Gravity: Estimation

ECON 245
Winter 2024

Gravity in international trade

- structural gravity equation from Armington model

$$X_{ij} = a_{ij} \times \tau_{ij}^{1-\sigma} \times \frac{Y_i}{\Theta_i} \times \frac{X_j}{P_j^{1-\sigma}}$$

- captures key features of trade data
  - exports X_{ij} rise proportionally with the size Y_i of the origin i and destination j, X_j
  - negative relationship between distance and trade flows
- theory highlights GE forces
  - bilateral exports decreasing in market access of i, Θ_i
  - bilateral exports decreasing in competition for j's imports, P_j
- similar structure in theoretical and empirical models of commuting, migration, offshoring, multinational production, financial flows, social interactions,…

Gravity in urban economics

- importing the gravity model into urban economics
  - gravity for commuting flows: Ahlfeldt Redding Sturm 15, Monte Redding Rossi-Hansberg 18, Owens Rossi-Hansberg Sarte 20, Tsivanidis 19, Dingel and Tintelnot 19
  - gravity for consumption in the city: Davis Dingel Monras Morales 19, Allen Arkolakis Li 19, Miyauchi Nakajima Redding 23
- settings differ slightly from canonical trade models
  - models of discrete choice rather than CES demand (see Anderson, de Palma, Thisse book)
  - trade flows need not balance due to commuting (workplace income is residential expenditure)
  - zeros are far more pervasive
  - commonalities: estimation with two-way HDFE, recursive market-access terms

Gravity and the "Trade Elasticity"

$$X_{ij} = a_{ij}\tau_{ij}^{1-\sigma}\left(\frac{Y_i}{\Theta_i}\right)\left(\frac{X_j}{P_j^{1-\sigma}}\right)$$

- the price elasticity $1-\sigma$ of import demand (trade elasticity) is key for welfare
  - Sufficient statistics result: Many different workhorse models imply that welfare analysis requires only (i) the share of expenditures on domestic goods, (ii) the price elasticity of imports
- in Armington, changes in welfare $d\ln U_i$ from arbitrary shocks to global trade costs can be shown to equal:

$$d\ln U_i = -\frac{1}{\sigma-1}d\ln\left(\frac{X_{ii}}{X_i}\right)$$

- we will focus on the trade elasticity when discussing estimation
  - Similar approaches to estimating key elasticities in other gravity models, e.g., the elasticity of migration/commuting decisions to changes in real wages or travel costs.

Trade elasticity estimation

- most common approach: high-dimensional fixed effects estimation
- apply logs to both sides of the gravity equation

$$\log X_{ij} = (1-\sigma)\log \tau_{ij} + \log\left(\frac{Y_i}{\Theta_i}\right) + \log\left(\frac{X_j}{P_j^{1-\sigma}}\right) + \log a_{ij}$$

  to obtain the following estimating equation

$$\log X_{ij} = (1-\sigma)\log \tau_{ij} + o_i + d_j + \epsilon_{ij}$$

- o_i and d_j are origin (exporter) and destination (importer) fixed effects
- idea: parameterize τ_{ij}, then use variation in bilateral trade flows across destination and source countries

Trade elasticity estimation

- estimating equation

$$\log X_{ij} = (1 - \sigma)\log \tau_{ij} + o_i + d_j + \epsilon_{ij}$$

- the keys to informative estimation are
  1. not being naive
  2. distinguishing the trade elasticity from reduced-form coefficients
  3. handling zeros appropriately
  4. recognizing the endogeneity of trade policy

Trade elasticity vs distance elasticity

- consider the OLS regression with two-way high-dimensional fixed effects given by the CES Armington model

$$\log X_{ij} = (1-\sigma)\log \tau_{ij} + o_i + d_j + \epsilon_{ij}$$

- if you assume the trade costs are a function of, say, distance with $\ln \tau_{ij} = \beta \log distance_{ij}$, then you would estimate

$$\log X_{ij} = (1-\sigma)\beta \log distance_{ij} + o_i + d_j + \epsilon_{ij}$$

- i.e., you will recover $(1-\sigma)\beta$. Do not mistake this for $(1-\sigma)$.
- trade elasticity is recovered with observed trade costs and pass-through assumptions: If $\log \tau_{ij} = \beta_1 \log distance_{ij} + \beta_2 \ln tariff_{ij}$ and you assume $\beta_2 = 1$, then $(1-\sigma)\beta_2 = 1-\sigma$

