Expressway Expansion, International Trade, and Spatial Imbalance*

Longzhou Wang† Xiaoying Wang‡

Abstract

Transportation infrastructure plays a crucial role in reshaping spatial structure by facilitating trade. We develop a unique microscopic dataset to assess how proximity to expressways influences spatial imbalances, particularly in terms of export performance. Results reveal that expressway access boosts firms' exports in Eastern China but reduces them in Central and Western China, with effects differing by industry, ownership, product type, and destination. The contrasting effects are attributed to shifts in costs, productivity, market power, resource distortion and reallocation, and market competition. We conclude that expressway access enhances international competitiveness and exacerbates regional inequalities.

JEL Classification: O18; F1; D2; R4

Keywords: Transportation infrastructure; International trade; Spatial structure

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†Alberta Business School, University of Alberta, Canada. Email: longzho1@ualberta.ca.

‡Haskayne School of Business, University of Calgary, Canada. Email: xiaoying.wang@ucalgary.ca.

1 Introduction

In the wake of the US-China trade war and the COVID-19 pandemic, global value chains are undergoing significant transformation, prompting a key question: Which country will succeed China as the next "world's factory"? What factors are essential for achieving this role? History shows that transportation infrastructure is crucial for national development and integration into global markets(Hummels, 2007; Ghani et al., 2016).[1] Measuring transportation efficiency carries significant implications for industry professionals and policymakers focused on international trade. This paper develops a unique dataset to examine China's rapid and extensive expressway network expansion, exploring its micro-level effects on international trade and spatial structure.

A substantial body of literature examines the impacts of infrastructure on various economic outcomes, such as economic growth (Faber, 2014; Alder et al., 2015; Baum-Snow et al., 2017; Asher and Novosad, 2020; Banerjee et al., 2020; He et al., 2020; Lin, 2017; Qin, 2017), welfare (Allen and Arkolakis, 2019; Asturias et al., 2019), productivity (Ghani et al., 2016; Fernald, 1999), and internal trade (Duranton et al., 2014; Donaldson, 2018; Asturias et al., 2019). Infrastructure investment is widely regarded as a key driver of international competitiveness; however, its effects at the micro level, particularly in developing countries, are still not well understood due to data constraints. Infrastructure development reduces trade costs (Fan et al., 2023; Donaldson, 2018), promotes agglomeration and learning effects (Baum-Snow, 2020; Gersbach and Schmutzler, 2000; Glaeser et al., 1992), and facilitates technological advancement (Ghani et al., 2016; Fernald, 1999), all of which could enhance international competitiveness. Importantly, these effects are heterogeneous across firms and regions, often exacerbating regional disparities.

[1] Hummels (2007) argue that the surge in international trade volumes during the latter half of the twentieth century was driven by advancements in air cargo transportation.

Therefore, we investigate the effects of the large-scale expansion of the Chinese expressway network (1992-2013) on firms' exports, with a particular focus on the resulting spatial imbalances. The Chinese expressway network is designed as a quasi-natural experiment, connecting transportation hubs, port cities, major tourist destinations, and cities with populations exceeding 200,000. Between 2000 and 2013, both the expressway network and export volumes increased more than sixfold. By 2011, China had constructed the world's largest expressway system, becoming the world's largest exporter by 2012. At the end of 2013, cities connected by the expressway network accounted for 89% of China's total export revenue. The expressway network has made long-distance freight transport in China faster, safer, and cheaper.[2]

The key challenge of this project is to accurately estimate the dynamic impacts of the expressway network expansion (ENE) on firms located at varying distances from the network. Previous studies typically rely on static comparisons and define treated and control groups based on fixed administrative boundaries, which can introduce potential biases into the analysis(Borusyak and Hull, 2023). For example, firms in a county not officially connected to the network may still be close enough to experience significant effects, while firms in a connected county might still be relatively distant. Additionally, changes in distance to the network can significantly alter effect sizes. To address this challenge, we define treated firms based on their annually changing distance to the nearest expressway, aiming to provide a more nuanced estimation of the ENE's effects and mitigate some of the limitations of earlier approaches.

To accurately capture the evolving proximity of firms to the expressway network, we develop a detailed process of manually collecting and digitizing yearly shapefiles of the Chinese expressway

[2]Before the expressway network, roads were often in poor condition, narrow, and plagued by high cross-regional transportation risks, including frequent robberies, extortion, and numerous tolls. Anderson and Van Wincoop (2004) estimated that transportation costs accounted for approximately 21% of the value of traded goods in industrialized countries.

system by combining the 2016 expressway data with transportation atlases spanning from 1992 to 2016. We also leverage Python to gather geocoding information for firms, allowing accurate tracking of each firm's location over time. This comprehensive approach precisely measures yearly changes in the distance between firms and their nearest expressway.

Our empirical results reveal two key findings using a difference-in-differences approach to evaluate the ENE effects on export amounts at the eight-digit product-firm-country-year level. First, access to the expressway network significantly increases exports, with the positive effects intensifying the closer firms are located to the network. Second, the ENE positively affects exports from firms in Eastern China but negatively impacts those from Central and Western China. This divergent impact suggests that infrastructure expansion, despite its broader benefits, has accelerated spatial economic imbalances, particularly during the early 21st century when exports were a major driver of China's rapid economic growth. These findings remain robust even after accounting for the influence of other transport modes, such as railways, waterways, and additional infrastructure amenities.

The ENE's effects on exports also vary markedly across different industries, types of ownership, product categories, and target markets. Manufacturing industries—especially those in textiles, clothing, and machinery—reap the most benefits, particularly in Eastern China. The expressway network has a notable positive impact on state-owned enterprises (SOEs) and private firms, while the effects on foreign firms are mixed across regions. Industries with high road reliance show substantial growth, whereas those less reliant on roads experience mixed effects. Interestingly, the most considerable gains are seen in the export of final goods from Eastern China, while intermediate goods face declines in the West. Furthermore, the network facilitates diversified trade types and boosts exports to OECD countries, with these advantages again concentrated in Eastern China.

In addition to boosting exports, the ENE also reshapes firm dynamics and market strategies. The analysis of extensive margins—including firms, products, and target markets—shows that the ENE significantly influences firm entry and exit strategies. It reduces firm entry rates in Eastern China but increases them in Central China, while slightly raising exit rates in both the central and western regions. Moreover, it encourages firms to diversify their product offerings and expand into new markets, particularly for the firms in Eastern China.

To address endogeneity concerns, such as omitted variables and reverse causality, we apply two instrumental variable (IV) strategies. First, we use the historical Ming Dynasty Courier Road network in 1587 as an IV to introduce exogenous variation through historical infrastructure. The use of historical roads as instruments is well-established in the literature (Donaldson and Hornbeck, 2016; Baum-Snow et al., 2015; Chong et al., 2013; Duranton and Turner, 2012). Second, we use a least-cost path spanning tree network as an IV, which provides a cost-efficient design connecting target cities while accounting for factors like slope and land cover. To introduce time variation and reflect the dynamic expansion of the network, we incorporate annual expressway construction budgets for each city. These IV strategies help address the potential bias arising from the strategic placement of the expressway network in response to contemporary economic activity. Consistent with the baseline findings, the results indicate significant positive impacts on exports in Eastern China and negative impacts in Central and Western China.

Changes in firm efficiency and competitive dynamics across regions can largely explain the differentiated impact of the ENE on exports. For firms in Eastern China, closer proximity to ports and improved connectivity significantly reduce transportation and production costs. Additionally, the expressway fosters agglomeration and spillover benefits that enhance productivity, strengthening these firms' market power and international competitiveness. However, in Central and Western

China, increased regional competition driven by expressway connectivity results in diminished export performance. Despite reduced transportation costs and enhanced local competition, the increased presence of Eastern firms in export markets weakens the competitiveness of firms in the Central and Western regions. Moreover, these less-developed regions have lower returns on factor inputs, making it challenging to compete with more economically advanced areas. As a result, the expressway network not only amplifies the economic benefits in already prosperous regions but also exacerbates regional disparities, accelerating resource misallocation in Central and Western China.

Our paper makes three primary contributions to the existing literature. First, we contribute to research on transportation infrastructure and international trade. Although much of the literature has focused on the effects of transportation infrastructure on various economic outcomes, the effects on international trade, particularly at the micro level in developing countries, remain underexplored. During the past two decades, developing countries such as China have invested heavily in transportation infrastructure, fueling a massive increase in international trade. For example, from 2000 to 2019, the Chinese expressway network and export revenue expanded ninefold (see Figure A1 in the Appendix).

China's expressway network has garnered much attention. For example, some studies find that the network leads to welfare gains (Fan et al., 2023) and increases productivity (Yang, 2018; Huang and Xiong, 2017). Others suggest that the expressway network slows the growth of rich rural counties (He et al., 2020), negatively impacts markups (Wu et al., 2023) and peripheral regions' economic development (Faber, 2014), and contributes to shifts in population and production away from city centers (Baum-Snow et al., 2017). Our paper develops disaggregated unique data on the annual dynamic distance between each firm and its nearest expressway at the 8-digit product-firm-

country-year level to analyze how improvements in domestic infrastructure influence exports.

Second, this paper contributes to the literature on how transportation infrastructure shapes firm behavior by offering a holistic analysis of multiple interconnected mechanisms. Existing research has separately examined various interesting impacts of infrastructure, such as transportation costs (Fan et al., 2023; Martincus and Blyde, 2013), technology adoption (Irwin, 2003; Fiorini et al., 2021), production efficiency (Donaldson and Hornbeck, 2016; Ghani et al., 2016), market power (De Loecker and Warzynski, 2012; Mayer et al., 2014; Asturias et al., 2021; Wu et al., 2023), and resource reallocation (Redding, 2016; Topalova, 2010). The impact of infrastructure is inherently multifaceted, with each of these elements affecting and amplifying the others. We contribute to this literature by examining how the ENE influences firm behavior through five interrelated mechanisms: costs, productivity, market power, competition, and resource reallocation. This integrated perspective provides a deeper understanding of transportation infrastructure's efficiency in shaping firms' strategies.

Third, we provide insight into how infrastructure impacts spatial development. The impact of transportation infrastructure on spatial dynamics is complex and can have dual effects. On the one hand, some studies argue that transportation infrastructure amplifies economic agglomeration in developed cities and limits growth in less developed areas by facilitating factor migration to developed cities (Calderon and Servén, 2004; He et al., 2020; Faber, 2014). On the other hand, other studies suggest that improved transportation can enhance economic diffusion, reduce regional barriers, and foster growth in less-developed areas (Baum-Snow, 2007, 2020; Baum-Snow et al., 2017). Our paper contributes to this debate, showing that the ENE enhances exports for firms closer to the network and exacerbates spatial imbalances across regions. We provide evidence for agglomeration, spillover, and siphoning effects, offering insights for policymakers by addressing

the benefits and potential inequalities associated with infrastructure-driven spatial development.

The remainder of the paper is structured as follows: Section 2 provides institutional background, Section 3 describes data and empirical methods, Section 4 reports the empirical findings, and Section 5 delves into the potential mechanisms behind the effects of the ENE. Finally, Section 6 concludes the paper.

2 Institutional Background

The Chinese road system comprises national, provincial, county, and township roads, as depicted in Figure A2. National roads include toll-charging expressways and toll-free highways. National expressways consist of national trunk expressways, which connect different provinces, as well as local short expressways that provide access to these trunk routes. Although the national highways and provincial roads also form a national-level road network, they are generally narrower, slower, in poorer condition, and less convenient than expressways. Since our study focuses on inter-regional cargo transportation, the term "national expressway network" in our paper specifically refers to the national trunk expressway network.

Figure 1 shows the evaluation of the Chinese national expressway network from 1992 to 2013. The expansion can be divided into three stages during our sample period. The first stage spans from the late 1970s to the early 1990s. In the late 1970s, bicycles were the most popular mode of transportation in China and expressways were a novel concept. There was extensive debate about whether and how to construct expressways. After numerous discussions, in 1984, China's central government began building its first expressway, which connected Shenyang and Dalian—two large cities in Northern China—and it was completed in 1990.

The second stage spans from the 1990s to 2004. In the 1990s, the Chinese government initiated the design and construction of a national transportation infrastructure network. In the "Eighth Five-Year Plan," the government outlined a long-term plan for expressway construction. In 1992, China launched the first expressway network plan, the "5-7" network. The plan aimed to create a network exceeding 35,000 kilometers (km) to connect all provincial capitals and cities with over 500,000 residents. This plan included five north-south and seven east-west expressways, eventually connecting more than 600 million people (50% of China's total population at that time). Although initially slated for completion in 2020, proactive fiscal policies developed after the Southeast Asian financial crisis accelerated construction. As a result, the network was completed by the end of 2007 (13 years ahead of schedule), with an average annual construction distance of 4,000 km.

The third stage occurs after 2004. By 2004, the Chinese expressway system had become the second largest in the world. Recognizing its substantial spillover effects and the growing demand for infrastructure, the government proposed the "7-9-18" network, comprising seven radial expressways from Beijing, nine north-south, and eighteen east-west expressways—totaling over 85,000 km. This expanded network aimed to link major transportation hubs, ports, tourist cities, and cities with populations exceeding 200,000, connecting over one billion people.[3] The network was initially projected to take 30 years, but the 2008 global financial crisis prompted a 4 trillion CNY infrastructure investment plan that accelerated construction. As a result, the network was nearly complete by 2013, 20 years ahead of schedule. As shown in Figure 1, between 2000 and 2013, the expressway network expanded from 16,000 to 104,500 km—more than six times its original length.

[3]It directly serves more than 90% of the eastern region, 83% of the central region, and nearly 70% of the western region. The GDP of the coverage area accounts for more than 85% of the national total.

The expressway network significantly reduced transportation time and costs and provided a safer, wider, and faster alternative to traditional roads. Fan et al. (2023) find that transport costs on expressways were 20% lower than on regular roads in China between 2000 and 2010. Cross-regional transportation by other roads often involved high tolls, including local government tolls, inspection fees, and non-government (e.g., gang-related) charges. Poor road conditions and the risk of muggings also made long-distance transport by other roads unsafe. Although rail transport is safer, its limited coverage and inability to transport goods directly from plants to ports made it less convenient than expressways.

The construction of expressways in each province is not simultaneous. Northeastern coastal provinces prioritized constructing expressways early, followed by the eastern coastal provinces in the mid-1990s and eventually the central and western regions. The funding model also reflected a mix of sources: 15% from the central government, 70%-80% from domestic bank loans and local government debt financing, and a small portion from private investors. Most construction contracts were awarded to SOEs.

Over the last three decades, the expressway network has played a major role in the growth of long-distance cargo transportation. While railway and waterway systems also contribute to cargo transport, their expansion has been less significant than that of expressways. As shown in Figure A3, the road system accounts for the vast majority of cargo movement and has grown faster than other forms of transportation. Although airline networks have expanded significantly, they are primarily used for passenger transport and thus are not the focus of this analysis. To further isolate effects, robustness checks exclude the influence of other transportation modes.

3 Data and Empirical Method

3.1 Data

Our study relies on annual data on the ENE, firm-level trade and production, GIS information, history road data, and raster data drawn from nine primary sources.

Annual Dynamic Expressway Network Data — Constructing yearly expressway shapefiles presents significant challenges. We use two main data sources to fill the challenges: the Chinese Geographical Information Monitoring Cloud Platform (2016) and the annual Chinese SinoMaps Press from 1992 to 2016.[4] The 2016 shapefile includes each expressway's name and the county-level areas (counties and districts) it traverses. Additionally, we gather yearly printed transportation atlases from Chinese publishing houses, as detailed in Table A1.

To ensure data reliability, we adhere to two criteria: using atlases from the same publisher (primarily SinoMaps Press) and selecting those published at the beginning of each year. These atlases indicate when expressways reached specific county-level areas from 1992 to 2016. Combining these sources, we manually collect and digitize shapefile data for each expressway, year by year. Since we focus on long-distance freight impacts, we include only national expressways and exclude feeder and ring roads.

Chinese Customs Trade Data — The trade data is sourced from the Chinese Customs Trade Statistics (CCTS) provided by the General Administration of Customs of China. This dataset offers highly detailed information on the annual trade activities of all Chinese exporters and importers. It includes specific data on trade transactions, covering 243 destination countries and 7,526 products classified under the eight-digit Harmonized System for all industries. It also captures a wide range

[4]Data from SinoMaps Press begins in 1992, as expressways were virtually nonexistent in China before then.

of transaction details, including product type, quantity, "free on board" price, revenue, units, and firm-specific identifiers such as the firm's name, trade nature, telephone number, zip code, and contact person. For the purposes of the analysis, we focus on the export data, aggregating it at the eight-digit product-firm-destination country-year level.

Chinese Industry Firm Data — The fourth database is the Chinese Annual Survey of Industrial Firms (CASIF) from the National Bureau of Statistics of China (NBS), used for mechanism analysis. It contains annual data covering all state-owned enterprises (SOEs) and non-SOEs with annual sales of at least 5 million CNY (approximately $785,053) before 2007, all firms with annual sales of at least 5 million CNY between 2007 and 2010, and all firms with annual sales of at least 20 million CNY (approximately $3.08 million) since 2011. The approximate number of firms covered by the CASIF varied from 169,031 to 411,407 from 2001 to 2008. Additionally, the CASIF database contains detailed information about manufacturing firms, including their identification (e.g., firm name, firm nature, setup year, setup month, telephone number, zip code, and contact person), output, employment, assets, and value-added. Like the U.S. SIS system, the CASIF classifies each firm into an industry using a four-digit Chinese Industry Classification system. To address reporting errors and missing observations, we provide a detailed description of the data-cleaning process in Appendix C.

Two Geocoding Data — The fifth and sixth databases contain geocoding data for firms sourced from Baidu Maps, which are used to estimate their distances from expressways in the CCTS and CASIF datasets. Although the CCTS and CASIF datasets lack explicit GIS information, they provide detailed address and firm name data.[5] Using Python, we geocode each firm's location via

[5]While more than half of the addresses in the CASIF dataset are invalid, 94% of the observations include a 12-digit address code that accurately represents the firm's village or neighborhood committee. Given China's high population density and the compact geographic area of these local units, we used Python to extract addresses based on the 12-digit codes, treating these as firm addresses where original address data is missing.

Baidu Maps, utilizing the detailed address and name information separately for both datasets. The output includes each firm's longitude and latitude, along with a geocoding accuracy and reliability assessment. To ensure robustness, we apply a credibility threshold of at least 25%, representing an analytical error of less than 8 km. Additionally, we only retain observations where the discrepancy between the two geocoding methods is under 1 km.[6] The final geocoded dataset covers 90% of the CCTS dataset and 92% of the CASIF dataset.

Three Datasets for Instrument Variables — We also use three more datasets to construct two instrumental variables. The first instrumental variable is created from the Ming Dynasty (1368-1644) Courier Road shapefile in 1587, which is sourced from the Harvard Dataverse (Berman and Zhang, 2017).[7] The courier road network was originally developed for military purposes and connected major cities during the Ming Dynasty, significantly promoting economic development and facilitating trade between regions.

The other instrumental variable is created by two other datasets: the land cover raster data obtained from the Scientific Data Center of the Chinese Academy of Sciences and the elevation raster data from the China Resources Satellite Application Center. Both datasets are from 2000 and have a resolution of 30x30 meters. We use these datasets to construct the least-cost path expressway network following Faber (2014), which serves as an instrument for the 2013 expressway network. The construction cost map is shown in Figure A6.

The remaining data used in our paper are sourced from the Chinese Statistical Yearbook and the Chinese Transportation Yearbook. For all datasets mentioned above, we deflate the monetary variables to the year 2000 using two-digit HS product-level price indices and two-digit industry

[6]The discrepancies in GIS information between the two methods may be due to measurement errors or firm relocations, both of which are outside the scope of our study.

[7]Data source: https://dataverse.harvard.edu/dataset.xhtml?persistentId=doi:10.7910/DVN/SB8ZTM.

deflators provided by the Chinese National Bureau of Statistics.[8]

Since intermediary firms do not engage in production but only facilitate product delivery, accurately determining the distance between production sites and the expressway network is challenging, which may introduce bias into the main results. To address this issue, we create a sample that excludes intermediary firms, enabling a more precise calculation of the distance between each production plant and the expressway network. [9]

Finally, we generate two distinct samples for analysis by merging the annual dynamic expressway network data and geocoding data with the CCTS and CASIF datasets, respectively. Both samples contain the annual distance from each firm to its nearest expressway between 2000 and 2013. We use Sample A to assess the effects of ENE on exports, while Sample B is used to explore the underlying mechanisms driving these effects. Furthermore, we define the treated and control groups based on the dynamic distance between each firm and the expressway network.

As shown in Table 1, Sample A includes over 35.7 million observations, and Sample B contains 2.4 million observations, suggesting that firms export multiple goods to multiple countries. Firms in both samples are situated near the expressway network, with the majority located in Eastern China, which contributes over 91% of total exports. Figure A4 illustrates that Eastern China is closer to the coastline than the other two regions. Most firms in Sample A are foreign-owned or privately owned, whereas Sample B mainly consists of private firms. Between 2000 and 2013, private firms and their exports experienced substantial growth, while the ENE contributed to increased export amounts, productivity, markups, market competition, and resource misallocation.[10]

[8]The deflated variables include export prices, total assets, fixed assets, currency assets, profits, subsidies, production costs, and intermediate inputs.

[9]Firms are classified as intermediaries if their names contain terms such as 'jing mao,' 'shang mao,' 'mao yi,' 'jin chu kou,' 'huo yun,' or 'wu liu.'

[10]Details about productivity, markups, market competition, and resource misallocation are provided in the mechanism section.

Additionally, Figure 2 demonstrates that the ENE significantly reduces the distance between firms and the expressway network in Eastern and Central China, as well as between SOEs, private firms, and the network. Figure 3 indicates that most exporters concentrate in coastal cities and produce a greater variety of products than inland firms.

