Spatial Frictions: Applications to Development

David Atkin (MIT)

STEG Lecture 12

Plan for Today's Lecture on Spatial Frictions

1. Introduction
2. Measuring spatial frictions
   - Estimating spatial frictions via direct measurement
   - Estimating spatial frictions via gravity equations
   - Estimating spatial frictions using price gaps
3. Estimating the impacts of spatial frictions
   - Trade and infrastructure
   - Information frictions

Introduction

- Spatial frictions affect developing countries in a myriad of ways
- Today I will focus on the impacts of spatial frictions that impede the movement of goods and services (i.e. trade costs) rather than people (i.e. migration costs)
  - Although these may interact, as in economic geography models where both labor and goods can move between locations but are subject to spatial frictions (see Caliendo, Dvorkin, and Parro 2019, Tombe and Zhu 2019, Fan 2019, Morten and Oliveira 2018)
- The first question is how large are these spatial frictions?
  - Important both as an input to quantitative models, and to explaining features of trade data (see Obstfeld and Rogoff (2000) for how trade costs explain 'six big puzzles' of international macro).
- If they are large, and we will show that they do appear to be, what are the effects of reducing these frictions?
  - Vast amounts spent to reduce trade costs (e.g. infrastructure investments), so relevant to many policy questions

Measuring Trade Costs: What do we mean by 'trade costs'?

- The sum total of all of the costs that impede trade from origin to destination.
- This includes:
  - Taxes, tariffs and non-tariff barriers (quotas etc).
  - Transportation costs.
  - Administrative hurdles.
  - Corruption (e.g. bribes).
  - Contractual frictions (Avner Greif's 'Fundamental Problem of Exchange').
  - Information frictions to doing business over space (or costs incurred to minimize these).
  - The need to secure trade finance (working capital while goods in transit).
- NB: these 'trade costs' impede movements of goods and services both within and across countries.

Are Trade Costs 'Large' for Developing Countries?

- There is considerable debate (still unresolved) about this question.
- One often hears the argument that a fundamental problem in developing countries is their high trade costs (e.g. road quality, bribe extraction, poor institutions making contracting difficult etc). E.g., see colorful anecdotes in *Economist* article "The road to hell is unpaved" on traveling with a beer truck driver in Cameroon.
- But inter- and intra-national shipping rates aren't that high: even on some of the more expensive international land routes (e.g. Mombasa, Kenya – Kampala, Uganda or Douala, Cameroon – N'Djamena, Chad) prices are around 10 cents per ton km (Teravaninthorn and Raballand 2009).
- Tariffs are not that big (nowadays). Where they are big they are massively evaded (Sequiera 2016).
- Repeated games and reputations may circumvent any high stakes contractual issues.

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Direct Measurement of Trade Costs

- The simplest way to measure TCs is to just go out there and measure them directly.
- Many components of TCs are probably measurable (e.g. transport prices, tariffs). But many aren't. Still, this sort of descriptive evidence is extremely valuable for getting a sense of things.
- Examples of creative sources of this sort of evidence:
  - Hummels (JEP, 2007) survey on transportation.
  - Anderson and van Wincoop (JEL, 2004) survey on trade costs.
  - Limao and Venables (2008) on shipping.
  - Djankov, Freund and Pham (2010) on time costs.
  - Barron and Olken (JPE 2008) on bribes and trucking in Indonesia.
  - Sequeira (2016) on bribes for customs agents.
  - Fafchamps (2004 book) on traders and markets in Africa.
  - Startz (2017) on traders in Nigeria

Direct Measures: Djankov, Freund and Pham ReStat 2010

'Doing business' style survey on freight forwarding firms around the world.

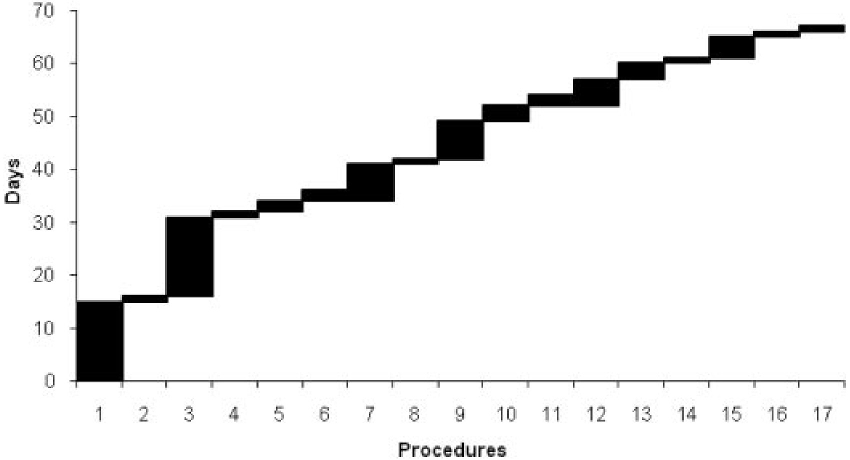
List of Procedures to Export from Burundi

1. Secure letter of credit
2. Obtain and load containers
3. Assemble and process export documents
4. Pre-shipment inspection and clearance
5. Prepare transit clearance
6. Inland transportation to port of departure
7. Arrange transport; waiting for pickup and loading on local carriage
8. Wait at border crossing
9. Transportation from border to port
10. Terminal handling activities
11. Pay of export duties, taxes or tariffs
12. Waiting for loading container on vessel
13. Customs inspection and clearance
14. Technical control, health, quarantine
15. Pass customs inspection and clearance
16. Pass technical control, health, quarantine
17. Pass terminal clearance

Direct Measures: Djankov, Freund and Pham (ReStat, 2010)

'Doing business' style survey on freight forwarding firms around the world.

FIGURE 1.—EXPORT PROCEDURES IN BURUNDI



Direct Measures: Djankov, Freund and Pham (ReStat, 2010)

'Doing business' style survey on freight forwarding firms around the world.

TABLE 1.—DESCRIPTIVE STATISTICS BY GEOGRAPHIC REGION
REQUIRED TIME FOR EXPORTS

	Mean	Standard Deviation	Minimum	Maximum	Number of Observations
Africa and Middle East	41.83	20.41	10	116	35
COMESA	50.10	16.89	16	69	10
CEMAC	77.50	54.45	39	116	2
EAC	44.33	14.01	30	58	3
ECOWAS	41.90	16.43	21	71	10
Euro-Med	26.78	10.44	10	49	9
SADC	36.00	12.56	16	60	8
Asia	25.21	11.94	6	44	14
ASEAN 4	22.67	11.98	6	43	6
CER	10.00	2.83	8	12	2
SAFTA	32.83	7.47	24	44	6
Europe	22.29	17.95	5	93	34
CEFTA	22.14	3.24	19	27	7
CIS	46.43	24.67	29	93	7
EFTA	14.33	7.02	7	21	3
ELL FTA	14.33	9.71	6	25	3
European Union	13.00	8.35	5	29	14
Western Hemisphere	26.93	10.33	9	43	15
Andean Community	28.00	7.12	20	34	4
CACM	33.75	9.88	20	43	4
MERCOSUR	29.50	8.35	22	39	4
NAFTA	13.00	4.58	9	18	3
Total sample	30.40	19.13	5	116	98

Note: Seven countries belong to more than one regional agreement.
Source: Data on time delays were collected by the Doing Business team of the World Bank/IFC. They are available at www.doingbusiness.org.

Direct Measures: Barron and Olken (JPE 2009)

Survey of truckers in Aceh, Indonesia.

TABLE 1
Summary Statistics

	Both Roads (1)	Meulaboh Road (2)	Banda Aceh Road (3)
Total expenditures during trip (rupiah)	2,901,345	2,932,687	2,863,637
	(725,003)	(561,736)	(883,308)
Bribes, extortion, and protection payments	361,323	415,263	296,427
	(182,563)	(180,928)	(162,896)
Payments at checkpoints	131,876	201,671	47,905
	(106,386)	(85,203)	(57,293)
Payments at weigh stations	79,195	61,461	100,531
	(79,405)	(43,090)	(104,277)
Convoy fees	131,404	152,131	106,468
	(176,689)	(147,927)	(203,875)
Coupons/protection fees	18,848	. . .	41,524
	(57,593)		(79,937)
Fuel	1,553,712	1,434,608	1,697,010
	(477,207)	(222,493)	(637,442)
Salary for truck driver and assistant	275,058	325,514	214,353
	(124,685)	(139,233)	(65,132)
Loading and unloading of cargo	421,408	471,182	361,523
	(336,904)	(298,246)	(370,621)
Food, lodging, etc.	148,872	124,649	178,016
	(70,807)	(59,067)	(72,956)
Other	140,971	161,471	116,308
	(194,728)	(236,202)	(124,755)
Number of checkpoints	20	27	11
	(13)	(12)	(6)
Average payment at checkpoint	6,262	7,769	4,421
	(3,809)	(1,780)	(4,722)
Number of trips	282	154	128

Note.—Standard deviations are in parentheses. Summary statistics include only those trips for which salary information was available. All figures are in October 2006 rupiah (US$1.00 = Rp. 9,200).

