The Welfare Effects of Passenger Transportation Infrastructure: Evidence from China

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Motivation

- Enormous public resources invested in passenger transportation infrastructure across the globe:
  - Airports, railways, highways, subways
  - New high-speed railway projects under discussion in UK, US, India
- Limited research on the importance of these large-scale projects:
  - Reduced form evidence on passenger transportation largely within city (e.g., subways)
  - Quantitative welfare evaluation mostly focuses on the flow of goods
  - Substantial data challenges in obtaining ideal data on bilateral passenger flows across the entire network

This paper

- Study China's high-speed railway system (HSR), one of the largest passenger infrastructure projects of the world
  - Total length exceeding 15,000 miles (25,000 km) in 2017, connecting cities from 29 provinces out of 33
  - Total investment of $300 billion from 2011 to 2015
- Draw on new data on universe of debit/credit card transactions (40 Trillion Yuan in 2015) to measure:
  - City-to-city passenger flows
  - City-to-city transactions
- Develop a quantitative model for evaluating the welfare implications of passenger transportation infrastructure improvements
  - Aggregate consumer welfare gain of the HSR network
  - Distributional impacts

Related literature

- Transportation infrastructure and development
  - Baum-Snow(2007), Michaels (2008), Donaldson (2014), Duranton and Turner (2012), Faber (2014), Baum-Snow et al. (2016), Storeygard (2016)
- Quantitative evaluation of infrastructure projects:
  - Donaldson (2014), Allen and Arkolakis (2014, 2017), Ahlfeldt, Redding and Sturm (2017), Donaldson and Hornbeck (2014), Alder (2016), Fajgelbaum and Schaal (2017)
- Evaluation of the HSR system
  - *China*: Zheng and Kahn (2013, 2017), Qin (2014), Lin (2017), Xu (2017)
  - *Other countries*: Bernard, Moxnes, and Saito (2015) in Japan, Charnoz, Lelarge, and Trevien (2016) in France

Roadmap

- Background and data construction
- CES model on demand for travel and goods
- Model estimation
- Ongoing: Random coefficient logit framework to capture passenger heterogeneity

Background

- China's HSR expansion
  - In 2003, the first line opened connecting Qinhuangdao and Shenyang
  - By 2017, over 20,000 km routes in service, with 7 bn cumulative number of trips
  - Operation speed: 250 km/h- 350 km/h, versus up to 120 km/h for regular railway
- Ministry of Railway plan (2008)
  - Main network: four horizontal and four vertical lines
  - Connect major cities with more efficient means of transportation
  - Environmental and national security concerns
- Planning and Financing
  - Centrally planned and managed by Ministry of Railway (later China Railway Corporation), mostly funded by MOR
  - Local government helps with compensation for land use; limited private investment

Expansion of HSR from 2003-2016

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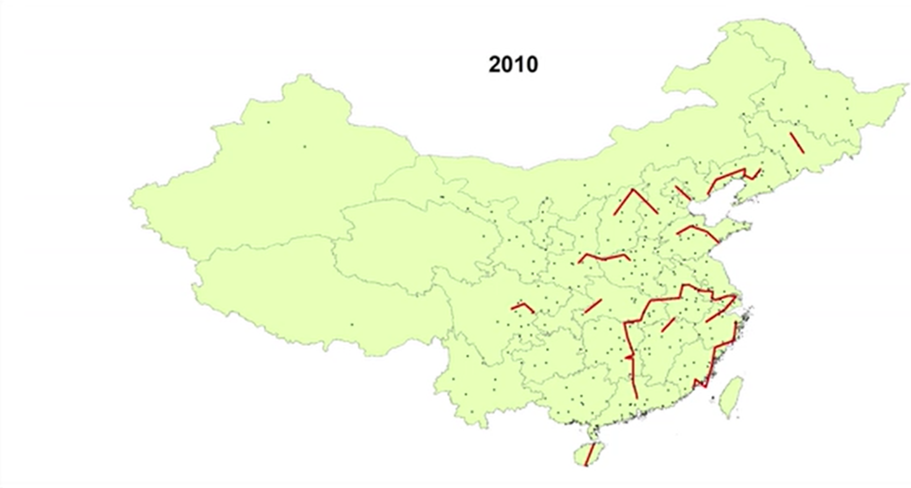
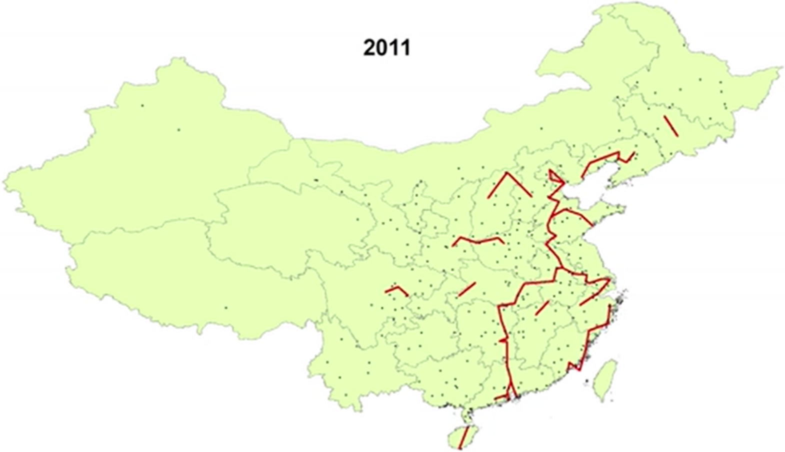