3.2 Empirical Method

Difference-in-Difference Approach — The expressway network's design and construction is a quasi-natural experiment. Therefore, we apply a difference-in-difference (DID) approach to investigate the effects of the ENE on exports. The first difference is the firm's exports before and after being connected by the expressway network. The second difference is the exports in the treated and control groups. According to the process of expressway network construction, we consider the main specification as follows:

$$ln(Y_{igdt}) = \beta_0 + \sum_{r \in R} \beta_r * \mathbb{1}\{Distance_{irt}\} + \lambda_{ig} + \gamma_{dt} + \varepsilon_{igdt} \tag{1}$$

Where $ln(Y_{igdt})$ represents the logarithm of export amounts of eight-digit product g in firm i to country d in year t; $\mathbb{1}\{Distance_{irt}\}$ indicates the dummy of a firm i is located in the range r from the expressway network in year t. We divide r into 0–10, 10–20, 20–30, 30-40, and 40–50 km ranges from the expressway network. Therefore, the firms located 50 km away make up the control group. The coefficient β_r, the primary focus of this analysis, captures the semi-elasticity of exports concerning proximity to the expressway network. The model includes firm-product fixed effects (λ_{ig}), which control for variations across firm-product combinations, industries, counties, cities, and provinces. Country-year fixed effects (γ_{dt}) are also incorporated to adjust for differences

in destination countries' incomes, exchange rates, geopolitical factors, and bilateral relationships. Standard errors are clustered at the firm level to address potential correlations across firms, industries, and administrative regions. Additionally, we combine the treated groups into one group by employing the following specifications:

$$ln(Y_{igdt}) = \beta_0 + \beta_1 * Treat_{it} + \lambda_{ig} + \gamma_{dt} + \varepsilon_{igdt} \tag{2}$$

where $Treat_{it}$ is a binary indicator for the treated group, taking the value of one if a firm is located within 40 km of the expressway network. All other variables in equation (2) are defined in the same manner as those in equation (1).

Event Study Approach — The impact of the ENE on firms depends on static but also on the length of time each firm has access to the expressway network. We use an event study design to capture these dynamic effects and examine how the ENE affects firm exports over time. Specifically, we estimate the following regression:

$$ln(Y_{igdt}) = \beta_0 + \sum_{k=-6}^{k=-2} \beta_k * \mathbb{1}\{After_{it} = k\} + \sum_{k=0}^{k=11} \beta_k * \mathbb{1}\{After_{it} = k\} + \lambda_{ig} + \gamma_{dt} + \varepsilon_{igdt} \tag{3}$$

where k represents the duration for which firm i has been influenced by the expressway network as of year t.[11] To limit the range, k is set to -6 if $k < -6$, and to 11 if $k > 11$. The variable $\mathbb{1}\{After_{it} = k\}$ is a dummy that equals one if the time span for firm i is k in year t. All other variables in equation (3) are defined in the same manner as those in equation (1).

[11] For instance, if a firm was within 40 km of the expressway network for the first time in 2005, k equals zero in 2005, one in 2006, and negative one in 2004.

4 Empirical Findings

Building on the empirical approaches outlined above, this section examines the ENE's varied effects on exports, export modes, and extensive margins across regions. To ensure the robustness of our findings, we employ two instrumental variables for the current expressway network to address potential endogeneity concerns. Additionally, we perform multiple robustness checks to confirm the reliability of the primary findings, demonstrating our study's rigor.

4.1 Average Effects

The impact of the ENE on exports varies depending on firms' proximity to the network. We provide evidence by designating the firms within 50 km of the expressway network as the treated group, further dividing them into five sub-groups based on their distance from the expressway. We estimate equation (1), and the results are reported in Table 2. Moreover, our empirical results indicate stronger effects for firms within 40 km of the network. We then use this 40 km threshold to estimate equation (2) and present the average effects in Table 3.

Table 2 suggests the effects on firms close to the network are more significant than the effects on those far away from the network, and the effects vary across regions. Column (1), with the whole sample, shows that the ENE positively affects exports and is statistically significant at a 99% confidence interval for the firms located within 40 km of the network, which is consistent with the results controlling different fixed effects in Table A2.[12] Additionally, when geographically dividing the sample into Eastern, Central, and Western China in Columns (2)-(4), the results still show stronger effects on the firms that are close to the network; however, the results also show that the

[12]Product fixed effects are included to account for the product and industry-specific differences.

ENE positively affects firms in Eastern China but negatively affects firms in Central and Western China, and the adverse effects in Western China are particularly significant. The reverse effects suggest that the ENE primarily promotes firms' exports in the eastern coastal areas but suppresses firms' exports in inland areas, which can be explained by regional competitive advantage and the siphon effect. Eastern China is closer to ports and has stronger incentives to engage in trade, which may attract more resources from Central and Western China. Moreover, when checking the effects in each province in Table 4A, the positive effects mostly come from the coastal regions.

Table 3 further shows the average effects of the ENE based on equation (2). Given the significance of the coefficient for firms located within 40 km of the expressway, in Columns (1)-(4), we choose 40 km as a threshold to redefine the treated group and examine the average effects in different regions. Moreover, to define the treated group, we also apply whether a county is crossed by the expressway network each year, with the results shown in Column 5. In Column (6), we analyze the elasticity of firm exports concerning the distance from the firm to the expressway network.

When comparing the firms located between 40 and 100 km, we find that the ENE increases exports for firms within 40 km by 4.5% ($e^{0.044} - 1$), as shown in Column (1) in Table 3.[13] Specifically, Columns (2)-(4) suggest that the network increases firms' exports by 5% in Eastern China and decreases firms' exports by 7% and 12.1% in Central and Western China.

When defining the treated group at the county level, as shown in Column (5), we note that the ENE increases firms' exports by 2.63%, indicating the presence of bias using the county level to define the treated group compared to the results in Columns (1)-(4). The bias is also shown in Columns (1)-(3) in Table A3. Additionally, Column (6) in Table 3 indicates that a 10% increase in

[13] We convert all semi-logarithmic model coefficients to linear regression model coefficients using the transformation $e^{\text{coefficient}} - 1$

the distance from a firm to the ENE can lead to a 2.3% decrease in its exports. The negative effect primarily comes from the firms in Eastern China. Columns (5)-(6) in Table A3 suggest that a 10% increase in the distance from a firm to the network can lead to 3.5% and 5.5% decreases in exports in Central and Western China, respectively.

4.2 Dynamic Effects

Various factors beyond the expressway network influence the effects on firms' exports. To assess the parallel trend assumption, we further examine the dynamic effects of the ENE on exports. The dynamic effects analysis provides insights into how the impact of the network evolves over time. We estimate equation (3), and the results are displayed in Figure 4.

Figure 4 illustrates that there are parallel trends between the treated and control groups across all graphs before the connection with the expressway network. After firms gain access to the expressway network, there are significant positive effects on exports for the entire sample and Eastern China, and the effects stabilize after nine years of connection. Moreover, Figure 4 also shows that exports in Central and Western China experienced a negative impact. Defining the treatment and control groups based on whether a county is connected to the expressway network, Figure A5 confirms the positive effects in Eastern China and the adverse effects in Central China; however, it indicates that the effects in Western China are statistically insignificant.

4.3 Heterogeneous Effects

This subsection delves into the ENE's heterogeneous impacts on firms' exports, aiming to identify which firm characteristics moderate these effects. Specifically, we assess how variations across

industry sectors, ownership structures, product types, production processes, and export modes shape the extent to which firms benefit from the improved infrastructure. Understanding these heterogeneous effects is crucial for uncovering whether the benefits of the ENE are evenly distributed or if certain types of firms gain disproportionately. We estimate equation (2), and the results summarized in Table 4 provide insights into firms' differential responses to the ENE and highlight regional disparities that have significant policy implications.

Manufacturing and Non-Manufacturing — Columns (1)-(2) indicate that manufacturing industries make up 99% of the observations, with the expressway network increasing manufacturing exports by 4.4% at the 99% confidence level. Figure 4A shows the most substantial impacts are on textile and clothing manufacturing, non-metallic mineral manufacturing, and equipment manufacturing. The ENE also positively affects non-manufacturing industries, primarily agriculture. Disaggregating the results by region and ownership in Table A4, we find that the positive effects on manufacturing firms are concentrated in Eastern China, particularly among SOEs and private firms, while firms in Central and Western China experience adverse effects. Similarly, for non-manufacturing industries, the ENE boosts exports for firms in Eastern China and private firms but decreases exports for SOEs and firms in Central and Western China.

Road Reliance — Columns (3)-(4) analyze industries with high versus low road-reliance, which is determined using the 2007 Chinese National Input–Output (IO) table to calculate the road-reliance index. Industries with high road-reliance experience an 8.2% increase in exports due to the ENE, whereas the effects on less road-reliant industries are statistically insignificant. Regionally, the positive impacts are concentrated in firms located in Eastern China, while the effects are negligible in Central China and negative in Western China (Table A5). In contrast, exports from less road-reliant industries in Central and Western China significantly decline. When considering

ownership structure, the positive effects on highly road-reliant industries are driven by SOEs and private firms, and the network also contributes to increased exports for SOEs in less road-reliant industries.

Ownership Structure Effects — Columns (5)-(7) suggest that the network expansion significantly boosts exports for SOEs and private firms, while the effects on foreign firms are insignificant. Despite accounting for just 4.2% of all exporters from 2000 to 2013, SOEs, benefiting from favorable policies such as subsidies and tax incentives, see an 18.7% increase in exports, mainly in Eastern China (Table A6). Foreign firms, already well-positioned with export advantages and policy benefits, are less sensitive to infrastructure changes; in fact, the ENE has an insignificant impact on foreign firms' exports and even negative effects in Central and Western China (Table A6). Private firms, despite facing many restrictions and lacking policy advantages, see a 3.5% increase in exports, especially in Eastern and Western China (Table A6).

Product Type Effects — Columns (8)-(10) indicate that the ENE primarily boosts final goods exports by 6%, and that effects on capital and intermediate goods exports are statically insignificant.[14] A regional and ownership decomposition of the effects, shown in Table A7, indicates that the network reduces intermediate goods exports for firms in Central and Western China, with a particularly large decrease of 36.9% in Western China. The increase in final goods exports is predominantly driven by firms in Eastern China. Additionally, the network significantly boosts capital and final goods exports for SOEs and private firms, while the effects on foreign firms remain statistically insignificant.

Processing and General Exports — Columns (11)-(13) show that the ENE significantly benefits

[14]Using the Classification by Broad Economic Categories (BEC) Revision 4, the six-digit product codes are categorized into capital goods, intermediate goods, and final goods.

firms engaged in both processing and general exports, while the impact on firms with only general exports is insignificant. Decomposing these effects (Table A8), we find that mixed trade benefits are concentrated in Eastern China and among SOEs and private firms. The network also substantially boosts private firms' processing and general exports but reduces foreign firms' general exports.

Export Destinations — Lastly, Columns (14)-(15) reveal that the ENE increases exports to OECD countries by 4.7%, while the effects on non-OECD countries are statistically insignificant. Positive impacts on OECD exports mainly originate from firms in Eastern China, particularly SOEs and private firms, whereas firms in Central and Western China show negative effects (Table A9). Furthermore, SOEs increase their exports to non-OECD countries. By decomposing effects into different continents (Table A10), we find that the network increases exports to Asia, Europe, and North America and reduces exports to Oceania.

4.4 Extensive Margins

Following the heterogeneous analysis, this subsection examines the extensive margins of firms, products, and destination countries, focusing on how the ENE influences firm entry and exit, as well as the diversification of exported products and destination markets. By exploring the extensive margins, we provide a broader perspective on the economic implications of the ENE beyond its average and heterogeneous effects on existing exports.

To investigate the effects on firm entry and exit and on product and market choices, we calculate the number of eight-digit products and export destinations for each firm annually, converting the dataset to the firm-year level. A firm's "entry" is defined as a binary variable equal to one if the firm

enters export markets in a given year, while "exit" equals one if the firm leaves export markets; otherwise, it is zero. Applying equation (2), we estimate the impact on entry, exit, number of products, and number of destination countries. The regressions include the firm and year fixed effects, with robust standard errors clustered at the firm level. The results are presented in Table 5.

Table 5 demonstrates that the ENE significantly affects firms' entry and exit decisions as well as their production and market diversification strategies. Columns (1)-(6) indicate that the ENE decreases firm entry probability by 3.6%, with this effect being most pronounced in Eastern China, where entry probability falls by 4.5%. However, the network increases entry probability in Central China by 2.1%. Additionally, the ENE slightly raises firm exit rates, particularly in Central and Western China. These results suggest that the ENE intensifies regional competition. In Eastern China, where firm density is high, the ENE reduces entry rates as firms increasingly opt to establish themselves in Central China. However, as competition grows in Central China, the ENE also leads to higher exit rates, reflecting a dynamic of increased exits alongside new entries—consistent with Schumpeter's theory of creative destruction (Schumpeter, 1942). Furthermore, the ENE diversifies firms' product portfolios and destination markets. Columns (9)-(12) show that the number of export products rises by 4.4%, and the number of destination countries increases by 6.6%. These positive effects are concentrated in Eastern China, while Central and Western China experience significantly negative impacts.

When analyzing extensive margins by ownership structure, Table A11 shows that private firms benefit most from the ENE. Specifically, the ENE increases private firm entry by 2.7% and decreases exit rates by 1.2%. Due to the ENE, the numbers of products and destination markets for private firms grow by 3.7% and 3.8%, respectively. The impact on SOEs and foreign firms is more mixed. SOEs experience increased entry and exit rates, aligning with the creative destruction

theory, but show no significant improvement in product or destination market diversification. For foreign firms, while the number of destination countries increases, entry rates decline and exit rates rise, and their product mix remains unaffected.

4.5 Endogenous Concerns

The Chinese government designed the expressway network to connect major cities while managing construction costs. However, assuming that the network's design and construction are entirely exogenous to economic activity would be overly simplistic.

To address potential endogeneity concerns regarding the ENE's impact on firms' exports, this subsection introduces two instrumental variable (IV) strategies. The first strategy uses the historical Ming Dynasty (1368–1644) Courier Road network in 1857 as an IV, leveraging the historical persistence of infrastructure to introduce exogenous variation. The second strategy follows Faber (2014) by employing a least-cost path spanning tree network as an IV. This method generates a construction cost-minimizing network that connects the administrative centers of target cities (those with populations exceeding 200,000) while accounting for slope and land cover types across each 30m x 30m grid cell.[15] Figure A6 displays the construction cost distribution map using the least-cost network. These two IV approaches aim to mitigate endogeneity biases arising from the possibility that the placement of the ENE is influenced by contemporary economic activity, thereby allowing for more robust estimates of the ENE's causal effects on firms' export behaviors.

Figure 6 compares the Ming Dynasty Courier Road network (a) and the least-cost spanning tree network (b) with the 2013 expressway network. Graph (a) shows considerable overlap between the 2013 expressway and Ming Dynasty networks, but the expressway network has a much higher

[15]The target cities' information comes from the Chinese Expressway Network Construction Plan in 2004.

density. Graph (b) suggests that the 2013 expressway network largely aligns with the least-cost network, consistent with the cost-oriented design goals of the expressway network.

Since these IVs do not account for dynamic road construction, we cannot use firm-to-road dynamic distance to define treated and control groups directly. Instead, we define these groups based on whether a county is connected to the road networks. To capture the time variation in network construction, we follow Wu et al. (2023) and model annual construction progress according to each city's yearly road construction budget. Assuming the cumulative road construction budget from 2000 to 2013 sums to 1, the ratio of each city's completed expressway length relative to its 2013 total length reflects the city's budget allocation for that year, introducing time variation in expressway construction. Thus, the explanatory variables are interactions between the dummy variable for county connectivity to the networks and the city's budget ratio for each year.

Using these two IVs, we re-estimate the regression in Column (5) of Table 3, and Table 6 shows the results. The findings are consistent with the main results in Table 3, showing significant positive impacts on firms' exports, particularly in Eastern China, and negative impacts in Central and Western China. The Kleibergen-Paap rk Wald F statistic in each column rejects the weak instrument assumption. These results imply that the expressway network's design aligns with factors like historical road networks and construction costs, suggesting that the network's layout is exogenous.

Table 6 also reveals that IV-based estimates are notably larger than those in Tables 3 and A3. This discrepancy may be due to two factors. First, the difference can be explained by network density. The expressway network, being denser than the courier road network, connects more regions, which results in a lower weighted average effect across the treated group when using the courier road network as an IV. Second, measurement errors may also account for the discrepancy. For instance, determining road construction progress based on city budgets may introduce bias.

4.6 Robustness

This subsection presents six robustness checks to validate the findings and address concerns related to model specification and data reliability. First, we address potential biases in the staggered DID approach. Second, we exclude potential effects from other transportation modes, including railways, waterways, and alternative road networks, to isolate the impact of the ENE. Finally, we examine the effects on exports specifically for intermediary and incumbent firms.

Staggered DID — Recent studies, such as Goodman-Bacon (2021); Sun and Abraham (2021); De Chaisemartin and d'Haultfoeuille (2020), have identified potential biases in the staggered DID method. Therefore, we re-estimate the main results from Table 3 using the approach suggested by De Chaisemartin and d'Haultfoeuille (2020). The findings indicate that the ENE increases firms' exports by 9.3%, with the coefficient being significant at the 99% confidence level.

Furthermore, Figure 7 presents the dynamic effects of the network on all firms, as well as on firms located in Eastern, Central, and Western China. The results indicate a positive impact on overall firm exports, consistent with Table 3 findings. Notably, the positive effects are driven primarily by firms in Eastern China, while the impacts on firms in Central and Western China remain negative. However, in contrast to Figure 4, the effects on Eastern firms' exports become statistically insignificant eight years after gaining expressway access, and the negative effects on Central China firms are more pronounced.

Overall, although the more significant coefficients observed in Figure 7 suggest potential estimation error, the results from the staggered DID analysis confirm the robustness of the main findings in Table 3.

Excluding the Effects of Waterways, Railways, and Other Amenities — In the third to fifth

robustness checks, we evaluate whether other forms of transportation infrastructure (e.g., railways, waterways, and urban amenities) influence the main findings.[16] To do this, we construct three subsamples from Sample A, each designed to isolate the impact of the railway network, waterway network, and other transport-related amenities. We use equation (2), and the results are presented in Table 7.

In Panel A, we exclude firms located in railway hub cities to mitigate the influence of the railway network on exports. In Panel B, we exclude firms located in inland port cities to control the effects of waterways.[17] In Panel C, we exclude firms in city districts (shi xia qu), where access to the expressway network is relatively convenient, to control the impact of such transport-related amenities.

The results in Table 7 align with the main findings reported in Table 3. The results continue to show positive effects for firms in Eastern China and negative effects for firms in Central and Western China. The coefficients are nearly identical to those in Table 3. Notably, in Panel C, the effects on firms' exports in Central and Western China are somewhat smaller than the main findings in Table 3, suggesting that the negative impact in these regions primarily stems from firms in more developed urban areas.

Intermediary Firms — Since intermediary firms are not involved in production but solely in facilitating product delivery, accurately measuring the distance between the production plants (from which intermediary firms source products) and the expressway network is challenging. As a result, the previous analysis excluded intermediary firms. In this subsection, we examine the impact of the ENE on the exports of intermediary firms.

[16] Other amenities include many factors that affect firms' access to the expressway network, such as the feeder and ring expressways, road quality between firms' location and the expressway network, road density around firms' location, etc.

[17] The data on railway and waterway hub cities is sourced from the 2004 National Expressway Network Plan.

The results are presented in Column (1) of Table 8. These findings indicate that the impact of the ENE on intermediary firms' exports across different distance ranges is statistically insignificant. However, they also suggest that the ENE has a more pronounced negative effect on intermediary firms located closer to the network than it does on those farther away. This outcome may be explained by non-intermediary firms opting to export products directly rather than relying on intermediary firms after gaining expressway access.

Balanced Panel — The final robustness check examines the impact of the ENE on the exports of incumbent firms. We construct a balanced panel from Sample A, including only continuously active firms from 2001 to 2013.[18] The results are presented in Columns (2)-(5) of Table 8.

The findings in Table 8 confirm the robustness of the main results. They align with the results in Table 2, showing the significant effects of the ENE on incumbent firms' exports. Specifically, the impact increases as the distance between the firms and the expressway network decreases. Moreover, the results indicate positive effects for firms in Eastern China and negative effects for those in Central and Western China. Compared to the results in Table 2, the ENE's effects on incumbent firms' exports are notably larger.

5 Discussion of Underlying Mechanisms

This section explores five specific mechanisms, focusing on export costs, productivity, market power, competition, and resource misallocation, to understand the impact of the ENE on firms' exports and spatial imbalances.

[18]The year 2000 is excluded because it includes only 28% of the firms present in 2001. China's accession to the WTO in 2001 triggered a surge in firm exports shortly afterward. Furthermore, the number of observations in the balanced panel varies each year as firms have differing numbers of products and export markets.

Intuitively, the ENE can influence firms' exports through multiple channels. Improved connectivity can significantly reduce production and export costs by lowering input costs and shortening delivery times (Fan et al., 2023; Martincus and Blyde, 2013). The ENE can also facilitate knowledge spillovers and generate agglomeration benefits, as advanced firms often cluster near well-connected infrastructure, thereby enhancing regional productivity (Fernald, 1999; Faber, 2014; Ghani et al., 2016; Donaldson and Hornbeck, 2016; Asturias et al., 2019; Fiorini et al., 2021). These cost reductions and spillover effects can improve firm competitiveness and encourage greater participation in export markets (Donaldson and Hornbeck, 2016; Asturias et al., 2019, 2021). However, competition increase may disadvantage firms located farther from the main transport nodes, such as ports, potentially eroding their competitive edge.

