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 in 47 major countries, half of which in China (2-5% of GDP)
- 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 $\rightarrow$ necessitates a structural model

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  - 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), ...

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- network distance $\xrightarrow{\text{trade cost elast.}}$ trade cost $\xrightarrow{\text{trade elast.}}$ trade flow $\xrightarrow{\text{GE}}$ emp./wage

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  - (2) external measure of freight rates: Baum-Snow et al. (2018)
  - (3) estimate using price gaps of homogeneous goods: Asturias et al. (2018), Atkin and Donaldson (2015), Donaldson (2018b)
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- Approach (1) does not allow for flexible regional fundamental; (2) rules out the non-monetary component of trade cost
- (3) and (4) both demanding in data $\rightarrow$ restricted to a small groups of products (thus one-sector models); trade cost elas. identified from cross-sectional variations in shipment flows

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  - Idea: A exports more through port a than port b $\implies$ $\tau_{\mathrm{A},\mathrm{a}} < \tau_{\mathrm{A},\mathrm{b}}$
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  - 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 $\Longrightarrow$ co-existence of regular and expressways; 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%)
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- Evaluate the return to expressway expansion: 1999-2010
  - 50,000 kilometer expressways built; total cost $570 billion (10 % of 2010 GDP)
  - Net 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 the effects of domestic trans. infra.
- Domestic trans. infra. promotes export
  - using **country-level** (Limao and Venables, 2001) and **region-level** variations (Coșar and Demir, 2016 and Martincus et al., 2017)
  - difference: focus are impact on trade cost and welfare, rather than export per se
- Chines 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
  - model-predicted export growth from expressways expansion a *potential* IV for city-level export

Outline

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

Data and Reduced-form Specifications

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

- Left: expressway network for 1999 and 2010
- Right: regular roads ('national' and 'provincial' roads) in 2007
- Find distance along the shortest path between o and d, $\{\mathrm{dist}_{od}^{t} : t = 1999, 2010\}$
  - 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 through fixed point algorithm in full quantification

Reduced-form specification: routing

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

- $q^t_{(o,RoW),d}$: *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: Aggregate Results

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	OLS					PPML	
$dist_{od,t}$	-0.346***	-0.103***	-0.136***	-0.144***		-0.470***	
	(0.010)	(0.025)	(0.033)	(0.040)		(0.066)	
-on express					-0.082*		-0.286**
					(0.042)		(0.117)
-on national					-0.148***		-0.488***
					(0.043)		(0.084)
Fixed Effects	o, d, t	od, t	od, ot, dt	od, ot, dt	od, ot, dt	od, ot, dt	od, ot, dt
Exclude major cities				yes	yes	yes	yes
Observations	3625	2768	2738	2002	2002	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		
$dist_{od,t}$	-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			

Notes: Standard errors are clustered at city-port level

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Reduced-form specification: price

- Assumption: $\tau_{od}^{i,t} = (\frac{h_i}{h_0})^{\mu} \exp(\kappa_L \times \mathrm{dist}_{od}^t)$
  - i is sector; h_i is 'heaviness' of i, μ captures importance of sector heterogeneity
  - Could've made κ_L vary by i; not supported by data
  - this specification is consistent with the routing regression
- $p^i_{(o,RoW),d} = p^i_o \cdot \tau^i_{od} \implies \log(\frac{p^i_{(o,RoW),d}}{p^i_o}) = \mu \log(h_i) - \kappa_L \mathrm{dist}^t_{od}$,
  - $p^i_{(o,RoW),d}$: unit value of a good from o exported to RoW through port d
  - p^i_o: the factory gate price, unobserved $\rightarrow$ focus on when o is a sea port, in which case $p^i_o \approx p^i_{(o,RoW),o}$
- Remarks
  - validity requires goods comparable: a good is a city-HS 8-dest. country cell
  - rich controls absorbing systematic price differences due to quality or preference
  - tradeoff: not enough observations in 1999 for identification $\implies$ focus on 2010
  - results robust when focusing on 'non-differentiated goods' (Rauch, 1999)

Price regression: estimate κ_L

Table 3: 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. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Price regression: estimate μ

Table 4: 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). * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Summary of reduced-form results

- Elasticity of shipment routing w.r.t. effective distance around 15%
  - Using cross-sectional variation overestimate by 100%
- Substantial heterogeneity in the *level* of transport cost across sectors with different weight-to-value ratios (elast. $\mu = 0.3$)

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- Additional hundred kilometer increases price by 6%
  - Under the reduced-form setting $\implies$ $\kappa_L = 0.06$ and $\theta_F = 2.5$
- 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; need to use indirect inference to separate θ_F, κ_L, κ_H
  - incorporates alternative modes
  - use the GE structure to infer the level of cost h_o; counterfactuals

Model

Routing block: from road network to domestic trade cost

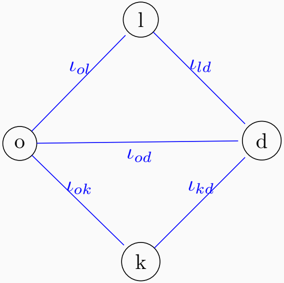

Figure 1: A trucker going from o to d

- 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:
  $\tau_{od,2} = \Gamma(\frac{\theta-1}{\theta})\big([\iota_{od}]^{-\theta} + [\iota_{ol}\iota_{ld}]^{-\theta} + [\iota_{ok}\iota_{kd}]^{-\theta}\big)^{-\frac{1}{\theta}},\ o \neq d$

