Valuing Domestic Transport Infrastructure: A View from the Route Choice of Exporters

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Inland trans. infrastructure investment

- Investment on inland trans. infrastructure: 850 billion/year in 47 major countries, half of which in China (2% GDP in 2000 ↗ 5% in 2010)
- Blue: Expressway network 1999. Red: Expressway network 2010

Background

- What are the impacts of transportation infrastructure improvement on regional and aggregate economy
  - Early work: first-order based measurement(Fogel, 1964) or reduced-form (Banerjee et al., 2012)
  - GE in nature → necessitates a structural model
- Recent progress:
  - Market access approach: Donaldson and Hornbeck (2016), Alder (2016), Baum-Snow et al. (2018), ...
  - Quantification via structural counterfactual: Donaldson (2018a), Allen and Arkolakis (2014, 2016), Fajgelbaum and Schaal (2017), ...

Background

Key to both approaches: identify the trade cost elasticity

- travel distance $\xrightarrow{\text{trade cost elast.}}$ trade cost $\xrightarrow{\text{trade elast.}}$ trade flow $\xrightarrow{\text{GE}}$ emp./wage
- How existing work recovers trade cost elast.
  - (1) external measure of freight rates: Baum-Snow et al. (2018)
  - (2) estimate using price gaps of homogeneous goods: Asturias et al. (2018), Atkin and Donaldson (2015), Donaldson (2018b)
  - (3) estimate using shipment flows: Allen and Arkolakis (2014, 2016)
- Approach (1) rules out the non-monetary component of trade cost
- (2) and (3) both demanding in data → restricted to a small groups of products (thus one-sector models); trade cost elas. identified from cross-sectional variations in shipment flows

What we do

- A novel source of information to measure domestic shipment
  - export data from the Chinese customs 1999-2010
  - location of exporter, port of exit, volume and quantity $\implies$ routing, price gap
- Combined with expressway expansion to estimate cost on expressway and regular roads
  - idea: A exports more through port a than port b $\implies$ $\tau_{\mathrm{A,a}} < \tau_{\mathrm{A,b}}$
  - use over-time variations and an IV (Faber, 2014) to address various concerns
  - allow trade cost heterogeneity by weight-to-value ratio; discipline extent of heterogeneity using prices
- Parameterize a regional GE model
  - routing module from Allen and Arkolakis (2016)
    idiosyncratic trucker preference over routes $\implies$ tractable for characterization of the welfare effects
  - Caliendo and Parro (2015) with sector heterogeneity in trade costs

Main findings

- Transport costs parameters:
  - ad valorem for each 100 kilometer on regular road (7.4%) and expressway (5.5%)
  - doubling weight-to-value ratio increases cost by 23%

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  - ad valorem for each 100 kilometer on regular road (7.4%) and expressway (5.5%)
  - doubling weight-to-value ratio increases cost by 23%
- Evaluate the return to expressway expansion: 1999-2010
  - 50,000 kilometer expressways built; total cost $570 billion (10 % of 2010 GDP)
  - welfare gains 5.6%, or 180% net return to investment
  - return smaller if shut down *regional specialization* (15% less), *sector heterogeneity in cost* (30% less), and *intermediate linkages* (75% less) $\Longrightarrow$ 0.74% welfare gains in one-sector model, or 63% negative return to investment

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- The effects can be approximated accurately using a 2nd-order characterization
  - after the model is parameterized, no need for computing counterfactuals
  - not for today