The ENE also influences exports by reshaping resource flows (Tamannaei et al., 2021; Asturias et al., 2019). By effectively reducing distances between regions, the ENE can facilitate the efficient movement of labor and capital, particularly towards industries and areas with higher potential returns.

5.1 Effects on Exports Costs

Due to the lack of transportation cost data, directly analyzing transportation costs is challenging. Instead, we use export prices as a proxy since price fluctuations often reflect underlying cost changes (Knetter, 1989; Anderson and Van Wincoop, 2004; Harrigan et al., 2015). However, it is worth noting that price variations can also result from changes in firms' production efficiency due to the ENE. To assess the impact on transportation costs, we re-estimate equation (1) using Sample A, with the logarithm of export prices as the dependent variable.[19] The results are presented in

[19]Export prices are adjusted to 2000 using the export commodity price index from the Chinese Statistical Yearbooks.

Table 9.

Table 9 indicates that the ENE reduces export prices for firms within 20 km of the network, particularly those in Eastern China. In contrast, the results reveal a positive effect on export prices for firms in Central and Western China, with the strongest effect observed in Central China. These opposite findings can be attributed to shifts in costs and competitive dynamics. First, the ENE reduces transportation and input costs, resulting in lower export prices. Second, the increased competition and resource mobility may raise production costs. For instance, firm clustering near the expressway network intensifies input competition, potentially leading to higher production costs and resource distortions.

Column (2) in Table 9 indicates that the cost savings from the ENE in Eastern China overshadow the cost increases, leading to reduced export prices. However, Columns (3) and (4) show that for firms in Central and Western China, the cost increases due to heightened competition and resource reallocation are greater than the savings in transportation costs. The firms in Central and Western China are located farther from major ports, and the ENE may not significantly reduce their delivery costs to these ports. At the same time, the improved connectivity increases market competition, and resources such as labor and capital may flow from the central and western regions to Eastern China, where returns are higher.[20] As a result, the ENE raises production costs and, subsequently, export prices for firms in these less-developed regions.

[20]Eastern China is more economically developed than Central and Western China, leading to higher returns on capital and labor.

5.2 Effects on Productivity

Access to efficient transportation networks can significantly enhance firm productivity. Improved infrastructure reduces transit times for raw materials and finished goods, minimizes supply chain disruptions, facilitates knowledge spillovers, and boosts operational efficiency. Analyzing the effects on productivity provides insights into whether the ENE has resulted in operational gains that are crucial for scaling production and improving international competitiveness.

Since Sample A does not contain the necessary variables to estimate productivity, we used Sample B to analyze the effects of the ENE on firms' productivity.[21]

We use total factor productivity (TFP) to indicate firm productivity. The existing literature does not provide a unified method for estimating productivity, and each approach has its own strengths and limitations (Olley and Pakes, 1996; Levinsohn and Petrin, 2003; Ackerberg et al., 2015). Using the available variables in our dataset, we measure total factor productivity (TFP) primarily by applying the Olley-Pakes (OP) method, as described by Ackerberg et al. (2015), with value-added as the dependent variable.[22] We use specifications similar to those in Table 2, and the results are reported in Columns (1)-(4) of Table 10, where the dependent variables are the logarithms of TFP.[23] Column (1) includes the full sample, while Columns (2)-(4) present results for firms in Eastern, Central, and Western China, respectively. All specifications also control for firm and industry-year fixed effects, and robust standard errors are clustered at the firm level.

[21] There is an inherent trade-off between maximizing the number of observations and focusing solely on exporters when attempting to merge Sample A and Sample B. Given that the goal of this mechanism analysis is to assess the effects of the ENE on the production performance of all firms, rather than just exporters, we decided against merging the two samples. Additionally, using the matching method from Wang (2023), the firm-year level matching rate was only 40%, which significantly limits the capacity to comprehensively analyze the broader firm population. By keeping the samples separate, we are able to ensure a more representative and holistic examination of the ENE's impact on the entire spectrum of firms.

[22] The variable of intermediate inputs in the data has been missing since 2008.

[23] Detailed specifications can be found in Appendix C.1.

Columns (1)-(4) in Table 10 indicate that the ENE significantly increases firms' productivity, with stronger effects observed for firms closer to the expressways. These findings remain robust when controlling for different fixed effects, as shown in Columns (1)-(3) of Table A12. The positive effects are mainly observed for firms in Eastern and Western China, particularly in Western China, whereas the impact on firms' productivity in Central China is mostly statistically insignificant.

The results are consistent with those obtained using the OP method as detailed in Olley and Pakes (1996) for productivity estimation in Columns (1)-(4) of Table A13. However, following Hsieh and Klenow (2009), when using revenue-based total factor productivity (TFPR), the results in Columns (5)-(8) of Table A13 suggest that the ENE significantly increases TFPR for firms in Eastern and Central China, while the effect in Western China is statistically insignificant. Additionally, we define the treated and control groups based on whether a county is intersected by the expressway network, and the results in Table A14 (Columns (1)-(4)) indicate positive effects on productivity across all three regions, though the impact on firms in Central China is slightly weaker compared to the impact on firms in the other two regions.

The heterogeneous effects suggest that the ENE enhances the technical efficiency of converting inputs into outputs, especially for firms in Western China, which is less developed than in Eastern and Central China. Despite the productivity improvements seen in Central China (Table A14), the impact on technical efficiency for firms closer to the expressways is statistically insignificant, while the effects on TFPR are significant, likely due to better market access, increased markups, or strategic pricing adjustments. Interestingly, the impact of the ENE on TFPR in Western China remains statistically insignificant, possibly indicating increased competition from firms in Eastern and Central China accessing Western markets.

Furthermore, we find that the ENE significantly increases the productivity of private firms, as

shown in Columns (1)-(4) of Table A15. Additionally, because Sample B only includes firms with total assets exceeding RMB 5 million before 2011, and the data for 2011-2013 is limited to firms with total assets exceeding RMB 20 million, the change in data structure could distort the results. Therefore, we reanalyzed Table 10 using data from 2000 to 2010 based on Sample B. The results, presented in Columns (1)-(4) of Table A15, are highly consistent with those found in Table 10 and Table A15.

5.3 Effects on Markups

The ENE affects not only cost structures and productivity but also firms' pricing power. With reduced costs and improved productivity, firms may have more flexibility to adjust their markups. Studying markups helps explain how firms can leverage cost savings to improve profitability or maintain competitive advantage. Markup analysis also indicates how firms balance competitive pressures with profitability in the face of changing infrastructure.

Measuring markups requires basic information about products' sales prices and marginal costs; however, as hidden information, products' marginal costs are usually difficult to obtain. Therefore, following De Loecker and Warzynski (2012), we measure markups by using the ratio of the output elasticity of labor to the share of labor return. Appendix D provides detailed information about this measurement. Then, we examine the ENE effects on markups by using Sample B to estimate equation (1) with different distance ranges. The dependent variables are the logarithm of markups. All specifications include the firm and industry-year fixed effects. The results are shown in Columns (5)-(8) in Table 10. Column (5) includes the full sample, and Columns (6)-(8) focus on the firms in Eastern, Central, and Western China, respectively. In the appendix, we also show the

robustness of the results with control of different fixed effects and definition of the treated group by county-level classification.

The results in Table 10 indicate that the ENE significantly increases firms' markups, especially for those in Eastern and Central China. This finding contrasts with the results of Wu et al. (2023), which report a negative effect when using total road length as a proxy for expressway infrastructure at the provincial level. Table 10 also suggests that the effects increase when the distance between firms and the expressway network decreases. When controlling different fixed effects in Columns (4)-(6) in Table A12, the findings are consistent with Column (5) in Table 10; however, the coefficients decrease due to province dynamic shocks.[24] The results in Table 10 are also consistent when defining the treated and control groups by whether a county is intersected by the expressway network (Columns (5)-(8) in Table A14) or when only using the data from 2000 to 2010 (Panel B in Table A16). Additionally, considering firms' ownership structure, the results in Table A15 suggest that the ENE increases foreign and private firms' markups, but the effects on SOEs are insignificant.

The effects of the ENE on firms' markups operate through both market power and cost adjustments. By expanding access to broader demand markets and boosting productivity, the ENE enhances firm competitiveness, which often leads to increased markups. As suggested by Brandt et al. (2017), firms may choose to retain the benefits from cost savings, leading to higher markups instead of reducing prices for consumers. However, as more firms establish themselves near the expressway network, the resulting rise in demand for inputs—such as rent, capital, and labor—may drive these input costs higher. Supporting this, Table A18 shows that the ENE contributes to

[24]China builds infrastructure very quickly, and the expressway networks in various provinces may change significantly within a year, so the dynamic shock effect of provinces may come from the construction of highways.

increased capital and labor distortions for firms located near the network.[25] Thus, firms might respond to higher input costs by increasing their markups, effectively passing these costs onto consumers.

5.4 Effects on Market Competition

The ENE reshapes the competitive landscape by reducing barriers to entry and enhancing firms' access to domestic and international markets. It also fosters corporate agglomeration in areas with improved transportation accessibility. Understanding the impact of increased competition is crucial to determining whether the ENE fosters a more dynamic and competitive market environment, thereby driving innovation and productivity gains.

To measure market competition, we use the Herfindahl-Hirschman Index (HHI), which evaluates changes in market concentration by summing the squares of each firm's export revenue share. A lower HHI indicates reduced market concentration and increased competition. Recognizing that industry-specific factors influence competition, we calculate HHI by aggregating firms' sales revenue ratios at both the county-year and county-industry-year levels. Using this approach, Sample B is aggregated accordingly. We then estimate equation (2), defining treated and control groups based on whether the county intersects with the expressway network. The regressions include city and year fixed effects at the county-year level and city and industry-year fixed effects at the county-industry-year level, with robust standard errors clustered at the county level. The results are presented in Panel A of Table 11.

Panel A of Table 11 shows that the ENE reduces HHI at both the county-year and county-industry-year levels, indicating increased market competition in counties connected to the express-

[25] Further details will be discussed in the misallocation subsection.

way network. Additionally, Columns (2)-(4) show that the impact on market competition is greater in Western and Central China than in Eastern China. The difference across regions is likely due to the initial number of firms in these regions—Eastern China had a higher number of firms before 2000, meaning that the entry of a new firm has a more pronounced effect on HHI in regions with fewer existing firms.

The decrease in HHI has several implications. First, increasing the number of firms in the same market enhances competition, encouraging firms to improve efficiency. Second, agglomeration can improve efficiency through economies of scale and learning effects. Third, heightened competition may force firms to lower product prices to maintain market share, which could explain a reduction in export prices. Finally, increased competition can drive out low-efficiency firms, thereby increasing the average efficiency of firms in the market—a concept known as creative destruction (Schumpeter, 1942).[26] Together, these forces contribute to increased exports. Moreover, while competition intensifies in counties connected to the expressway network, these firms can still increase their markups due to improvements in productivity, operational efficiency, and enhanced market demand more than firms situated farther from the network.

5.5 Effects on Misallocation

The ENE can help mitigate inefficiencies by providing better access to resources—such as labor, capital, and intermediate inputs—across regions. By analyzing misallocation, we aim to assess whether the ENE leads to a more efficient allocation of resources or contributes to spatial imbalances, particularly where it has disproportionately boosted firms' exports in Eastern China

[26] Schumpeter (1942) described creative destruction as a "process of industrial mutation that incessantly revolutionizes the economic structure from within, incessantly destroying the old one, incessantly creating a new one."

compared to exports in Central and Western China. In this subsection, we analyze how the ENE impacts firms' marginal revenue product of capital and labor, as well as the impacts on the distortion of capital and labor. Then, we explore the ENE impacts on regional resource misallocation.

We measure these factors by following the methodology of Hsieh and Klenow (2009).[27] Focusing on the ENE's impacts on firms' marginal revenue product and distortions, we use Sample B to estimate equation (1) with different dependent variables. All specifications control the firm and industry-year fixed effects. The results are shown in Tables A17 and A18. Tables A17 and A18 suggest the ENE improves firms' marginal revenue product of capital and labor but also increases their capital and labor distortions.

We further discuss the ENE impact on regional misallocation. Misallocation is assessed by examining distortions in aggregate TFP, represented by the variance of the logarithm of TFPR. A higher variance in TFPR implies greater misallocation of resources. In our study, we measure misallocation by calculating the variance of TFPR at both the county-year and county-industry-year levels. To do this, Sample B is aggregated to these respective levels and is used to estimate equation (2) with the treated and control groups defined based on whether a county intersects with the expressway network. The regressions include city and year fixed effects for the county-year level and city and industry-year fixed effects for the county-industry-year level, with robust standard errors clustered at the county level. The results are presented in Panel B of Table 11.

Columns (1)-(4) in Panel B of Table 11 suggest that the ENE has slightly increased resource misallocation in China. Specifically, while the expansion appears to improve resource allocation efficiency in Eastern markets, it reduces efficiency in Central and Western markets. The home market effect theory (Faber, 2014; He et al., 2020) can explain this heterogeneous effect. According to

[27]The details are shown in Appendix D.

this theory, resources in connected but less-developed areas (such as Central and Western China) are drawn toward more developed regions (such as Eastern China) following improved transportation connectivity. As a result, growth in these connected, less-developed areas tends to lag behind growth in already-developed areas. Given that Eastern China is more developed, resources tend to migrate there in pursuit of higher returns following the connection to the expressway network. At the county-industry-year level, the results indicate that the ENE has significantly increased resource misallocation in Central China, whereas the effects on all firms and those in Eastern and Western China are statistically insignificant.

Driven by reduced resource misallocation, the production efficiency improvement in Eastern China contributes to increased exports. Conversely, as resources flow from Central and Western China to Eastern China, the resultant decreases in input availability and production efficiency in these less-developed regions can suppress their exports and reduce their competitiveness compared to Eastern China. Therefore, while the ENE positively affects firms' productivity and efficiency, it also increases spatial imbalances.

In summary, the ENE exerts substantial and diverse effects on firms' export performance across multiple dimensions. First, it significantly reduces production and export costs for firms near the expressways, enhancing their competitiveness in both domestic and international markets. Second, improved connectivity boosts productivity, particularly benefiting firms in Eastern and Western China, though these gains remain uneven across regions. Third, the expansion affects firms' pricing power, increasing markups driven by resource distortions and strategic responses to heightened competition. The ENE also reshapes market dynamics, reducing market concentration—as indicated by declines in the Herfindahl-Hirschman Index—and fostering a more competitive business environment. However, while the ENE improves resource allocation efficiency in Eastern China,

it exacerbates resource misallocation and deepens spatial imbalances, with firms in Central and Western China struggling to retain resources and maintain competitiveness. These findings underscore the complex relationship between the ENE and firm performance, revealing both the positive effects on export capabilities and the unintended spatial disparities intensified across regions.

6 Conclusion

Transportation infrastructure reshapes a country's spatial structure by facilitating trade. While many studies explore its impact on economic outcomes, research on its effects on international trade and spatial imbalances at the micro level is limited due to data constraints. We calculate yearly changes in the distance between each firm and the nearest expressway to examine how the Chinese expressway network expansion (ENE) affects firm exports and spatial imbalances at the eight-digit product-firm-country-year level. Additionally, we conduct a comprehensive mechanism analysis to explain these findings, focusing on the ENE's effects on export costs, productivity, markups, market competition, and resource misallocation.

Our research yields three key findings. First, the ENE significantly increases exports for firms in Eastern China while reducing exports for those in Central and Western China, with more pronounced effects for firms closer to the network. These findings are robust even when accounting for the impacts from other transportation modes and controlling for endogeneity using two instrumental variables. Second, the ENE reshapes firms' trade patterns and production strategies. Manufacturing and road-reliant industries, especially SOEs and private firms, experienced the greatest benefits. The network also encouraged firms to produce more final goods and diversify products and export destinations. Third, the expansion lowered export prices in Eastern China but raised

them in Central and Western China. It enhanced productivity, markups, and competition nationally but worsened resource misallocation in Central and Western China. While regional efficiency improved, competition across regions intensified.

Several areas warrant further research. First, the welfare impact of the ENE globally remains unclear. Second, examining how the network facilitates internal trade across provinces could provide additional insights. Finally, future research could explore how improved infrastructure affects information flow, which may be crucial for firm productivity and economic development.

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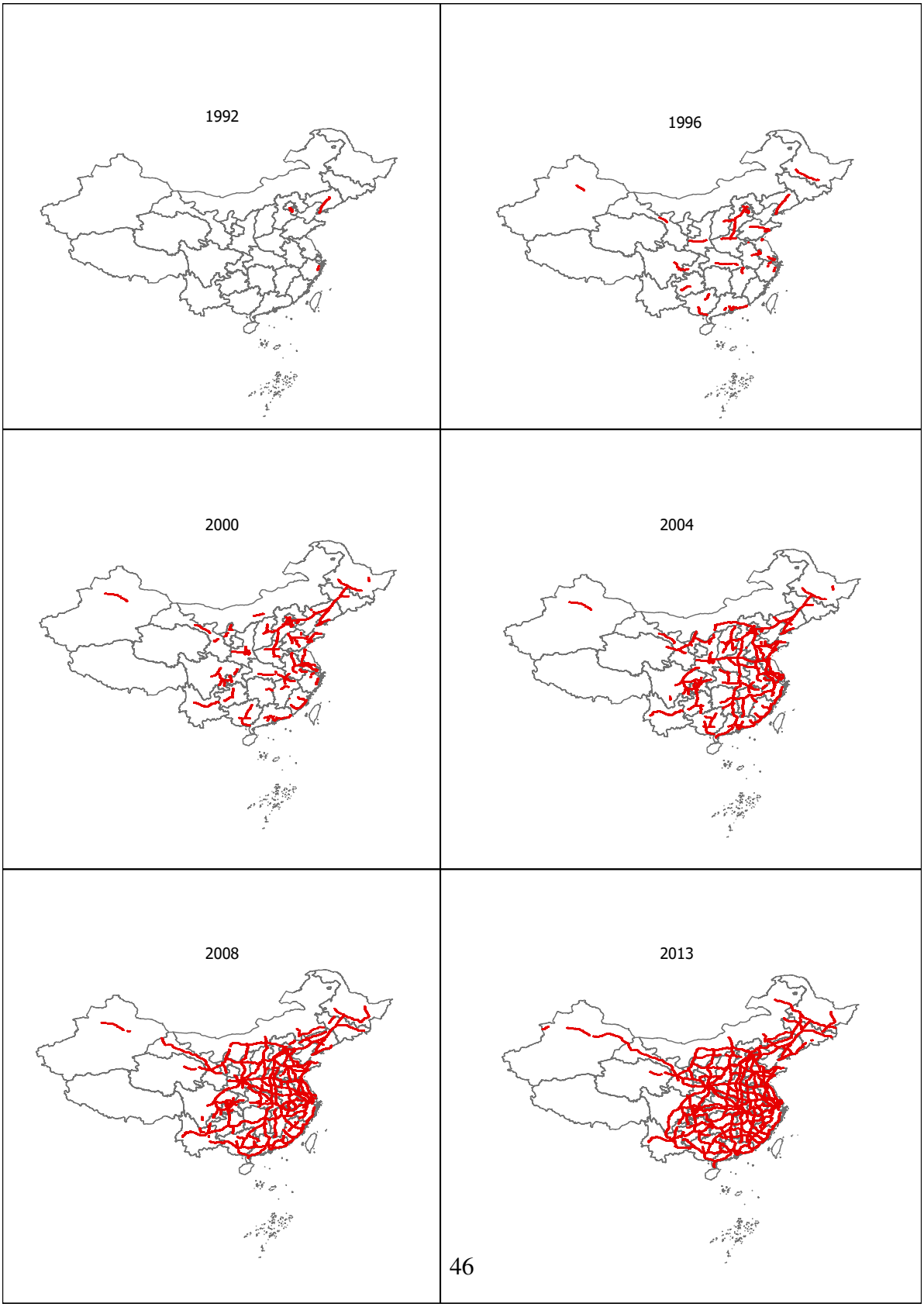
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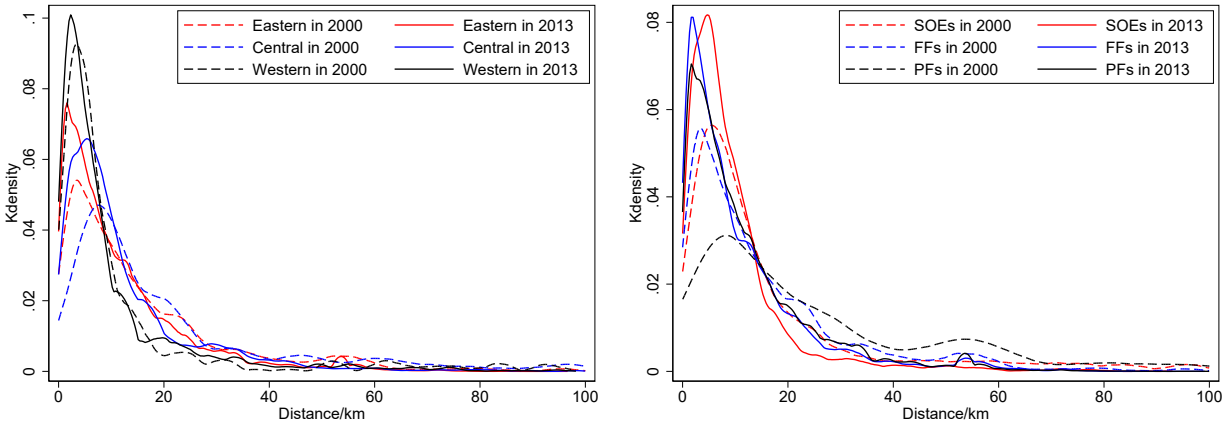
Figures

Figure 1: The Evolution of the Chinese National Expressway Network from 1992 to 2013



Notes: The red lines represent the expressway network, and the gray lines represent province and country boundaries.

