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COLLEGE

Gravity

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Trade Flows

- US exports data
 - What patterns do you notice?

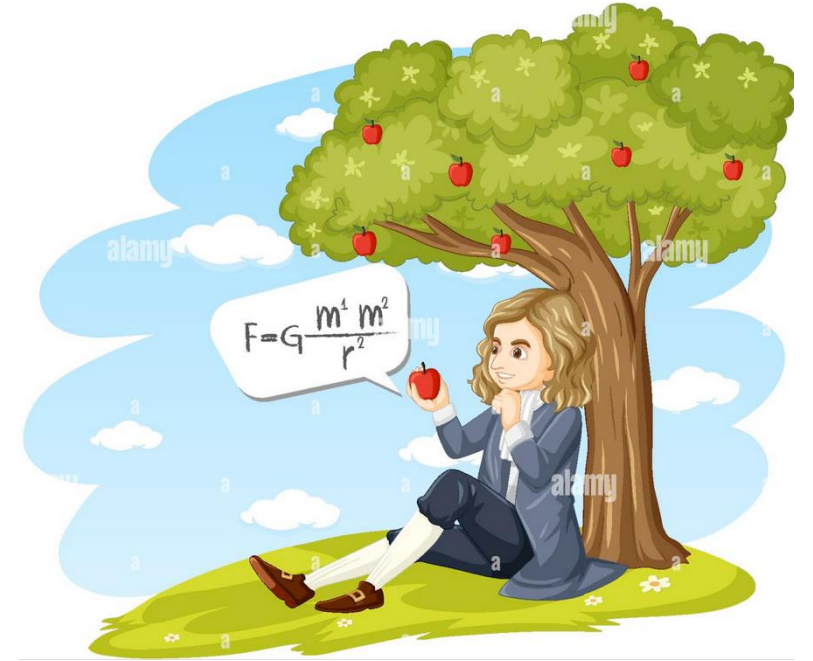
Partner	GDP (\$T)	Distance to US (km)	US exports (\$B)
Canada	2.1	735	292
Mexico	1.3	920	256
Germany	4.5	7,900	60
Brazil	2.2	7,700	43
Australia	1.4	15,500	26
South Africa	0.4	13,000	5

Newton's Law of Gravity

- Newton found that

$$F = G \times \frac{(M_i \times M_j)}{r_{ij}^2}$$

- G : gravitational constant
 - M_i, M_j : mass of two bodies
 - r_{ij} : distanced between two bodies
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- Two large masses attract strongly but the gravitational pull falls off with distance squared

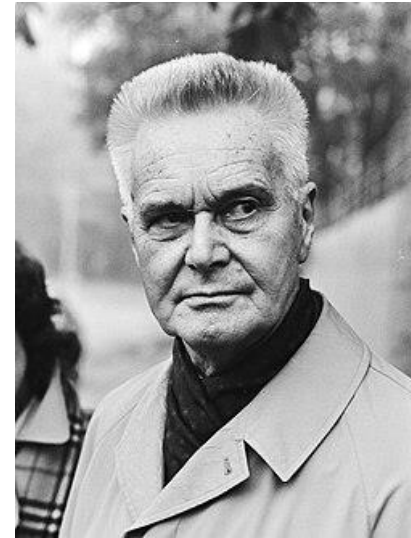


Trade Gravity

- Jan Tinbergen found that

$$\ln(X_{ij}) = \ln\left(G \times \frac{(Y_i \times Y_j)}{T_{ij}^\theta}\right)$$

- Y_i, Y_j : GDPs of exporter and importer
 - T_{ij} : trade costs → distance, borders, tariffs, language, time zones
 - θ : elasticity → how sensitive trade is to trade costs (typical: 1.0 to 1.5)
 - G : world constant that absorbs global factors (rarely interesting)
-
- Trade from i to j rises with economic size and falls with trade costs



Trade Gravity

Naïve Gravity:

- $\ln X_{ij} = \alpha + \beta_1 \ln Y_i + \beta_2 \ln Y_j + \beta_3 \ln Distance_{ij} + \varepsilon$
- Estimates have found:
 - $\beta_1 \approx 1$: 1% increase in exporter GDP $\rightarrow$ 1% increase in exports
 - $\beta_2 \approx 1$: 1% increase in importer GDP $\rightarrow$ 1% increase in imports
 - $\beta_3 \approx -1$: 1% increase in distance $\rightarrow$ 1% decrease in trade
 - $R^2 \approx 0.6$ to 0.8 with three variables across 200 countries.
- Few empirical equations in economics come close to this kind of fit!

Size Effect

Example:

- Four European trade partners and the US
- Larger economies trade proportionally more -- the $Y_i Y_j$ effect.

Country	GDP (\$T)	US exports (\$B)
Germany	4.5	76
Netherlands	1.1	69
Belgium	0.6	35
Denmark	0.4	5

Is the World Flatter?

Globalization led to

- Ocean freight rates down by 90% since 1950
- Development of air freight, internet, fiber optics, real-time logistics
- Did the distance coefficient move toward zero?
- Disdier & Head (2008) meta-analysis of 1,467 estimates
 - Average $\beta \approx -0.9$
 - Interpretation: services, just-in-time supply chains, and face-to-face contracting keep distance costly even as shipping falls



Additional Variables

Augmented gravity:

$$\ln X_{ij} = \alpha + \beta_1 \ln Y_i + \beta_2 \ln Y_j + \beta_3 \ln Dist_{ij} + \beta_4 Contig + \beta_5 Language + \beta_6 Colony + \beta_7 RTA + \varepsilon$$

- Contiguity: shared border
- Common language: lower communication and contracting costs
- Colonial ties: residual network effects from empire
- RTA: regional trade agreement (USMCA, EU, ASEAN)
- These dummies absorb frictions we can't measure in kilometers
 - Language, institutions, trust

Typical Values

- Head and Mayer (2014)

Friction	Coefficient β	$(\exp(\beta) - 1) \times 100$	Interpretation
Log distance	-1.10	—	Doubling distance $\rightarrow$ -54% trade
Common border	+0.66	+93%	Neighbors $\rightarrow$ ~2 $\times$ trade
Common language	+0.33	+39%	Shared language $\rightarrow$ +40% trade
Colonial tie	+0.84	+132%	Former colony $\rightarrow$ more than double
RTA	+0.47	+60%	RTA members $\rightarrow$ ~60% more

McCallum (1995) Border Puzzle

Canada-US share: 5,525-mile unguarded border, a common language, similar institutions, and the CUSFTA free-trade agreement.