Direct Measures: Barron and Olken (JPE 2009)

Extract more at later checkpoints (more surplus to extract as closer to payoff at end)

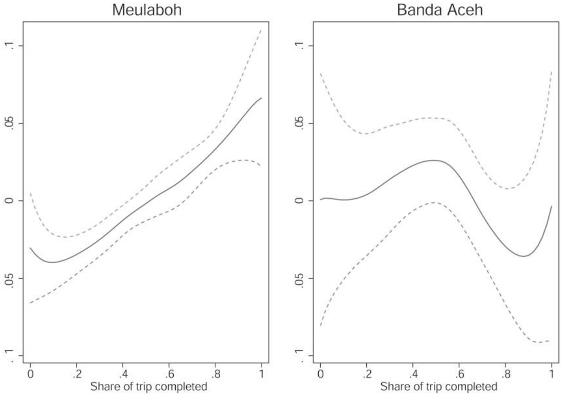


FIG. 4.—Payments by percentile of trip. Each graph shows the results of a nonparametric Fan (1992) locally weighted regression, where the dependent variable is log payment at checkpoint, after removing checkpoint × month fixed effects and trip fixed effects, and the independent variable is the average percentile of the trip at which the checkpoint is encountered. The bandwidth is equal to one-third of the range of the independent variable. Dependent variable is log bribe paid at checkpoint. Bootstrapped 95 percent confidence intervals are shown in dashes, where bootstrapping is clustered by trip.

Direct Measures: Sequeira (AER 2016)

Mozambique: When tariffs are high, pay bribes to assign to different tariff code

Table 6: **Summary Statistics: Bribe Payments**

	Pre Tariff Change	**Post Tariff Change**	
	2007	2008	2011-2012
Probability of Paying a Bribe (%)	80	26	16
Avg Bribe Amount per Ton (Metical 2007, CPI Adjusted)	2,164 (7,800)	280 (963)	494 (2,746)
Primary Bribe Recipient	Customs (97%)	Customs (84%)	Customs (72%)
Primary Reason for Bribe Payment	Tariff Evasion (61%)	Congestion (59%)	Congestion (38%)
Ratio of Bribe Amount to Tariff Duties Saved [0-1]*	0.07 (0.13)	0.028 (0.09)	0.008 (0.02)
Avg clearing time for all shipments (days)	2.4 (1.4)	2.6 (1.4)	2.6 (3.6)
Avg clearing time with the payment of a bribe (days)	2.5 (1.5)	2.3 (1.2)	2.5 (3.1)
Avg clearing time without the payment of a bribe (days)	1.9 (0.74)	2.7 (1.38)	2.6 (3.7)
Avg clearing time with bribe payment for tariff evasion (days)	2.2 (1.7)	2.6 (1.4)	2.4 (1.8)

[a] *Conditional on the bribe being paid for tariff evasion.

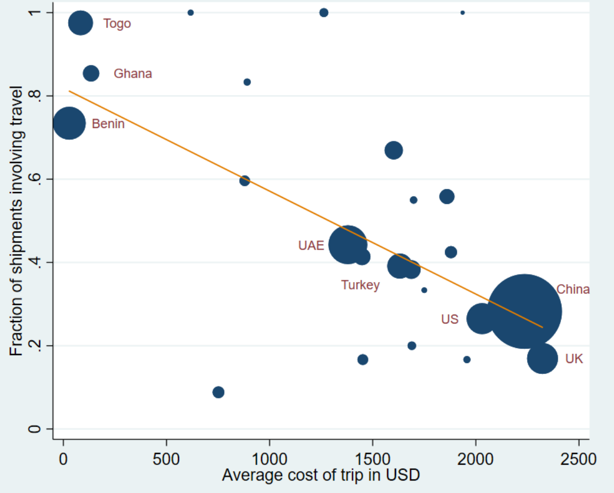
[b] Source: Audit study conducted by the author.

[c] NOTES: Average clearing times moved in tandem with increases in the overall volume of cargo handled at the port between 2007 and 2011. Total volumes increased by 13% in 2008 and 18% in 2011. Note that in 2009, the port of Maputo was still functioning at 30% of capacity so it was capable of handling the observed increase in volumes without substantially increasing congestion.

Direct Measures: Startz (2021)

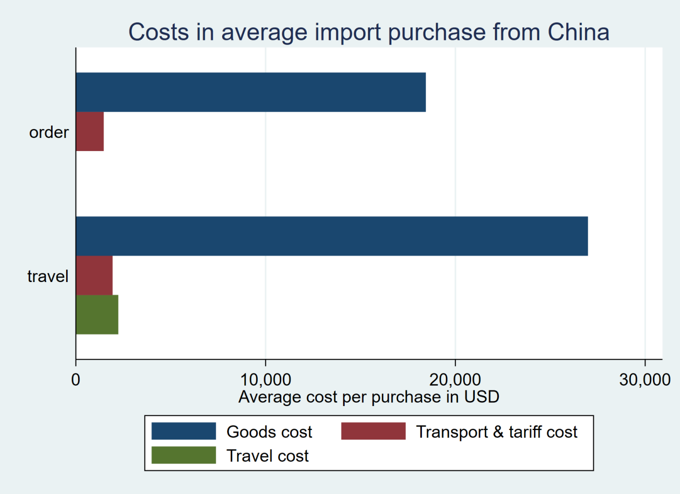
Distance creates search (what goods are available?) and contracting (have goods or money been sent?) problem

Nigerian Consumer Goods Traders: Travel frequently to make purchase, although less when buying from afar



Direct Measures: Startz (2021)

Nigerian Traders: Travel costs as large as transportation/tariff costs



Direct Measures: Startz (2021)

Nigerian Traders: Keep on traveling even after many years trading with country/supplier

Table 3: Probability of traveling when importing

Dependent variable:	(1) Traveled	(2) Traveled	(3) Traveled
Business age	0.007		
	(0.005)		
Years buying from country	0.008	-0.014**	
	(0.007)	(0.007)	
Years buying from supplier	-0.004	0.005	0.001
	(0.006)	(0.004)	(0.005)
Observations	3048	3019	3241
Sector x country FEs	yes		
Trader and country FEs		yes	
Trader x country FEs			yes
Mean business age	10.65	10.64	10.79
Mean years buying from country	5.46	5.45	5.46
Mean years buying from supplier	3.84	3.84	4.04

Notes: Observations are at the purchase level. All columns are linear probability models. Standard errors clustered at the trader level are shown in parentheses. Observations for which the profit ratio (i.e. revenue divided by purchase cost) is in the top 5% or bottom 5% are

Direct Measures: Startz (2021)

Nigerian Traders: When travel pay lower prices, charge higher markups, buy newer styles, change suppliers

Table 4: Relationship between travel and transaction features

Panel A – Across traders

Dependent variable:	(1) Log unit cost	(2) New style	(3) New supplier	(4) Months between purchases	(5) Total goods cost ($US)
Traveled	-0.32**	0.07*	0.08***	1.98***	7,046.65**
	(0.113)	(0.043)	(0.030)	(0.412)	(2,889.024)
Observations	2,736	3,531	3,349	1,047	1,346
Mean of outcome	1.90	0.51	0.20	5.77	21,225.37
Sector x country FEs	yes	yes	yes	yes	yes
Trader x country FEs					

Panel B – Within trader

Dependent variable:	(6) Log unit cost	(7) New style	(8) New supplier	(9) Months between purchases	(10) Total goods cost ($US)
Traveled	-0.14**	0.01	0.12***	0.59	9,966.93***
	(0.064)	(0.046)	(0.042)	(0.57)	(2,173.04)
Observations	2,644	3,428	3,256	1,042	1,134
Mean of outcome	1.90	0.51	0.20	5.37	21,225.37
Sector x country FEs					
Trader x country FEs	yes	yes	yes	yes	yes

Notes: Outcomes in columns 1 - 3 and 6 - 8 are measured at the purchase level, and observations for which the profit margin of the transaction is in the top 5% or bottom 5% are excluded, . Outcomes in columns 5, 6, 9 and 10 are measured at the shipment level, and observations for which the profit ratio is in the top or bottom 2% or for which the total revenue is in the top or bottom 2% are excluded. Results are robust to various specifications of outliers, available on request. Columns 2, 3, 7, and 8 are linear probability models.

* significant at 10% ** significant at 5% *** significant at 1%.

Direct Measures: Startz (2021)

- Embeds optimal stocking, search, and a repeated game with moral hazard into a monopolistically competitive trade framework
  - Trader pay premium to ensure seller doesn't cheat
  - More frequent travel allows more up to date vintages of goods (and mitigates temptation for seller to cheat)
  - Probability of buying from same supplier again pins down contracting friction, choice between travel versus ordering and frequency of new styles pins down search friction
- Removing both frictions increases welfare in sector by 14% (2/3rds of gains from eliminating physical and regulatory costs).
- Issues more severe for developing countries:
  - If Nigerian consumers spent like American ones, (fixed) travel costs to address information problems are inconsequential (e.g. Walmart versus Nigerian trader)
  - International travel particularly expensive for dev country traders (visa costs, few flights)

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Measuring Trade Costs from Trade Flows

- As in Startz (2021), descriptive statistics can only get us so far. No one records the full extent of costs of trading and doing business afar.
    - E.g. transportation-related cost is not just the freight rate but also the time cost of goods in transit, etc.
- The most commonly-employed method (by far) for measuring the full extent of trade costs is the gravity equation.
    - This is a particular way of inferring trade costs from trade flows.
    - Implicitly, we are comparing the amount of trade we see in the real world to the amount we'd expect to see in a frictionless world; the 'difference'—according to this logic—must be due to trade costs.
    - Gravity models put a lot of structure on the model (typically identical CES preferences, less restrictive on supply side), in order to transparently back out trade costs as a residual:

$$\ln X_{ij}^k(\boldsymbol{\tau}, \mathbf{E}) = A_i^k(\boldsymbol{\tau}, \mathbf{E}) + B_j^k(\boldsymbol{\tau}, \mathbf{E}) + \varepsilon^k \ln \tau_{ij}^k$$

Estimating τ_{ij}^k from the Gravity Equation: 'Residual Approach'

- One natural approach would be to use the above structure to back out what trade costs τ_{ij}^k must be. Let's call this the 'residual approach'.
- Head and Ries (2001) propose a way to do this:
  - Suppose that intra-national (or intra-city) trade is free: $\tau_{ii}^k = 1$. This can be thought of as a normalization of all trade costs (e.g. assume distributional retail/wholesale costs apply equally to domestic goods and international goods, after the latter arrive at the port).
  - And suppose that inter-national (or intra-national) trade is symmetric: $\tau_{ij}^k = \tau_{ji}^k$.
  - Then we have the 'phi-ness' of trade:

$$\phi_{ij}^k \equiv (\tau_{ij}^k)^{1-\varepsilon^k} = \sqrt{\frac{X_{ij}^k X_{ji}^k}{X_{ii}^k X_{jj}^k}} \tag{1}$$

  - I.e. if you trade as much with others as you do with yourself, there must be no frictions.