Figure 2: Distance Changes by Districts and Ownership Types, 2000 to 2013

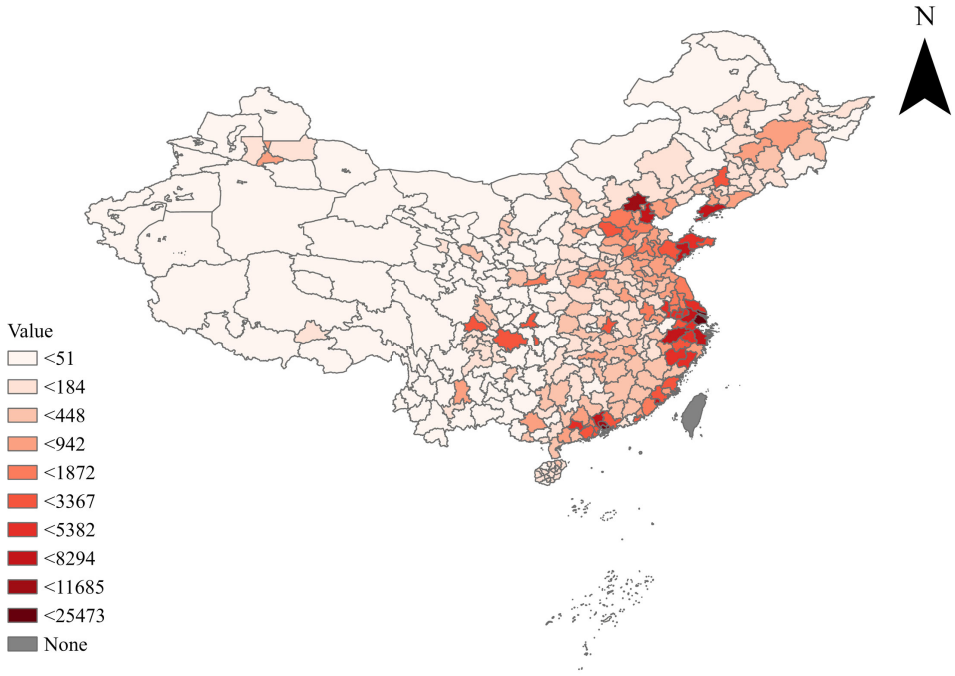


(a) Distance Change by Districts

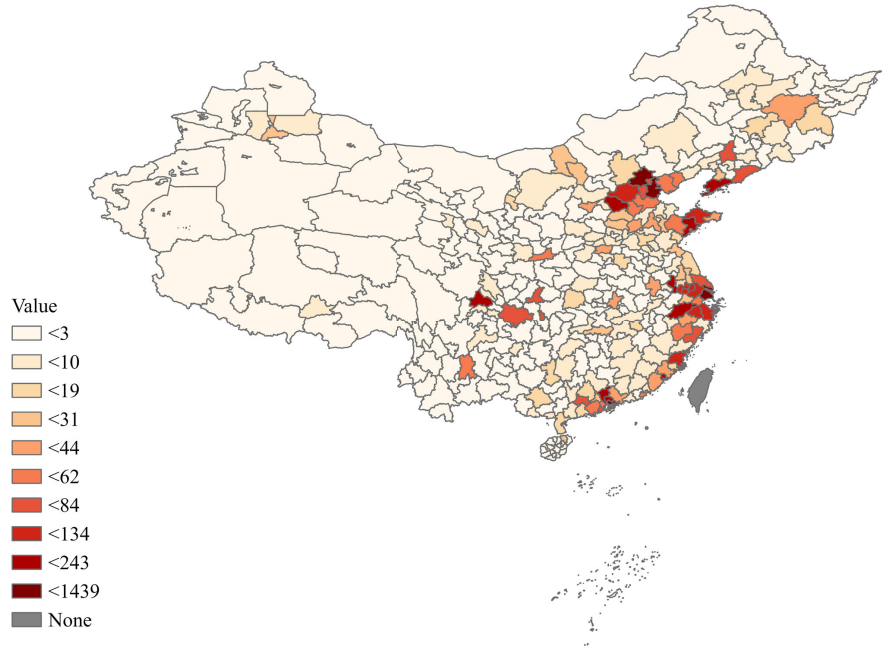
(b) Distance Changes by Ownership Types

Notes: The figure shows the distribution of the number of exporters in each city.

Figure 3: Geographic Distributions of Firms and Products Across Cities



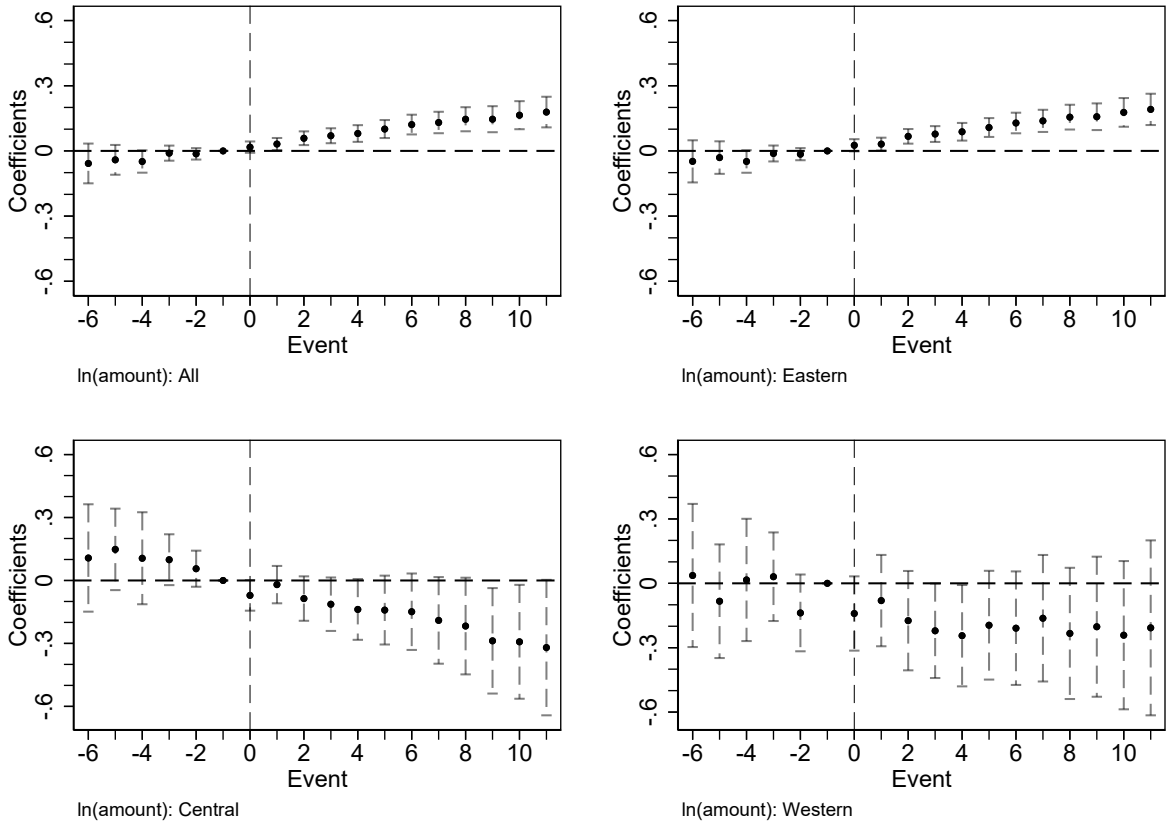
(a) Distribution of Firms



(b) Distribution of 8-digit Products

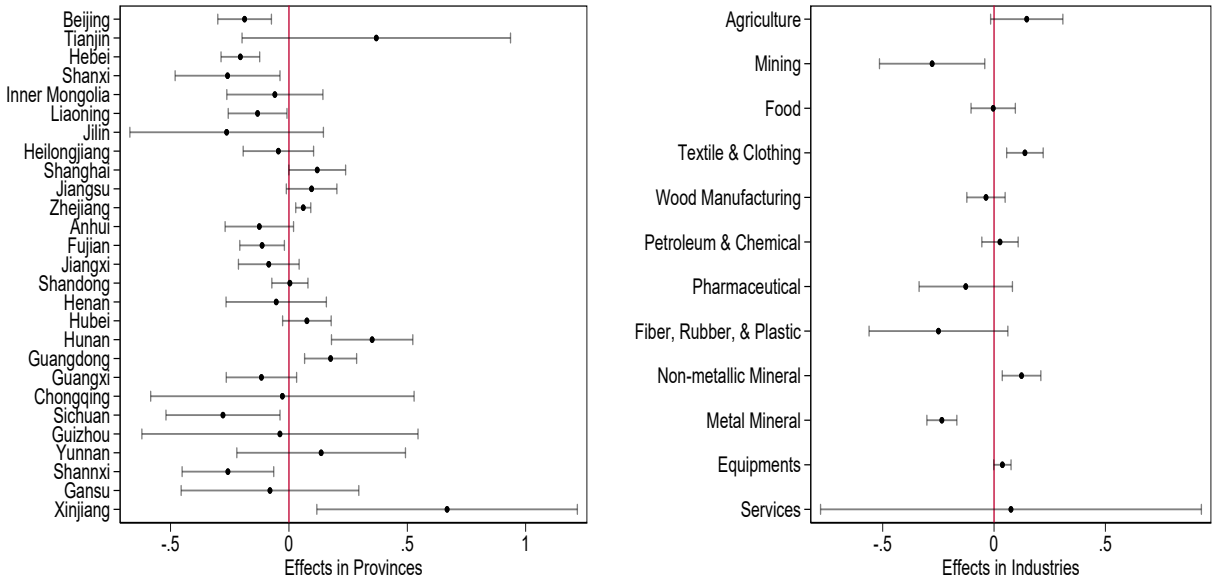
Notes: The figure shows the distribution of exporters and 8-digit products across cities in 2013. We applied the Natural Breaks classification to segment the sample, grouping similar values while maximizing differences between classes.

Figure 4: Dynamic Effects on Exports



Notes: The figure shows the dynamic effects of the ENE on exports by estimating equation (3). The black dots represent the changes in the effects on export amounts over time for the whole country, as well as for the Eastern, Central, and Western regions of China. The upper and lower bounds represent 95% confidence intervals. The regressions also control the firm-product and country-year fixed effects, and the robust standard errors are clustered at the firm level.

Figure 5: Differential Effects Across Provinces and Industries



(a) Effects Across Provinces

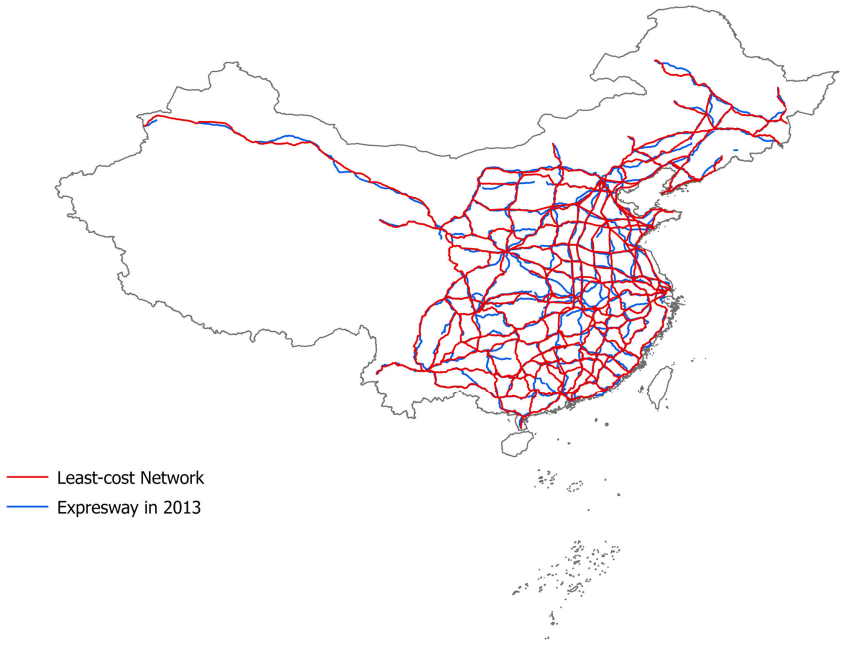
(b) Effects Across Industries

Notes: This figure illustrates the impact of the ENE on firms' exports across provinces and industries, using a 40 km threshold to define the treated group. The black dots represent estimated coefficients for each province and industry, while the error bars indicate 95% confidence intervals. The regressions control for firm-product and country-year fixed effects, with robust standard errors clustered at the firm level. Industries are classified based on the 2002 Chinese Industry Classification (CIC) system: Agriculture (CIC code ¡ 6), Mining (CIC codes 6-12), Food Manufacturing (CIC codes 13-15), Textiles and Clothing (CIC codes 17-19), Wood Manufacturing (CIC codes 20-24), Petroleum and Chemical (CIC codes 25, 26), Pharmaceuticals (CIC codes 7, 27), Fiber, Rubber, and Plastics (CIC codes 8, 28-29), Non-metallic Minerals (CIC codes 9, 30), Metal Minerals (CIC codes 10, 31-33), Equipment Manufacturing (CIC codes 34-43), and Services (CIC codes $\geq$ 62). Other CIC industries are excluded due to limited observations.

Figure 6: Ming Roads and Least-Cost Paths vs. 2013 Expressways



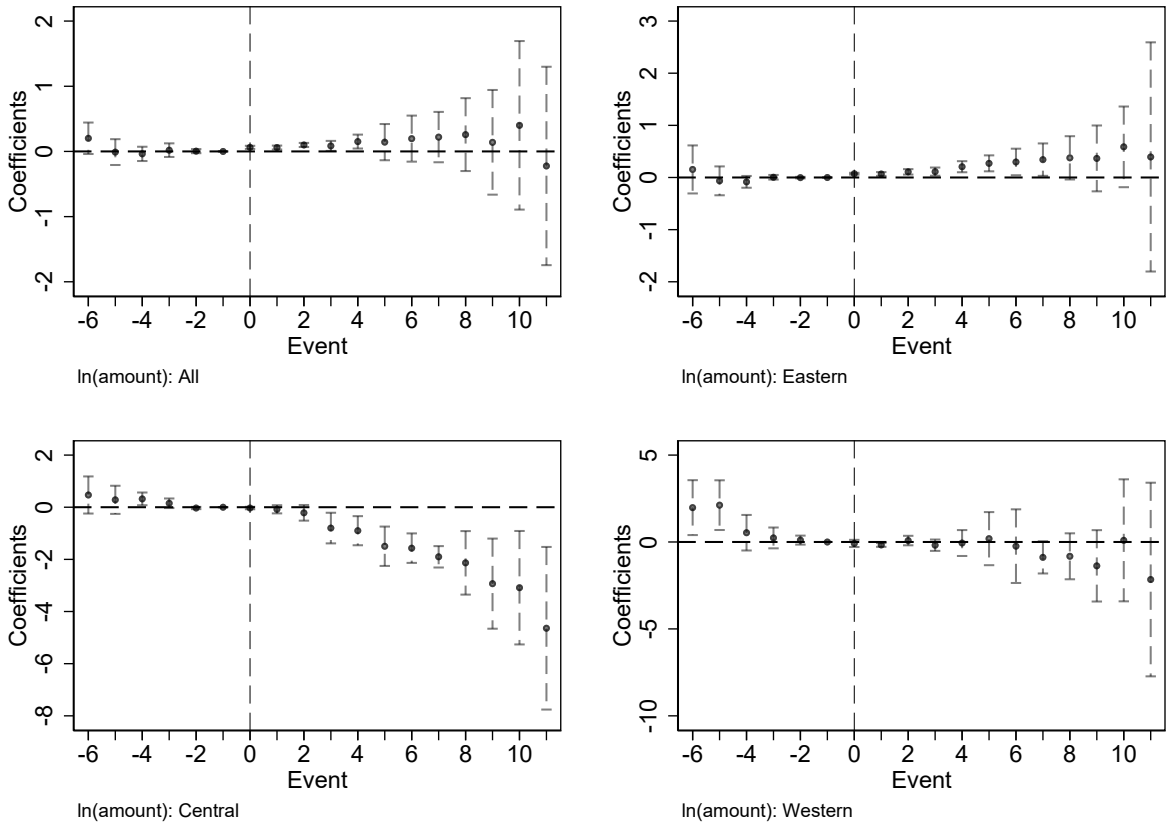
(a) Ming Dynasty Courier Road Network



(b) Least-cost Spanning Tree Network

Notes: The figure compares the differences between the 2013 expressway network and the roads used as instrumental variables. Both graphs display the 2013 expressway network: graph (a) overlays the Ming Dynasty Courier road network, while graph (b) includes the least-cost spanning tree network.

Figure 7: Dynamic Effects on Exports With a Staggered DID Approach



Notes: This figure presents the results obtained using the De Chaisemartin and d'Haultfoeuille (2020) estimator to address concerns related to the staggered difference-in-differences approach. The first graph displays the effects on all firms, while the subsequent three graphs illustrate the dynamic effects on firms' exports in Eastern, Central, and Western China, respectively. The black dots represent the estimated changes in export effects over time, with the upper and lower bounds indicating the 95% confidence intervals. The regressions incorporate firm-product and country-year fixed effects, with robust standard errors clustered at the firm level.

Tables

Table 1: Descriptive Statistics

	Group	2000-2013			2000			2013		
		Obs.	Mean	Std. Dev.	Obs.	Mean	Std. Dev.	Obs.	Mean	Std. Dev.
Panel A: Sample A - Customs data										
Distance to Expressways	All	1,597,587	12.819	13.990	15,137	16.008	16.996	179,225	11.685	12.243
	Eastern	1,445,632	12.711	13.709	14,074	15.916	16.700	161,443	11.686	12.139
	Central	104,654	15.124	16.622	670	20.277	20.927	12,754	12.291	12.869
	Western	47,301	10.994	15.485	393	12.024	18.642	5,028	10.126	13.703
	SOEs	70,190	11.737	14.107	1,246	16.552	19.677	4,299	9.542	10.315
	FFs	799,509	12.688	14.081	13,029	15.416	16.121	63,798	11.259	12.294
	PFs	727,888	13.066	13.870	862	24.175	22.661	111,128	12.013	12.266
ln(amount)	All	35,786,072	7.377	3.289	471,223	5.422	3.893	4,121,678	6.840	3.495
	Eastern	32,836,500	7.381	3.274	455,684	5.466	3.889	3,665,682	6.848	3.497
	Central	1,689,358	7.460	3.652	10,607	4.224	3.811	242,200	6.795	3.792
	Western	1,260,214	7.153	3.142	4,932	3.893	3.715	213,796	6.753	3.087
	SOEs	4,894,046	7.494	3.323	20,474	4.531	3.945	335,737	6.560	3.652
	FFs	15,054,912	7.295	3.456	443,355	5.454	3.885	1,539,060	6.592	3.699
	PFs	15,837,114	7.418	3.109	7,394	5.958	3.892	2,246,881	7.051	3.309
ln(price)	All	35,786,072	6.454	2.384	471,223	2.750	3.056	471,223	7.232	2.390
	Eastern	32,836,500	6.441	2.358	455,684	2.704	3.043	455,684	7.229	2.361
	Central	1,689,358	6.628	2.769	10,607	3.965	3.040	10,607	7.349	2.795
	Western	1,260,214	6.547	2.495	4,932	4.340	3.266	4,932	7.149	2.373
	SOEs	4,894,046	6.358	2.543	20,474	3.977	3.342	20,474	7.467	2.796
	FFs	15,054,912	6.589	2.348	443,355	2.698	3.031	443,355	7.422	2.308
	PFs	15,837,114	6.355	2.362	7,394	2.458	2.957	7,394	7.067	2.367
Panel B: Sample B - Industry firm data										
Distance to Expressways	All	2,410,761	15.473	16.271	72,537	23.201	22.990	253,212	13.706	14.124
	Eastern	1,790,813	14.579	14.705	54,636	21.957	21.648	169,572	13.005	12.627
	Central	454,131	18.409	19.471	11,998	29.481	26.216	62,987	15.307	16.372
	Western	165,817	17.089	20.990	5,903	21.947	25.781	20,653	14.582	17.507
	SOEs	71,970	17.224	20.345	10,007	23.941	24.953	2,069	12.618	14.171
	FFs	541,051	12.942	14.050	19,015	17.040	18.015	42,110	11.653	12.440
	PFs	1,797,740	16.186	16.651	43,515	25.723	23.938	209,033	14.131	14.403
ln(TFP)	All	2,410,761	3.093	1.015	72,537	3.469	0.936	253,212	2.388	0.403
	Eastern	1,790,813	3.110	1.017	54,636	3.518	0.911	169,572	2.361	0.402
	Central	454,131	3.067	1.024	11,998	3.400	0.998	62,987	2.442	0.399
	Western	165,817	2.986	0.965	5,903	3.155	0.965	20,653	2.438	0.403
	SOEs	71,970	3.088	0.970	10,007	2.968	0.969	2,069	2.574	0.436
	FFs	541,051	3.217	1.030	19,015	3.535	0.957	42,110	2.447	0.428
	PFs	1,797,740	3.064	1.011	43,515	3.555	0.882	209,033	2.374	0.396
ln(markups)	All	2,410,761	1.286	1.028	72,537	0.786	0.910	253,212	1.364	0.997
	Eastern	1,790,813	1.264	1.024	54,636	0.802	0.907	169,572	1.280	0.992
	Central	454,131	1.405	1.048	11,998	0.812	0.937	62,987	1.598	0.993
	Western	165,817	1.203	0.988	5,903	0.581	0.860	20,653	1.338	0.927
	SOEs	71,970	0.644	1.004	10,007	0.341	0.863	2,069	0.815	1.027
	FFs	541,051	1.032	1.033	19,015	0.758	0.908	42,110	0.916	0.947
	PFs	1,797,740	1.386	1.004	43,515	0.901	0.889	209,033	1.459	0.980
ln(HHI)	All	37,433	0.200	0.239	2,756	0.277	0.268	2,736	0.134	0.201
	Eastern	12,500	0.096	0.145	918	0.149	0.182	889	0.069	0.141
	Central	15,328	0.197	0.211	1,129	0.295	0.254	1,099	0.123	0.184
	Western	9,605	0.339	0.301	709	0.414	0.306	748	0.228	0.247
ln(misallocation)	All	35,723	0.667	0.393	2,558	0.582	0.370	2,661	0.702	0.350
	Eastern	12,368	0.696	0.333	899	0.627	0.280	879	0.716	0.265
	Central	14,871	0.670	0.404	1,055	0.575	0.356	1,073	0.721	0.375
	Western	8,484	0.620	0.446	604	0.528	0.486	709	0.659	0.398

Notes: This table describes Samples A and B, spanning the years 2000 to 2013, along with specific snapshots from 2000 and 2013. Sample A is organized at the 8-digit product-firm-destination-country-year level, while Sample B is structured at the firm-year level. The last two dependent variables in Sample B are aggregated at the county-year level. The table also provides descriptions of firms located in Eastern, Central, and Western China, as well as state-owned enterprises (SOEs), foreign firms (FFs), and private firms (PFs).