Routing block: Matrix representation

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

- If made choose among the three, the expected cost is:
  $\tau_{od,2} = \Gamma(\frac{\theta-1}{\theta})\big([\mathbb{L}_{(o,d)}] + [\mathbb{L}^2_{(o,d)}]\big)^{-\frac{1}{\theta}},\ o \neq d$
- Allowing detours, expected cost among all path with less than N edges is:
  $\tau_{od,N} \equiv \Gamma(\frac{\theta-1}{\theta})\big(\sum_{s=1}^{N}[\mathbb{L}^s_{(o,d)}]\big)^{-\frac{1}{\theta}}, o \neq d$
- 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 sector heterogeneity: $\tau^{i}_{od} = (\frac{h_i}{h_0})^{\mu} \cdot \Gamma(\frac{\theta-1}{\theta})[\mathbb{B}_{(o,d)}]^{-\frac{1}{\theta}}$

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- With sector heterogeneity: $\tau^i_{od} = (\frac{h_i}{h_0})^{\mu} \cdot \Gamma(\frac{\theta-1}{\theta})[\mathbb{B}_{(o,d)}]^{-\frac{1}{\theta}}$
- With alternative transport mode and export:

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

where $\bar{\tau}^i_{od} = (\frac{h_i}{h_0})^{\mu}\exp(\bar{\kappa} \cdot \overline{\text{dist}}_{od}),\ o \neq d$

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

$$\log(q^{i,t}_{(o,RoW),d}) = \frac{\theta_F}{\theta}\log\left([\tilde{\mathbb{B}}_t(\kappa^H\theta,\kappa^L\theta)_{(o,d)}]\right) + \underbrace{+\mu\log(\frac{h_i}{h_0}) - \theta_F\log(\tau^i_{d,RoW}) - \log(\sum_{\text{All ports k}} \tau_{ok}^{-\theta_F}\cdot\tau_{k,RoW}^{-\theta_F})}_{\text{fixed effects: } f_o^{i,t} + f_d^{i,t} + f_{od}^{i,t}}$$

- 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
- Can identify $\kappa^H\theta$, $\kappa^L\theta$, and $\frac{\theta_F}{\theta}$, but not individual parameters
- $\max_{\frac{\theta_F}{\theta},\kappa^H\theta,\kappa^L\theta,\mathbf{fe}}\left[\frac{\theta_F}{\theta}\log\left([\tilde{\mathbb{B}}_t(\kappa^H\theta,\kappa^L\theta)_{(o,d)}]\right) + \mathbf{fe} - \log(\hat{\pi}_{(o,RoW),d,t})\right]^2$,
- $\implies \kappa^H\theta = 4.44$, $\kappa^L\theta = 5.98$, $\frac{\theta_F}{\theta} = 0.03$

Parameterize the rest of the model

Table 5: 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	
κ_H	Expressway route cost	0.055	
κ_L	Regular route cost	0.074	
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
τ^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

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 growth
  - Robust when focusing on non-major cities

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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- 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) $\implies$ 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).

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- (2) $\rightarrow$ (3): In the data and model (2) trade happens between large regions specializing in different sectors and expressway built in this period connected these regions; model (3) predicts more trade between close partners. Map

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%

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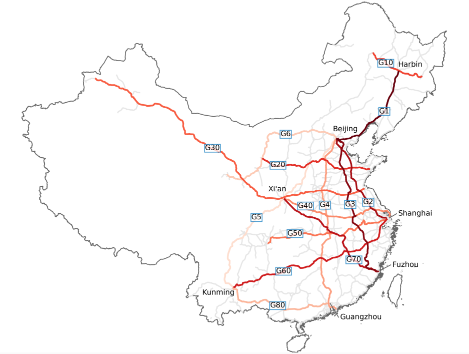
- (4) $\rightarrow$ (5): inferred wrong sales/VA ratio (same as in international trade)

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

- Accounting regional specialization / sectoral heterogeneity / intermediate input is important
  - neglecting these underestimate the gains 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

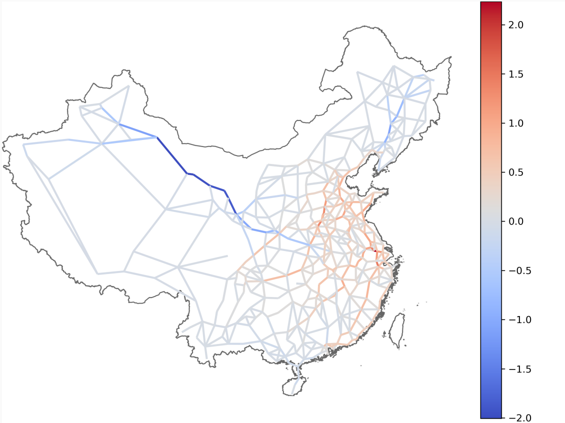
    2nd-order characterization quite accurate, but requires full information on shipment and routing
  - reduce the data requirement while retaining accuracy

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

Back

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

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