Literature

- Impacts of infrastructure projects on
  - **regional development or growth** (Cosar et al., 2019, Fajgelbaum and Redding, 2014), **migration** (Morten and Oliveira, 2018), **within city activity** (Gu et al., 2018, Severen, 2018, Tsivanidis, 2018), **seller buyer match** (Xu, 2018), and **optimality for the aggregate economy** (Alder and Kondo, 2019, Allen and Arkolakis, 2016, Fajgelbaum and Schaal, 2019)
  - difference: a new way of estimating trade cost elasticity
- Domestic trans. infra. promotes export
  - using **country-level** (Limao and Venables, 2001) and **region-level** variations (Coşar and Demir, 2016 and Martincus et al., 2017)
  - difference: focus are impact on trade cost and welfare, rather than export per se
- Chinese spatial economy.
  - Fan (2019), Ma and Tang (2019), Tombe and Zhu (2019), Zi (2016),...
  - determine transport cost using **railway shipments** (account for only 10% of shipment; province level) or **regional input-output** table (imputed from railway)
  - new: parameterize a domestic trade cost matrix

Outline

- Data and Reduced-form Specification
- Model
    - Road network $\longrightarrow$ trade cost
    - Multi-sector EK
- Quantification and Counterfactuals

Data and Reduced-form Specifications

Data: transportation network (Baum-Snow et al., 2018)

- Left: expressways for 1999 and 2010
- Right: regular roads ('national' and 'provincial' roads) in 2007
- Find distance along the shortest path between o and d, $\{\text{dist}_{od}^{t} : t = 1999, 2010\}$
  - necessary to take a stand on relative costs of expressway and regular road
  - for now: 1 km on expressway equals to 0.5 km on regular road
  - later: pined down in full quantification

Reduced-form specification: routing

$$ln(q^t_{(o,RoW),d}) = \beta_{od} + \beta^t_o + \beta^t_d + \gamma \cdot \text{dist}^t_{od} + \epsilon^t_{od}$$

- $q^t_{(o,RoW),d}$: *quantity* (tons) exported from city o via port d in year t
- dist^t_{od}: *shortest* effective distance from o to d: $0.5 \times \mathrm{dist}^t_{o\to d,H} + \mathrm{dist}^t_{o\to d,L}$
- γ: composite of $\kappa_L \times \theta^F$
  - κ_L: effective cost for regular roads; θ^F: elasticity of substitution between ports

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- Remarks
  - limit case of the structural equation w/o. trucker preference heterogeneity
  - omitting β_{od} leads to biased $\hat{\gamma}$
  - address endogeneity of road networks: (1) exclude major cities; (2) minimum-spanning tree IV; (3) sectoral-level specification

Minimum-spanning Tree

Exporting share elasticity w.r.t. distance

Table 1: Expressway and Routing of Export Shipments

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
			OLS				PPML	
$\text{dist}_{o,d}$	-0.346***	-0.103***	-0.136***	-0.144***		-0.655***	-0.470***	
	(0.010)	(0.025)	(0.033)	(0.040)		(0.062)	(0.066)	
-on express					-0.082*			-0.286**
					(0.042)			(0.117)
-on regular					-0.148***			-0.488***
					(0.043)			(0.084)
Fixed Effects	o, d, t	od, t	od, ot, dt	od, ot, dt	od, ot, dt	ot, dt	od, ot, dt	od, ot, dt
Exclude major cities				yes	yes	yes	yes	yes
Observations	3625	2768	2738	2002	2002	2740	2002	2002
R^2	0.601	0.820	0.893	0.882	0.882	-	-	-

Notes: Standard errors are clustered at city-port level

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Robustness test: IV and sectoral-level specification

Table 2: IV and Sectoral Results

	(1)	(2)	(3)	(4)	(5)
	Aggregate IV		Sectoral OLS		
$\mathrm{dist}_{od,t}$	-0.156***		-0.092***	-0.110***	
	(0.050)		(0.030)	(0.037)	
-on express		-0.096			-0.088**
		(0.067)			(0.040)
-on national		-0.164***			-0.120***
		(0.060)			(0.039)
Fixed Effects	*od*, *ot*, *dt*	*od*, *ot*, *dt*	*odi*, *ot*, *dt* *it*	*odi*, *oit*, *dit*	*odi*, *oit*, *dit*
Exclude major cities	yes	yes	yes	yes	yes
Observations	1926	1926	13006	11044	11044
R^2	-	-	0.839	0.896	0.896
First Stage KP-F statistic	1748.984	212.052			