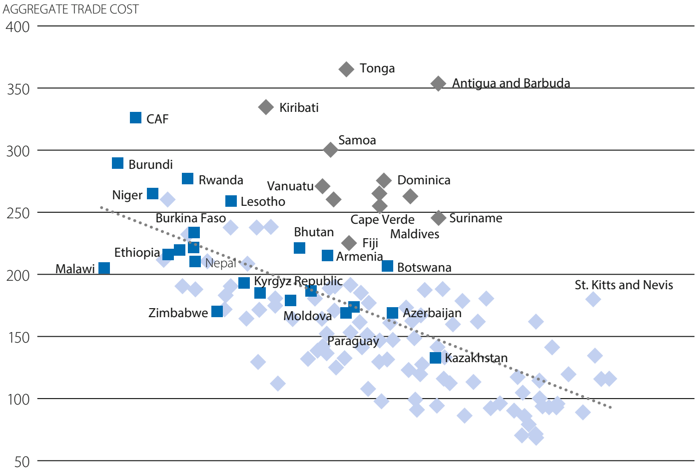
Estimating τ_{ij}^k from the Gravity Equation: 'Residual Approach'

- There are some drawbacks of this approach:
    - We have to be able to measure internal trade, X_{ii}^k.
    - We have to know ε^k. (But of course this should come as no surprise. We are inferring prices from quantities so clearly it would be impossible to proceed without an estimate of supply/demand elasticities, i.e. the trade elasticity ε^k.)

Residual Approach to Measuring Trade Costs

Arvis et al. (2013), UNESCAP-World Bank Trade Costs database

Figure 2.15 GDP per capita and Aggregate Trade Costs



Estimating τ_{ij}^k from the Gravity Equation: 'Determinants Approach'

- A more common approach to measuring τ_{ij}^k is to give up on measuring the full τ, and instead parameterize τ as a function of observables.
  - E.g. $\tau_{ij}^k = \beta D_{ij}^{\rho}$ where D_{ij} is distance.
  - So we give up on measuring the full set of τ_{ij}^k's, and instead estimate just the elasticity of TCs with respect to distance, ρ.

Other elements of Trade Costs

- Many determinants of TCs have been investigated in the literature.
- Anderson van Wincoop (2004) summarize these:
  - Tariffs, NTBs, etc.
  - Transportation costs (directly measured). Roads, ports. (Feyrer (2009) on Suez Canal had this feature).
  - Currency policies.
  - Being a member of the WTO.
  - Language barriers, colonial ties.
  - Information barriers. (Rauch and Trindade (2002), Allen (2014).)
  - Contracting costs and insecurity (Evans (2001), Anderson and Marcoulier (2002)).
  - US CIA-sponsored coups. (Easterly, Nunn and Sayananth (2010).)
- Aggregating these trade costs together into one representative number is not trivial (assuming the costs differ across goods).
  - Anderson and Neary (2005) have outlined how to solve this problem (conditional on a given theory of trade).

AvW (2004): Summary of Gravity Results

TABLE 7
TARIFF EQUIVALENT OF TRADE COSTS

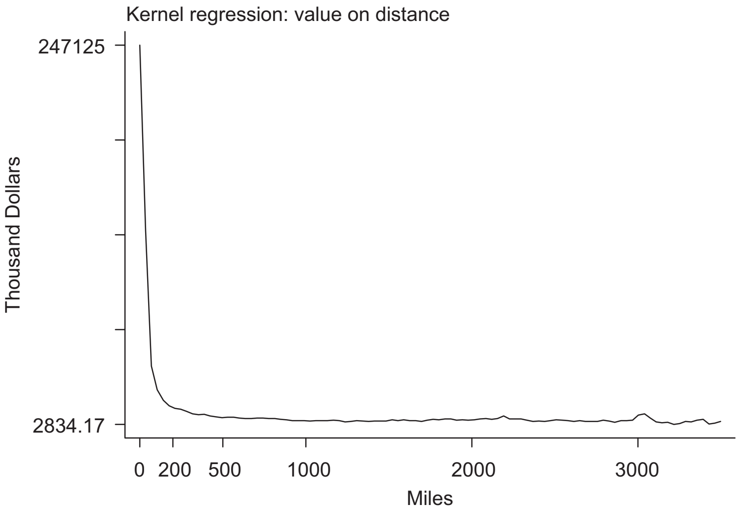
	method	data	reported by authors	$\sigma=5$	$\sigma=8$	$\sigma=10$
all trade barriers						
Head and Ries (2001) U.S.-Canada, 1990-1995	new	disaggr.	48 ($\sigma=7.9$)	97	47	35
Anderson and van Wincoop (2003) U.S.-Canada, 1993	new	aggr		91	46	35
Eaton and Kortum (2002) 19 OECD countries, 1990 750-1500 miles apart	new	aggr.	48–63 ($\sigma=9.28$)	123–174	58–78	43–57
national border barriers						
Wei (1996) 19 OECD countries, 1982-1994	trad.	aggr.	5 ($\sigma=20$)	26–76	14–38	11–29
Evans (2003a) 8 OECD countries, 1990	trad.	disaggr.	45 ($\sigma=5$)	45	30	23
Anderson and van Wincoop (2003) U.S.-Canada, 1993	new	aggr.	48 ($\sigma=5$)	48	26	19
Eaton and Kortum (2002) 19 OECD countries, 1990	new	aggr.	32–45 ($\sigma=9.28$)	77–116	39–55	29–41
language barrier						
Eaton and Kortum (2002) 19 OECD countries, 1990	new	aggr.	6 ($\sigma=9.28$)	12	7	5
Hummels (1999) 160 countries, 1994	new	disaggr.	11 ($\sigma=6.3$)	12	8	6
currency barrier						
Rose and van Wincoop (2001) 143 countries, 1980 and 1990	new	aggr.	26 ($\sigma=5$)	26	14	11

A Concern About Identification

- Do neighbors trade more because:
  - They have low trade costs as gravity approach implies?
  - Integrated supply chains choose to locate near each other (i.e. τ_{ij}^k is some combination of a trade shock and a_{ij}^k technology shock).
    - Hummels and Hilberry (EER, 2008) look at this on US trade data by checking whether imports of a zipcode's goods are correlated with the upstream input demands of that zipcode's industry-mix.
  - They have tastes for similar goods (i.e. τ_{ij}^k is some combination of a trade shock and a_{ij}^k demand shock).
    - Perhaps because tastes evolve through habit formation and hence historic endowments as in Atkin (AER 2013).

Hilberry and Hummels (EER 2008) using zipcode-to-zipcode US data

Is it really plausible that trade costs fall this fast with distance?



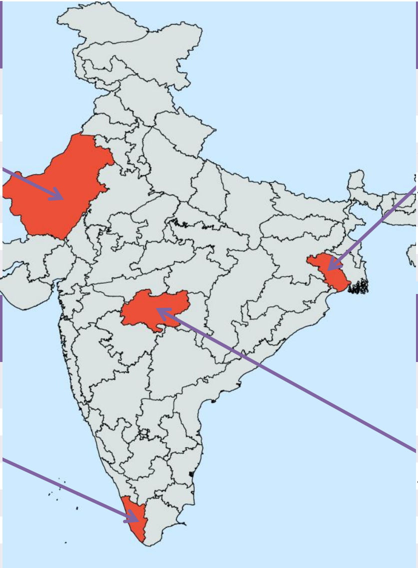
Atkin (AER 2012): Endogenous Tastes?

