is improved and therefore lower $\overline{d}$ for all domestic firms, it can lead to lower P_F, that is, a higher level of competition in the foreign market, and make it more difficult to export. The overall effect is ambiguous. Our empirical specification is based on Equation (B1).

APPENDIX C. ADDITIONAL ROBUSTNESS CHECKS

TABLE C1 Additional robustness checks

	Export	Ln(Export)		
	(1) PPML	(2) Pop<8M	(3) Slope<10	(4) Private firms
Highway density (20 km)	2.048***	0.214**	0.215***	0.221*
	[0.513]	[0.084]	[0.079]	[0.117]
TFP^{op}	0.323***	0.239***	0.192***	0.216***
	[0.023]	[0.012]	[0.011]	[0.015]
Other control variables	Yes	Yes	Yes	Yes
Firm FE	No	Yes	Yes	Yes
City*year FE	No	Yes	Yes	Yes
R^2	0.3	0.86	0.87	0.86
N	223,098	161,505	167,211	94,095

Note: The dependent variable is export value (column 1) or the log of export value (columns 2–4) measured in 1000 RMB. Column 1 reports PPML estimates with year fixed effects. Columns 2–4 use OLS estimates. The IV results share the same sign and significance pattern. Other control variables are the same as in Table 6. Highway density is calculated as the total length of highways within a 20 km radius centered by the firm divided by the area of the circle; TFP^{op} is measured using the Olley–Pakes method; cities are at the prefecture level; standard errors are reported in brackets and all clustered at the firm level; *$p < .1$, **$p < .05$, ***$p < .01$.

TABLE C2 Results using long-differences

	(1)	(2)	(3)	(4)	(5)
Highway density improved	0.012***	0.010***			
	[0.002]	[0.002]			
Highway density change			0.173**		
			[0.072]		
Highway distance improved				0.009***	0.009***
				[0.003]	[0.003]
Control variables	No	Yes	Yes	No	Yes
Industry-province FE	Yes	Yes	Yes	Yes	Yes
City FE	Yes	Yes	Yes	Yes	Yes
R^2	0.06	0.07	0.07	0.06	0.07
N	14,104	14,104	14,104	14,104	14,104

Note: The dependent variable is the average annual growth rate of exports from 2006 to 2000, that is, [ln(exports in 2006) – ln(exports in 2000)]/6. "Highway density improved" is an indicator equal to 1 if highway density within a 50 km radius is higher in 2006 than in 2000, and 0 if otherwise. "Highway density" is the change in highway density from 2000 to 2006. "Highway distance improved" is an indicator equal to 1 if the distance to highways is shorter in 2006 than in 2000, and 0 if otherwise. Industry*province fixed effects and city fixed effects are controlled for in all regressions. Furthermore, columns (2), (3), and (5) control for ownership type, initial highway access and initial firm size. *$p < .1$, **$p < .05$, ***$p < .01$.