Table 2: Effects on Exports of Firms in Different Distance Intervals

	ln(amount)			
	(1)	(2)	(3)	(4)
$\text{Distance}_{it}(0-10)$	0.104***	0.112***	-0.098*	-0.216**
	(0.024)	(0.024)	(0.051)	(0.095)
$\text{Distance}_{it}(10-20)$	0.073***	0.076***	-0.142***	-0.190*
	(0.022)	(0.022)	(0.054)	(0.103)
$\text{Distance}_{it}(20-30)$	0.077***	0.077***	-0.016	-0.105
	(0.021)	(0.021)	(0.054)	(0.118)
$\text{Distance}_{it}(30-40)$	0.067***	0.069***	-0.043	-0.149
	(0.023)	(0.022)	(0.058)	(0.129)
$\text{Distance}_{it}(40-50)$	0.048*	0.062**	-0.064	-0.132
	(0.025)	(0.026)	(0.065)	(0.120)
Constant	7.287***	7.286***	7.557***	7.354***
	(0.020)	(0.020)	(0.045)	(0.085)
Firm-Product FE	Yes	Yes	Yes	Yes
Country-Year FE	Yes	Yes	Yes	Yes
District		Eastern	Central	Western
Observations	35,786,072	32,836,500	1,689,358	1,260,214
Adjusted R^2	0.660	0.672	0.779	0.732

Notes: This table, based on equation (1), presents the effects of the ENE on exports for firms situated at varying distances from the network. The treated groups consist of firms located within 50 km of the expressway network each year, while the control group comprises firms situated between 50 and 100 km away. Column (1) reports results for the full sample, whereas Columns (2)-(4) present findings for firms located in Eastern, Central, and Western China, respectively. Robust standard errors, clustered at the firm level, are shown in parentheses. Statistical significance is indicated by *** at the 1% level, ** at the 5% level, and * at the 10% level.

Table 3: Average Effects on Exports

	ln(amount)					
	(1)	(2)	(3)	(4)	(5)	(6)
Treat_{it}	0.044***	0.049***	-0.073*	-0.129*		
	(0.016)	(0.017)	(0.041)	(0.078)		
$\text{Treat}_{it}(County)$					0.026*	
					(0.014)	
$\ln(\text{Distance}_{it})$						-0.023***
						(0.007)
Constant	7.335***	7.334***	7.529***	7.279***	7.362***	7.586***
	(0.015)	(0.016)	(0.038)	(0.076)	(0.009)	(0.058)
Firm-Product FE	Yes	Yes	Yes	Yes	Yes	Yes
Country-Year FE	Yes	Yes	Yes	Yes	Yes	Yes
District		Eastern	Central	Western		
Observations	35,786,072	32,836,500	1,689,358	1,260,214	35,930,382	35,930,382
Adjusted R^2	0.679	0.672	0.779	0.732	0.679	0.680

Notes: This table explores the average effects of the ENE on firms' exports. The first four columns use a 40 km threshold to define the treated and control groups, with Column (1) including all firms and Columns (2)-(4) focusing on firms in Eastern, Central, and Western China. Column (5) defines the treated group based on whether a county is crossed by the expressway network each year, without excluding firms located more than 100 km from the network. The final column examines the elasticity of firm exports with respect to the distance from the firm to the expressway network. All specifications control for firm-product and country-year fixed effects. Robust standard errors are clustered at the firm level and reported in parentheses. *** Statistically significant at the 1% level; ** at the 5% level; and * at the 10% level.

Table 4: Heterogeneous Effects on Exports

	ln(amount)							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	
$Treat_{it}$	0.043***	0.081	0.079***	0.014	0.171***	-0.006	0.034**	
	(0.016)	(0.107)	(0.027)	(0.017)	(0.042)	(0.026)	(0.016)	
Constant	7.321***	8.669***	7.955***	6.933***	7.328***	7.301***	7.385***	
	(0.015)	(0.101)	(0.025)	(0.016)	(0.041)	(0.025)	(0.015)	
Firm-Product FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
Country-Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
Group	Manu	Non-Manu	High Relience	Less Relience	SOEs	FFs	PFs	
Observations	35,410,072	376,000	14,214,195	21,571,877	4,894,046	15,054,912	15,837,114	
Adjusted R^2	0.677	0.781	0.592	0.705	0.678	0.670	0.699	
	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
$Treat_{it}$	0.039	-0.014	0.058***	0.068	-0.004	0.043**	0.046**	0.026
	(0.043)	(0.032)	(0.017)	(0.201)	(0.052)	(0.018)	(0.020)	(0.016)
Constant	5.441***	7.201***	7.976***	8.024***	7.725***	7.388***	7.487***	7.203***
	(0.042)	(0.031)	(0.016)	(0.190)	(0.049)	(0.017)	(0.019)	(0.016)
Firm-Product FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country-Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Group	Capital Goods	Intermediate Goods	Final Goods	Processing Trade	General Trade	Mixed Trade	OECD	Non-OECD
Observations	4,803,899	4,626,043	23,115,702	350,936	1,585,952	21,223,716	17,539,390	18,246,682
Adjusted R^2	0.735	0.644	0.617	0.836	0.791	0.726	0.657	0.738

Notes: This table presents the heterogeneous effects of the ENE on exports across different industries, ownership structures, production types, and destination countries. All columns in each panel are estimated using separate regressions based on equation (2), with the dependent variable being the logarithm of exports. Columns (1)-(2) distinguish between manufacturing and non-manufacturing industries. Columns (3)-(4) compare industries with high versus less road-reliance, categorized by their transportation investment share. Columns (5)-(7) consider variations by firms' ownership types. Columns (8)-(10) assess exports of capital goods, intermediate goods, and final goods. Columns (11)-(13) examine firms involved in both processing and general exports, as well as those engaged solely in either processing or general exports. Finally, Columns (14)-(15) report the effects on exports to OECD versus non-OECD countries. Robust standard errors are clustered at the firm level and are reported in parentheses. Statistical significance is indicated by *** at the 1% level, ** at the 5% level, and * at the 10% level.

Table 5: Extensive Marginal Effects

	Entry				Exit			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
$Treat_{it}$	-0.036***	-0.045***	0.021**	0.009	0.006**	-0.004	0.017**	0.046
	(0.004)	(0.005)	(0.010)	(0.029)	(0.003)	(0.003)	(0.008)	(0.029)
Constant	0.220***	0.225***	0.193***	0.218***	0.098***	0.104***	0.113***	0.113***
	(0.004)	(0.004)	(0.009)	(0.026)	(0.003)	(0.003)	(0.007)	(0.025)
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
District		Eastern	Central	Western		Eastern	Central	Western
Observations	1,530,914	1,381,567	103,076	46,271	1,369,443	1,236,542	91,313	41,588
Adjusted R^2	0.201	0.200	0.213	0.204	0.161	0.160	0.167	0.158
	ln(Number of Product)				ln(Number of Destination Country)			
	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
$Treat_{it}$	0.043***	0.079***	-0.064***	-0.134**	0.064***	0.096***	-0.030	-0.113**
	(0.009)	(0.011)	(0.019)	(0.053)	(0.010)	(0.012)	(0.020)	(0.055)
Constant	1.272***	1.261***	1.110***	1.295***	1.299***	1.285***	1.262***	1.247***
	(0.008)	(0.010)	(0.017)	(0.047)	(0.009)	(0.011)	(0.017)	(0.049)
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
District		Eastern	Central	Western		Eastern	Central	Western
Observations	1,545,354	1,394,990	103,729	46,635	1,545,354	1,394,990	103,729	46,635
Adjusted R^2	0.713	0.714	0.702	0.682	0.738	0.740	0.719	0.685

Notes: This table explores the effects of the ENE on firms' entries and exits by using the firm-year level data in Sample A to estimate equation (2). The dependent variables are the dummy of firms' entries or exits. The regressions also control the firm and county-year fixed effects, and the robust standard errors are clustered at the firm level. *** Statistically significant at the 1% level; ** 5% level; and * 10% level.

Table 6: Instrumental Variable Estimation

	ln(amount)			
	(1)	(2)	(3)	(4)
Panel A: Ming Dynasty Courier Road Network (1368 - 1644)				
$\text{Treat}_{it}(County)$	0.523**	0.715**	-0.540*	-0.375*
	(0.241)	(0.342)	(0.295)	(0.223)
Firm-Product FE	Yes	Yes	Yes	Yes
Country-Year FE	Yes	Yes	Yes	Yes
District		Eastern	Central	Central
Observations	35,620,537	32,866,476	1,533,806	1,220,255
First stage F-Stat	87.410	50.858	39.546	40.451
Panel B: Least-cost Path Spanning Tree Network				
$\text{Treat}_{it}(County)$	0.362***	0.487***	-0.704**	-0.243
	(0.131)	(0.151)	(0.275)	(0.194)
Firm-Product FE	Yes	Yes	Yes	Yes
Country-Year FE	Yes	Yes	Yes	Yes
District		Eastern	Central	Central
Observations	35,930,382	32,869,556	1,747,192	1,313,634
First stage F-Stat	215.208	159.901	66.094	45.509

Notes: This table addresses concerns regarding endogeneity. Panel A presents results using the Ming Dynasty courier road network as the instrumental variable (IV), while Panel B shows results using the least-cost path spanning tree network as the IV. Because the Ming Dynasty did not encompass Inner Mongolia, Jilin, Heilongjiang, Tibet, Qinghai, and Xinjiang, firms from these provinces are excluded from Panel A. The independent variable is the interaction between whether the firm's county is traversed by the network and the budget ratio of the firm's city. The dependent variable is the logarithm of export amounts. Column (1) reports results for the full sample, whereas Columns (2)-(4) provide results for firms located in Eastern, Central, and Western China, respectively. All regressions include firm-product and country-year fixed effects, with robust standard errors clustered at the firm level, reported in parentheses. Statistical significance is denoted by *** at the 1% level, ** at the 5% level, and * at the 10% level.

Table 7: Impacts From Other Transportation Systems

	ln(amount)			
	(1)	(2)	(3)	(4)
Panel A: Control the Impact From Railways				
$Treat_{it}$	0.051***	0.055***	-0.071	-0.112
	(0.016)	(0.018)	(0.048)	(0.094)
Constant	7.594***	7.573***	8.014***	8.085***
	(0.015)	(0.017)	(0.043)	(0.079)
Product-Year FE	Yes	Yes	Yes	Yes
Country-Year FE	Yes	Yes	Yes	Yes
District		Eastern	Central	Western
Observations	24,389,063	23,162,762	1,017,431	208,870
Adjusted R^2	0.662	0.655	0.766	0.770
Panel B: Control the Impact From Waterways				
$Treat_{it}$	0.038**	0.041**	-0.088*	-0.129
	(0.015)	(0.017)	(0.048)	(0.079)
Constant	7.353***	7.340***	7.907***	7.409***
	(0.015)	(0.016)	(0.044)	(0.077)
Product-Year FE	Yes	Yes	Yes	Yes
Country-Year FE	Yes	Yes	Yes	Yes
District		Eastern	Central	Western
Observations	32,625,435	30,689,202	971,219	965,014
Adjusted R^2	0.677	0.672	0.777	0.749
Panel C: Control the Impact From Other Amenities				
$Treat_{it}$	0.051**	0.052**	-0.032	-0.006
	(0.021)	(0.023)	(0.046)	(0.098)
Constant	7.771***	7.736***	8.372***	8.069***
	(0.019)	(0.020)	(0.039)	(0.072)
Product-Year FE	Yes	Yes	Yes	Yes
Country-Year FE	Yes	Yes	Yes	Yes
District		Eastern	Central	Western
Observations	9,100,283	8,500,289	493,438	106,556
Adjusted R^2	0.662	0.654	0.760	0.808

Notes: This table examines the effects of the ENE on exports while controlling for the influence of railways, waterways, and other transport-related amenities. Using Sample A as a baseline, Panel A excludes firms located in railway hub cities, Panel B excludes firms in inland port cities, and Panel C excludes firms in urban districts (shi xia qu) to mitigate the impact of these transport-related factors. Columns (1)-(4) present the results for all firms, as well as for firms in Eastern, Central, and Western China across each subsample. All regressions include firm-product and country-year fixed effects, with robust standard errors areclustered at the firm level (reported in parentheses). Statistical significance is indicated by *** at the 1% level, ** at the 5% level, and * at the 10% level.

Table 8: Effects on Exports of Intermediary and Incumbent Firms

	ln(amount)				
	(1)	(2)	(3)	(4)	(5)
Distance$_{it}$ $(0-10)$	-0.100	0.162***	0.194***	-0.194*	-0.535***
	(0.082)	(0.043)	(0.048)	(0.105)	(0.165)
Distance$_{it}$ $(10-20)$	-0.067	0.145***	0.175***	-0.177*	-0.271*
	(0.097)	(0.038)	(0.042)	(0.093)	(0.141)
Distance$_{it}$ $(20-30)$	-0.093	0.133***	0.154***	0.027	-0.253
	(0.087)	(0.037)	(0.041)	(0.096)	(0.200)
Distance$_{it}$ $(30-40)$	-0.073	0.119***	0.135***	-0.055	-0.915***
	(0.076)	(0.046)	(0.051)	(0.092)	(0.174)
Distance$_{it}$ $(40-50)$	-0.087	0.212***	0.236***	-0.038	-0.783***
	(0.081)	(0.052)	(0.054)	(0.127)	(0.242)
Constant	7.494***	7.414***	7.398***	7.505***	7.734***
	(0.081)	(0.034)	(0.038)	(0.083)	(0.138)
Firm-Product FE	Yes	Yes	Yes	Yes	Yes
Country-Year FE	Yes	Yes	Yes	Yes	Yes
District			Eastern	Central	Western
Intermediary	Yes				
Observations	42,400,091	7,407,857	7,001,667	298,197	107,993
Adjusted R^2	0.641	0.650	0.642	0.766	0.760

Notes: This table explores the ENE effects on exports of the intermediary firms in Column (1) and the incumbent firms in Columns (2)-(5). Columns (1) and (2) include all firms in each subsample. Columns (3)-(5) include the firms in Eastern, Central, and Western China, respectively. All regressions include firm-product and country-year fixed effects, with robust standard errors clustered at the firm level (reported in parentheses). Statistical significance is indicated by *** at the 1% level, ** at the 5% level, and * at the 10% level.

Table 9: Effects on Export Prices

	ln(price)			
	(1)	(2)	(3)	(4)
Distance$_{it}$ (0 – 10)	-0.039***	-0.051***	0.067*	0.054
	(0.012)	(0.013)	(0.038)	(0.056)
Distance$_{it}$ (10 – 20)	-0.030***	-0.043***	0.074*	0.036
	(0.011)	(0.012)	(0.038)	(0.070)
Distance$_{it}$ (20 – 30)	0.003	0.001	0.007	0.048
	(0.011)	(0.012)	(0.033)	(0.049)
Distance$_{it}$ (30 – 40)	-0.000	-0.005	0.040	0.027
	(0.011)	(0.011)	(0.031)	(0.072)
Distance$_{it}$ (40 – 50)	-0.022*	-0.018	-0.067	-0.114
	(0.012)	(0.012)	(0.047)	(0.078)
Constant	6.485***	6.482***	6.570***	6.500***
	(0.009)	(0.010)	(0.033)	(0.047)
Firm-Product FE	Yes	Yes	Yes	Yes
Country-Year FE	Yes	Yes	Yes	Yes
District		Eastern	Central	Western
Observations	35,786,072	32,836,500	1,689,358	1,260,214
Adjusted R^2	0.908	0.906	0.934	0.912

Notes: Building on Table 2, this table examines the effects of the ENE on export prices for firms located at different distances from the network. The dependent variable is the logarithm of export prices. The treated groups include firms within 50 km of the expressway network each year, while the control group consists of firms located between 50 and 100 km away. Column (1) reports the results for the full sample, while Columns (2)-(4) present findings for firms in Eastern, Central, and Western China, respectively. All regressions incorporate firm-product and country-year fixed effects, and robust standard errors are clustered at the firm level are reported in parentheses. Statistical significance is denoted by *** at the 1% level, ** at the 5% level, and * at the 10% level.

Table 10: Effects on Productivity and Markups

	ln(TFP)				ln(markups)			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Distance$_{it}$ (0 – 10)	0.067***	0.071***	0.016	0.145***	0.147***	0.169***	0.118***	0.090***
	(0.007)	(0.008)	(0.012)	(0.024)	(0.007)	(0.008)	(0.013)	(0.022)
Distance$_{it}$ (10 – 20)	0.042***	0.045***	-0.000	0.158***	0.113***	0.141***	0.088***	0.024
	(0.007)	(0.009)	(0.013)	(0.030)	(0.007)	(0.008)	(0.014)	(0.027)
Distance$_{it}$ (20 – 30)	0.031***	0.022**	0.027*	0.080**	0.099***	0.113***	0.088***	0.064*
	(0.007)	(0.009)	(0.014)	(0.036)	(0.007)	(0.008)	(0.015)	(0.034)
Distance$_{it}$ (30 – 40)	0.034***	0.032***	0.012	0.023	0.060***	0.082***	0.039**	0.054
	(0.008)	(0.009)	(0.015)	(0.034)	(0.008)	(0.009)	(0.016)	(0.033)
Distance$_{it}$ (40 – 50)	0.026***	0.013	0.026	0.069**	0.025***	0.034***	0.031*	0.015
	(0.008)	(0.010)	(0.017)	(0.033)	(0.008)	(0.010)	(0.017)	(0.034)
Constant	3.043***	3.058***	3.054***	2.869***	1.169***	1.124***	1.316***	1.139***
	(0.006)	(0.007)	(0.010)	(0.019)	(0.005)	(0.007)	(0.010)	(0.018)
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry-Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
District		Eastern	Central	Western		Eastern	Central	Western
Observations	2,410,761	1,790,813	454,131	165,817	2,410,761	1,790,813	454,131	165,817
Adjusted R^2	0.669	0.670	0.688	0.639	0.618	0.639	0.575	0.622

Notes: This table examines the effects of the ENE on firms' productivity and markups across varying distances from the network. The dependent variables in Columns (1)-(4) are the logarithms of firms' TFP, measured following Ackerberg et al. (2015), while the dependent variables in Columns (5)-(8) are the logarithms of firms' markups, measured following De Loecker and Warzynski (2012). Column (1) and Column (5) include the full sample, whereas the remaining columns present results for firms in Eastern, Central, and Western China, respectively. All regressions include firm and industry-year fixed effects, with robust standard errors clustered at the firm level shown in parentheses. Statistical significance is indicated by *** at the 1% level, ** at the 5% level, and * at the 10% level.

Table 11: Effects on Market Competition and Misallocation

	At the County-Year Level				At the County-Industry-Year Level			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Panel A: Dependent Variable - ln(HHI)								
$Treat_{it}(County)$	-0.070***	-0.051***	-0.075***	-0.092***	-0.063***	-0.073***	-0.054***	-0.053***
	(0.004)	(0.005)	(0.006)	(0.010)	(0.004)	(0.008)	(0.005)	(0.009)
Constant	0.227***	0.120***	0.224***	0.370***	0.633***	0.560***	0.694***	0.729***
	(0.003)	(0.004)	(0.005)	(0.007)	(0.003)	(0.006)	(0.004)	(0.006)
District		Eastern	Central	Western		Eastern	Central	Western
City FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes				
Industry-Year FE					Yes	Yes	Yes	Yes
Observations	37,433	12,500	15,328	9,605	440,139	213,463	159,661	67,015
Adjusted R^2	0.447	0.365	0.316	0.439	0.244	0.255	0.173	0.171
Panel B: Dependent Variable - missallocation								
$Treat_{it}(County)$	0.015*	-0.024*	0.035***	0.046***	0.004	-0.012	0.026**	0.014
	(0.008)	(0.014)	(0.011)	(0.015)	(0.006)	(0.009)	(0.010)	(0.016)
Constant	0.661***	0.708***	0.657***	0.604***	0.613***	0.637***	0.588***	0.576***
	(0.005)	(0.010)	(0.007)	(0.010)	(0.005)	(0.007)	(0.007)	(0.012)
District		Eastern	Central	Western		Eastern	Central	Western
City FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes				
Industry-Year FE					Yes	Yes	Yes	Yes
Observations	35,723	12,368	14,871	8,484	278,281	153,995	89,620	34,666
Adjusted R^2	0.122	0.193	0.098	0.088	0.041	0.050	0.033	0.039

Notes: This table analyzes the effects of the ENE on market competition and resource misallocation. The dependent variables in Panel A are the Herfindahl-Hirschman Index (HHI), while those in Panel B represent misallocation, measured by the variance of ln(TFPR). Data in Columns (1)-(4) is aggregated at the county-year level, while data in Columns (5)-(8) is aggregated at the county-industry-year level. Columns (1) and (5) present results for all regions, whereas the remaining columns provide results for firms in Eastern, Central, and Western China, respectively. The regressions in Columns (1)-(4) include city and year fixed effects, while those in Columns (5)-(8) include city and industry-year fixed effects. Robust standard errors, clustered at the county level, are reported in parentheses. Statistical significance is denoted by *** at the 1% level, ** at the 5% level, and * at the 10% level.