Western Rajasthan

Item	Food Share	Price (1000 Cal)
Rice	0.4	1.4
Wheat	31.0	0.7
Jowar	2.7	0.6
Bajra	7.9	0.8
Milk	25.4	4.0
Fish	0.0	19.0

Southern Kerala

Item	Food Share	Price (1000 Cal)
Rice	34.0	1.1
Wheat	1.9	1.0
Jowar	0.0	0.9
Bajra	0.0	1.4
Milk	8.0	4.3
Fish	10.6	8.1



Western Plains West Bengal

Item	Food Share	Price (1000 Cal)
Rice	57.0	1.1
Wheat	2.1	0.9
Jowar	0.2	0.7
Bajra	0.0	-
Milk	4.1	4.0
Fish	4.6	14.3

Inland Eastern Maharashtra

Item	Food Share	Price (1000 Cal)
Rice	5.3	1.1
Wheat	9.2	0.8
Jowar	18.9	0.4
Bajra	0.2	0.8
Milk	8.7	4.0
Fish	0.4	14.8

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Using price dispersion to estimate trade costs

- A large literature does this instead of using quantities/expenditure as in the gravity approach.
  - See, e.g., Fackler and Goodwin (2001 Handbook survey) or Anderson and van Wincoop (2004, JEL)
- The attraction is that it is less parametric. Purely rests on the arbitrage idea that if i is currently exporting homogeneous product k to location j at time t (ie $X^k_{ijt} > 0$ is true) then we must have, if we believe in arbitrage:

$$\ln p^k_{jt} - \ln p^k_{it} = \ln \tau^k_{ijt} \tag{2}$$

Challenges in doing this

1. Have to observe homogeneous products. (Otherwise price gaps will reflect quality differences.)
2. Have to know whether two locations are trading that product
   - This is challenging in practice since at the level of 'products' for which you can plausibly overcome problem 1, it is often impossible to see trade flow data that narrowly
3. Have to believe in perfect arbitrage (and hence also perfect competition) or else have a convincing way of correcting for this

Some recent progress has been made on this. Examples include:

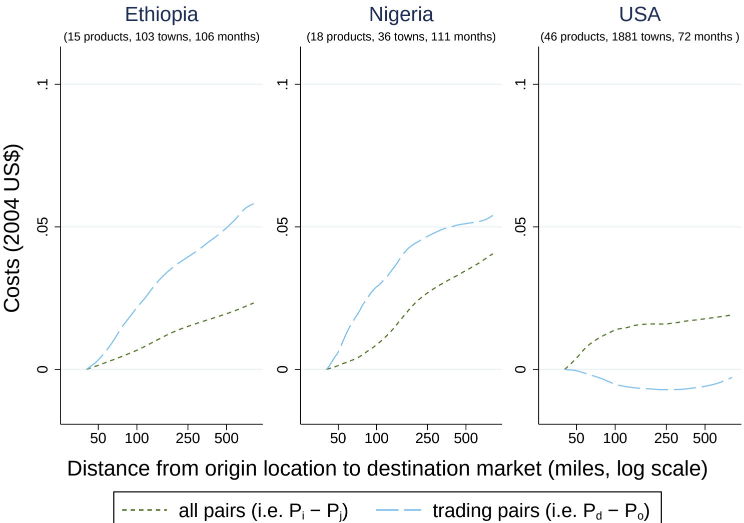
- Donaldson (2018) on solving 1 and 2 using Salt in India.
- Atkin and Donaldson (2015) on attempts to solve 1-2 and also make progress on 3.
- Econ History and Ag Econ have tried to make progress working with the week inequality $|\ln p_{jt}^k - \ln p_{it}^k| \leq \ln \tau_{ijt}^k$

Atkin and Donaldson (2015) try to uncover $\partial\tau(Z_{ij})/\partial Z_{ij}$

1. Have to observe homogeneous products.
    - Collect sample of barcode-level products from CPI data collection in Nigeria and Ethiopia (compare to US)
2. Have to know whether two locations are trading that product
    - Collect data on factory locations for all products in sample

Are two locations trading?

Slope of price gap on distance: all pairs versus trading pairs



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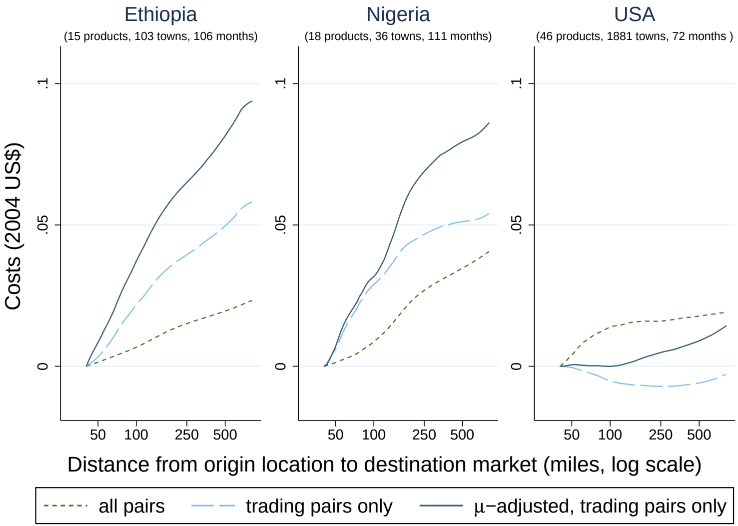
   - Collect sample of barcode-level products from CPI data collection in Nigeria and Ethiopia (compare to US)
2. Have to know whether two locations are trading that product
   - Collect data on factory locations for all products in sample
3. Imperfect competition: oligopolistic traders buy at factory gate and markup before selling to consumers: $p_d - p_o = \tau(Z_{od}) + \mu_{od}$
   - Mark-ups respond to higher $\tau(Z_{od})$ through effect on marginal costs. Price gaps confound effect of trade costs increase and mark ups changing with these higher trade costs.
   - However, another marginal cost shifter, the response of destination prices to procurement price shocks, reveals how the markup responds for each location/product pair (a function of second derivatives of demand and market structure).
   - Observable sufficient statistic (price pass-through) allows $\partial\tau(Z_{od})/\partial Z_{od}$ to be recovered from $\partial(p_d - p_o)/\partial Z_{od}$

Imperfect competition

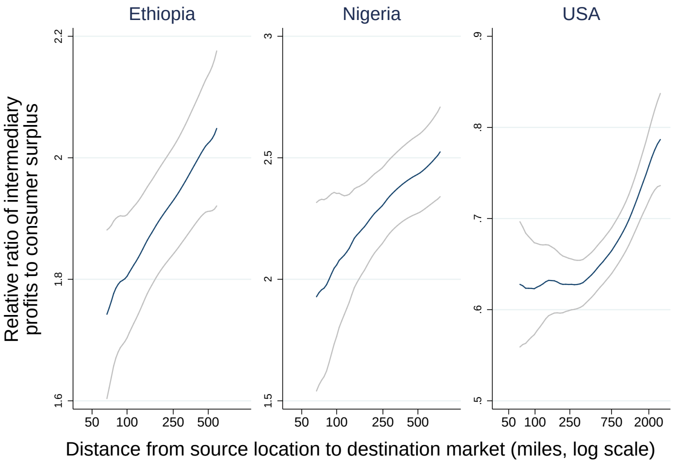
Slope of price gap on distance: accounting for imperfect competition



Implications for incidence of (positive) globalization shock

High $\tau(Z_{od})$ means smaller increase in size of pie in remote locations

Less competition means smaller share of pie goes to consumers



95% confidence intervals shown. Locally weighted polynomial (Epanechnikov kernel, bandwidth=0.5).

Plan for Today's Lecture on Spatial Frictions

1. Introduction

2. Measuring spatial frictions
   - Estimating spatial frictions via direct measurement
   - Estimating spatial frictions via gravity equations
   - Estimating spatial frictions using price gaps

3. Estimating the impacts of spatial frictions
   - **Trade and infrastructure**
   - Information frictions

Lowering trade costs through infrastructure investments

- Infrastructure investment in the major way governments reduce trade costs
- But not easy to identify effects of infrastructure:

Lowering trade costs through infrastructure investments

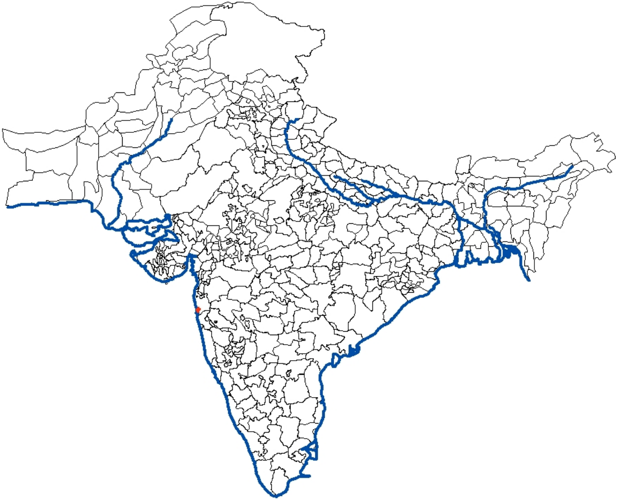
- Infrastructure investment in the major way governments reduce trade costs
- But not easy to identify effects of infrastructure:
  - Placement responds to economic opportunities/growth.
  - Govt. may use infrastructure as tool to encourage growth in poor areas.