Expansion of HSR from 2003-2016



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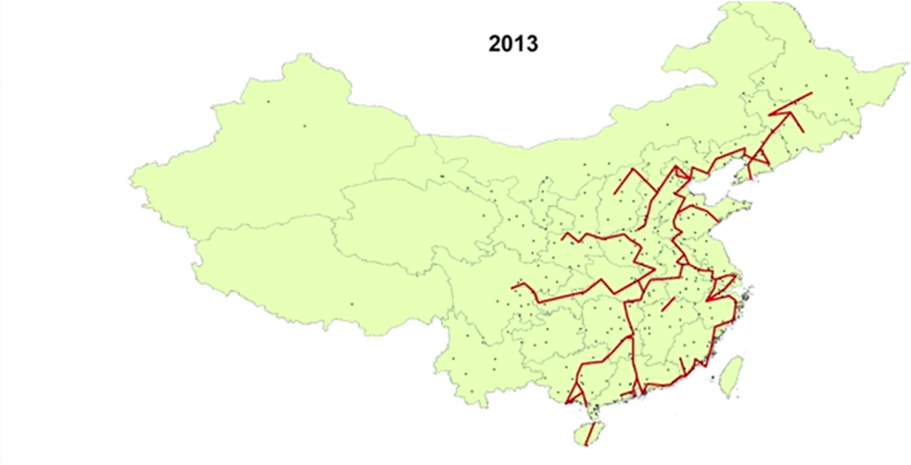

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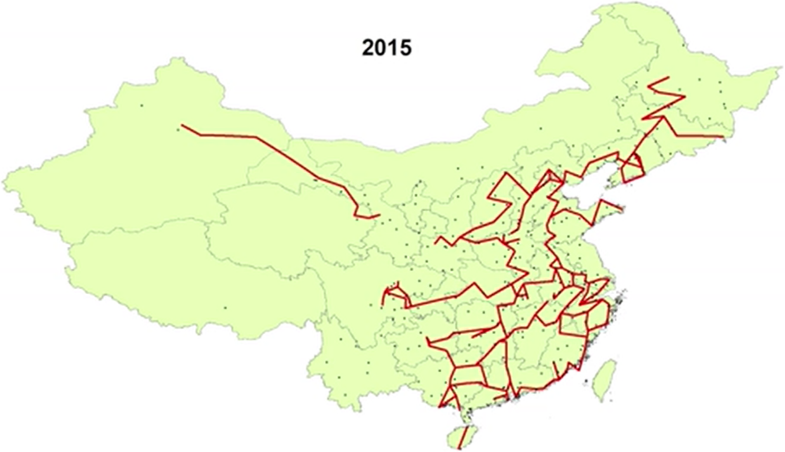
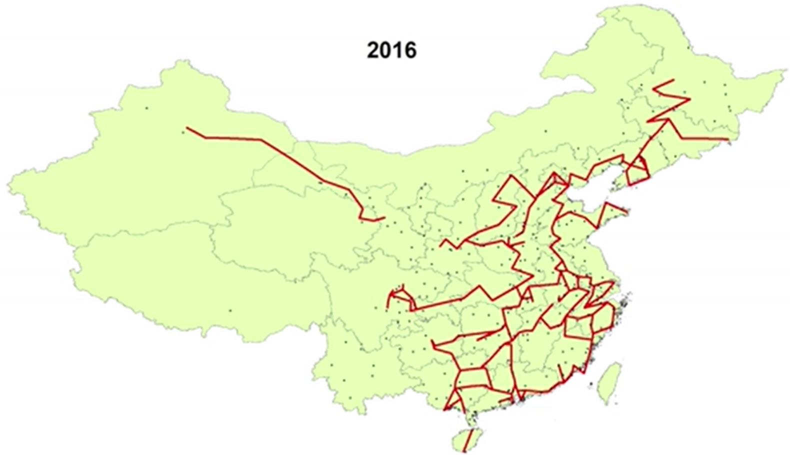