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Summary and Motivation for a routing model

- Reduced-form elasticity of routing w.r.t. effective distance around 15%
  - Using cross-sectional variations more than doubles the estimate
  - Needs to take a stand on the relative cost of express/national, for shortest path
  - Confounding with port choice elasticity and router preference heterogeneity

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- Reduced-form elasticity of routing w.r.t. effective distance around 15%
  - Using cross-sectional variations more than doubles the estimate
  - Needs to take a stand on the relative cost of express/national, for shortest path
  - Confounding with port choice elasticity and router preference heterogeneity
- Extend the routing problem and embed into a GE model
  - allow truckers to have heterogeneous preference for routes $\implies$ both regular roads and expressways used; identify θ_F, κ_L, κ_H
  - incorporates alternative modes
  - use the GE structure to infer the level of cost; counterfactuals

Model

Routing block: from road network to domestic trade cost

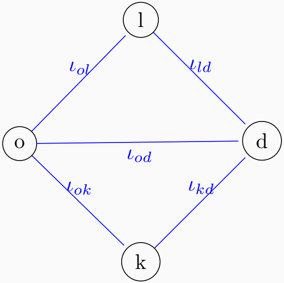

Figure 1: A trucker going from o to d

- iceberg cost $\iota_{ol} = \exp(\kappa_L \mathrm{dist}_{ol})$
- Three direct paths; trucker draws a preference shock from Frechet for each
- if made choose among the three, the expected cost is:
  $\tau_{od,2} = \Gamma(\frac{\theta-1}{\theta})\left([\iota_{od}]^{-\theta} + [\iota_{ol}\iota_{ld}]^{-\theta} + [\iota_{ok}\iota_{kd}]^{-\theta}\right)^{-\frac{1}{\theta}},\ o \neq d$

Routing block: Matrix representation

$$
\begin{array}{c c}
 & \begin{array}{cccc} o & l & d & k \end{array} \\
\begin{array}{c} o \\ l \\ d \\ k \end{array} &
\begin{pmatrix}
0 & \iota_{ol}^{-\theta} & \iota_{od}^{-\theta} & \iota_{ok}^{-\theta} \\
\iota_{lo}^{-\theta} & 0 & \iota_{ld}^{-\theta} & 0 \\
\iota_{do}^{-\theta} & \iota_{dl}^{-\theta} & 0 & \iota_{dk}^{-\theta} \\
\iota_{ko}^{-\theta} & 0 & \iota_{kd}^{-\theta} & 0
\end{pmatrix}
\end{array}
$$

- $[\mathbb{L}_{(o,d)}]$ is (o, d) element of $\mathbb{L}$. $[\mathbb{L}^2_{(o,d)}]$ is (o, d) of $\mathbb{L}^2$
- $\tau_{od,2} = \Gamma(\frac{\theta-1}{\theta})\big([\mathbb{L}_{(o,d)}] + [\mathbb{L}^2_{(o,d)}]\big)^{-\frac{1}{\theta}},\ o \neq d$
- Allowing detours, expected cost among all path with less than N edges is: $\tau_{od,N} = \Gamma(\frac{\theta-1}{\theta})\big(\sum_{s=1}^{N}[\mathbb{L}^s_{(o,d)}]\big)^{-\frac{1}{\theta}}, o \neq d$
- Allowing arbitrary detours:

$$\tau_{od} \equiv \lim_{N\to\infty} \tau_{od,N} = \Gamma(\frac{\theta-1}{\theta})\big(\sum_{s=1}^{\infty}[\mathbb{L}^s_{(o,d)}]\big)^{-\frac{1}{\theta}} = \Gamma(\frac{\theta-1}{\theta})\big([\mathbb{I}-\mathbb{L}]^{-1}_{(o,d)}\big)^{-\frac{1}{\theta}}.$$