Donaldson (AER 2018)

- Did the expansion of railroads in colonial India promote agricultural development?
- If so, was it due to gains from trade caused by reduced trade costs?
- Eaton-Kortum style spatial model that Melanie covered in the last lecture to explore welfare effects of reductions in spatial frictions
    - Theory both guides empirical specifications and provides test of mechanism via a sufficient statistic for the gains from trade

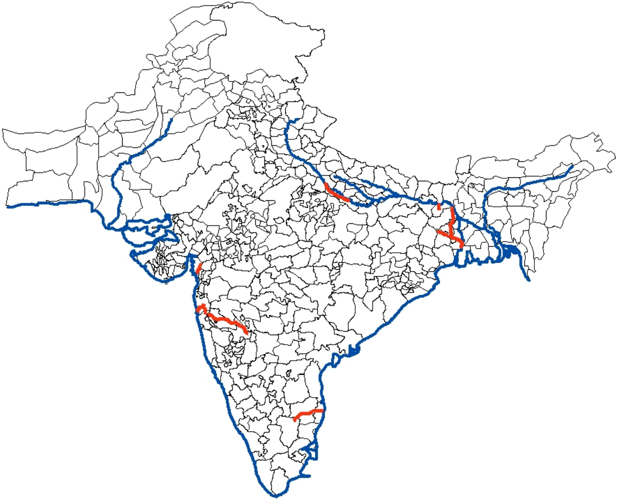
Indian Transportation Network: 1853

Eve of railroad age: first track in 1853



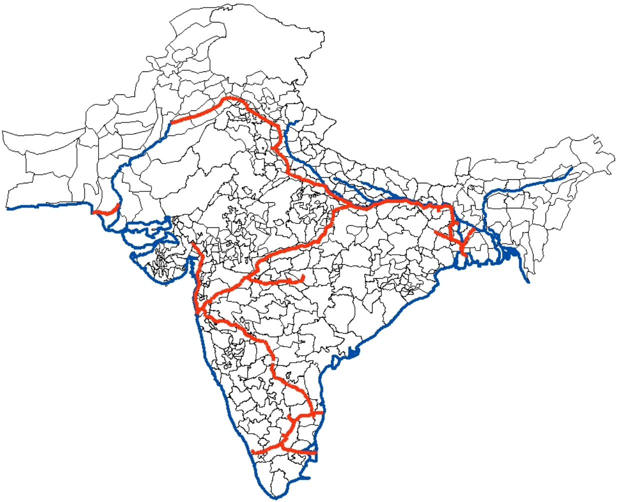
Indian Transportation Network: 1860

Each railroad ‘pixel’ coded with its year of opening

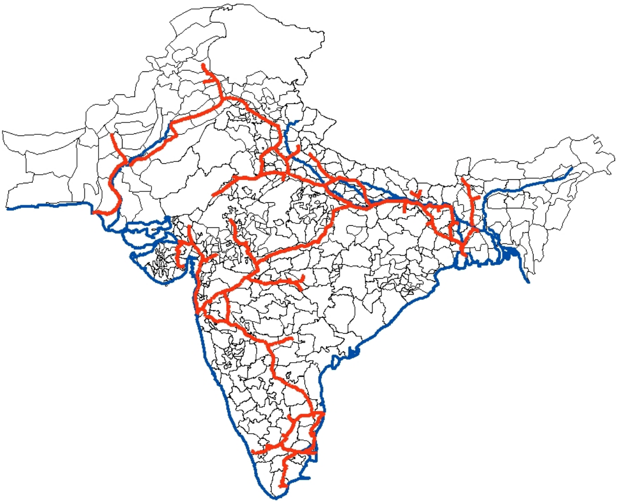


Indian Transportation Network: 1870

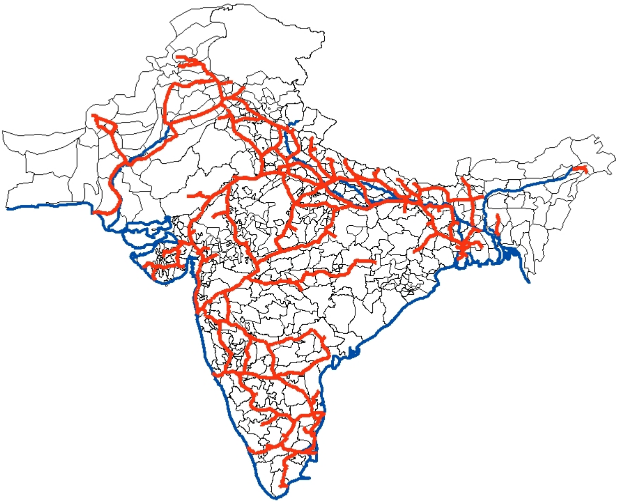
Seven provincial capitals connected



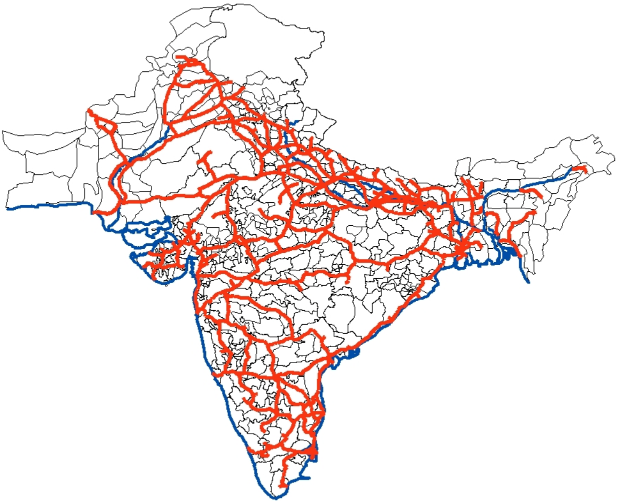
Indian Transportation Network: 1880



Indian Transportation Network: 1890

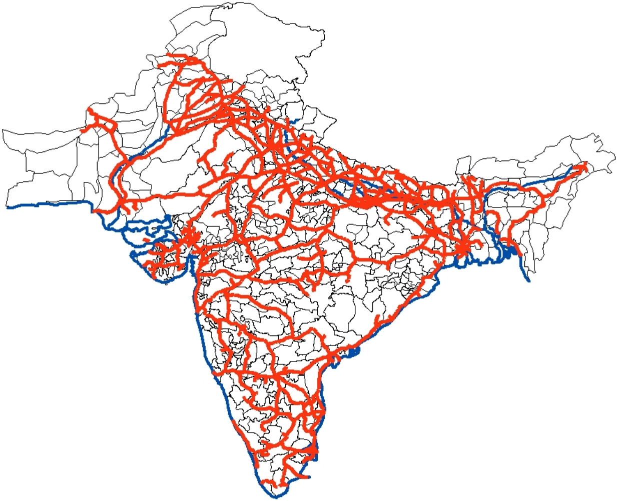


Indian Transportation Network: 1900

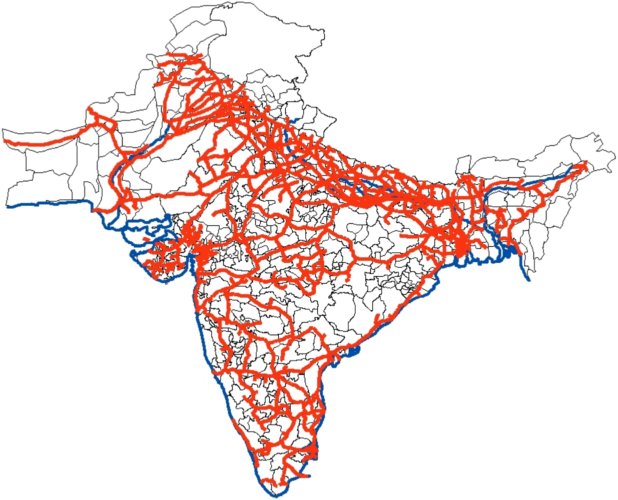


Indian Transportation Network: 1910

4th largest railroad network in the world

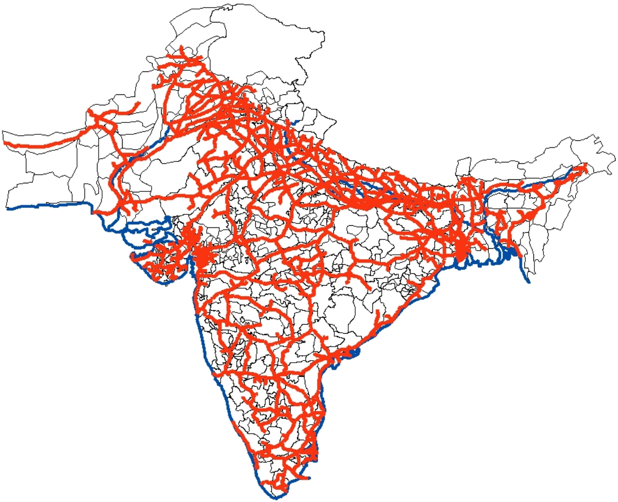


Indian Transportation Network: 1920



Indian Transportation Network: 1930

Network in 2009 is effectively that in 1930. 67,247 km of line open.



The Colonial Indian Economy

- Primarily agricultural:
  - 66 % of GDP in 1900 (Heston 1983)
  - Factory-based manufacturing extremely small: 1-3 % of GDP
- Agriculture was primarily rain-fed: 14 % irrigation in 1900
- $\Rightarrow$ Focus on agriculture, and use rainfall as exogenous (and observable) shock to productivity

Transportation in Colonial India

- Pre-rail transportation (Deloche 1994, 1995):
  - Roads: bullocks, 10-30 km per day (ie 2-3 months to port)
  - Rivers: seasonal, slow
  - Coasts: limited port access for steamships
- Railroad transportation:
  - Faster: 600 km per day
  - Safer: predictable, year-round, limited damage, limited piracy
  - Cheaper:
    - $\sim 4.5\times$ cheaper than roads
    - $\sim 3\times$ cheaper than rivers
    - $\sim 2\times$ cheaper than coast

Model Environment

- Multi-sector extension of Eaton and Kortum (2002)—general equilibrium with:
  - Many (≥ 2) regions
  - Many (≥ 2) goods
  - Trade costs $T \in [1, \infty)$
- K goods (e.g. rice, wheat):
  - indexed by k
  - each in continuum of varieties (j)
- D regions (districts, foreign countries)
  - o = origin
  - d = destination
- Static model