Expansion of HSR from 2003-2016



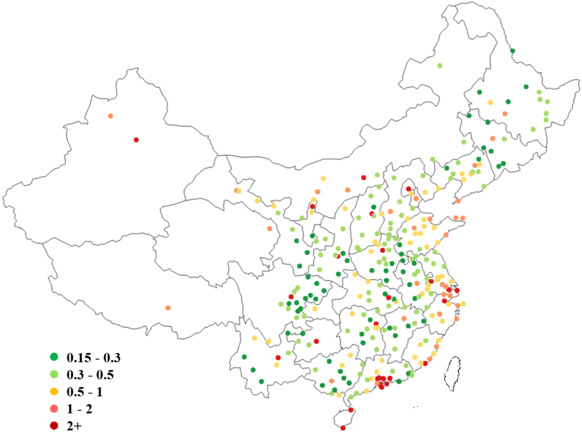
Data at the City-pair and Month Level

- Transport network and cost features:
  - HSR and traditional train: routes, schedule, and fares
  - Air travel: routes, schedule, and number of seats; fares for a small subsample
  - Road: highway distance and travel time for all city pairs in 2017
- Bilateral passenger flows and transaction values constructed from Unionpay card (credit and debit card) transactions
- Consumption goods price indices constructed from Unionpay data

Coverage of the Bank Card Data 2011-2017

- In 2015: 2.7 bn cards, 48% of retail sales of consumer goods, 40 tn RMB worth of transactions (China's GDP is 69 tn RMB)
- Number of active bank cards per capita similar across cities

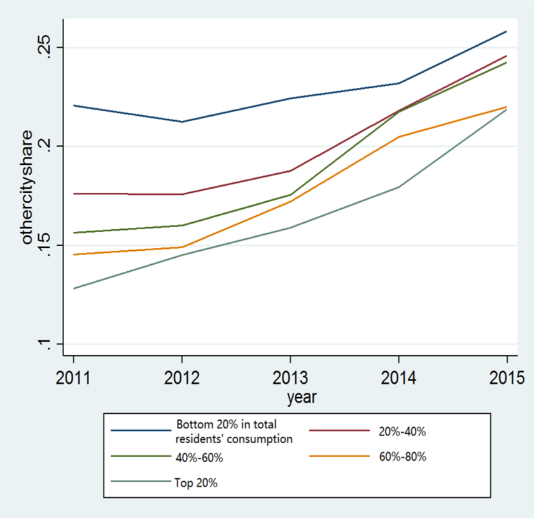
Figure: Number of Active Cards per Capita, 2015



Out-of-town Spending 2011-2015

- About 20% of the transactions are made out-of-town, increasing over time

Figure: Share of out-of-town spending: by the size of resident city



Summary Statistics

Bilateral transaction and trip flows

Bilateral Card Transactions (1% Unionpay sample)

	Exclude Own city Flows				
	Obs	Mean	Variance	Min	Max
Transaction value (Y)	1,935,262	82453.5	663243.6	1	8.32E+07
Transaction count (N)	1,936,603	35.5	284.4	1	31580
Number of trips (T)	1,783,886	21.53	146.73	1	11635

Motivating Evidence

- Question: how does direct HSR connection change cross-city travel and consumption behavior?