- Question: does Ontario trade more with British Columbia (3,400 km, same country) or with California (similar distance, different country)?

$$\ln X_{ij} = \alpha + \beta_1 \ln Y_i + \beta_2 \ln Y_j + \beta_3 \ln Dist_{ij} + \beta_4 SameCountry + \varepsilon$$

- The β_4 coefficient measures how much more "same-country" pairs trade, holding size and distance fixed

McCallum (1995) Border Puzzle

Estimate: $\beta_4 = 3.09$

- $(\exp(3.09) - 1) \times 100 \approx 2,100\%$
- Canadian provinces trade $\sim 22\times$ more within Canada than across the border to the US
- Is the US-Canada border REALLY that significant? Implausible!
 - Tariffs averaged 1-2% (cannot generate a $22\times$ gap)
 - Transport costs: Toronto to Buffalo < Toronto to Vancouver
 - Common language, shared institutions, integrated firms
- Anderson & van Wincoop (2003): McCallum's gravity equation was misspecified

Anderson and van Wincoop (2003)

Multilateral Resistance

- Trade between i and j depends on all OTHER options available to both
- If Canada's outside trading options are cheap, the border's friction looks large
- If Canada's outside options are expensive, the border looks small
- Fix: add exporter and importer "resistance" indices Π_i and P_j
- Structural gravity:
$$X_{ij} = \left(\frac{Y_i \times Y_j}{Y^W} \right) \times \left(\frac{T_{ij}}{(\Pi_i \times P_j)} \right)^{1-\sigma}$$

Specification	Interpretation
McCallum (1995): naïve gravity, Canada data	Provinces trade x22 more w/ each other than comparable states
A-vW: Same regression, U.S.data	U.S. states trade x1.5 more w/ each other than comparable provinces
A-vW full model	Canada x10, U.S. x2.5

Russian counter-sanctions and smuggling: Forensics with structural gravity estimation

Tyazhelnikov and Romalis

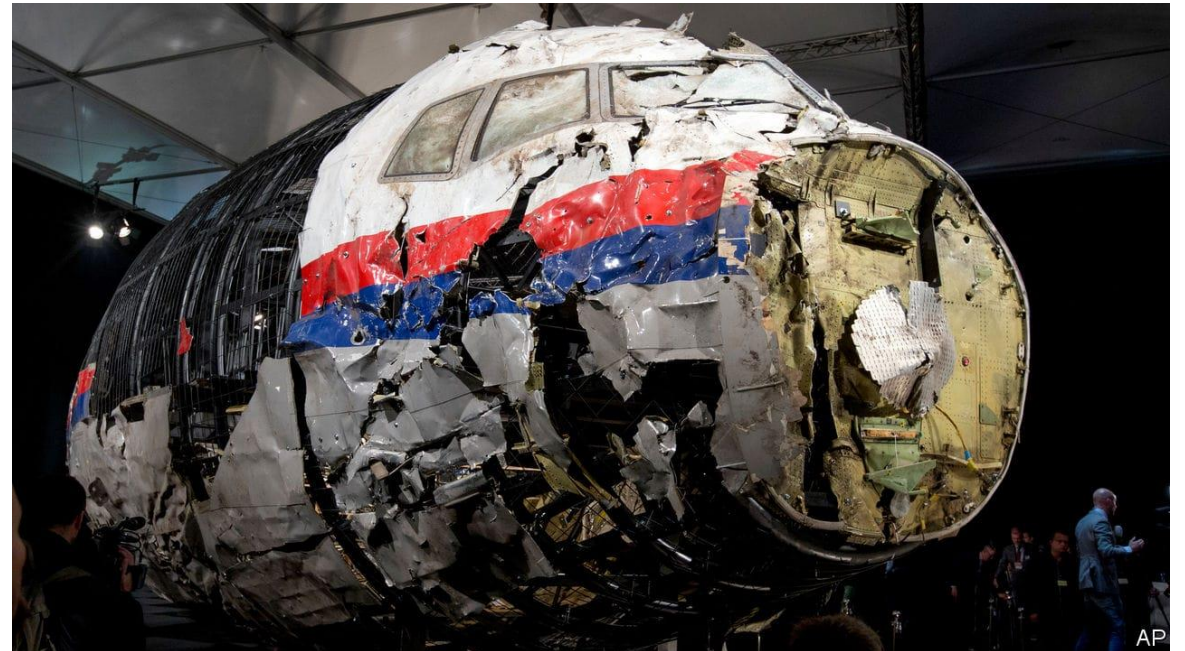
Journal of International Economics

2024

Motivation

Russian Invasion of Crimea

- Feb-Mar 2014
 - Putin's little green men invade and annex Crimea



Russian Invasion of Crimea

- US+EU respond with sanctions of Russian finance, energy, defense
- Putin's *counter*-sanctions
 - Bans imports of most meat, fish, dairy, vegetables, and fruit from sanctioning countries
- Question: did the embargo actually stop the trade?
 - Hard to tell because smuggling is.... illegal.
 - If you were a forensic economist, what would you look for?

Approach

Mirror Statistics

- A exports to B = B imports from A
- True 2012-2014
- From 2015, exports >> imports