Production

- Technology: constant-returns; one composite, immobile factor (land)

$$q_o^k(j) = L_o^k \, z_o^k(j) \qquad\qquad p_{oo}^k(j) = \frac{r_o}{z_o^k(j)}$$

- Stochastic productivity $z_o^k(j)$ drawn from:

$$z_o^k(j) \sim F_o^k(z) = \exp(-A_o^k \, z^{-\theta_k})$$

Consumption and Trade

- Preferences:

$$\ln U_o = \sum_{k=1}^{K} \left(\frac{\mu_k}{\varepsilon_k} \right) \ln \int_0^1 (C_d^k(j))^{\varepsilon_k} dj$$

- Trading: 'iceberg' trade costs $T_{od}^k \geq 1$, $T_{oo}^k = 1$

$$\Rightarrow p_{od}^k(j) = T_{od}^k \, p_{oo}^k(j)$$

Equilibrium Prices

- Consumers in d face many potential suppliers of each variety
  - They consume the cheapest: $p_d^k(j) = \min_o\{p_{od}^k(j)\}$

$$p_d^k(j) \sim G_d^k(p) = 1 - \exp\left[-[\sum_{o=1}^{D} A_o^k \left(r_o T_{od}^k\right)^{-\theta_k}]\, p^{\theta_k}\right]$$

- Average price within good k:

$$E[p_d^k(j)] \doteq p_d^k = \lambda_1^k \left[\sum_{o=1}^{D} A_o^k \left(r_o T_{od}^k\right)^{-\theta_k}\right]^{-1/\theta_k}$$

Prediction 1: Trade Costs

- Prediction 1: If good 'o' can only be made in one region (region o) but this good is consumed elsewhere (region d), then:

$$\ln p_d^o - \ln p_o^o = \ln T_{od}^o$$

- Allows estimation of determinants of (unobserved) T_{od}^o

Prediction 2: Trade Flows

- Prediction 2: Exports take 'gravity' form:

$$\pi_{od}^{k} \equiv \frac{X_{od}^{k}}{X_{d}^{k}} = \lambda^{k} A_{o}^{k} \left(r_{o} T_{od}^{k}\right)^{-\theta_{k}} \left(p_{d}^{k}\right)^{\theta_{k}}$$

- Allows estimation of (unknown) θ_k, and relation of (unobserved) A_o^k to observed rainfall shocks

Prediction 3: Real Income Levels

- Welfare (of representative agent owning unit of land):

$$V(\mathbf{p}_o, r_o) = \frac{r_o}{\widetilde{P}_o} = \frac{Y_o}{L_o \widetilde{P}_o}$$

- Prediction 3: Welfare and trade costs (T) around a symmetric equilibrium:

$$\underbrace{\frac{d\left(\frac{r_o}{\widetilde{P}_o}\right)}{dT^k_{od}} < 0}_{\text{own railroads good}} \qquad \underbrace{\frac{d\left(\frac{r_o}{\widetilde{P}_o}\right)}{dT^k_{jd}} > 0 \quad j \neq o}_{\text{others' railroads bad}}$$

Prediction 4: Sufficient Statistic Property

- Prediction 4: Despite complex GE interactions, welfare can be written as:

$$\ln\left(\frac{Y_o}{L_o \widetilde{P}_o}\right) = \Omega + \sum_k \frac{\mu_k}{\theta_k} \ln A_o^k - \sum_k \frac{\mu_k}{\theta_k} \ln \pi_{oo}^k$$

- Useful: 'Autarkiness' (π_{oo}^k) is a "sufficient statistic" for all of the effects of the railroad network on welfare

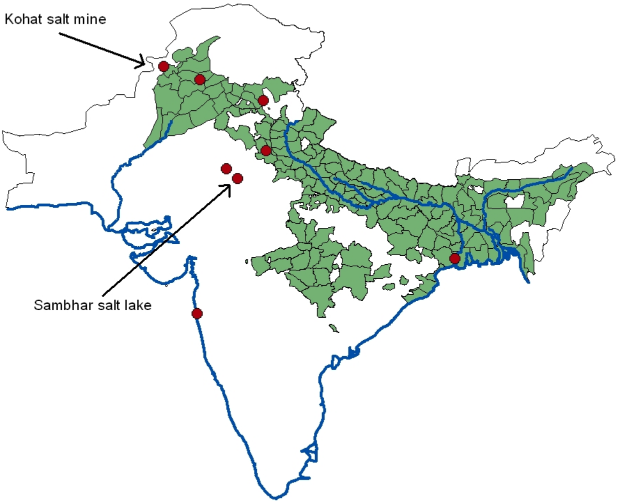
Conditions (Plausibly) Satisfied by Salt

Prediction 1: $\ln p^o_{dt} - \ln p^o_{ot} = \ln T^o_{odt}$

- Good differentiated by source
  - Each type could only be made in one location
  - "Kohat salt" vs. "Sambhar salt" (and 6 others)
- Good consumed widely at regions away from source
  - Biologically essential
- Free spatial arbitrage
  - Sold to unrestricted trading sector at 'factory' gate
- Homogeneous good

8 Salt Sources and 125 Sample Districts

Annual data, 1861-1930



Empirical Specification

- Theory: $\ln p^o_{dt} = \ln p^o_{ot} + \ln T^o_{odt}$

- Empirical version:

$$\ln p^o_{dt} = \overbrace{\beta^o_{ot}}^{=\ln p^o_{ot}} + \overbrace{\beta^o_{od} + \phi^o_{od} t + \delta \ln LCR(\mathbf{R}_t; \boldsymbol{\alpha})_{odt} + \varepsilon^o_{dt}}^{=\ln T^o_{odt}}$$

- $LCR(\mathbf{R}_t, \boldsymbol{\alpha})_{odt}$: 'lowest-cost route'

Trade Costs: Extensions

$\ln p^o_{dt} = \beta^o_{ot} + \beta^o_{od} + \phi^o_{od} t + \rho RAIL_{odt} + \varepsilon^o_{dt}$

Dependent variable: log destination salt price	OLS (1)	OLS (2)	OLS (3)	OLS (4)
Railroad from source to to destination	-0.112 (0.046)***			
Observations	7,329			
R-squared	0.84			

Note: Regressions include salt type x year and salt type x destination fixed effects, and a salt type x destination trend. Column 3 also contains bilateral district pair fixed effects. OLS standard errors clustered at the destination district level.

Trade Costs: Extensions

$\ln p^o_{dt} = \beta^o_{ot} + \beta^o_{od} + \phi^o_{od} t + \rho RAIL_{odt} + \varepsilon^o_{dt}$

Dependent variable: log destination salt price	OLS (1)	OLS (2)	OLS (3)	OLS (4)
Railroad from source to to destination	-0.112	-0.009		
	(0.046)***	(0.041)		
		camels, elephants, carts and inland boats		
Observations	7,329	5,176		
R-squared	0.84	0.73		

Note: Regressions include salt type x year and salt type x destination fixed effects, and a salt type x destination trend. Column 3 also contains bilateral district pair fixed effects. OLS standard errors clustered at the destination district level.

Railroads and Trade Flows

$$\ln \frac{X_{od}^k}{X_d^k} = \ln \lambda^k + \ln A_o^k - \theta_k \ln r_o - \theta_k \ln T_{od}^k + \theta_k \ln p_d^k$$

- Suggests empirical specification:

$$\begin{aligned} \ln X_{odt}^k = \beta_{ot}^k &+ \beta_{dt}^k + \beta_{od}^k + \phi_{od}^k t \\ &- \theta_k \widehat{\delta} \ln LCR(\mathbf{R}_t; \widehat{\boldsymbol{\alpha}})_{odt} + \varepsilon_{odt}^k \end{aligned}$$

- Data: 6 million observations on trade flows
  - Geography: 45 Indian 'trade blocks', 23 foreign countries
  - Goods: salt, 17 agricultural, 67 others
  - Modes: Rail, River, Coast (and some Road)

Railroads and Real Income Levels

- Prediction 3: $\frac{d(\frac{Y_{ot}}{L_{ot}\widetilde{P}_{ot}})}{dT^k_{odt}} < 0$ $\frac{d(\frac{Y_{ot}}{L_{ot}\widetilde{P}_{ot}})}{dT^k_{jdt}} > 0$
- Suggests linear approximation:

$$\ln(\frac{Y_{ot}}{L_{ot}\widetilde{P}_{ot}}) = \beta_o + \beta_t + \gamma RAIL_{ot} + \phi \frac{1}{N_o} \sum_{d \in N_o} RAIL_{dt} + \varepsilon_{ot}$$

- Data on real agricultural income per acre:
  - $Y_{ot} = \sum_k p^k_{ot} q^k_{ot}$ (NB: $\neq \int p^k_{ot}(j) q^k_{ot}(j) dj$), 17 agricultural crops (ignores: taxes/transfers, intermediate inputs, income from other sectors, income inequality)
  - $\widetilde{P}_{ot} =$ (chain-weighted) Fisher ideal price index, 17 agricultural crops (ignores: other costs of living, gains from new varieties)

Real Income Levels: Reduced-form Results

$$\ln\left(\frac{Y_{ot}}{L_{ot}\widetilde{P}_{ot}}\right) = \beta_o + \beta_t + \gamma RAIL_{ot} + \phi \frac{1}{N_o} \sum_{d \in N_o} RAIL_{dt} + \varepsilon_{ot}$$

Dependent variable: log real agricultural income	OLS (1)	OLS (2)
Railroad in district	0.165	0.182
	(0.056)***	(0.071)***
Railroad in neighboring district		-0.042
		(0.020)**
Observations	14,340	14,340
R-squared	0.744	0.758

Note: Regressions include district and year fixed effects. OLS standard errors clustered at the district level.