$$ln(y_{ijt}) = \beta connect_{ijt} + \alpha_{ij} + \eta_{it} + \gamma_{jt} + \epsilon_{ijt} \quad (1)$$

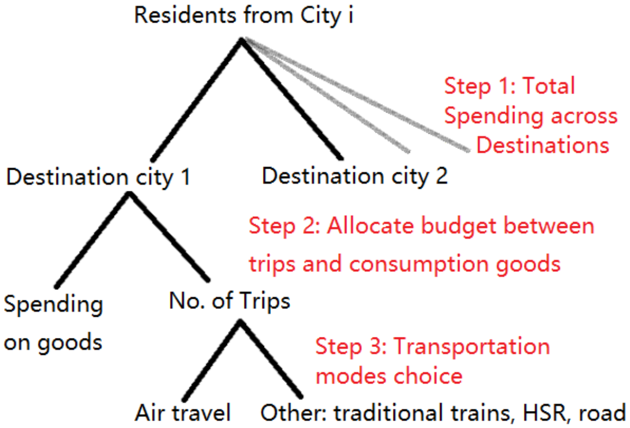
  - y_{ijt}: number of trips or total transaction value made by residents in city i to city j
  - $Connect_{ijt} = 1$ if city i and city j are connected by HSR at month t
  - α_{ij} city pair FE; η_{it} and γ_{jt} are origin/destination*month FE.

Motivating Evidence

	ln(Trips)	ln(Value)	ln(Trips)	ln(Value)
HSR connection	0.37***	0.37***	0.35***	0.28***
	(0.02)	(0.02)	(0.02)	(0.03)
Observations	2,214,670	2,214,670	2,214,597	2,214,597
Pair FE, Month FE	Y	Y	Y	Y
Origin*month FE, Destination*month FE	N	N	Y	Y
R-squared	0.83	0.58	0.86	0.63

Model: Setup

- Representative agents from city i with fixed income X_i make travelling decisions in three steps (3-layer nested CES)
  - Inner nest: transportation mode choices
  - Middle nest: trips and consumption goods
  - Outer nest: decision about travelling across all destinations



Model of Demand for Travel and Goods

- Basic idea draws on logic of revealed preference: use changes in ridership and consumption associated with changes in travel cost to back out consumers' willingness to pay for HSR
- Outer layer:

$$U_{it} = \left(Q_{ijt} \phi_{ijt}^{\frac{\sigma-1}{\sigma}} \right)^{\frac{\sigma}{\sigma-1}}$$

- Middle layer:

$$Q_{ijt} = \left[(q_{ijt})^{\frac{\delta-1}{\delta}} + (T_{ijt}\epsilon_{ijt})^{\frac{\delta-1}{\delta}} \right]^{\frac{\delta}{\delta-1}}$$

- Inner layer:

$$T_{ijt} = \left[(t_{ij1t}\eta_{ijt})^{\frac{\rho-1}{\rho}} + (t_{ij2t})^{\frac{\rho-1}{\rho}} \right]^{\frac{\rho}{\rho-1}}$$

Model: Inner Nest

- Holding constant spending and the number of trips made from i to each destination j at month t, agents decide on transportation

$$T_{ijt} = \left[(t_{ij1t}\eta_{ijt})^{\frac{\rho-1}{\rho}} + (t_{ij2t})^{\frac{\rho-1}{\rho}} \right]^{\frac{\rho}{\rho-1}}$$

  - Two modes: air and other (including HSR, traditional trains, and highway)
  - η_{ijt} idiosyncratic demand shifter for air travel
  - Travel cost for air c_{ij1t}: a function of both travel time and fare cost
  - Travel cost for non-air mode c_{ij2t}: the minimum travel cost among HSR, traditional trains, and highway

Preferences: Inner Nest

- Intermodal choice can be used to identify ρ:

$$\frac{t_{ij1t}}{t_{ij2t}} = \left(\frac{c_{ij1t}}{c_{ij2t}}\right)^{-\rho} (\eta_{ijt})^{\rho-1}$$

- Once ρ (and residual η_{ijt}) estimated, obtain travel cost index c_{ijt} across all transportation modes as follows:

$$c_{ijt} = \left[(c_{ij1t}/\eta_{ijt})^{1-\rho} + (c_{ij2t})^{1-\rho} \right]^{\frac{1}{1-\rho}}$$