Routing block: extension for quantification

- With both expressways $\mathbb{H}$ and regular roads $\mathbb{L}$ to choose from:
    - $\mathbb{A} \equiv \mathbb{H} + \mathbb{L}, \ \mathbb{B} \equiv (\mathbb{I} - \mathbb{A})^{-1}$.
    - $\tau_{od} \equiv \lim_{N\to\infty} \tau_{od,N} = \Gamma(\frac{\theta-1}{\theta})\big(\sum_{s=1}^{\infty}[\mathbb{A}^{s}_{(o,d)}]\big)^{-\frac{1}{\theta}} = \Gamma(\frac{\theta-1}{\theta})[\mathbb{B}_{(o,d)}]^{-\frac{1}{\theta}}$

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- With alternative transport mode and export:
  $\bar{\tau}^{i}_{od} \propto \exp(\bar{\kappa} \cdot \overline{\text{dist}}_{od}),\ \ o \neq d$

$$\tilde{\tau}^{i}_{od} \propto \begin{cases} [(\bar{\tau}^{i}_{od})^{-\theta_M} + (\tau^{i}_{od})^{-\theta_M}]^{-\frac{1}{\theta_M}}, & \text{if } d \neq RoW \\ \left\{(\tau^{i}_{RoW})^{-\theta_M} + \left([\sum_{\text{ports } k} (\tau^{i}_{ok}\tau^{i}_{RoW})^{-\theta_F}]^{-\frac{1}{\theta_F}}\right)^{-\theta_M}\right\}^{-\frac{1}{\theta_M}}, & \text{if } d = RoW \end{cases}$$

The rest of the model

- 323 regions (prefectures)+RoW, 25 sectors (2-digit). Regions differ by population and sector productivity
- Consumption: immobile workers with CB preference over sector final goods
- Intermediate good production: labor and sector final goods from other sectors
- Final good production: aggregate intermediate inputs within the sector across all source regions a la Armington

Quantification

Estimating the routing model

$$\log(q^{i,t}_{(o,RoW),d}) = \frac{\theta_F}{\theta} \log\left([\tilde{\mathbb{B}}_t(\kappa^H\theta, \kappa^L\theta)_{(o,d)}]\right) + \underbrace{+\text{cons}_i - \theta_F \log(\tau^i_{d,RoW}) - \log(\sum_{\text{All ports k}} \tau_{ok}^{-\theta_F} \cdot \tau_{k,RoW}^{-\theta_F})}_{\text{fixed effects: } f^{i,t}_o + f^{i,t}_d + f^{i,t}_{od}}$$

- Recall $\mathbb{B} = [\mathbb{I} - \mathbb{H} - \mathbb{L}]^{-1}$; write as function of $\kappa^H\theta$ and $\kappa^L\theta$ to highlight the dependence
- Estimate the following without solving model equilibrium:

$$\min_{\frac{\theta_F}{\theta}, \kappa^H\theta, \kappa^L\theta, \mathbf{fe}} \left[\frac{\theta_F}{\theta} \log\left([\tilde{\mathbb{B}}_t(\kappa^H\theta, \kappa^L\theta)_{(o,d)}]\right) + \mathbf{fe} - \log(q_{(o,RoW),d,t})\right]^2$$

- Point estimates: $\kappa^H\theta = 4.44$, $\kappa^L\theta = 5.98$, $\frac{\theta_F}{\theta} = 0.03$