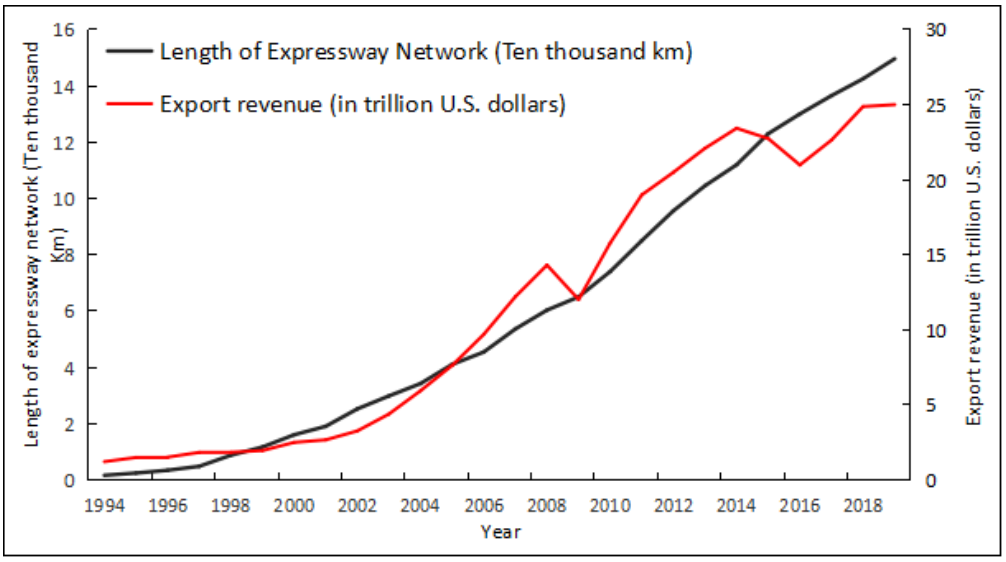
Online Appendix

Expressway Expansion, International Trade, and Spatial Imbalance

The online appendix shows additional figures, tables, and supplementary that are omitted from the main paper due to space constraints.

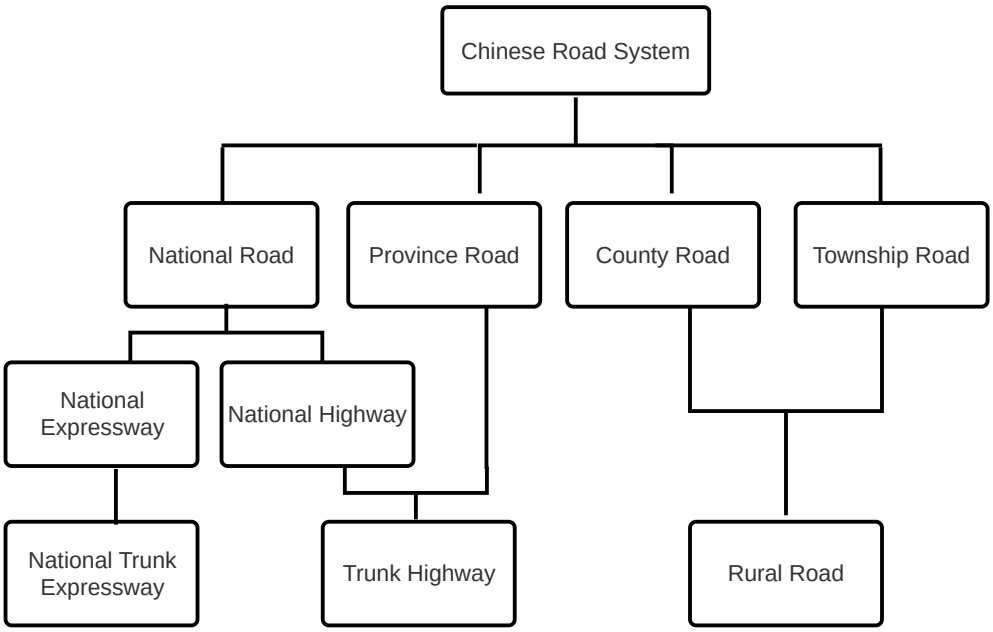
Appendix A: Other figures

Figure A1: Development of Chinese Expressways and Exports



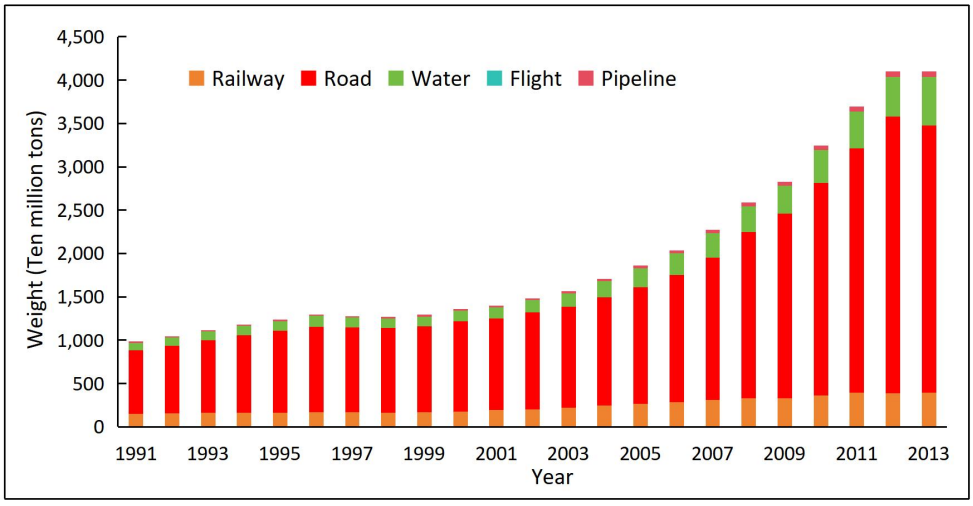
Note: The data are from The Chinese Statistical Yearbooks. The black line is the cumulative total length of the expressway network each year. The red line is the Chinese export revenue each year.

Figure A2: Chinese Road Framework



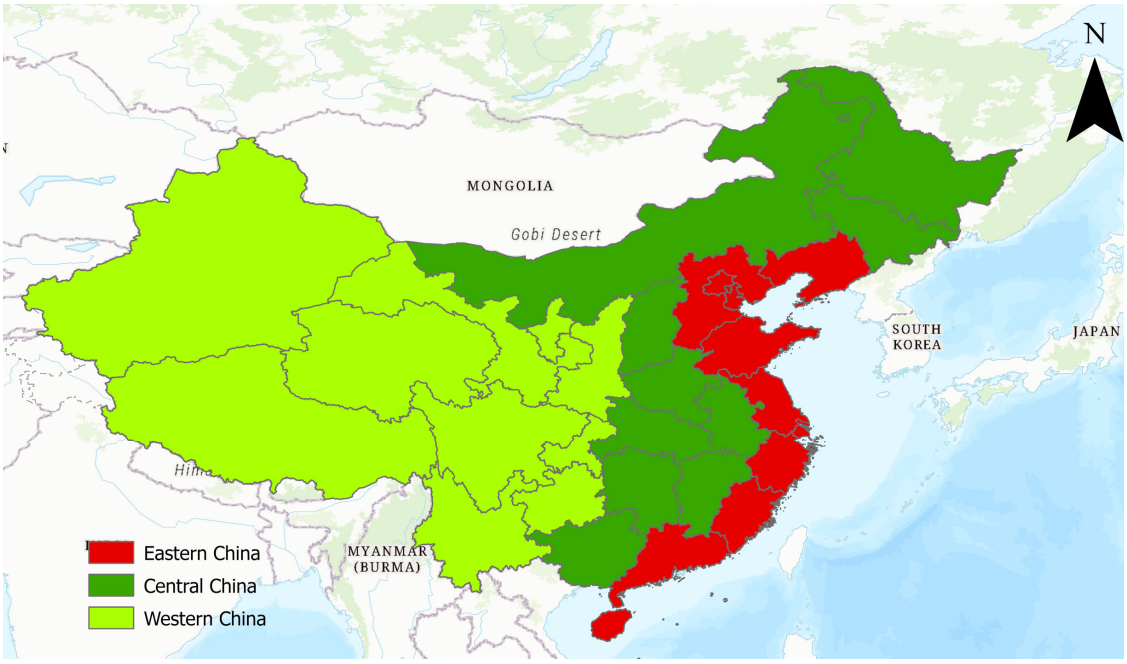
Notes: This figure shows the Chinese road system. The Chinese road system includes national, province, county, and township roads. Each type of road is designed to meet specific transportation needs, from high-speed travel between major cities to local access in rural areas. The main differences between these roads are their width, quality, speed, and the areas they connect. Also, expressways charge tolls.

Figure A3:Proportion of Different Types of Cargo Transportation in China



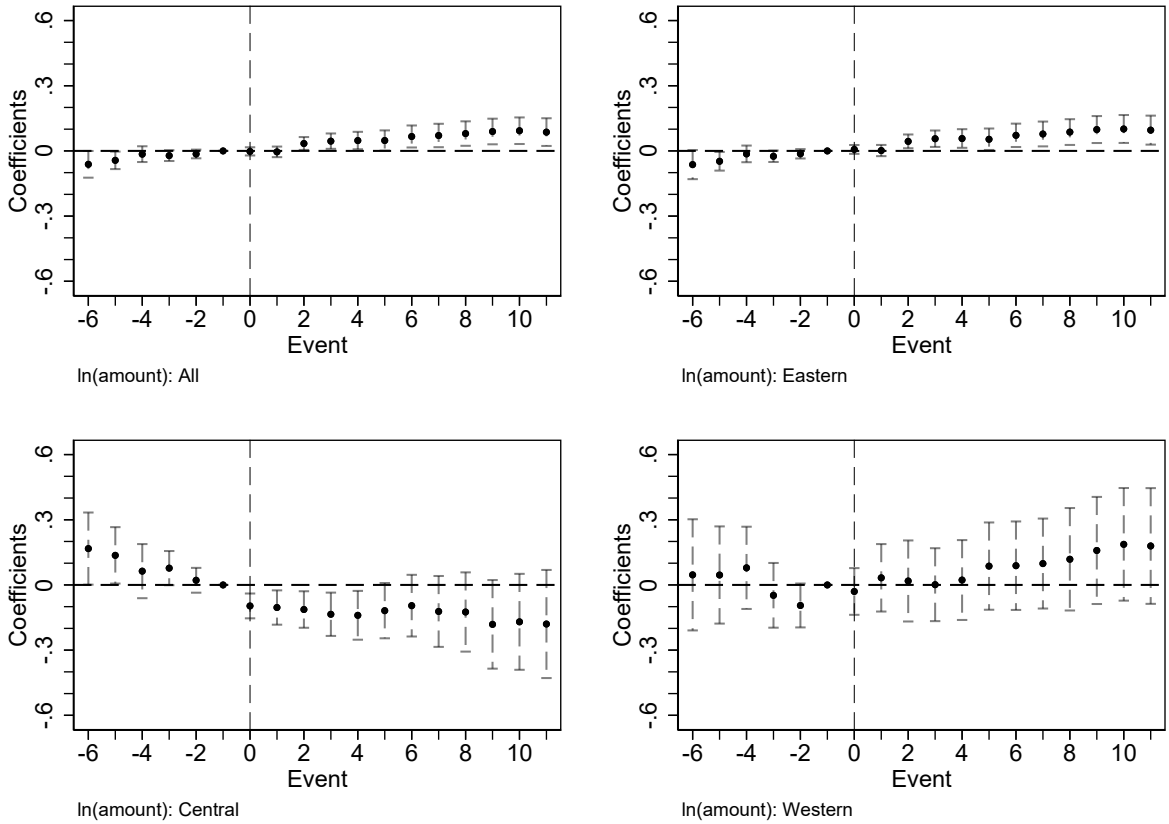
Notes: This figure presents cargo transportation volumes by different modes from 1991 to 2013, using data from the China Transportation Yearbook.

Figure A4: Dynamic Effects on Exports



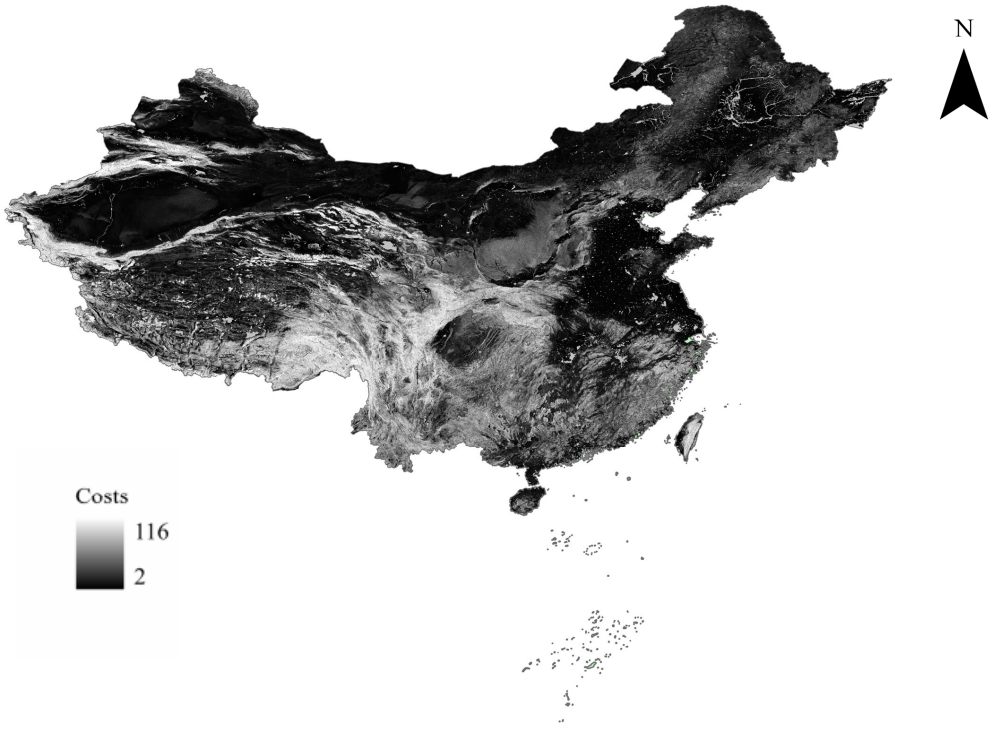
Notes: The figure shows the geographical distribution of Eastern, Central, and Western China.

Figure A5: Dynamic Effects on Exports



Notes: The figure shows the dynamic effects of the ENE on exports by estimating equation (3), while the treated group is defined by whether the county where the firm is located has been crossed by an expressway each year. The black dots represent the changes in the effects on export amounts over time for the whole country, as well as for the Eastern, Central, and Western regions of China. The upper and lower bounds represent 95% confidence intervals. The regressions also control the firm-product and country-year fixed effects, and the robust standard errors are clustered at the firm level.

Figure A6:Construction Cost Grid



Notes: The figure illustrates the construction cost grid used as input for the least-cost path algorithm. The color gradient ranges from white to black, from high traversal costs to low per 900 square meters. Following Faber (2014), cost values are assigned based on factors such as terrain gradient (slope) and land cover types, including features like water bodies, wetlands, and urbanized areas.

Appendix B: Other tables

Table A1: Chinese Transportation Atlases (1992 - 2013)

Year	Title (English)	Publisher	Edition number	Print number
2013	China Transport and Tourism Atlas	China Communications Press	Version 2, January 2014	1st printing, January 2014
2012	Newly compiled China Transport and Tourism Atlas	Shandong Provincial Map Publishing House	Version 6, January 2013	6th printing, January 2013
2011	China Transportation Atlas	SinoMaps Press	Version 1, January 2012	1st printing, January 2012
2010	China Transportation Atlas	Shandong Provincial Map Publishing House	Version 5, January 2011	9th printing, January 2011
2010	China Transportation Atlas	SinoMaps Press	Version 1, January 2009	8th printing, January 2011
2009	China Transport and Tourism Atlas	China Tourism Publishing House	Version 4, February 2010	8th printing, February 2010
2009	China Transportation Atlas	SinoMaps Press	Version 1, January 2009	4th printing, January 2010
2008	China Transportation Atlas	SinoMaps Press	Version 1, January 2009	2nd printing, April 2009
2007	China Transport and Tourism Atlas	Shandong Provincial Map Publishing House	Version 4, January 2008	11th printing, April 2008
2006	China Transportation Atlas	Fujian Map Publishing House	Version 1, January 2007	1st printing, January 2007
2006	China Transportation Atlas	SinoMaps Press	Version 2, March 2007	4th printing, April 2007
2006	China Transportation Atlas	SinoMaps Press	Version 1, January 2007	2nd printing, January 2007
2005	China Transport and Tourism Atlas	China Communications Press	Version 1, April 2006	5th printing, April 2006
2005	China Transport and Tourism Atlas	SinoMaps Press	Version 1, January 2006	2nd printing, January 2006
2004	China Transportation Atlas	China Communications Press	Version 2, January 2005	7th printing, January 2005
2003	China Transportation Atlas	China Communications Press	Version 1, October 2004	6th printing, October 2004
2003	Mini China Atlas	SinoMaps Press	Version 1, January 2004	7th printing, January 2004
2002	China Transportation Atlas	SinoMaps Press	Version 2, June 2003	12th printing, June 2003
2001	China Transportation Atlas	SinoMaps Press	Version 3, July 2002	10th printing, July 2002
2000	China Transportation Atlas	Hunan Map Publishing House	Version 1, January 2001	2nd printing, April 2001
1999	China Traffic Atlas	SinoMaps Press	Version 1, July 2000	2nd printing, July 2000
1999	Newly China Traffic Atlas	Academy Press	Version 3, February 2000	3rd printing, February 2000
1998	China Transportation Atlas	Xi'an Map Publishing House	Version 3, May 1999	3rd printing, May 1999
1997	Newly China Traffic Atlas	SinoMaps Press	Version 1, March 1998	1st printing, March 1998
1996	China Traffic Atlas	Surveying and Mapping Publishing House	Version 1, January 1997	1st printing, January 1997
1995	Newly China Traffic Atlas	Geological Publishing House	Version 1, January 1996	1st printing, January 1996
1994	China Transport and Tourism Atlas	SinoMaps Press	Version 1, March 1995	7th printing, March 1995
1993	China Transportation Atlas	SinoMaps Press	Version 5, February 1994	46th printing, March 1995
1992	China Transportation Atlas	SinoMaps Press	Version 5, February 1993	45th printing, February 1993

Notes: This table shows the atlases that used to hand-collect and digitize the expressway information each year.

Table A2: Effects on Exports of Firms in Different Distance Intervals

	ln(amount)			
	(1)	(2)	(3)	(4)
$\text{Distance}_{it}(0-10)$	0.104***	0.110***	0.099***	0.076***
	(0.024)	(0.029)	(0.025)	(0.023)
$\text{Distance}_{it}(10-20)$	0.073***	0.079***	0.066***	0.062***
	(0.022)	(0.029)	(0.023)	(0.021)
$\text{Distance}_{it}(20-30)$	0.077***	0.125***	0.074***	0.075***
	(0.021)	(0.026)	(0.021)	(0.019)
$\text{Distance}_{it}(30-40)$	0.067***	0.079**	0.064***	0.047**
	(0.023)	(0.035)	(0.022)	(0.021)
$\text{Distance}_{it}(40-50)$	0.048*	0.048	0.050**	0.008
	(0.025)	(0.029)	(0.025)	(0.023)
Constant	7.287***	7.278***	7.292***	7.309***
	(0.020)	(0.023)	(0.021)	(0.020)
Firm-Product FE	Yes		Yes	Yes
Firm FE		Yes		
Year FE	Yes	Yes	Yes	
Product FE		Yes		
Country FE			Yes	
Product-Year FE				Yes
Observations	35,786,072	35,786,072	35,786,072	35,786,072
Adjusted R^2	0.660	0.510	0.679	0.664

Notes: Aligned with Table 2, this table reports the impact of the ENE on firm exports across different distance ranges, incorporating various fixed effects. Robust standard errors, clustered at the firm level, are provided in parentheses. Statistical significance is indicated by *** at the 1% level, ** at the 5% level, and * at the 10% level.

Table A3: Average Effects on Exports

	ln(amount)					
	(1)	(2)	(3)	(4)	(5)	(6)
$\text{Treat}_{it}(County)$	0.038***	-0.130***	-0.041			
	(0.015)	(0.034)	(0.049)			
$\ln(\text{Distance}_{it})$				-0.029***	0.034**	0.054**
				(0.007)	(0.015)	(0.023)
Constant	7.356***	7.561***	7.219***	7.636***	7.169***	6.719***
	(0.010)	(0.020)	(0.030)	(0.065)	(0.134)	(0.200)
Firm-Product FE	Yes	Yes	Yes	Yes	Yes	Yes
Country-Year FE	Yes	Yes	Yes	Yes	Yes	Yes
District	Eastern	Central	Western	Eastern	Central	Western
Observations	32,869,556	1,747,192	1,313,634	32,869,556	1,747,192	1,313,634
Adjusted R^2	0.672	0.778	0.737	0.672	0.778	0.737

Notes: This table presents the estimation results for the specifications in Columns (5) and (6) of Table 3, disaggregated by firms located in Eastern, Central, and Western China. All models include firm-product and country-year fixed effects to account for unobserved heterogeneity. Robust standard errors, clustered at the firm level, are shown in parentheses. Statistical significance is indicated by *** at the 1% level, ** at the 5% level, and * at the 10% level.