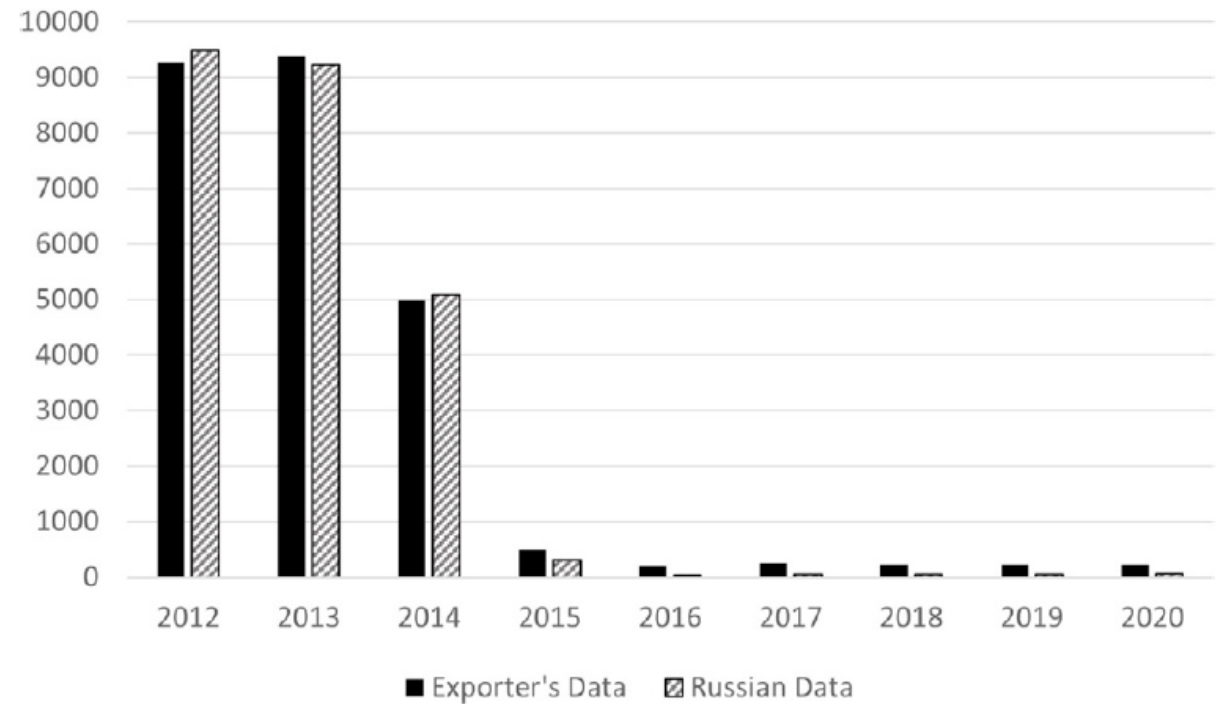


Fig. 2. Exports of embargoed products to Russia (USD million).

Mirror Statistics

- For peach imports in particular..

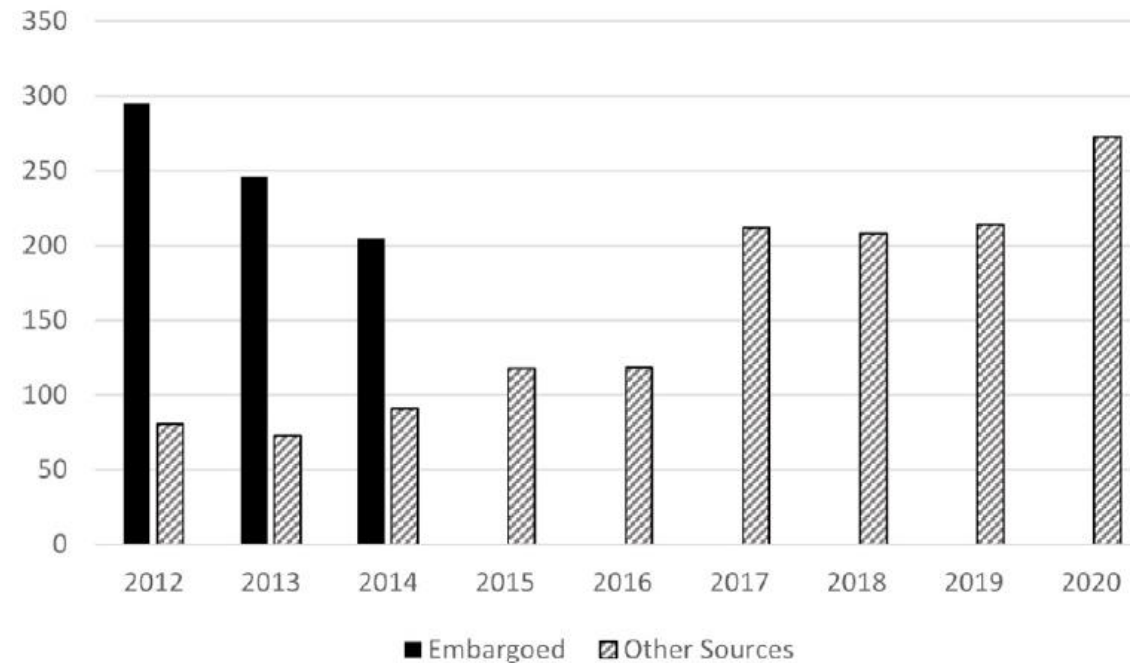


Fig. 3. Russian fresh peach and nectarine imports (USD million).

Mirror Statistics

- What is Belarus up to? Are they smuggling goods into Russia?

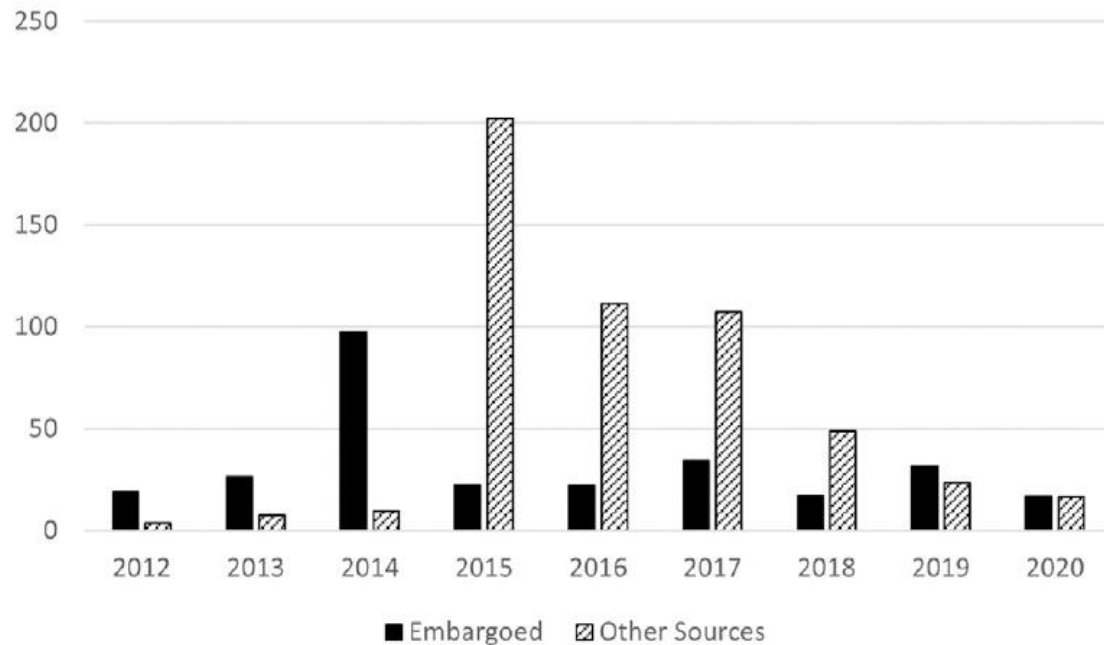


Fig. 4. Belarus fresh peach and nectarine imports (USD million).