Trade elasticity estimation

$$\log X_{ij} = (1 - \sigma)\log \tau_{ij} + o_i + d_j + \epsilon_{ij}$$

- Solution: Tariffs + full pass-through assumption
- more general parametrization of trade costs

$$\log \tau_{ij} = \log \text{tariff}_{ij} + \beta \mathbf{D}_{ij}$$

- $\mathbf{D}_{ij}$: Vector of bilateral “gravity indicators”, typically including
  - Distance, dummies for common language, shared border, common currency, EU and trade agreement membership
  - See CEPII data

Trade elasticity estimation

$$\log X_{ij} = (1 - \sigma)\log \tau_{ij} + o_i + d_j + \epsilon_{ij}$$

$$\log \tau_{ij} = \log \text{tariff}_{ij} + \beta \mathbf{D}_{ij}$$

- combining yields the estimating equation:

$$\log X_{ij} = \theta \log \text{tariff}_{ij} + \tilde{\beta}\mathbf{D}_{ij} + o_i + d_j + \epsilon_{ij}$$

  $\theta = (1 - \sigma)$ is the trade elasticity

  $\tilde{\beta} = (1 - \sigma)\beta$

- given data on bilateral trade flows, estimate via two-way fixed effect regressions
  - two sets of fixed effects for each country, depending on whether it is an origin or destination
- can estimate across or within time-periods, by industry, or products

Trade Elasticity Estimates from cModel

Industry	Elasticity
87 Soap cleaning & cosmetic preparations	−7.05
88 Other chemical products n.e.c.	−7.46
89 Man-made fibres	−3.65
90 Rubber tyres and tubes	−6.66
91 Other rubber products	−6.52
92 Plastic products	−3.46
93 Glass and glass products	−5.79
94 Pottery china and earthenware	−5.16
95 Refractory ceramic products	−5.09
96 Non-refractory clay; ceramic products	−5.50
97 Cement lime and plaster	−4.24
98 Articles of concrete cement and plaster	−3.97
99 Cutting shaping & finishing of stone	−2.52
100 Other non-metallic mineral products n.e.c.	−7.86
101 Basic iron and steel	−6.33
102 Basic precious and non-ferrous metals	−4.00
103 Casting of iron and steel	−4.00
104 Structural metal products	−6.03
105 Tanks reservoirs and containers of metal	−6.64

Industry	Elasticity
128 Accumulators primary cells and batteries	−7.45
129 Lighting equipment and electric lamps	−7.35
130 Other electrical equipment n.e.c.	−4.26
131 Electronic valves tubes etc.	−4.65
132 TV/radio transmitters; line comm. apparatus	−7.14
133 TV and radio receivers and associated goods	−7.19
134 Medical surgical and orthopaedic equipment	−5.88
135 Measuring/testing/navigating appliances etc.	−2.79
136 Optical instruments & photographic equipment	−4.34
137 Watches and clocks	−2.79
138 Motor vehicles	−2.32
139 Automobile bodies trailers & semi-trailers	−6.45
140 Parts/accessories for automobiles	−7.69
141 Building and repairing of ships	−0.58

Trade elasticity estimates in the literature

Table 3.5 Descriptive Statistics of Price Elasticities in Gravity Equations

Estimates:	**Median**	**Mean**	**s.d.**	**#**
Full sample	−3.19	−4.51	8.93	744
Naive gravity	−1.31	−1.35	5.17	122
Structural gravity	−3.78	−5.13	9.37	622
Split structural estimates by:				
Estimation method:				
Country FEs	−3.5	−4.12	8.2	447
Ratios	−4.82	−7.7	11.49	175
Identifying variable:				
Tariffs/Freight rates	−5.03	−6.74	9.3	435
Price/Wage/Exchange rate	−1.12	−1.38	8.46	187

Notes: The number of statistically significant estimates is 744, obtained from 32 papers.

Gravity Variables

Table 3.4 Estimates of Typical Gravity Variables

	All Gravity				Structural Gravity			
Estimates:	**Median**	**Mean**	**s.d.**	**#**	**Median**	**Mean**	**s.d.**	**#**
Origin GDP	.97	.98	.42	700	.86	.74	.45	31
Destination GDP	.85	.84	.28	671	.67	.58	.41	29
Distance	−.89	−.93	.4	1835	−1.14	−1.1	.41	328
Contiguity	.49	.53	.57	1066	.52	.66	.65	266
Common language	.49	.54	.44	680	.33	.39	.29	205
Colonial link	.91	.92	.61	147	.84	.75	.49	60
RTA/FTA	.47	.59	.5	257	.28	.36	.42	108
EU	.23	.14	.56	329	.19	.16	.5	26
NAFTA	.39	.43	.67	94	.53	.76	.64	17
Common currency	.87	.79	.48	104	.98	.86	.39	37
Home	1.93	1.96	1.28	279	1.55	1.9	1.68	71

Notes: The number of estimates is 2508, obtained from 159 papers. Structural gravity refers here to some use of country fixed effects or ratio-type method.