Table A4: Heterogeneous Effects on Exports of Manufacturing and Non-manufacturing

	ln(amount)					
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A: Manufacturing Industries						
$Treat_{it}$	0.048***	-0.071*	-0.102	0.173***	-0.008	0.033**
	(0.017)	(0.042)	(0.081)	(0.042)	(0.026)	(0.015)
Constant	7.322***	7.485***	7.222***	7.308***	7.289***	7.372***
	(0.016)	(0.039)	(0.078)	(0.041)	(0.025)	(0.015)
Firm-Product FE	Yes	Yes	Yes	Yes	Yes	Yes
Country-Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Group	Eastern	Central	Western	SOEs	FFs	PFs
Observations	32518574	1658071	1233427	4838061	14894690	15677321
Adjusted R^2	0.670	0.778	0.732	0.676	0.668	0.698
Panel B: Non-manufacturing Industries						
$Treat_{it}$	0.158	-0.105	-0.716***	-0.069	0.040	0.153
	(0.121)	(0.123)	(0.176)	(0.265)	(0.099)	(0.192)
Constant	8.519***	9.773***	9.232***	9.086***	8.480***	8.738***
	(0.114)	(0.110)	(0.163)	(0.257)	(0.094)	(0.177)
Firm-Product FE	Yes	Yes	Yes	Yes	Yes	Yes
Country-Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Group	Eastern	Central	Western	SOEs	FFs	PFs
Observations	317926	31287	26787	55985	160222	159793
Adjusted R^2	0.786	0.773	0.731	0.748	0.804	0.768

Notes: This table presents the heterogeneous effects of the ENE on exports from manufacturing and non-manufacturing industries across different regions and ownership types. Each panel column represents separate regression estimates based on equation (2), with the dependent variable being the logarithm of exports. Panel A covers manufacturing industries, while Panel B covers non-manufacturing industries. Columns (1)-(3) focus on firms' exports in Eastern, Central, and Western China, respectively, whereas Columns (4)-(6) examine the exports of state-owned enterprises (SOEs), foreign firms, and private firms. Robust standard errors, clustered at the firm level, are reported in parentheses. Statistical significance is denoted by *** at the 1% level, ** at the 5% level, and * at the 10% level.

Table A5: Heterogeneous Effects on Exports by Industry Road Reliance

	ln(amount)					
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A: High Road-reliance Industries						
$Treat_{it}$	0.080***	0.001	-0.117	0.245***	0.036	0.071***
	(0.029)	(0.059)	(0.122)	(0.059)	(0.045)	(0.024)
Constant	7.926***	8.641***	8.109***	8.069***	7.836***	8.032***
	(0.028)	(0.055)	(0.119)	(0.058)	(0.042)	(0.023)
Firm-Product FE	Yes	Yes	Yes	Yes	Yes	Yes
Country-Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Group	Eastern	Central	Western	SOEs	FFs	PFs
Observations	13,215,631	608,099	390,465	1,921,400	6,091,885	6,200,910
Adjusted R^2	0.587	0.670	0.675	0.540	0.604	0.604
Panel B: Less Road-reliance Industries						
$Treat_{it}$	0.021	-0.126**	-0.086	0.126**	-0.033	-0.000
	(0.018)	(0.056)	(0.086)	(0.055)	(0.027)	(0.019)
Constant	6.942***	6.915***	6.859***	6.846***	6.935***	6.979***
	(0.017)	(0.053)	(0.083)	(0.053)	(0.026)	(0.018)
Firm-Product FE	Yes	Yes	Yes	Yes	Yes	Yes
Country-Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Group	Eastern	Central	Western	SOEs	FFs	PFs
Observations	19,620,869	1,081,259	869,749	2,972,646	8,963,027	9,636,204
Adjusted R^2	0.698	0.795	0.738	0.713	0.690	0.726

Notes: This table presents the heterogeneous effects of the ENE on exports for industries with high and less road-reliance across different regions and ownership types. Each column within a panel represents a separate regression estimate based on equation (2), with the dependent variable being the logarithm of exports. Panel A focuses on high road-reliance industries, while Panel B addresses less road-reliance industries. Columns (1)-(3) present results for firms in Eastern, Central, and Western China, respectively, while Columns (4)-(6) provide estimates for state-owned enterprises (SOEs), foreign firms, and private firms. Robust standard errors are clustered at the firm level and reported in parentheses. Statistical significance is indicated by *** at the 1% level, ** at the 5% level, and * at the 10% level.

Table A6: Heterogeneous Effects on Exports by Ownership

	ln(amount)								
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
$Treat_{it}$	0.186***	-0.002	-0.164	0.004	-0.219***	-0.458**	0.036**	0.021	0.134
	(0.043)	(0.087)	(0.122)	(0.028)	(0.071)	(0.195)	(0.017)	(0.045)	(0.118)
Constant	7.361***	7.129***	7.381***	7.289***	7.862***	6.886***	7.389***	7.503***	7.111***
	(0.042)	(0.082)	(0.119)	(0.026)	(0.066)	(0.189)	(0.016)	(0.043)	(0.114)
Firm-Product FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country-Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
District	Eastern	Central	Western	Eastern	Central	Western	Eastern	Central	Western
Ownership	SOEs	SOEs	SOEs	FFs	FFs	FFs	PFs	PFs	PFs
Observations	4,278,774	405,298	209,974	14,521,379	399,021	134,512	14,036,347	885,039	915,728
Adjusted R^2	0.656	0.799	0.783	0.667	0.735	0.749	0.692	0.791	0.710

Notes: This table presents the heterogeneous effects of the ENE on exports by firm ownership across different regions. Each column represents a separate regression estimate based on equation (2), with the dependent variable being the logarithm of exports. Columns (1)-(3), (4)-(6), and (7)-(9) report results for state-owned enterprises (SOEs), foreign firms, and private firms, respectively, across Eastern, Central, and Western China. Robust standard errors are clustered at the firm level and reported in parentheses. Statistical significance is denoted by *** at the 1% level, ** at the 5% level, and * at the 10% level.

Table A7: Heterogeneous Effects on Exports by Product Types

	ln(amount)					
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A: Capital Goods						
$Treat_{it}$	0.032	0.028	-0.004	0.384***	-0.100	0.094**
	(0.047)	(0.090)	(0.168)	(0.092)	(0.072)	(0.042)
Constant	5.303***	3.610***	4.675***	4.483***	5.795***	4.841***
	(0.045)	(0.088)	(0.164)	(0.090)	(0.069)	(0.041)
Firm-Product FE	Yes	Yes	Yes	Yes	Yes	Yes
Country-Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Group	Eastern	Central	Western	SOEs	FFs	PFs
Observations	4,904,061	243,284	191,994	790,817	2,164,687	2,383,835
Adjusted R^2	0.736	0.798	0.759	0.767	0.708	0.767
Panel B: Intermediate Goods						
$Treat_{it}$	-0.004	-0.163	-0.460***	0.093	-0.051	-0.024
	(0.034)	(0.121)	(0.151)	(0.102)	(0.049)	(0.040)
Constant	7.065***	7.011***	6.908***	7.022***	7.024***	7.079***
	(0.033)	(0.115)	(0.148)	(0.099)	(0.047)	(0.039)
Firm-Product FE	Yes	Yes	Yes	Yes	Yes	Yes
Country-Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Group	Eastern	Central	Western	SOEs	FFs	PFs
Observations	4,589,583	286,042	195,745	656,462	2,356,168	2,058,740
Adjusted R^2	0.642	0.734	0.665	0.654	0.644	0.662
Panel C: Final Goods						
$Treat_{it}$	0.065***	-0.055	-0.061	0.153***	0.018	0.042**
	(0.018)	(0.042)	(0.090)	(0.045)	(0.028)	(0.018)
Constant	7.812***	8.462***	7.914***	8.023***	7.677***	7.964***
	(0.017)	(0.039)	(0.088)	(0.044)	(0.027)	(0.017)
Firm-Product FE	Yes	Yes	Yes	Yes	Yes	Yes
Country-Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Group	Eastern	Central	Western	SOEs	FFs	PFs
Observations	23,342,856	1,160,032	872,475	3,446,767	10,534,057	11,394,539
Adjusted R^2	0.619	0.697	0.678	0.569	0.647	0.619

Notes: This table presents the heterogeneous effects of the ENE on exports of capital, intermediate, and final goods across different regions and ownership types. Each panel column represents a separate regression estimate based on equation (2), with the dependent variable being the logarithm of exports. Panels A, B, and C focus on capital goods, intermediate goods, and final goods, respectively. Columns (1)-(3) in each panel show results for firms in Eastern, Central, and Western China, while Columns (4)-(6) provide estimates for state-owned enterprises (SOEs), foreign firms, and private firms. Robust standard errors are clustered at the firm level and are reported in parentheses. Statistical significance is denoted by *** at the 1% level, ** at the 5% level, and * at the 10% level.

Table A8: Heterogeneous Effects on Exports by Export Types

	ln(amount)					
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A: Processing Trade						
$Treat_{it}$	0.094	-0.197			0.049	0.327
	(0.276)	(0.321)			(0.224)	(0.305)
Constant	8.053***	7.547***			8.306***	6.977***
	(0.261)	(0.299)			(0.212)	(0.292)
Firm-Product FE	Yes	Yes			Yes	Yes
Country-Year FE	Yes	Yes			Yes	Yes
Group	Eastern	Central			FFs	PFs
Observations	325,103	11,723			258,765	87,289
Adjusted R^2	0.712	0.845			0.690	0.796
Panel B: General Trade						
$Treat_{it}$	-0.018	0.094	-0.210	0.033	-0.157**	0.180**
	(0.058)	(0.126)	(0.272)	(0.095)	(0.075)	(0.081)
Constant	7.693***	8.286***	8.163***	7.613***	8.027***	7.541***
	(0.055)	(0.108)	(0.263)	(0.090)	(0.069)	(0.076)
Firm-Product FE	Yes	Yes	Yes	Yes	Yes	Yes
Country-Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Group	Eastern	Central	Western	SOEs	FFs	PFs
Observations	1,444,869	77,489	63,594	407,629	259,742	918,581
Adjusted R^2	0.644	0.774	0.726	0.667	0.730	0.630
Panel C: Mixed Trade						
$Treat_{it}$	0.048**	-0.069	-0.094	0.178***	-0.008	0.033*
	(0.019)	(0.045)	(0.088)	(0.039)	(0.030)	(0.018)
Constant	7.386***	7.604***	7.282***	7.467***	7.335***	7.436***
	(0.018)	(0.042)	(0.085)	(0.038)	(0.028)	(0.017)
Firm-Product FE	Yes	Yes	Yes	Yes	Yes	Yes
Country-Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Group	Eastern	Central	Western	SOEs	FFs	PFs
Observations	19,610,114	929,856	683,746	3,166,001	9,791,743	8,265,972
Adjusted R^2	0.647	0.761	0.723	0.657	0.641	0.682

Notes: This table presents the heterogeneous effects of the ENE on exports by firms engaged exclusively in processing exports, general exports, or both, across different regions and ownership types. Each panel column represents a separate regression estimate based on equation (2), with the dependent variable being the logarithm of exports. Panels A, B, and C focus on firms involved solely in processing exports, general exports, and mixed exports, respectively. Columns (1)-(3) in each panel present results for firms in Eastern, Central, and Western China, while Columns (4)-(6) provide estimates for state-owned enterprises (SOEs), foreign firms, and private firms. Missing results in Columns (3) and (4) of Panel A are due to the limited availability of observations. Robust standard errors are clustered at the firm level and are reported in parentheses. Statistical significance is denoted by *** at the 1% level, ** at the 5% level, and * at the 10% level.

Table A9: Heterogeneous Effects on Exports by OECD and non-OECD

	ln(amount)					
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A: OECD Countries						
$Treat_{it}$	0.053**	-0.050	-0.388***	0.140**	-0.015	0.055***
	(0.022)	(0.047)	(0.127)	(0.059)	(0.031)	(0.019)
Constant	7.472***	7.962***	7.603***	7.782***	7.434***	7.489***
	(0.021)	(0.044)	(0.124)	(0.058)	(0.030)	(0.018)
Firm-Product FE	Yes	Yes	Yes	Yes	Yes	Yes
country-Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Group	Eastern	Central	Western	SOEs	FFs	PFs
Observations	16,468,756	682,623	388,011	2,246,023	8,409,307	6,884,060
Adjusted R^2	0.652	0.739	0.709	0.603	0.667	0.662
Panel B: Non-OECD Countries						
$Treat_{it}$	0.029	-0.079	-0.042	0.138***	-0.019	0.020
	(0.018)	(0.048)	(0.097)	(0.048)	(0.028)	(0.020)
Constant	7.210***	7.226***	7.162***	7.000***	7.153***	7.305***
	(0.017)	(0.046)	(0.094)	(0.046)	(0.026)	(0.019)
Firm-Product FE	Yes	Yes	Yes	Yes	Yes	Yes
country-Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Group	Eastern	Central	Western	SOEs	FFs	PFs
Observations	16,367,744	1,006,735	872,203	2,648,023	6,645,605	8,953,054
Adjusted R^2	0.731	0.818	0.759	0.748	0.726	0.751

Notes: This table presents the heterogeneous effects of the ENE on exports to OECD and non-OECD countries across different regions and ownership types. Each panel column represents a separate regression estimate based on equation (2), with the dependent variable being the logarithm of exports. Panel A focuses on exports to OECD countries, while Panel B focuses on exports to non-OECD countries. Columns (1)-(3) in each panel present results for firms in Eastern, Central, and Western China, respectively, while Columns (4)-(6) provide estimates for state-owned enterprises (SOEs), foreign firms, and private firms. Robust standard errors, clustered at the firm level, are reported in parentheses. Statistical significance is indicated by *** at the 1% level, ** at the 5% level, and * at the 10% level.

Table A10: Heterogeneous Effects on Exports by Continents

	ln(amount)					
	(1)	(2)	(3)	(4)	(5)	(6)
$Treat_{it}$	0.047***	0.044*	0.071***	-0.038	-0.034	-0.097**
	(0.018)	(0.022)	(0.026)	(0.036)	(0.029)	(0.042)
Constant	7.287***	7.361***	7.732***	7.341***	7.041***	7.065***
	(0.017)	(0.022)	(0.025)	(0.034)	(0.028)	(0.040)
Firm-Product FE	Yes	Yes	Yes	Yes	Yes	Yes
Country-Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Continent	Asia	Europe	North America	South America	Africa	Oceania
Observations	15,298,770	9,866,788	4,824,584	1,916,804	2,442,478	1,436,648
Adjusted R^2	0.715	0.675	0.719	0.778	0.807	0.775

Notes: This table presents the heterogeneous effects of the ENE on exports to different continents. Each panel column represents a separate regression estimate based on equation (2), with the dependent variable being the logarithm of exports. Robust standard errors, clustered at the firm level, are reported in parentheses. Statistical significance is indicated by *** at the 1% level, ** at the 5% level, and * at the 10% level.

Table A11: Extensive Marginal Effects by Ownership

	Entry			Exit		
	(1)	(2)	(3)	(4)	(5)	(6)
$Treat_{it}$	0.024*	-0.025***	0.027***	0.027*	0.008*	-0.012***
	(0.014)	(0.006)	(0.007)	(0.016)	(0.005)	(0.005)
Constant	0.162***	0.176***	0.198***	0.123***	0.090***	0.118***
	(0.013)	(0.005)	(0.006)	(0.014)	(0.004)	(0.004)
Group	SOEs	FFs	PFs	SOEs	FFs	PFs
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	68,335	772,679	689,900	65,351	720,929	583,163
Adjusted R^2	0.350	0.245	0.175	0.157	0.153	0.170
	ln(Number of Product)			ln(Number of Destination Country)		
	(7)	(8)	(9)	(10)	(11)	(12)
$Treat_{it}$	0.005	0.017	0.036***	0.011	0.033**	0.037***
	(0.040)	(0.014)	(0.012)	(0.042)	(0.015)	(0.014)
Constant	1.760***	1.315***	1.211***	1.637***	1.229***	1.408***
	(0.037)	(0.013)	(0.011)	(0.038)	(0.014)	(0.013)
Group	SOEs	FFs	PFs	SOEs	FFs	PFs
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	69,621	784,973	690,760	69,621	784,973	690,760
Adjusted R^2	0.758	0.708	0.708	0.734	0.759	0.712

Notes: This table explores the effects of the ENE on firms' entries and exits by using the firm-year level data in Sample A to estimate equation (2). The dependent variables are the dummy of firms' entries or exits. The regressions also control the firm and county-year fixed effects, and the robust standard errors are clustered at the firm level. *** Statistically significant at the 1% level; ** 5% level; and * 10% level.

Table A12: Effects on Productivity and Markups With Different Controls

	ln(TFP)			ln(markups)		
	(1)	(2)	(3)	(4)	(5)	(6)
Distance$_{it}$ $(0-10)$	0.078***	0.057***	0.051***	0.114***	0.049***	0.077***
	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)
Distance$_{it}$ $(10-20)$	0.053***	0.039***	0.033***	0.081***	0.032***	0.057***
	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)
Distance$_{it}$ $(20-30)$	0.039***	0.015**	0.013*	0.075***	0.034***	0.047***
	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)
Distance$_{it}$ $(30-40)$	0.042***	0.025***	0.022***	0.042***	0.019**	0.025***
	(0.008)	(0.008)	(0.008)	(0.008)	(0.008)	(0.008)
Distance$_{it}$ $(40-50)$	0.031***	0.018**	0.016**	0.009	0.005	0.015*
	(0.008)	(0.008)	(0.008)	(0.009)	(0.009)	(0.008)
Constant	3.034***	3.051***	3.056***	1.198***	1.249***	1.226***
	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)	(0.005)
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes		Yes	Yes		Yes
Industry-Year FE			Yes			Yes
Province-Year FE		Yes	Yes		Yes	Yes
Observations	2,410,761	2,410,761	2,410,761	2,410,761	2,410,761	2,410,761
Adjusted R^2	0.663	0.673	0.679	0.591	0.628	0.651

Notes: Building on Columns (1) and (5) from Table 10, this table examines the effects of the ENE on firms' productivity and markups across varying distances from the network, incorporating different fixed effects for robustness. The dependent variables in Columns (1)-(3) are the logarithms of firms' TFP, measured as per Ackerberg et al. (2015), while those in Columns (4)-(6) are the logarithms of firms' markups, measured following De Loecker and Warzynski (2012). Columns (1) and (4) include firm and year fixed effects to capture variations between firms and across years. Columns (2) and (5) add province-year fixed effects to account for province-specific dynamics over time. Columns (3) and (6) incorporate firm, industry-year, and province-year fixed effects to account for variations between firms, industry-specific dynamics, and province-level characteristics over time. Robust standard errors are clustered at the firm level are reported in parentheses. Statistical significance is indicated by *** at the 1% level, ** at the 5% level, and * at the 10% level.

Table A13: Effects on Productivity by Different Measures

	ln(TFP-OP)				ln(TFPR)			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
$\text{Distance}_{it}(0-10)$	0.080***	0.071***	0.016	0.145***	0.124***	0.145***	0.096***	0.019
	(0.007)	(0.008)	(0.012)	(0.024)	(0.006)	(0.008)	(0.012)	(0.023)
$\text{Distance}_{it}(10-20)$	0.056***	0.045***	-0.000	0.158***	0.095***	0.122***	0.060***	-0.008
	(0.007)	(0.009)	(0.013)	(0.030)	(0.007)	(0.008)	(0.013)	(0.028)
$\text{Distance}_{it}(20-30)$	0.043***	0.022**	0.027*	0.080**	0.091***	0.110***	0.068***	-0.017
	(0.007)	(0.009)	(0.014)	(0.036)	(0.007)	(0.008)	(0.014)	(0.034)
$\text{Distance}_{it}(30-40)$	0.043***	0.032***	0.012	0.023	0.057***	0.083***	0.016	-0.000
	(0.008)	(0.009)	(0.015)	(0.034)	(0.008)	(0.009)	(0.015)	(0.034)
$\text{Distance}_{it}(40-50)$	0.027***	0.013	0.026	0.069**	0.022***	0.035***	0.001	0.029
	(0.008)	(0.010)	(0.017)	(0.033)	(0.008)	(0.010)	(0.016)	(0.035)
Constant	4.851***	3.058***	3.054***	2.869***	4.405***	4.411***	4.400***	4.293***
	(0.006)	(0.007)	(0.010)	(0.019)	(0.005)	(0.007)	(0.009)	(0.018)
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry-Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
District		Eastern	Central	Western		Eastern	Central	Western
Observations	2,410,761	1,790,813	454,131	165,817	2,410,761	1,790,813	454,131	165,817
Adjusted $R\hat{2}$	0.669	0.670	0.688	0.623	0.618	0.6769	0.641	0.687

Notes: Extending the analysis from Columns (1)-(4) of Table 10 and using different productivity measurement methods, this table explores the effects of the ENE on firms' productivity across varying distances from the network. The dependent variables in all columns represent the logarithms of firms' productivity. Productivity in Columns (1)-(4) is measured following Olley and Pakes (1996), while Columns (5)-(8) use revenue-based total factor productivity, calculated according to Hsieh and Klenow (2009). All regressions include firm and industry-year fixed effects, with robust standard errors clustered at the firm level shown in parentheses. Statistical significance is indicated by *** at the 1% level, ** at the 5% level, and * at the 10% level.