Estimating the routing model

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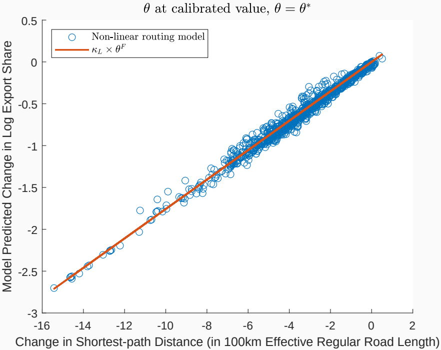
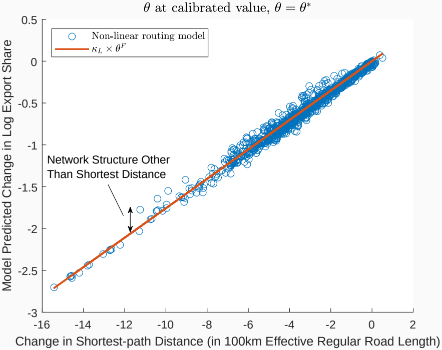
- Point estimates: $\kappa^H\theta = 4.44$, $\kappa^L\theta = 5.98$, $\frac{\theta_F}{\theta} = 0.03$
- Given κ_L, can identify κ^H/κ^L, θ_F, θ; will use price-distance regression to separate κ_L and θ combining structural models

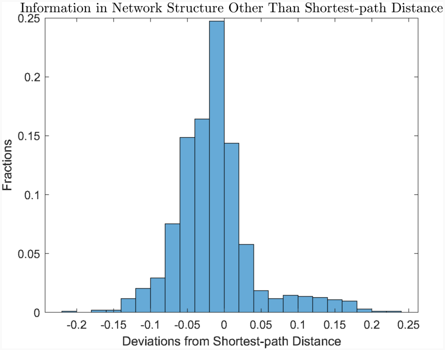
Identification for θ_F



- Given κ_L and θ, θ_F is identified by the export share-distance elasticity

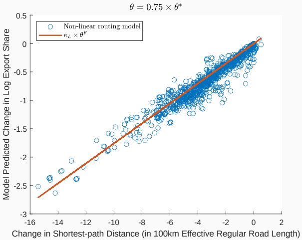
What is new to the nonlinear routing model?



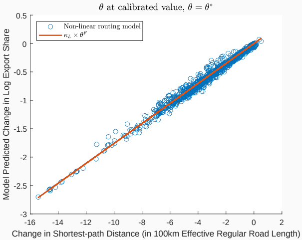


- The deviation of the nonlinear routing model from the linear model captures other network structure than the shortest-path distance

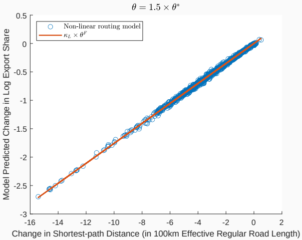
Varying θ affects how large this deviation contributes to model prediction



(a) $\theta = 0.75 \times \theta^*$



(b) $\theta = \theta^*$

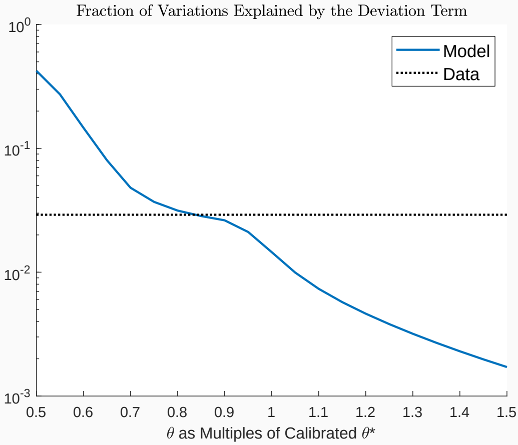


(c) $\theta = 1.5 \times \theta^*$

- Increasing θ brings the non-linear model closer to the linear model
  - converged to the linear model when $\theta \to \infty$

Identification for θ

- Identification: how much does network structure other than the shortest-path distance, measured by the deviation term, explain the data
- Compare $\frac{R^2_{\text{deviation}}}{R^2_{\text{shortest length + deviation}}}$ between model and data