Trade costs and preference shifters

$$\log X_{ij} = (1 - \sigma)\log \tau_{ij} + o_i + d_j + \epsilon_{ij}$$

- in Armington, the error term captures bilateral preference shifters
- could bilateral preference shifters be correlated with common language, colonial status, tariffs, or distance? of course.
- Blum and Goldfarb (2006): “Americans are more likely to visit websites from nearby countries, even controlling for language, income, immigrant stock, etc. Furthermore, we show that this effect only holds for taste-dependent digital products such as music, games, and pornography.”
- suggests the need to instrument tariffs.

Tariff endogeneity

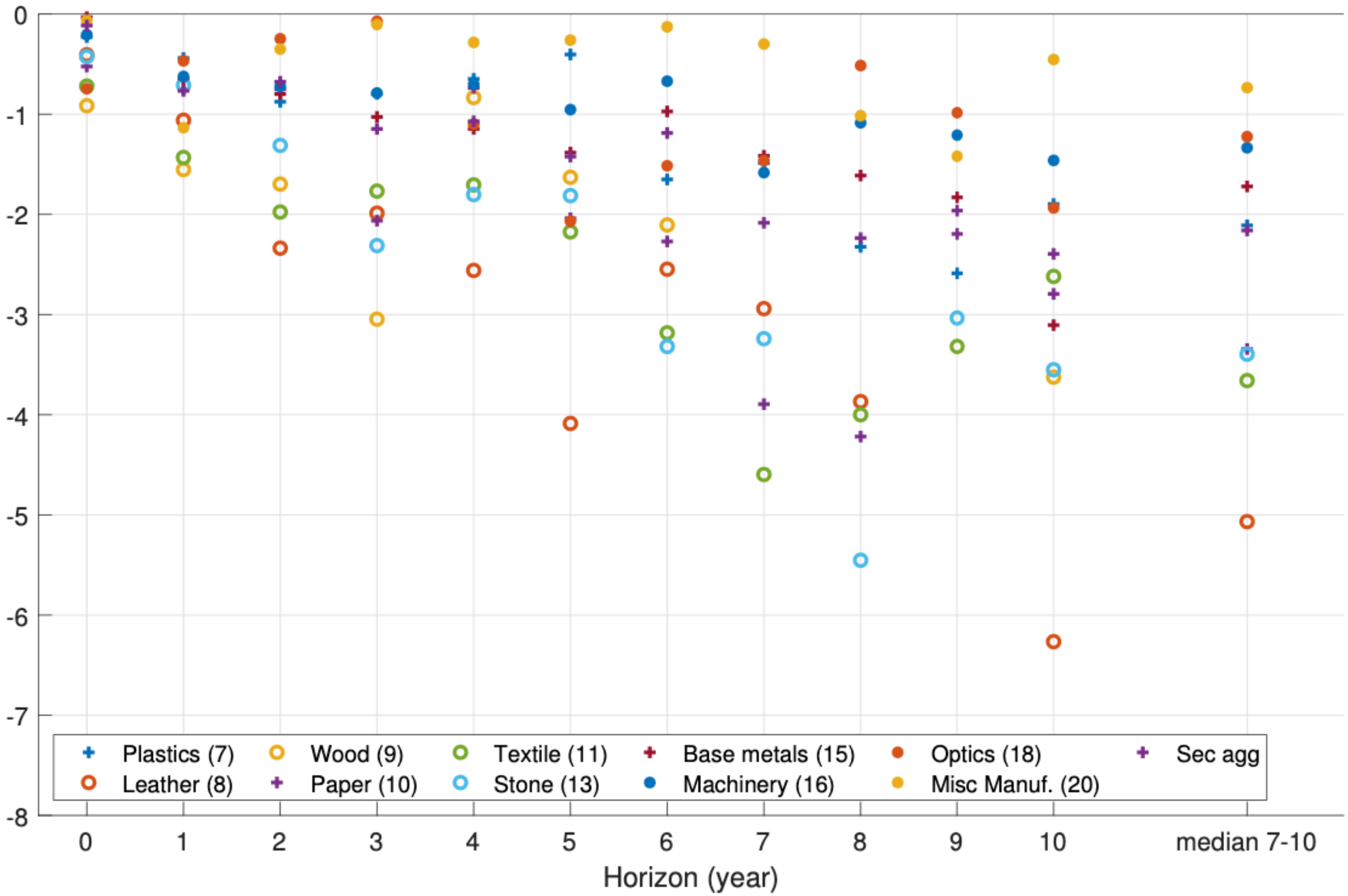
- $\log X_{ij} = \theta \log \text{tariff}_{ij} + \tilde{\beta}\mathbf{D}_{ij} + o_i + d_j + \epsilon_{ij}$
- reverse causality and omitted variables potentially an issue
- time-differencing the data helps, but, even then, research in political economy suggests that tariffs are not random
  - e.g., a surge in imports due to high productivity growth in an exporting country may intensify lobbying for protection, leading to higher tariffs
- Boehm et al 22 (optional readings) suggest an instrument based on the MFN (most-favored-nation) principle
  - WTO members are bound to apply tariffs uniformly to all other WTO members, the “MFN tariff”