Table 1

Top 10 exporters of peaches to Belarus in 2015 (\$m).

Exporter	Belarusian Data	Exporter's Data
Morocco	64.5	0.0
Turkey	42.8	0.1
South Africa	23.5	0.0
Egypt	18.5	0.0
Ecuador	16.4	0.0
Spain	14.7	2.9
Peru	9.8	0.0
Bosnia Herzegovina	9.6	0.0
Brazil	5.6	0.0
Greece	5.2	1.0

Gravity

- Isn't this enough proof?
 - Sudden increase in exports...
- Economists always think about the *counterfactual*
 - Legal substitution is... legal.
 - It is not illegal for Spain to sell more peaches to Belarus after the Russian market is closed
- Given the new market realities and if everybody was law-abiding, what would be the trade flows?
- Gravity tells you what trade *should* be, given the GDP, distance, RTA, etc.
 - Deviations from predictions carry information then

Gravity

Estimation strategy (VERY SIMPLIFIED)

- Estimate gravity product-by-product on pre-embargo trade (2009-13)
- Impose the embargo in the model and let trade *legally* re-route
 - banned flows $\rightarrow 0$
 - substitutes and transit countries expected to rise)
- Flag *chains* of surprise:
 - the same banned product flowing into a transit country
 - AND out to Russia, both far above prediction

Results

Top Transit Countries

- Smuggling $\approx$ \$1.1-1.6 billion per year in agri-food
- Equivalent to 11-17% of pre-embargo trade in the banned goods
- Channels: neighboring non-sanctioning countries, Belarus above all

Table 2

Top 10 smuggling transit countries to Russia in 2015 (\$m).

Transit Country	Raw	Raw Placebo	Normalised	Normalised Placebo	Residual	Residual Placebo
Belarus	266.1	44.5	265.6	13.6	263.1	5.1
China	140.1	26.2	67.0	0.0	67.0	0.0
Vietnam	31.1	7.0	29.6	4.3	25.4	4.3
Israel	23.3	1.8	19.0	0.0	19.0	0.0
Chile	21.0	0.8	0.0	0.0	0.0	0.0
Turkey	21.0	4.4	10.2	0.0	10.2	0.0
Thailand	17.4	1.8	1.4	1.8	1.4	1.8
India	16.7	7.0	0.9	0.6	0.9	0.4
Egypt	13.7	0.0	13.0	0.0	12.9	0.0
United Arab Emirates	11.5	6.2	11.5	6.2	11.5	0.0
ALL COUNTRIES	666.5	126.4	465.4	43.0	461.2	27.7

Implications

- For policy: partial embargoes can be circumvented
 - Enforcement has to watch the *neighbors*, not just the border
- For economics: the gravity trade model is doing police work
 - Predictions precise enough that *deviations* identify crime

WSJ:



Trade, Merchants, and the Lost Cities of the Bronze Age

Barjamovic, Chaney, Coşar, and Hortaçsu

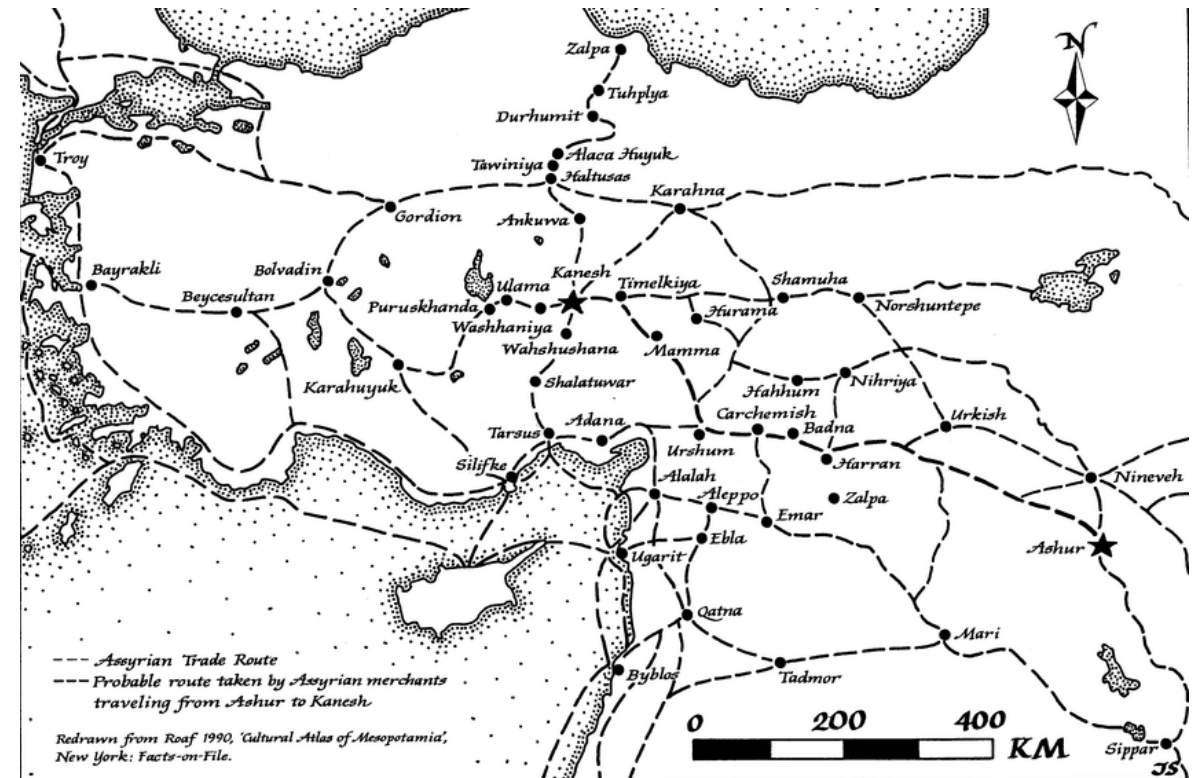
Quarterly Journal of Economics

2019

Motivation

Assyrian Trade

- Assyrian merchants (c. 1930–1775 BC) ran caravans from northern Iraq into central Turkey
- Can gravity locate cities that have been lost for 4,000 years?