Preferences: Middle Nest

- Holding constant total consumption quantity at each destination j as Q_{ijt}, agents allocate it across goods consumption q_{ijt} and trips T_{ijt}

$$Q_{ijt} = \left[(q_{ijt})^{\frac{\delta-1}{\delta}} + (T_{ijt}\epsilon_{ijt})^{\frac{\delta-1}{\delta}} \right]^{\frac{\delta}{\delta-1}}$$

  - Intuition: consumers derive utility from access to consumption goods (q) in city j, as well as free local amenity (tourist attractions, visiting family/friends etc.), which is a function of trips made (T)
  - Reductions in travel cost might induce consumers to make more frequent trips, but spend less per trip
  - ϵ_{ijt}: idiosyncratic demand shifter between goods consumption and trips

Preferences: Outer Nest

- Consumers from city i allocate total spending across all destination cities to maximize utility, subject to the budget constraint

$$U_{it} = \left(Q_{ijt} \phi_{ijt}^{\frac{\sigma-1}{\sigma}} \right)^{\frac{\sigma}{\sigma-1}}$$

$$Q_{ijt} = \frac{P_{ijt}^{-\sigma}}{P_{it}^{1-\sigma}} X_{it} \phi_{ijt}^{\sigma-1}$$

$$P_{ijt} = \left[(p_{jt})^{1-\delta} + (c_{ijt}/\epsilon_{ijt})^{1-\delta} \right]^{\frac{1}{1-\delta}}$$

$$P_{it} = \left[\sum_{j=1}^{J} (P_{ijt}/\phi_{ijt})^{1-\sigma} \right]^{\frac{1}{1-\sigma}}$$

  - Q_{ijt}: total consumption quantity in city j; X_{it}: total spending for consumers from city i; ϕ_{ijt}: taste shocks across destination cities

Welfare Impact

$$U_{it} = \frac{X_{it}}{P_{it}}$$

- We focus on the "consumer" benefits of HSR, which appear purely through P_{it}. Further, impact of HSR on P_{it} comes purely through impact of HSR on c_{ijt}
- So far, following effects omitted:
  - HSR changes the price of consumption goods in cities
  - $\Rightarrow$ No business stealing effects in this model: cities will not be worse off after the HSR connection
  - HSR changes incomes (and hence X_{it})

Estimation of the demand system

- Estimation in three steps
- Step 1: Inner layer:

$$\ln(\frac{t_{ij1t}}{t_{ij2t}}) = -\rho \ln(\frac{c_{ij1t}}{c_{ij2t}}) + \alpha_{ij} + \beta_{it} + \gamma_{jt} + \tilde{\eta}_{ijt}$$

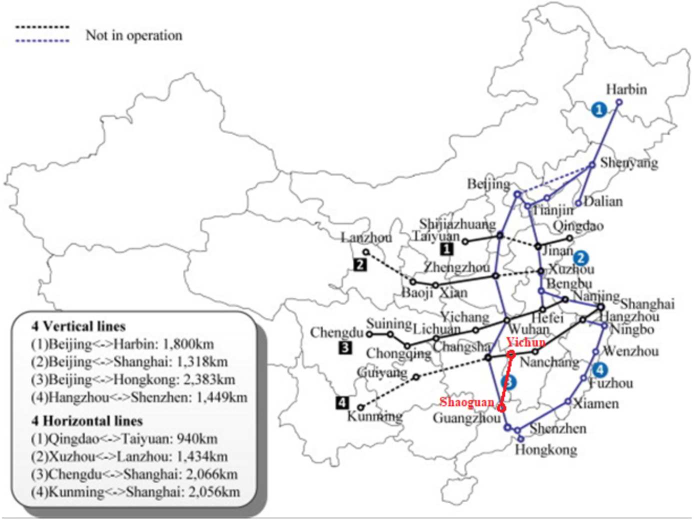
  - Obtain ρ and η_{ijt} from estimating the equation above, using data on travel cost and frequency (air travels measured by seat capacity) for different modes of transportation
  - Construct c_{ijt} from c_{ij1t},c_{ij2t}, ρ, and η_{ijt}
  - Construct T_{ijt} from t_{ij1t}, t_{ij1t}, ρ, and η_{ijt}
  - Instrument $\ln(\frac{c_{ij1t}}{c_{ij2t}})$ with HSR indirect connection dummy