Boehm Levchenko Pandalay-Nayar (AER, 23)

- idea: identify trade elasticity from export changes of minor exporters in response to importers' adjustments of MFN tariffs
  - "Major" = Top 10 exporters of given product to a given importer
  - If minor exporters are "not important enough", then importers' decisions to change MFN tariff is arguably exogenous
- use local projection methods to estimate short-run and long-run trade elasticities
  - Of particular interest given that trade models are typically static + focused on long-run steady states.

Boehm-Levchenko-Pandalay-Nayar (AER,23)

FIGURE 3: Trade Elasticity: Sectoral Heterogeneity



Notes: This figure displays the trade elasticity point estimates by HS Section based on specification (2.4) and using the baseline instrument (2.5). All specifications include exporter-HS4-year, importer-HS4-year, and exporter-importer-HS4 fixed effects as well as one lag of the log change in tariffs and trade. Some HS Sections are grouped into a single aggregate section "Sec agg" as described in the text.

Boehm-Levchenko-Pandalay-Nayar (AER,23)

- key finding:
  - 1-year estimates of trade elasticity range from -0.2 to -0.8
  - Long-run estimates range from -0.7 to -5
- implication: welfare estimates in static trade models may severely understate the gains (and losses) from trade shocks
- Chen-Goes-Muendler-Trottner: Rationalize evidence on short- and long-run trade elasticities in a dynamic model with sourcing frictions
  - Calvo-Fairy-type shocks determines wether agents get to reoptimize their sourcing decisions on the extensive margin
  - aggregate gravity equation for trade flows only in steady state
  - even short-lasted disruptions (trade wars, shortages) - in single sectors or countries distort trade patterns in the global economy for some time

Issues: Dimensionality

$$\log X_{ij} = \theta \log \text{tariff}_{ij} + \tilde{\beta}\mathbf{D}_{ij} + o_i + d_j + \epsilon_{ij}$$

- number of fixed effects that need to be estimated can quickly become prohibitively large
- two common alternative estimators that get rid of this problem

$$\log \frac{X_{ij}}{X_{jj}} = \theta \log \text{tariff}_{ij} + \tilde{\beta}\mathbf{D}_{ij} + o_i + \log \frac{\epsilon_{ij}}{\epsilon_{jj}}$$

$$\log \frac{X_{ij}X_{ji}}{X_{ii}X_{jj}} = \theta \log \frac{\text{tariff}_{ij}}{\text{tariff}_{ji}} + \log \frac{\epsilon_{ij}\epsilon_{ji}}{\epsilon_{jj}\epsilon_{ii}}$$

- note that we used the fact that tariffs to oneself equal 1, $\mathbf{D}_{ij} = 0$ for $i = j$, and $\mathbf{D}_{ij} = \mathbf{D}_{ji}$

Logs vs levels and the Poisson PIML estimator

$$X_{ij} = \tau_{ij}^{1-\sigma}\left(\frac{Y_i}{\Theta_i}\right)\left(\frac{X_j}{P_j^{1-\sigma}}\right)a_{ij}$$

$$\log X_{ij} = (1-\sigma)\log\tau_{ij} + \log\left(\frac{Y_i}{\Theta_i}\right) + \log\left(\frac{X_j}{P_j^{1-\sigma}}\right) + \log a_{ij}$$