Assyrian Trade

- Assyrian traders left ~12,000 clay tablets at the city of Kaneš
- Kaneš burned down c. 1836 BC
 - Which baked the clay tablets
- 25 trading cities are named in the tablets
 - Archaeologists have located 15
 - 10 remain lost



- Example text:

(I paid) 6.5 shekels (of tin) from the Town of the Kanishites to Timelkiya. I paid 2 shekels of silver and 2 shekels of tin for the hire of a donkey from Timelkiya to Hurama. From Hurama to Kaneš I paid 4.5 shekels of silver and 4.5 shekels of tin for the hire of a donkey and a packer.

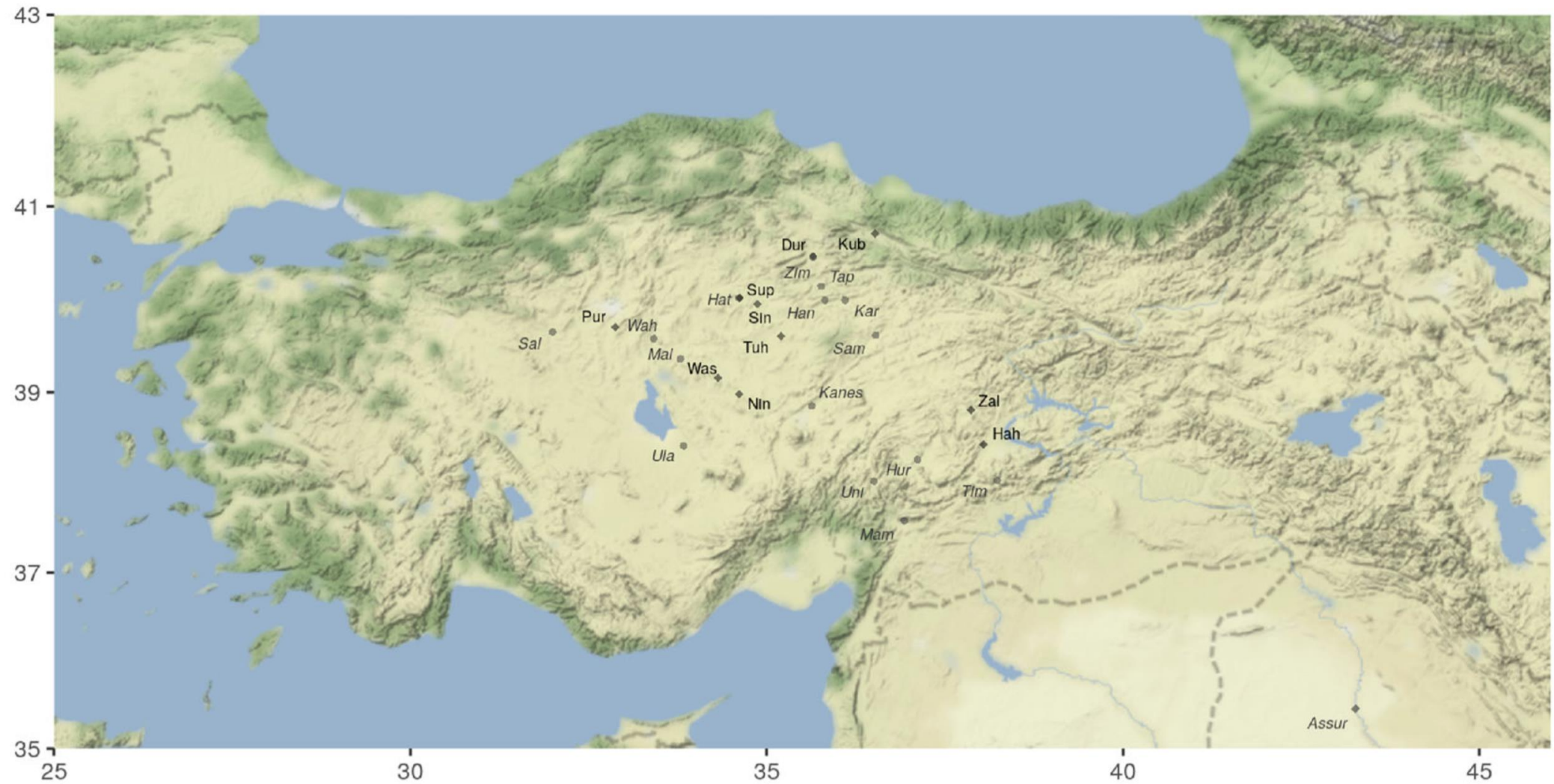
Relevance

- For history: a quantitative tool
 - Historians have debated lost-city locations for a century using qualitative clues
 - Gravity provides quantitative evidence
- For economics: a stress test for gravity
 - Does gravity work also for donkey-caravan economy without states or currencies?
- For geography: persistence
 - Do cities that mattered in 2000 BCE still matter today?
 - Topography and transport have shaped urban hierarchies for millennia

Setting

- Period: c. 1930–1775 BC (Middle Bronze Age)
- Where: Anatolia (modern Turkey) and Upper Mesopotamia
- Who: Assyrian merchants from Aššur
 - Operating a trading colony (karum) at Kaneš
- What: long-distance caravan trade
 - Tin and textiles west, silver and copper east

Setting



Approach

Model

- Iceberg trade cost: $\tau_{ij} = (d_{ij})^{\zeta} \times \tau_i^o \times \tau_j^d$
- ζ is key: the distance elasticity of trade costs
- τ_i^o and τ_j^d : origin and destination frictions
 - Like the multilateral resistance terms from Anderson & van Wincoop