Instrument

- Instrument $\ln(\frac{c_{ij1t}}{c_{ij2t}})$ with HSR indirect connection dummy to take care of:
  - Measurement errors in travel cost
  - Fare price endogeneity
  - Endogeneity in the availability of new transportation modes
- Idea of Instrument
  - China's HSR network is quite intensive with four main horizontal lines and four main vertical lines
  - When a (segment of) a horizontal line gets joined with a vertical line, non-nodal cities from both lines get "indirectly connected", which are less likely to be planned in advance

Instrument

Exploiting indirect connections



- Yichun and Shaoguan is considered to be indirectly connected after both Changsha-Nanchang and Changsha-Guangzhou lines are in operation

Reduced form evidence

	ln(Trips)	ln(Value)	ln(Trips)	ln(Value)
Indirect connection	0.171***	0.194***	0.148***	0.117***
	(0.0201)	(0.0368)	(0.0207)	(0.0364)
Observations	2,147,311	2,147,311	2,147,241	2,147,241
Pair FE, Month FE	Y	Y	Y	Y
Origin*month FE, Destination*month FE	N	N	Y	Y
R-squared	0.799	0.549	0.835	0.595

Estimation of the demand system

Constructing c_{ij1t} and c_{ij2t}

- Travel cost for different modes of transportation
  - $c_{ijkt} = farecost_{ijkt} + ValueforTravelTime(VTT) * traveltime_{ijkt}$; VTT assumed to be 1/3 of hourly wage
  - Air: distance and duration of all flights from 2010 to 2017, price data available for a small subset
  - HSR and traditional trains: railway timetable data that report duration and ticket price for all train schedules from 2008 to 2016
  - Road: calculate duration and distance of travel by road for any city pairs using OpenStreetMap
  - c_{ij2t}: the minimum of travel cost across HSR, traditional trains, and road

Estimation of the demand system

Constructing passenger flows and consumption

- Bilateral passenger transportation ridership on air (t_{ij1t}) and the rest (t_{ij2t})
  - Air: total seats of all flights serving each city pair
  - Total number of trips made by card holders from city i in city j: constructed using UnionPay data
- Bilateral consumption q_{ijt} and destination city price index p_{jt}
  - Assume the distribution of quantity purchased per transaction constant over time, and use the average value per transaction as a proxy for p_{jt} (alternative approaches)

Estimation of the demand system

Parameter estimation

- Step 2: Middle layer:

$$\ln\left(\frac{T_{ijt}}{q_{ijt}}\right) = -\delta \ln\left(\frac{c_{ijt}}{p_{jt}}\right) + \alpha_{ij} + \beta_{it} + \gamma_{jt} + (\delta - 1)\ln(\tilde{\epsilon}_{ijt})$$

  - Plug in T_{ijt} and c_{ijt} from the inner nest
  - Obtain δ and ϵ_{ijt}
  - Construct $P_{ijt} = \left[(p_{jt})^{1-\delta} + (c_{ijt}/\epsilon_{ijt})^{1-\delta}\right]^{\frac{1}{1-\delta}}$
  - Instrument $\ln(\frac{c_{ijt}}{p_{jt}})$ with HSR indirect connection dummy
  - In practice, inclusion of γ_{jt} means that regressor is effectively just $\ln(c_{ijt})$.

Estimation of the demand system

Parameter estimation

- Step 3: Outer layer:

$$\ln(X_{ijt}) = (1-\sigma)\ln(P_{ijt}) - (1-\sigma)\ln(P_{it}) + \ln(X_{it}) + (\sigma-1)\ln(\phi_{ijt})$$

  - $X_{ijt} = p_{jt}q_{ijt} + c_{ijt}T_{ijt}$: total spending by consumers from city i in destination city j
  - Plug in $P_{ijt} = \left[(p_{jt})^{1-\delta} + (c_{ijt}/\epsilon_{ijt})^{1-\delta}\right]^{\frac{1}{1-\delta}}$ from the previous step
  - Add city-pair FE and origin/destination*monthFE, absorbing $\ln(P_{it})$ and $\ln(X_{it})$
  - Obtain σ and ϕ_{ijt} to construct final city-level price index P_{it}
  - Instrument $\ln(P_{ijt})$ with HSR indirect connection dummy