- levels regression requires $\mathbb{E}[a_{ij} \quad Y_i, \Theta_i, X_j, P_j, \tau_{ij}] = 1$. what does the logs regression require?
- stack the fixed effects and $\log\tau_{ij}$ in a vector $\mathbf{Z}_{ij}$ and the associated coefficients in a vector β. Contrast OLS and PPML FOCs:

OLS: $\sum_{ij}[\ln X_{ij} - \beta\mathbf{Z}_{ij}]\mathbf{Z}_{ij} = 0$

PPML: $\sum_{ij}[X_{ij} - \exp(\beta\mathbf{Z}_{ij})]\mathbf{Z}_{ij} = 0$

- Silva and Tenreyro 06 note that OLS FOC has a log difference; the PPML FOC has a level difference

Zeros, a useful property of PPML

- how to handle zeros (on the left side)?
  - $\ln 0$ is not defined
  - use the PPML estimator to handle zeros
  - aside: to generate $X_{ij} = 0$ in "structural gravity", need $\tau_{ij} = \infty$ or $a_{ij} = 0$
- PPML estimator estimated FE deliver model-consistent estimates for Θ_i and P_j because fitted output equals observed output and fitted expenditures equal observed expenditures
  - Poisson is the only PML estimator with this property

Trade costs

- trade costs τ_{ij} are the frictions that make international and international trade distinct and interesting, yet we struggle to measure them
    - tariffs (easy to define, but go download TRAINS data)
    - transportation costs (money + time + trade finance)
    - communication costs
    - contractual frictions
- trade costs are important
    - almost essential to rationalizing observed prices and quantities
    - Obstfeld and Rogoff 01 propose that trade frictions are key to six puzzles in international macro (Eaton Kortum Neiman 16)
    - key to evaluating welfare and government investment in transportation infrastructure from roads to ports

Are trade costs large?

- arguments for large trade costs
  - exchange declines dramatically with geographic distance
  - large price gaps from within cities to across countries are not arbitraged away
- arguments for trade costs not being a big deal
  - MFN tariffs are in the single digits for most of world economy
  - the costs of moving manufacturing goods fell 90% over the 20th century (Glaeser and Kohlhase 04)
- is τ_{ij} a good description for international business frictions?
  - contrast ad valorem tariffs with specific tariffs
  - contrast border barriers with income or regulatory differences