Table A14: Effects on Productivity and Markups by County-Level Classification

	ln(TFP)				ln(markups)			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
$\text{Treat}_{it}(County)$	0.037***	0.038***	0.020***	0.047***	0.067***	0.068***	0.067***	0.030**
	(0.004)	(0.004)	(0.007)	(0.014)	(0.003)	(0.004)	(0.007)	(0.012)
Constant	3.071***	3.085***	3.066***	2.966***	1.238***	1.216***	1.352***	1.162***
	(0.002)	(0.003)	(0.004)	(0.008)	(0.002)	(0.003)	(0.004)	(0.007)
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry-Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
District		Eastern	Central	Western		Eastern	Central	Western
Observations	2,452,755	1,790,813	454,131	165,817	2,452,755	1,790,813	454,131	165,817
Adjusted R^2	0.667	0.670	0.688	0.639	0.618	0.639	0.575	0.622

Notes: Building on Table 10, this table investigates the effects of the ENE on firms' productivity and markups, using county-level definitions for treated and control groups. Firms in counties intersected by the expressway network are classified as the treated group, while firms in counties without expressway access constitute the control group. The dependent variables in Columns (1)-(4) are the logarithms of firms' TFP, measured following Ackerberg et al. (2015), whereas those in Columns (5)-(8) represent the logarithms of firms' markups, measured according to De Loecker and Warzynski (2012). All regressions include firm and industry-year fixed effects, with robust standard errors clustered at the firm level shown in parentheses. Statistical significance is indicated by *** at the 1% level, ** at the 5% level, and * at the 10% level.

Table A15: Effects on Productivity and Markups With Different Ownership

	ln(TFP)			ln(markups)		
	(1)	(2)	(3)	(4)	(5)	(6)
$\text{Distance}_{it}\,(0-10)$	0.066**	0.014	0.078***	0.007	0.134***	0.137***
	(0.034)	(0.019)	(0.007)	(0.030)	(0.018)	(0.007)
$\text{Distance}_{it}\,(10-20)$	0.042	-0.023	0.059***	-0.018	0.102***	0.103***
	(0.038)	(0.020)	(0.008)	(0.033)	(0.019)	(0.008)
$\text{Distance}_{it}\,(20-30)$	-0.014	-0.043**	0.050***	0.041	0.103***	0.084***
	(0.041)	(0.020)	(0.008)	(0.035)	(0.019)	(0.008)
$\text{Distance}_{it}\,(30-40)$	0.113**	-0.050**	0.047***	-0.002	0.083***	0.044***
	(0.045)	(0.022)	(0.008)	(0.039)	(0.021)	(0.009)
$\text{Distance}_{it}\,(40-50)$	0.006	0.005	0.030***	-0.027	-0.024	0.031***
	(0.049)	(0.025)	(0.009)	(0.042)	(0.023)	(0.009)
Constant	3.040***	3.221***	3.003***	0.642***	0.919***	1.281***
	(0.027)	(0.017)	(0.006)	(0.024)	(0.017)	(0.006)
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Industry-Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Ownership	SOEs	FFs	PFs	SOEs	FFs	PFs
Observations	71,772	538,902	1,781,442	71,772	538,902	1,781,442
Adjusted R^2	0.554	0.620	0.694	0.682	0.646	0.595

Notes: Building on Table 10, this table examines the effects of the ENE on the productivity and markups of firms with different ownership structures. The dependent variables in Columns (1)-(3) are the logarithms of firms' TFP, measured using the approach of Ackerberg et al. (2015), while those in Columns (4)-(6) are the logarithms of firms' markups, measured according to De Loecker and Warzynski (2012). Columns (1) and (4) focus on state-owned enterprises (SOEs), Columns (2) and (5) on foreign firms (FFs), and Columns (3) and (6) on private firms (PFs). All regressions include firm and industry-year fixed effects, with robust standard errors clustered at the firm level shown in parentheses. Statistical significance is indicated by *** at the 1% level, ** at the 5% level, and * at the 10% level.

Table A16: Effects on Productivity and Markups (2000-2010)

	ln(TFP)						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Panel A: Dependent Variable - ln(TFP)							
$Distance_{it}(0-10)$	0.060***	0.065***	0.016	0.115***	0.072**	0.015	0.069***
	(0.007)	(0.008)	(0.013)	(0.030)	(0.033)	(0.019)	(0.007)
$Distance_{it}(10-20)$	0.043***	0.047***	0.001	0.171***	0.049	-0.016	0.058***
	(0.007)	(0.009)	(0.014)	(0.038)	(0.037)	(0.021)	(0.008)
$Distance_{it}(20-30)$	0.030***	0.025***	0.016	0.058	-0.013	-0.038*	0.049***
	(0.007)	(0.009)	(0.015)	(0.043)	(0.040)	(0.021)	(0.008)
$Distance_{it}(30-40)$	0.036***	0.035***	0.019	0.009	0.104**	-0.036	0.047***
	(0.008)	(0.010)	(0.016)	(0.044)	(0.046)	(0.023)	(0.009)
$Distance_{it}(40-50)$	0.027***	0.010	0.040**	0.100**	-0.007	0.023	0.031***
	(0.009)	(0.010)	(0.017)	(0.045)	(0.048)	(0.026)	(0.009)
Constant	3.322***	3.324***	3.374***	3.151***	3.086***	3.440***	3.299***
	(0.006)	(0.007)	(0.010)	(0.023)	(0.026)	(0.017)	(0.006)
District		Eastern	Central	Western	SOEs	FFs	PFs
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry-Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1,729,756	1,318,553	300,219	110,984	65,053	415,588	1,249,115
Adjusted R^2	0.624	0.623	0.650	0.582	0.560	0.581	0.649
Panel B: Dependent Variable - ln(markups)							
$Distance_{it}(0-10)$	0.067***	0.104***	0.079***	0.033	0.003	0.074***	0.061***
	(0.007)	(0.008)	(0.014)	(0.025)	(0.030)	(0.019)	(0.008)
$Distance_{it}(10-20)$	0.069***	0.099***	0.061***	-0.004	-0.027	0.073***	0.063***
	(0.007)	(0.009)	(0.015)	(0.031)	(0.033)	(0.020)	(0.008)
$Distance_{it}(20-30)$	0.066***	0.084***	0.079***	0.023	0.058*	0.081***	0.053***
	(0.007)	(0.008)	(0.016)	(0.040)	(0.035)	(0.020)	(0.008)
$Distance_{it}t(30-40)$	0.036***	0.061***	0.054***	-0.003	0.003	0.067***	0.026***
	(0.008)	(0.009)	(0.017)	(0.038)	(0.039)	(0.021)	(0.009)
$Distance_{it}(40-50)$	0.001	0.000	0.060***	0.048	-0.005	-0.087***	0.015
	(0.009)	(0.010)	(0.017)	(0.038)	(0.039)	(0.024)	(0.010)
Constant	1.178***	1.146***	1.216***	1.100***	0.621***	0.976***	1.281***
	(0.006)	(0.007)	(0.010)	(0.020)	(0.024)	(0.017)	(0.006)
District		Eastern	Central	Western	SOEs	FFs	PFs
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry-Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1,729,756	1,318,553	30,0219	110,984	65,053	415,588	1,249,115
Adjusted R^2	0.621	0.644	0.561	0.651	0.693	0.652	0.597

Notes: Since Sample B includes firms with total assets exceeding RMB 5 million, while data from 2011-2013 only covers firms with total assets exceeding RMB 20 million, this table focuses exclusively on the data from 2000-2010. Extending the analysis from Table 10, this table examines the effects of the ENE expansion on firms' productivity and markups at varying distances from the network. The dependent variables in Panel A are the logarithms of firms' TFP, measured according to Ackerberg et al. (2015), whereas those in Panel B are the logarithms of firms' markups, measured following De Loecker and Warzynski (2012). Column (1) in both panels includes all firms, while subsequent columns present results for firms by different regions and ownership structures, respectively. All regressions include firm and industry-year fixed effects, with robust standard errors clustered at the firm level shown in parentheses. Statistical significance is indicated by *** at the 1% level, ** at the 5% level, and * at the 10% level.

Table A17: Effects on Marginal Revenue Product of Capital and Labor

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Panel A: Dependent Variable - ln(Marginal Revenue Product of Capital)							
$\text{Distance}_{it}(0-10)$	0.098***	0.118***	0.102***	-0.006	0.036	0.054**	0.114***
	(0.008)	(0.010)	(0.014)	(0.028)	(0.033)	(0.021)	(0.008)
$\text{Distance}_{it}(10-20)$	0.067***	0.096***	0.044***	-0.021	-0.014	0.004	0.091***
	(0.008)	(0.010)	(0.016)	(0.034)	(0.036)	(0.022)	(0.009)
$\text{Distance}_{it}(20-30)$	0.069***	0.088***	0.061***	-0.039	0.005	-0.006	0.093***
	(0.008)	(0.010)	(0.017)	(0.041)	(0.039)	(0.022)	(0.009)
$\text{Distance}_{it}(30-40)$	0.041***	0.061***	0.025	-0.003	0.025	-0.034	0.059***
	(0.009)	(0.011)	(0.018)	(0.040)	(0.042)	(0.024)	(0.010)
$\text{Distance}_{it}(40-50)$	0.019*	0.030**	0.007	0.043	-0.029	-0.047*	0.032***
	(0.010)	(0.012)	(0.020)	(0.043)	(0.044)	(0.028)	(0.011)
Constant	0.754***	0.781***	0.674***	0.562***	-0.075***	0.723***	0.797***
	(0.006)	(0.008)	(0.011)	(0.022)	(0.026)	(0.019)	(0.007)
District		Eastern	Central	Western	SOEs	FFs	PFs
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry-Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	2,410,761	1,790,813	454,131	165,817	71,970	541,051	1,797,740
Adjusted R^2	0.665	0.674	0.625	0.683	0.776	0.718	0.636
Panel B: Dependent Variable - ln(Marginal Revenue Product of Labor)							
$\text{Distance}_{it}(0-10)$	0.202***	0.212***	0.062***	0.120***	0.074**	0.248***	0.154***
	(0.007)	(0.008)	(0.013)	(0.027)	(0.033)	(0.019)	(0.008)
$\text{Distance}_{it}(10-20)$	0.176***	0.195***	0.074***	0.052	0.055	0.203***	0.137***
	(0.007)	(0.009)	(0.014)	(0.034)	(0.035)	(0.020)	(0.008)
$\text{Distance}_{it}(20-30)$	0.162***	0.174***	0.056***	0.045	-0.005	0.213***	0.126***
	(0.007)	(0.009)	(0.015)	(0.037)	(0.038)	(0.020)	(0.008)
$\text{Distance}_{it}(30-40)$	0.111***	0.128***	0.001	0.049	0.052	0.171***	0.073***
	(0.008)	(0.010)	(0.016)	(0.038)	(0.042)	(0.022)	(0.009)
$\text{Distance}_{it}(40-50)$	0.055***	0.058***	0.000	0.071*	-0.087*	0.094***	0.043***
	(0.009)	(0.011)	(0.016)	(0.042)	(0.047)	(0.024)	(0.010)
Constant	7.574***	7.572***	7.684***	7.542***	7.003***	7.501***	7.651***
	(0.006)	(0.007)	(0.010)	(0.021)	(0.026)	(0.017)	(0.006)
District		Eastern	Central	Western	SOEs	FFs	PFs
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry-Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	2,410,761	1,790,813	454,131	165,817	71,970	541,051	1,797,740
Adjusted R^2	0.688	0.690	0.702	0.685	0.786	0.741	0.667

Notes: This table examines the effects of the ENE on firms' marginal revenue product of capital and labor across varying distances from the network. The dependent variables in Panels A and B are the logarithms of firms' marginal revenue product of capital and marginal revenue product of labor, respectively. Both dependent variables are measured following Hsieh and Klenow (2009). Column (1) includes the full sample, whereas the remaining columns present results for firms in different regions and ownership, respectively. All regressions include firm and industry-year fixed effects, with robust standard errors clustered at the firm level shown in parentheses. Statistical significance is indicated by *** at the 1% level, ** at the 5% level, and * at the 10% level.

Table A18: Effects on the Distortion of Capital and Labor

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Panel A: Dependent Variable - ln(Capital distortion)							
$Distance_{it}(0-10)$	0.098***	0.118***	0.102***	-0.006	0.036	0.054**	0.114***
	(0.008)	(0.010)	(0.014)	(0.028)	(0.033)	(0.021)	(0.008)
$Distance_{it}(10-20)$	0.067***	0.096***	0.044***	-0.021	-0.014	0.004	0.091***
	(0.008)	(0.010)	(0.016)	(0.034)	(0.036)	(0.022)	(0.009)
$Distance_{it}(20-30)$	0.069***	0.088***	0.061***	-0.039	0.005	-0.006	0.093***
	(0.008)	(0.010)	(0.017)	(0.041)	(0.039)	(0.022)	(0.009)
$Distance_{it}(30-40)$	0.041***	0.061***	0.025	-0.003	0.025	-0.034	0.059***
	(0.009)	(0.011)	(0.018)	(0.040)	(0.042)	(0.024)	(0.010)
$Distance_{it}(40-50)$	0.019*	0.030**	0.007	0.043	-0.029	-0.047*	0.032***
	(0.010)	(0.012)	(0.020)	(0.043)	(0.044)	(0.028)	(0.011)
Constant	3.680***	3.706***	3.599***	3.487***	2.850***	3.649***	3.722***
	(0.006)	(0.008)	(0.011)	(0.022)	(0.026)	(0.019)	(0.007)
District		Eastern	Central	Western	SOEs	FFs	PFs
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry-Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	2,410,761	1,790,813	454,131	165,817	71,970	541,051	1,797,740
Adjusted R^2	0.665	0.674	0.625	0.683	0.776	0.718	0.636
Panel B: Dependent Variable - ln(Labor distortion)							
$Distance_{it}(0-10)$	0.147***	0.169***	0.118***	0.090***	0.007	0.134***	0.137***
	(0.007)	(0.008)	(0.013)	(0.022)	(0.030)	(0.018)	(0.007)
$Distance_{it}(10-20)$	0.113***	0.141***	0.088***	0.024	-0.018	0.102***	0.103***
	(0.007)	(0.008)	(0.014)	(0.027)	(0.033)	(0.019)	(0.008)
$Distance_{it}(20-30)$	0.099***	0.113***	0.088***	0.064*	0.041	0.103***	0.084***
	(0.007)	(0.008)	(0.015)	(0.034)	(0.035)	(0.019)	(0.008)
$Distance_{it}(30-40)$	0.060***	0.082***	0.039**	0.054	-0.002	0.083***	0.044***
	(0.008)	(0.009)	(0.016)	(0.033)	(0.039)	(0.021)	(0.009)
$Distance_{it}(40-50)$	0.025***	0.034***	0.031*	0.015	-0.027	-0.024	0.031***
	(0.008)	(0.010)	(0.017)	(0.034)	(0.042)	(0.023)	(0.009)
Constant	1.387***	1.342***	1.534***	1.356***	0.862***	1.138***	1.500***
	(0.005)	(0.007)	(0.010)	(0.018)	(0.024)	(0.017)	(0.006)
District		Eastern	Central	Western	SOEs	FFs	PFs
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry-Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	2,410,761	1,790,813	454,131	165,817	71,970	541,051	1,797,740
Adjusted R^2	0.618	0.639	0.575	0.622	0.683	0.647	0.596

Notes: This table examines the effects of the ENE on the distortion of capital and labor across varying distances from the network. The dependent variables in Panels A and B are the logarithms of firms' capital and labor distortion, respectively. Both dependent variables are measured following Hsieh and Klenow (2009). Column (1) includes the full sample, whereas the remaining columns present results for firms in different regions and ownership, respectively. All regressions include firm and industry-year fixed effects, with robust standard errors clustered at the firm level shown in parentheses. Statistical significance is indicated by *** at the 1% level, ** at the 5% level, and * at the 10% level.

Appendix C: Data

Processing Chinese Industry Firm Data — To ensure data reliability and eliminate reporting errors, we cleaned the CASIF database by excluding entries that violated generally accepted accounting principles (GAAP), as outlined by Cai and Liu (2009) and Wang (2023). Specifically, the following criteria are applied: (1) Firm identification numbers must be unique and non-missing; (2) The establishment year must be between 1800 and the current year; (3) Sales revenue must exceed 5 million CNY before 2011 and 20 million CNY from 2011 onward; (4) Main financial variables (e.g., total assets, annual payroll, intermediate inputs, net capital balance, gross output) must be greater than zero; (5) The number of employees must be at least 10; (6) Fixed and current assets must be less than or equal to total assets; (7) Current-year depreciation cannot exceed accumulated depreciation; (8) Income tax cannot exceed total assets or sales profit. Applying these criteria led to the removal of 8.6% of the observations.

Some crucial variables in the CASIF dataset (e.g., value-added tax, depreciation, annual payroll, value-added) are missing in specific years, especially the data after 2008, which affects total factor productivity (TFP) calculations. To address this, we employ imputation based on accounting standards: (1) Value-Added Tax is calculated by "Output tax - Input tax"; (2) Set the rental rate of capital as 10% (Hsieh and Klenow, 2009) and fill depreciation of fixed assets by using fixed assets multiplied by 10%; (3) Calculate the average ratio of each firm's annual payroll to its sales revenue from 2000 to 2007, and use this ratio to estimate annual payroll for 2009 and 2010 by multiplying it by the corresponding sales revenue; (4) Value-added is imputed using two accounting standards: "value-added = Total output - Intermediate inputs + Value-added tax" and "Value-added = Sales revenue - Beginning inventory + Ending inventory - Intermediate inputs + Value-added tax"; (5)

Intermediate inputs variable is further imputed based on the formula “Intermediate inputs = Total output * Main business cost/Main business income - Annual payroll - Depreciation of fixed assets.” These methods provide a consistent framework for reconstructing missing variables, thereby improving the robustness of TFP calculations.

Appendix D: Supplementary Measurements

Markups measurement — Measuring markups requires basic information about products' sales prices and marginal costs; however, as hidden information, products' marginal costs are usually difficult to obtain. For this reason, we measure markups by following De Loecker and Warzynski (2012). Basically, given factor price P_i^X and output Q, a firm selects element X_i to minimize the production cost using the following Lagrange equation:

$$L = \sum_{i=1}^{n} P_i^{\mathbf{x}} X_i + \lambda (Q - Q(\mathbf{X})) \tag{4}$$

where λ is the shadow price of a firm, and it reflects the marginal cost (MC) of the firm; thus, $\lambda = MC$. X is a factor vector in which $X \equiv (X_1, ..., X_n)$. The first-order condition of equation (4) is: $P_i^X = MC(\partial Q(X)/\partial X_i)$. It can also be expressed as:

$$\frac{P}{MC} = \frac{\frac{\partial Q(\mathbf{X})}{\partial X_i}\frac{X_i}{Q(\mathbf{X})}}{\frac{P_i^{\mathbf{x}} \cdot X_i}{P \cdot Q(\mathbf{X})}} \tag{5}$$

where P represents the product sales price; the numerator on the right is the output elasticity εX_i of factor X_i, and the denominator on the right is the share of factor X_i's return. The left side of the equation exactly indicates the firm's markups. Moreover, there are several advantages of equation (5). First, measuring markups no longer requires knowing the product price and the marginal costs. Second, it is not necessary to calculate the output elasticity and the share of all factors' returns, and one only needs to know a single factor's output elasticity and return share. Third, in most cases, it does not need to assume a production function, and the production function can be diverse, such as a linear, Cobb–Douglas, and constant elasticity of substitution production function. Because

our data contain labor demand and annual payroll information, we measure markups by using the ratio of the output elasticity of labor to the share of labor return. Clearly, firms' output elasticity of labor can be measured by the OP method, and the annual payroll and sales revenue variables are represented by $P_i^X X_i$ and $PQ(X)$, respectively.

Marginal Revenue Product of Capital and Labor measurements — Following Hsieh and Klenow (2009), a firm i uses labor (L_{it}) and capital (K_{it}) to produce product in each year t at technology level A_{it}. Its production function is given by a Cobb-Douglas function, $Y_{it} = A_{it} L_{it}^{\alpha} K_{it}^{\beta}$. Its profit function can be written as $\pi_{it} = P_{it} Y_{it} - (1+\tau_{L_{it}}) w L_{it} - (1+\tau_{K_{it}}) r K_{it}$, where P_{it} is the product price, Y_{it} is the production, τ_L and τ_K are the labor and capital distortion, and w and r are the labor and capital prices. Sample B provides information on labor L_{it}, capital K_{it}, sales revenue, and annual payroll. We choose the capital interest rate as 10% by following Hsieh and Klenow (2009). Moreover, labor share α and capital share β are measured by the approach in Ackerberg et al. (2015). After maximizing the firm's profit, the firm's marginal revenue product of capital ($MRPK_{it}$) and marginal revenue product of labor ($MRPK_{it}$) are measured by the following equations.

$$MRPK_{it} = \frac{d(P_{it}Y_{it})}{d(K_{it})} = r^*(1+\tau_{K_{it}}) = \frac{\sigma-1}{\sigma} * \frac{\alpha P_{it} Y_{it}}{K_{it}} \tag{6}$$

$$MRPL_{it} = \frac{d(P_{it}Y_{it})}{d(L_{it})} = w^*(1+\tau_{L_{it}}) = \frac{\sigma-1}{\sigma} * \frac{\beta P_{it} Y_{it}}{L_{it}} \tag{7}$$

Distortion of Capital and Labor measurements — Based on Hsieh and Klenow (2009), a firm's

capital distortion $\tau_{K_{it}}$ and labor distortion $\tau_{L_{it}}$ can be measured by following equations.

$$(1+\tau_{K_{it}}) = \frac{\alpha}{\alpha+\beta} * \frac{P_{it}Y_{it}}{rK_{it}} \tag{8}$$

$$(1+\tau_{L_{it}}) = \frac{\beta}{\alpha+\beta} * \frac{P_{it}Y_{it}}{wL_{it}} \tag{9}$$

TFPR measurement — Following Hsieh and Klenow (2009), a firm's revenue productivity is measured by the following equation.

$$TFPR_{it} = P_{it}A_{it} = \frac{P_{it}Y_{it}}{K_{it}^{\beta}(wL_{it}^{\alpha})} \tag{10}$$