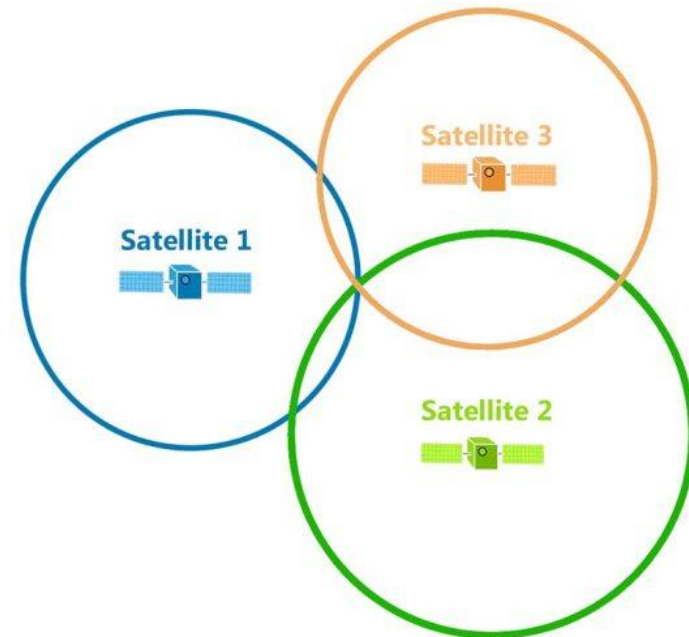
Estimation Strategy (VERY SIMPLIFIED)

Adapts Eaton-Kortum-Sotelo (2012) structural gravity

Estimate:

$$\ln X_{ij} = \alpha + \beta_1 \ln Y_i + \beta_2 \ln Y_j + \zeta \ln Dist_{ij} + \varepsilon$$

- Know or estimate $X_{ij}, \alpha, \beta_1, \beta_2, Y_i, Y_j, \zeta$
- Back out $Dist_{ij}$
- Then triangulate



Estimation Strategy

Usually,

- Location is known and we find the distance elasticity
- This paper takes the distance elasticity ζ as known and solves for locations

Instead

- Step 1: Estimate ζ from known-to-known city pairs using nonlinear least squares
- Step 2: Take ζ as given. For each lost city, solve for the latitude and longitude that best match observed trade flows
- Step 3: Back out a measure of ancient economic size (population $\times$ productivity) for all 25 cities