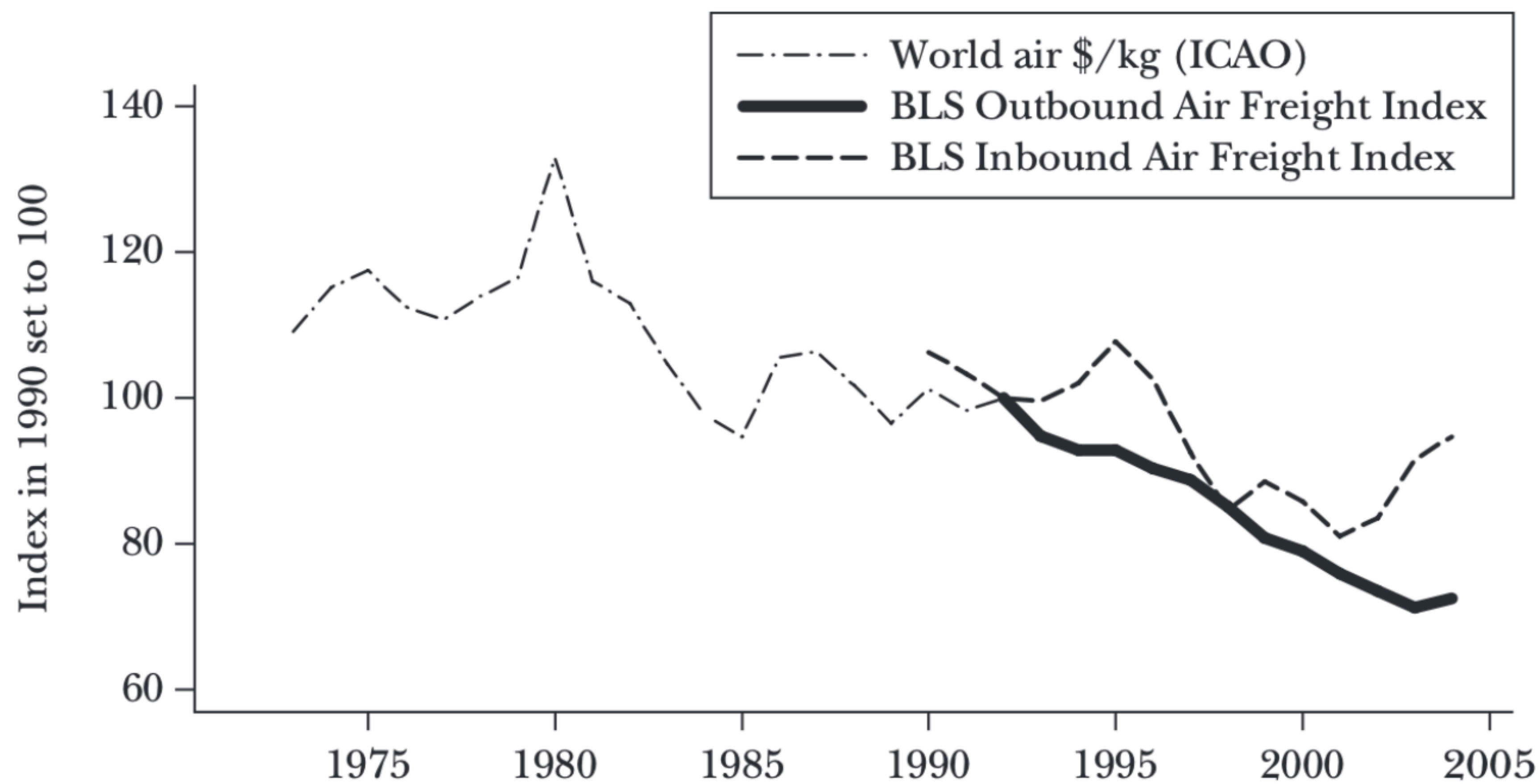
Measuring trade costs

- three strategies
  1. measure trade costs directly
  2. infer trade costs from observed exchange volumes
  3. infer trade costs from observed price gaps

Direct measurement: transport prices

- Hummels 07 has lots of direct measurement

Air Transport Price Indices



Source: International Civil Aviation Organization (ICAO), "Survey of Air Fares and Rates," various years; U.S. Department of Labor Bureau of Labor Statistics (BLS) import/export price indices,

Direct measurement of trade costs

- See Anderson and van Wincoop 04 for a survey
- endogenous price quotes for freights and insurance
- UNCTAD TRAINS for tariffs
- UNCTAD trains for non-tariff barriers
- World Bank's Doing Business measures for port/border costs
- Concerns: these variables do not capture all trade costs related to coordination, contracts, intermediaries' market power, uncertainty, etc.

Inferring from observed exchanges

- idea: use gravity residuals
- Head and Ries 11 suggest backing out the freeness of trade by assuming $D_{ii} = 1 \ \forall i$ (normalization) and $D_{ij} = D_{ji} \ \forall i \neq j$ (symmetry)
  - $X_{ij} = D_{ij} \times \frac{Y_i}{\Theta_i} \times \frac{X_j}{P_j^{1-\sigma}} \Rightarrow \hat{D}_{ij} = \sqrt{\frac{X_{ij} X_{ji}}{X_{jj} X_{ii}}}$
- requires assumptions on tastes and trade elasticity ($D_{ij} = a_{ij} \tau_{ij}^{1-\sigma}$) to turn into trade costs

Head and Ries 11: Inferred trade costs

TABLE 1
The Trade Cost Measure for the United States

Partner Country	Tariff Equivalent τ_{ij} in % 1970	2000	Percentage Change
Canada	50	25	−50
Germany	95	70	−26
Japan	85	65	−24
Korea	107	70	−35
Mexico	96	33	−66
UK	95	63	−34
Simple average	88	54	−38
Trade-weighted average	74	42	−44

Notes: All numbers are in percent and rounded off to integers. Countries listed are the six biggest U.S. export markets as of 2000. Computations based on Equation (5).

Open Questions

- structural trade elasticity for services?
  - share of services in world trade is rising rapidly, welfare effects not understood
  - not subject to tariffs, so no obvious 1-1 shifter for import prices
- granularity
  - Industry-level exports, even at relatively aggregate levels, are dominated by few firms
  - Granularity challenging for estimation, but high returns, e.g., Mayara Felix's 2021 job market paper
- dynamics
  - A general issue for models in trade, but also for gravity