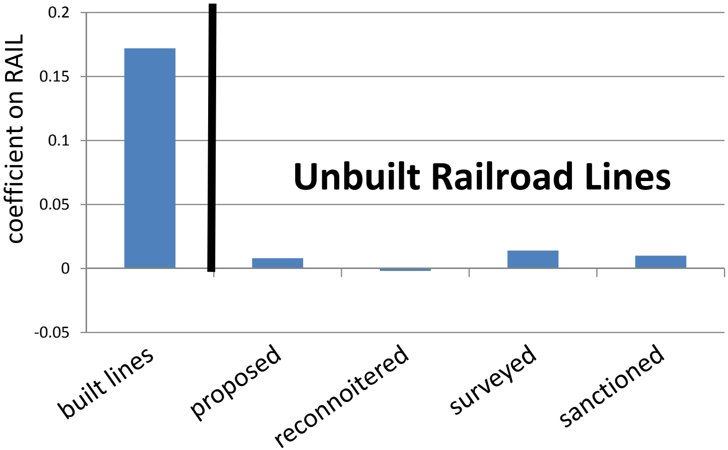
Alternative RAIL measures Robustness

Robustness Checks

1. 4 Placebo checks
   - Over 40,000 km of planned lines that were not built for 4 different reasons
2. Instrumental variable
   - 1880 Famine Commission: rainfall in 1876-78 predicts railroad construction post-1884
3. Bounds check
   - Lines explicitly labeled as ‘commercial’, ‘military’ or ‘redistributive’ display similar effects

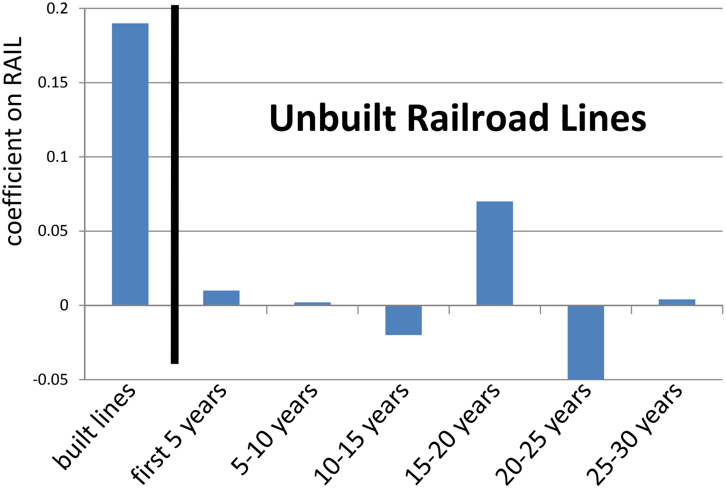
‘Placebo’ I: 4-Stage Planning Hierarchy

14,000 km: Lines reached increasingly costly stages but then abandoned



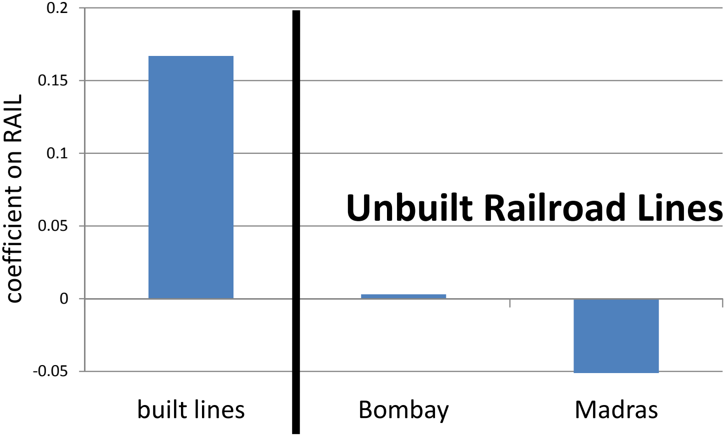
‘Placebo’ II: 1869 Lawrence Plan

12,000 km: Grand 30-year plan scrapped *en masse* by successor



‘Placebo’ III: Chambers of Commerce Plan

7,500 km: Bombay and Madras Chambers submit (commercially attractive) plan

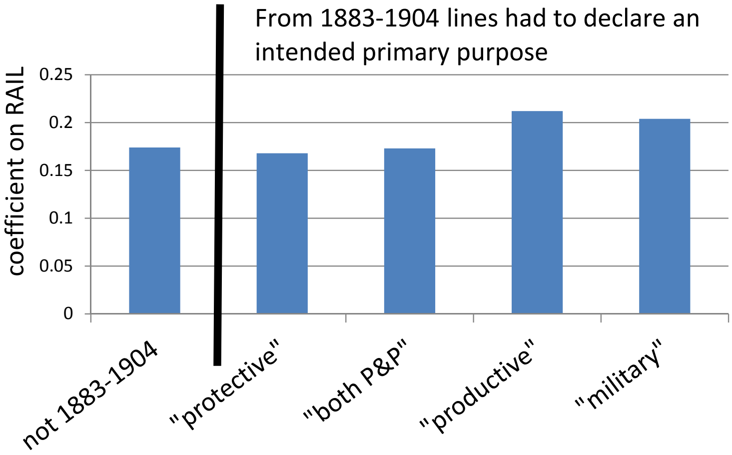


Instrumental Variable

- 1876-78 famine led to 1880 Famine Commission:
  - 1880 Commission unique in recommending railroads
- Instrumental variable:
  - Rainfall anomalies in 1876-78 agricultural years predict railroad construction post-1884
  - Control for contemporaneous and lagged rain
- Falsification:
  - Does rainfall in other "famine" (Commission) years predict railroads? No.
  - Does rainfall in other "famine" (Commission) years correlate with real income? No.

Bounds Check

$$\ln\left(\frac{Y_{ot}}{L_{ot}\widetilde{P}_{ot}}\right) = \beta_o + \beta_t + \sum_j \gamma^j PURPOSE^j \times RAIL_{ot} + \phi \frac{1}{N_o} \sum_{d \in N_o} RAIL_{dt} + \varepsilon_{ot}$$



Real Income Rise Was Static Gains from Trade?

- Prediction 4: Autarkiness (π^k_{oot}) is a sufficient statistic for the impact of railroads on real income:

$$\ln\left(\frac{Y_{ot}}{L_{ot}\widetilde{P}_{ot}}\right) = \Omega + \sum_k \frac{\mu_k}{\theta_k} \ln A^k_{ot} - \sum_k \frac{\mu_k}{\theta_k} \ln \pi^k_{oot}$$

- Use this to compare reduced-form real income estimates (Step 4) to model predictions:

$$\ln\left(\frac{Y_{ot}}{L_{ot}\widetilde{P}_{ot}}\right) = +\rho_1 \sum_k \frac{\widehat{\mu}_k}{\widehat{\theta}_k} \widehat{\kappa} RAIN^k_{ot} + \rho_2 \sum_k \frac{\widehat{\mu}_k}{\widehat{\theta}_k} \ln \pi(\widehat{\boldsymbol{\Theta}}, \mathbf{Z}_t)^k_{oot}$$
$$+ \alpha_o + \beta_t + \gamma RAIL_{ot} + \phi \frac{1}{N_o} \sum RAIL_{dt} + \varepsilon_{ot}$$

Real Income: Gains from Trade?

$$\ln\left(\frac{Y_{ot}}{L_{ot}\widetilde{P}_{ot}}\right) = \gamma RAIL_{ot} + \frac{1}{N_o}\sum_{d \in N_o} RAIL_{dt} + \rho_1 \sum_k \frac{\widehat{\mu}_k}{\widehat{\theta}_k}\widehat{\kappa} RAIN_{ot}^k + \rho_2 \sum_k \frac{\widehat{\mu}_k}{\widehat{\theta}_k} \ln \widehat{\pi}_{oot}^k$$

Dep. var: log real agricultural income	OLS	OLS
Railroad in district	0.182	0.021
	(0.071)***	(0.096)
Railroad in neighboring district	-0.042	0.003
	(0.020)**	(0.041)
Rainfall in district		1.044
		(0.476)**
"Autarkiness" measure (computed in model)		-0.942
		(0.152)***
Observations	14,340	14,340
R-squared	0.744	0.788

Note: Regressions include district and year fixed effects. OLS standard errors clustered at the district level.

Summary

1. Railroads improved the trading environment in India
2. Railroads raised real incomes in India
3. Real income gains from railroads are well accounted for by a Ricardian model of trade—suggests that static gains from trade were important economic mechanism behind the benefits of railroads

Plan for Today's Lecture on Spatial Frictions

1. Introduction
2. Measuring spatial frictions
   - Estimating spatial frictions via direct measurement
   - Estimating spatial frictions via gravity equations
   - Estimating spatial frictions using price gaps
3. Estimating the impacts of spatial frictions
   - Trade and infrastructure
   - **Information frictions**

Jensen (QJE 2007)

- Touched on information costs when discussing Startz (2021) above.
- Communications infrastructure has ability to dramatically lower information frictions.