Parameterize the rest of the model

Table 3: Parameter Values

Parameters	Descriptions	Value	Targets/Source
Parameters calibrated externally			
$\beta^i, \gamma^{ij}, \alpha^j$	IO structure and consumption share	-	2007 IO table for China
L_d	Total employment	-	2010 Population Census
σ	Trade elasticity	6	
θ_M	Elasticity of substitution across modes	2.5	
Parameters calibrated in equilibrium			
θ	Routing elasticity	81.21	joint estimate of $\kappa^H\theta = 4.44, \kappa^L\theta = 5.98, \frac{\theta_F}{\theta} = 0.03, \frac{\partial \log p}{\partial dist} = 0.06$
θ_F	Port choice elasticity	2.45	(joint estimate, as above)
κ_H	Expressway route cost	0.055	(joint estimate, as above)
κ_L	Regular route cost	0.074	(joint estimate, as above)
h_0	Trade cost level	1.295	Average ground shipment distance: 177 km
$\bar{\kappa}$	Alternative mode cost	0.210	Share of non-road shipment: 0.24
μ	Cost-weight to value elasticity	0.3	estimated
$\tau^i_{RoW}, \tau^{i'}_{RoW}$	Export and import costs	-	Sectoral export and import
T^i_d	Region-sector productivity	-	City-sector sales in 2008 Economic Census

Price-distance Regression

Price- weight-to-value elasticity

Model validation

Figure 2: Model Predicted Shipment Flows

- Model predicts trans-shipment by city well, controlling for city size and prov. fe
- City-sector export change in the model due to expressway expansion between 1999-2010 correlates with actual export growth

Counterfactuals

The Effects of the Expressway Expansion, 1999-2010

Change in	Value
Aggregate welfare	0.056
Log(Domestic trade / GDP)	0.113
Log(Exports / GDP)	0.157
Std Log(real wage) across regions	-0.0288

- Numbers in perspective: between 1999 and 2010, aggregate TFP increased by 36% (Penn World Table), trade/GDP increased by 70%
- Expressway expansion explains about 16% of the former; a quarter of the latter

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- Numbers in perspective: between 1999 and 2010, aggregate TFP increased by 36% (Penn World Table), trade/GDP increased by 70%
- Expressway expansion explains about 16% of the former; a quarter of the latter
- Total cost: 10% of 2010 GDP. Assuming 10% depreciation rate (Bai and Qian, 2010), 10% return to capital (Bai et al., 2006) $\Longrightarrow$ 180% net return to investment

The role of sectors

	Baseline	Model (2)	Model (3)	Model (4)	Model (5)
International trade	✓				
Regional specialization	✓	✓			
Trade cost heterogeneity	✓	✓	✓		
Intermediate input	✓	✓	✓	✓	
Welfare gains	5.64%	5.27%	4.54%	3.18%	0.74%

Each model recalibrated to match the same sales by city ($\{T_d^i\}$) and average shipment distance (h_0).

- baseline $\rightarrow$ (2): overlooks that expressways reduces import and export cost

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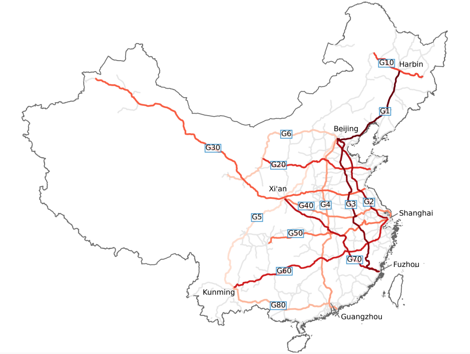
- (4) → (5): inferred wrong sales/VA ratio (same as in international trade)

Evaluating mega projects



ID	Length	Cost/GDP (%)	Welfare gains	%Change in Export/GDP
G1	1533.61	0.3	0.52	0.94
G2	1768.29	0.38	0.45	1.28
G3	2513.38	0.54	0.79	4.37
G4	2924.88	0.65	0.4	1.12
G5	2829.75	0.73	0.26	0.51