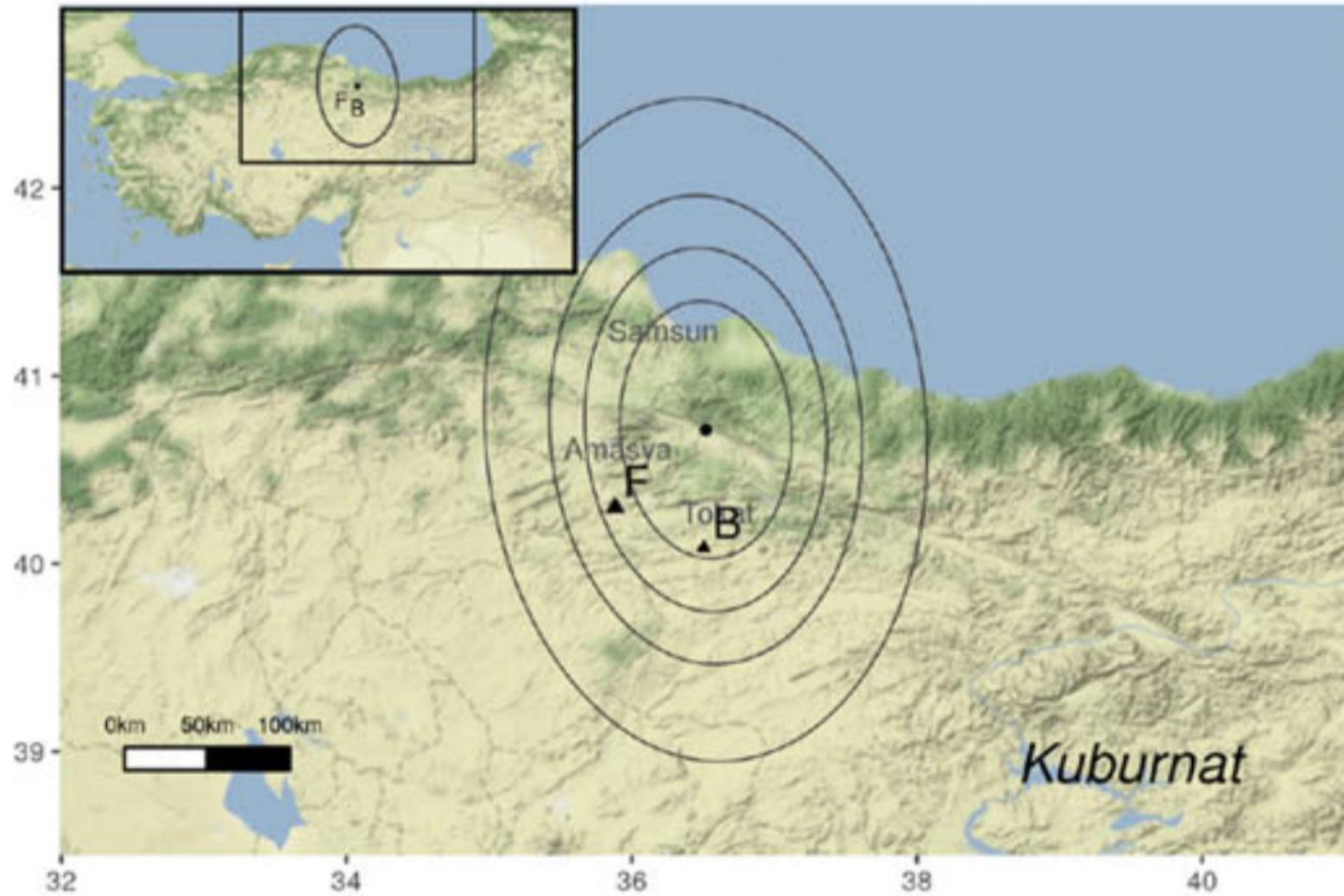
Results

Parameters

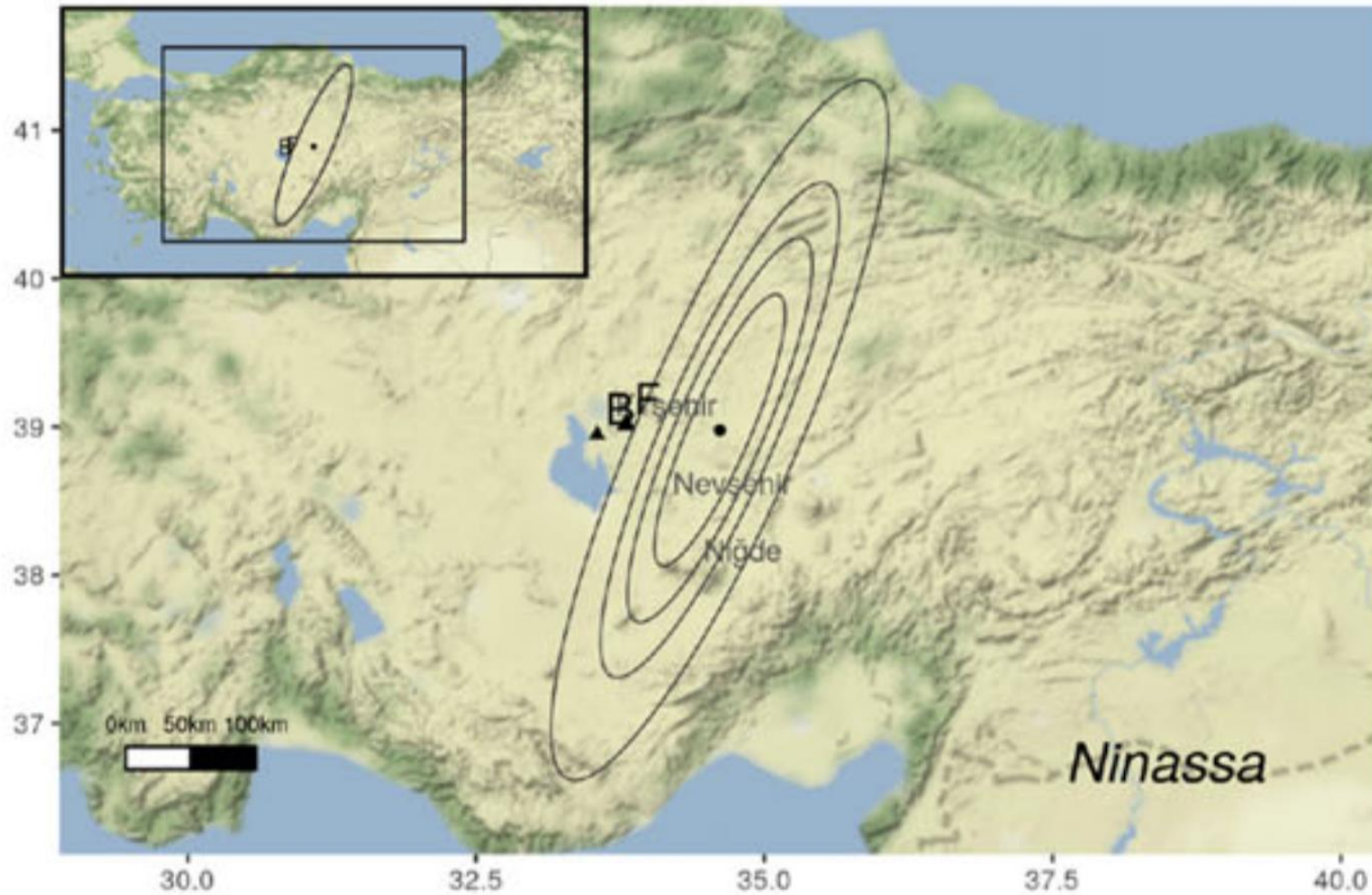
- Point estimate: $\hat{\zeta} = 1.912$ (SE 0.189)
 - Interpretation: doubling distance between two Bronze Age cities cuts expected trade by ~73%
- Modern distance elasticities (Head & Mayer 2014): 1.0 to 1.5
- Bronze Age estimate is modestly larger
 - Reasonable, since donkey caravans face steeper distance penalties than container ships