Estimation of the demand system: Results

Columns Variables	(1) ln(air/non-air)	(2) ln(trip/consumption)	(3) $\ln(X_{ijt})$
Estimation steps	Inner layer	Middle Layer	Outer layer
ln(cost air/cost non-air)	-2.33**		
	(0.97)		
ln(travel cost)		-0.07	
		(0.20)	
$\ln(P_{ijt})$			-1.92*
			(1.15)
Model interpretation	$-\rho$	$-\delta$	$1-\sigma$
Estimation method		IV with connect dummy	
Observations	81,807	1,927,482	1,927,482
R-squared	0.69	0.18	-1.89

Results using direct connect dummy

Results

- A direct HSR connection leads to 13% drop in bilateral travel costs
- Trips and spending in destination city very closely complementary, with an elasticity of substitution around 0.07
- Substitution elasticity between different cities around 2.9
- Removing the whole HSR network increases P_{it} by 2.8% on average
    - Our model did not take into consideration of utility from local consumption. Accounting for it would mean the total effects on aggregate welfare to be around 0.2*2.8% given the share of out-of-city spending

Ongoing Work

- Limitations of the current framework:
  - Limited substitution patterns across different transportation modes
  - Choice over transportation mode is multi-dimensional: fare cost, time, frequency, delays etc.
  - Passenger heterogeneity: different groups of people have different valuation over these characteristics (income; business vs. personal trips)
  - Distributional consequences
- Extend the current framework to allow for:
  - Multiple transportation mode characteristics
  - Heterogeneity across income distribution

Random Coefficient Mixed Logit Framework

- Nested logit: consumers choose destination city first, then transportation modes
- The utility of consumer i travelling to city k by travel mode j is defined as

$$U_{ijt} = x_{kt}\beta_i + x_{ijt}\eta_i - \alpha_i p_{ijt} + \nu_{ikt} + \xi_{ijt} + \mu_{ijt}(\lambda), j \in C_{ikt} \qquad (2)$$

  - x_{ikt} is a vector of destination city characteristics, such as city GDP, population, tourist attractions, etc.
  - x_{ijt} is a vector of transportation mode characteristics (duration, frequency of flights etc.),
  - ν_{ikt} is the unobserved (to researchers) characteristic/amenities of city k to residents from city i.
  - ξ_{ijt} is the unobserved (to researchers) characteristic of travel mode j that deviates from the nest average
  - μ_{ijt} is a nested logit random taste shock (Type I extreme-value distribution)

Random Coefficient Mixed Logit Framework

$$U_{ijt} = x_{kt}\beta_i + x_{ijt}\eta_i - \alpha_i p_{ijt} + \nu_{ikt} + \xi_{ijt} + \mu_{ijt}(\lambda), j \in C_{ikt} \tag{3}$$

- Passenger Heterogeneity: We assume β_i and η_i to be functions of observed and unobserved household demographics:

$$\beta_i = \beta + \alpha_h z_{ih} + \epsilon_i \tag{4}$$

- We randomly draw individuals from city income distributions and pick parameters to minimize the distance between simulated market shares and
    - The share of origin i passengers travelling to different destination k
    - The share of passengers travelling by air for each city pair per month

Conclusion

- Goal of paper: combine various novel datasets to evaluate the impacts of HSR in China
  - Bilateral consumption and travel patterns in China using card transaction information
  - Evolution of transportation network and travel cost of various modes of transportation over time
- Framework for assessing welfare impact of passenger transportation infrastructure improvements via a "revealed-preference"-like approach

Estimation of the demand system: Results

Columns Variables	(1) ln(air/non-air)	(2) ln(trip/consumption)	(3) $\ln(X_{ijt})$
Estimation steps	Inner layer	Middle Layer	Outer layer
ln(cost air/cost non-air)	-3.86***		
	(1.22)		
ln(travel cost)		-0.67***	
		(0.20)	
$\ln(P_{ijt})$			-1.46***
			(0.35)
Model interpretation	$-\rho$	$-\delta$	$1-\sigma$
Estimation method	IV with indirectconnect dummy		
Observations	82,027	2,000,336	2,000,336
R-squared	0.90	0.24	-6.64

Back