Conclusion

Conclusion

- Exploit over-time variations in city-to-port export to estimate the impact of transportation infrastructure on trade cost
  - construction of expressway reduces cost-distance elasticity by 25%
  - sectoral heterogeneity in cost levels that systematically correlates with weight-to-value ratios
- Accommodating regional specialization / sectoral heterogeneity / intermediate input is important
  - neglecting these underestimate the gains and turns positive NPV into negative
- Our approach requires data on sectoral production and is computational intensive. For future work useful to think about ways to
  - circumvent parameterizing the full model and computing counterfactuals
    - 2nd-order characterization quite accurate, but requires full information on shipment and routing
  - reduce the data requirement while retaining accuracy

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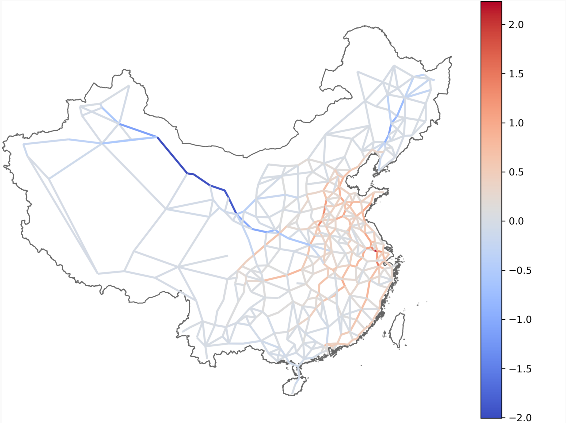
The minimum-spanning tree IV (Faber, 2014)

- Red: min-distance network connecting 55 major cities; Blue: 2010 expressway
- IV for $dist_{ij}^{2010}$: Effective length of shortest-path along the (Blue) network
- IV for $dist_{ij}^{1999}$: $dist_{ij}^{1999}$
- Identification: National Trunk Highway System exogenous to small cities

Change in shipment flows between 3 and 2



Note: The numbers are the differences in shipment value/GDP between Model (2) and Model (3). Cold colors indicate that there is less shipment in Model (3) than in Model (2).

Back

Price-distance regression

Table 4: Price Distance Regression

	(1)	(2)	(3)	(4)
	OLS		IV	
dist_{od}	0.055***	0.061***	0.053***	0.058***
	(0.013)	(0.022)	(0.012)	(0.021)
Fixed Effects	*dci*, *oci*	*dci*, *oci*	*dci*, *oci*	*dci*, *oci*
Exclude major cities	yes	yes	yes	yes
Exclude differentiated goods		yes		yes
Observations	1829372	232609	1829372	232609
R^2	0.323	0.340	-	-
First Stage KP-F statistic			1515.787	1156.297

Notes: *o*, *d*, *c*, *i* stand for origin city, port, destination country, and HS-8 product fixed effects, respectively. Standard errors are clustered at city-port level. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Back

Price regression: estimate trade cost-weight elasticity

Table 5: Transport cost and weight-to-value ratio

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Dependent variable	log price ratio				log price ratio		
Heaviness- HS2 Category	0.163***	0.161***	0.278***	0.199**			
	(0.056)	(0.056)	(0.086)	(0.089)			
Heaviness- HS4 Category					0.303***	0.362***	0.253***
					(0.044)	(0.050)	(0.043)
Fixed Effects	*o*, *d*, *c*	*odc*	*fdc*	*fdc*	*fdc*, *i*	*fdci*	*fdci*
Exclude major cities	yes	yes	yes	yes	yes	yes	yes
Exclude differentiated goods				yes			yes
Observations	1987140	1985946	1805563	190836	1805563	1126941	119077
R^2	0.063	0.074	0.375	0.481	0.417	0.596	0.639

Notes: *o*, *d*, *c*, *f*, *i* stand for origin city, port, destination country, firm, and HS2 category fixed effects, respectively.

Standard errors are clustered at HS2 category level (Columns 1-4) or HS4 category level (Columns 5-7). * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Back