Jensen (QJE 2007)

- Touched on information costs when discussing Startz (2021) above.
- Communications infrastructure has ability to dramatically lower information frictions.
- Jensen (2007) explores impact of 1997 -2001 mobile phone service roll out in Kerala, India.
    - Explores fishing industry: prior to introduction boats returned to home village and sold their catch.
    - Conduct weekly survey of 300 fishing fleets 1996-2001: measure phone adoption, prices, waste, quantities.
    - Event-study-like design: compare pre-post staggered mobile phone entry

Jensen (QJE 2007)

Price dispersion ↓ (towards LOOP), waste ↓ $\implies$ Cons and prod welfare increase

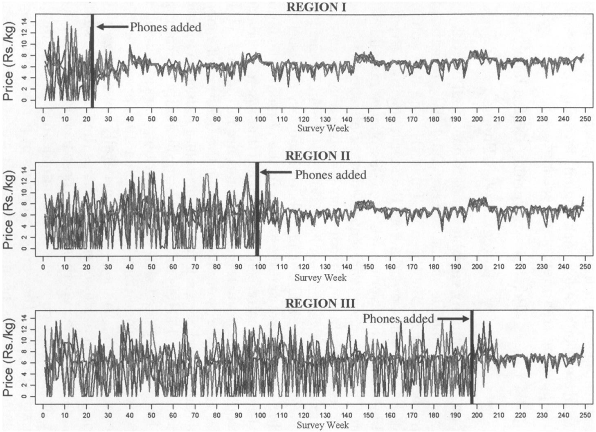


FIGURE IV
Prices and Mobile Phone Service in Kerala

Jensen (QJE 2007)

TABLE III
PRICE DISPERSION AND WASTE IN KERALA SARDINE MARKETS

	Period 0 (pre-phone)	Period 1 (region I adds phones)	Period 2 (region II adds phones)	Period 3 (region III adds phones)
Max–min spread (Rs/kg)				
Region I	7.60	1.86	1.32	1.22
	(0.50)	(0.22)	(0.10)	(0.44)
Region II	8.19	7.30	1.79	1.57
	(0.44)	(0.29)	(0.19)	(0.16)
Region III	8.24	7.27	7.60	2.56
	(0.47)	(0.27)	(0.25)	(0.34)
Coefficient of variation (percent)				
Region I	.68	.14	.08	.07
	(0.07)	(0.01)	(0.01)	(0.01)
Region II	.62	.55	.12	.08
	(0.04)	(0.04)	(0.01)	(0.01)
Region III	.69	.57	.54	.14
	(0.09)	(0.04)	(0.03)	(0.02)
Waste (percent)				
Region I	0.08	0.00	0.00	0.00
	(0.01)	(0.00)	(0.00)	(0.00)
Region II	0.05	0.04	0.00	0.00
	(0.01)	(0.01)	(0.00)	(0.00)
Region III	0.07	0.06	0.06	0.00
	(0.01)	(0.01)	(0.01)	(0.00)

Jensen and Miller (AER 2018)

- Follow up paper: fisherman learn about boat price and quality by visiting other markets, seeing other fishermen
- What do we think will happen to firm sizes, productivity, costs etc?

Fisherman's Behavior and Information

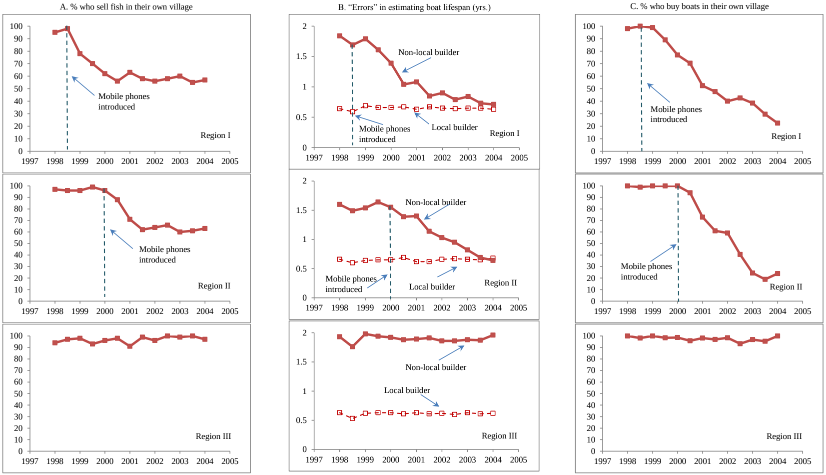
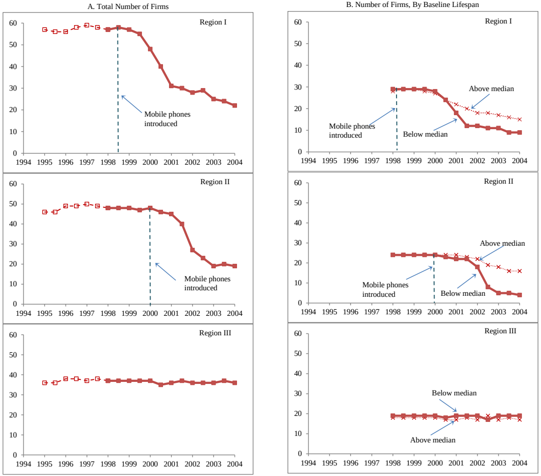


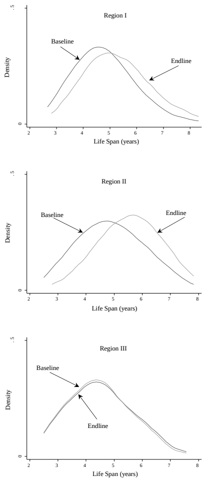
FIGURE 2: MOBILE PHONES AND FISHERMEN'S BEHAVIOR AND INFORMATION

Notes: The left-hand panels represent the fraction of fishermen in each round of our fishermen survey who report selling their catch in their local market. The central panels represent the average of the absolute value of the difference between our estimates of life expectancy for boats (based on "previous boat" estimates) and fishermen's estimates, measured in years. "Local

Number of Firms By Baseline Quality



Distribution of Productivity



Employment

TABLE 2: REGRESSION RESULTS: EXIT, MARKET SHARE AND EMPLOYMENT

A. "Previous Boat" Life Expectancy (years)	(1) Exit	(2) Market Share	(3) # Workers	(4) Boats Built
Phone*Baseline Quality	-0.0503	0.00464	0.551	9.177
	(0.00870)	(0.000969)	(0.123)	(1.914)
Phone	0.291	-0.0212	-2.489	-41.96
	(0.0448)	(0.00495)	(0.609)	(9.760)
Baseline Quality	0.00463	-4.72e-05	-0.00562	-0.0991
	(0.00371)	(0.000324)	(0.0358)	(0.644)
Observations	1,524	1,524	1,524	1,524
B. Auditor's Assessment (years)	Exit	Market Share	# Workers	Boats Built
Phone*Baseline Quality	-0.0270	0.00363	0.475	7.187
	(0.00689)	(0.000867)	(0.110)	(1.713)
Phone	0.162	-0.0143	-1.859	-28.27
	(0.0346)	(0.00404)	(0.489)	(7.970)
Baseline Quality	-0.00173	-0.000134	-0.0286	-0.269
	(0.00270)	(0.000307)	(0.0242)	(0.608)
Observations	1,524	1,524	1,524	1,524
C. Fishermen's Estimates (years)	Exit	Market Share	# Workers	Boats Built
Phone*Baseline Quality	-0.0584	0.00556	0.699	11.01
	(0.0105)	(0.00118)	(0.144)	(2.323)
Phone	0.314	-0.0242	-3.017	-47.82
	(0.0497)	(0.00554)	(0.668)	(10.94)
Baseline Quality	0.00728	-6.34e-05	-0.0142	-0.128
	(0.00540)	(0.000414)	(0.0392)	(0.823)
Observations	1,524	1,524	1,524	1,524
D. TFP Residuals	Exit	Market Share	# Workers	Boats Built
Phone*Baseline Quality	-0.0487	0.00444	0.547	8.786
	(0.00942)	(0.00101)	(0.125)	(1.985)
Phone	0.0511	0.000871	0.135	1.745
	(0.0148)	(0.00104)	(0.136)	(2.072)
Baseline Quality	0.00503	0.000309	0.00616	0.608
	(0.00395)	(0.000305)	(0.0372)	(0.606)
Observations	1,524	1,524	1,524	1,524

Notes: Dependent variable listed at the top of each column. Each panel represents the primary regression specification using a different measure of builder quality, indicated at the top of the panel. Regressions include region and round fixed effects. All data are from the boat builder survey. Units of observation are builder*round, with builders dropping from the sample once they have exited. Standard errors, clustered at the builder level, in parentheses.

Jensen and Miller (AER 2018)

- Follow up paper: fisherman learn about boat price and quality by visiting other markets, seeing other fishermen.
  - Reduction in quality differences across builders through expansion of good, contraction of bad.
  - Aggregate productivity up 21%. Life expectancy of boat increased 32%.
  - Mainly through increased labor specialization in bigger firms, average production costs decrease.
    - Industry produced same number of boats, 25% fewer labor hours and 37% less capital.
    - Average worker performed approximately 7-8 major job tasks (e.g., cutting wood, drilling, etc.) at baseline, but less than half as many by endline.
    - Allowed owner to concentrate on highly-skilled fastening and finishing (35% $\rightarrow$ 80% of time for owners of larger firms).
  - Quality-adjusted consumer prices (cost-per boat year) decline 20%.

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- Best evidence we have for Melitz model of trade?

Conclusion

- Was only able to touch the surface of the vast literature on the effect of spatial frictions on developing countries.
- Some useful review articles:
  - Donaldson "The Gains from Market Integration" (Annual Review of Economics, 2015)
  - Atkin and Khandelwal "How Distortions Alter the Impacts of International Trade in Developing Countries" (Annual Review of Economics, 2020)
  - Bryan, Glaeser and Tsivanidis "Cities in the Developing world" (Annual Review of Economics, 2020)
  - Redding "Trade and Geography" (Handbook of International Economics, forthcoming)