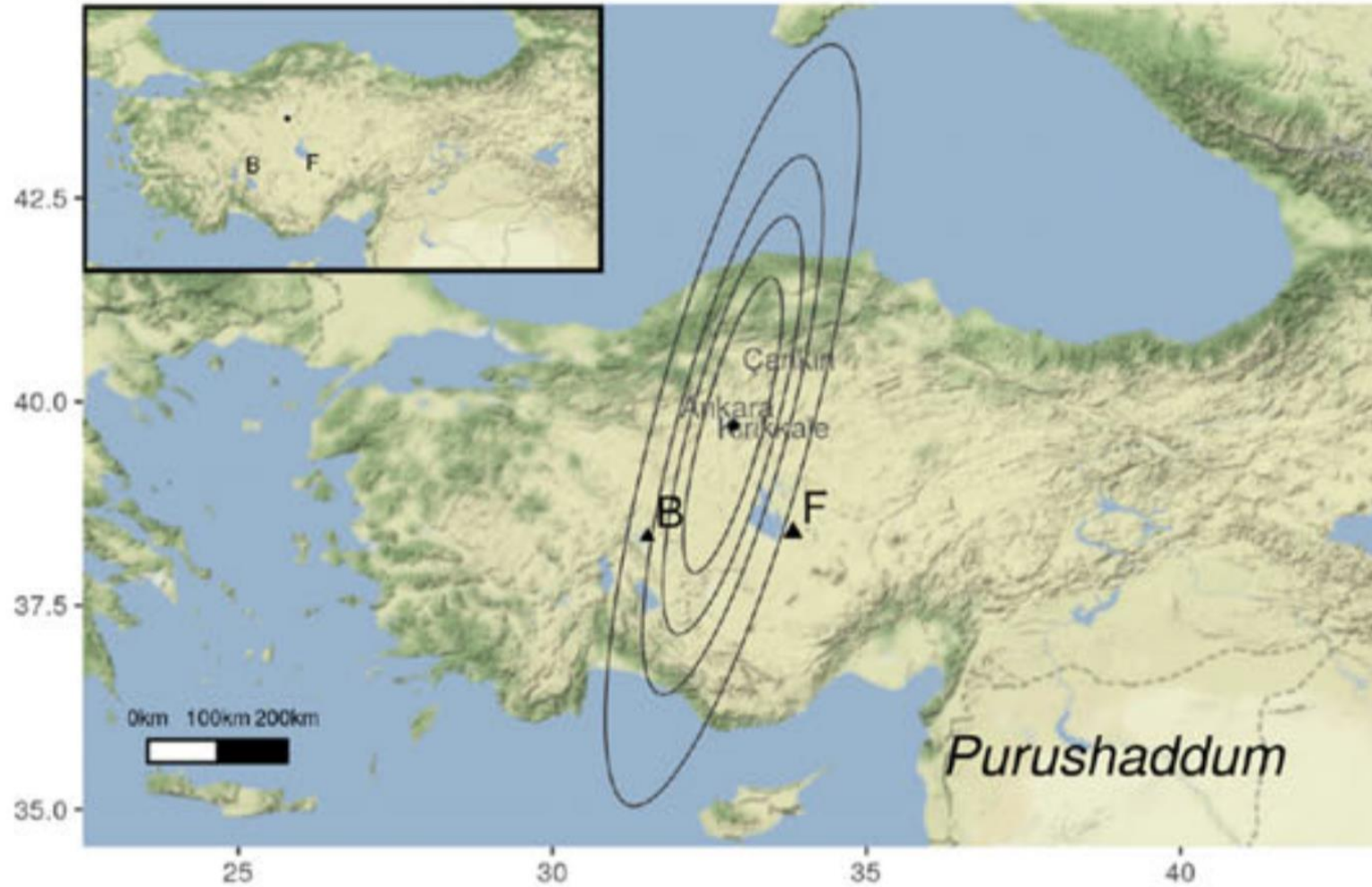
Lost Cities



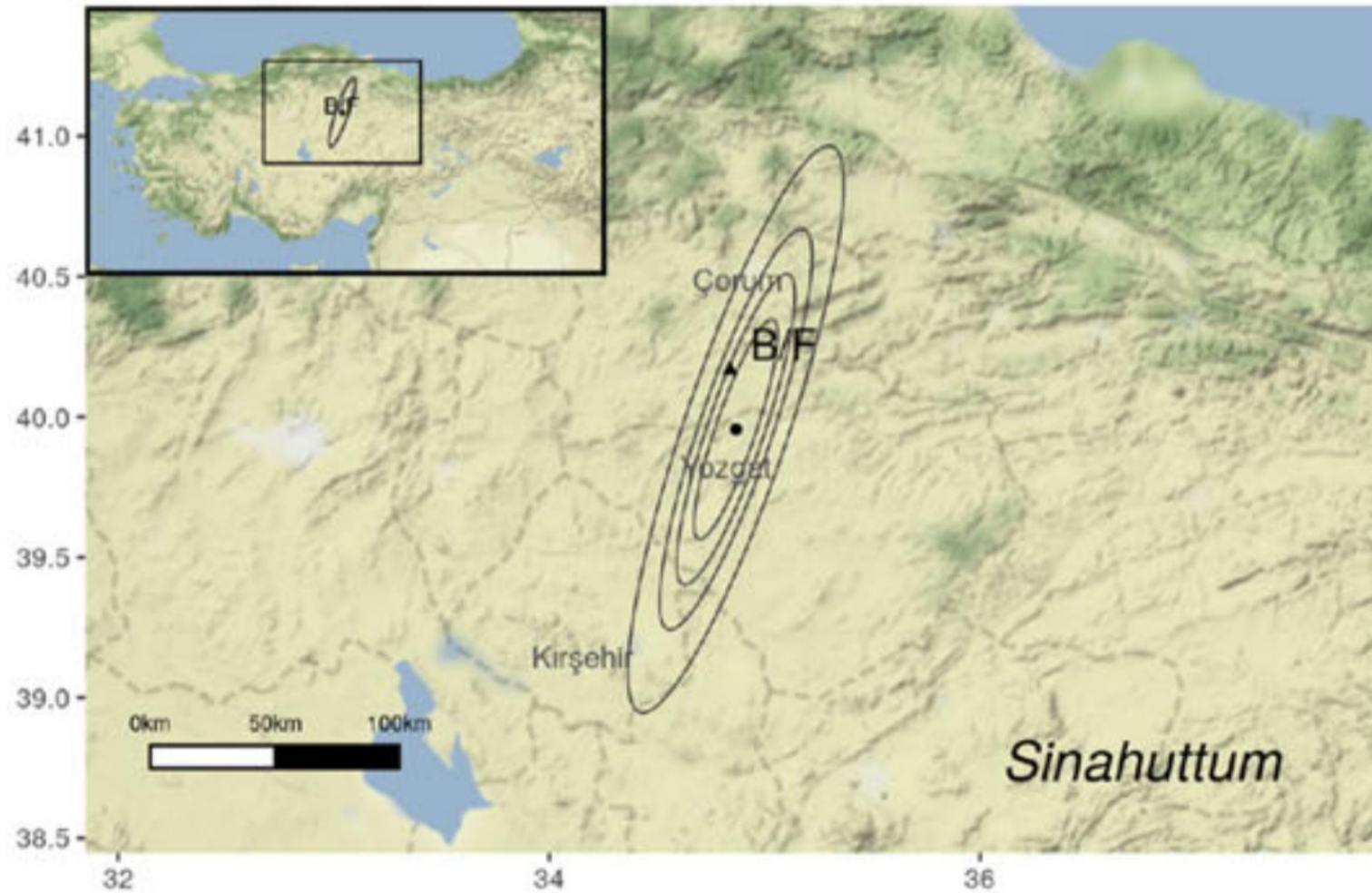
Lost Cities



Lost Cities



Lost Cities



City Persistence

Match Bronze Age cities to modern districts (20 km radius)

- Regress $\log(\text{2012 district population})$ on $\log(\text{ancient city size})$

→ coefficient +0.23 (SE 0.035)

- Regress $\log(\text{night lights})$ on $\log(\text{ancient city size})$

→ coefficient +0.12 (SE 0.036)

- Despite 4,000 years of invasions, collapses, migrations, and climate shocks, the city hierarchy of Anatolia is roughly unchanged!

Implications

Implications

- For theory: gravity is pretty good
 - The same equation with roughly the same elasticity describes 4000 years of trade
- For method: structural beats naïve
- For geography: topography rules
 - Once a place is a hub, it stays a hub
 - Hard to try to relocate economic activity away from established centers