

Trade and the End of Antiquity

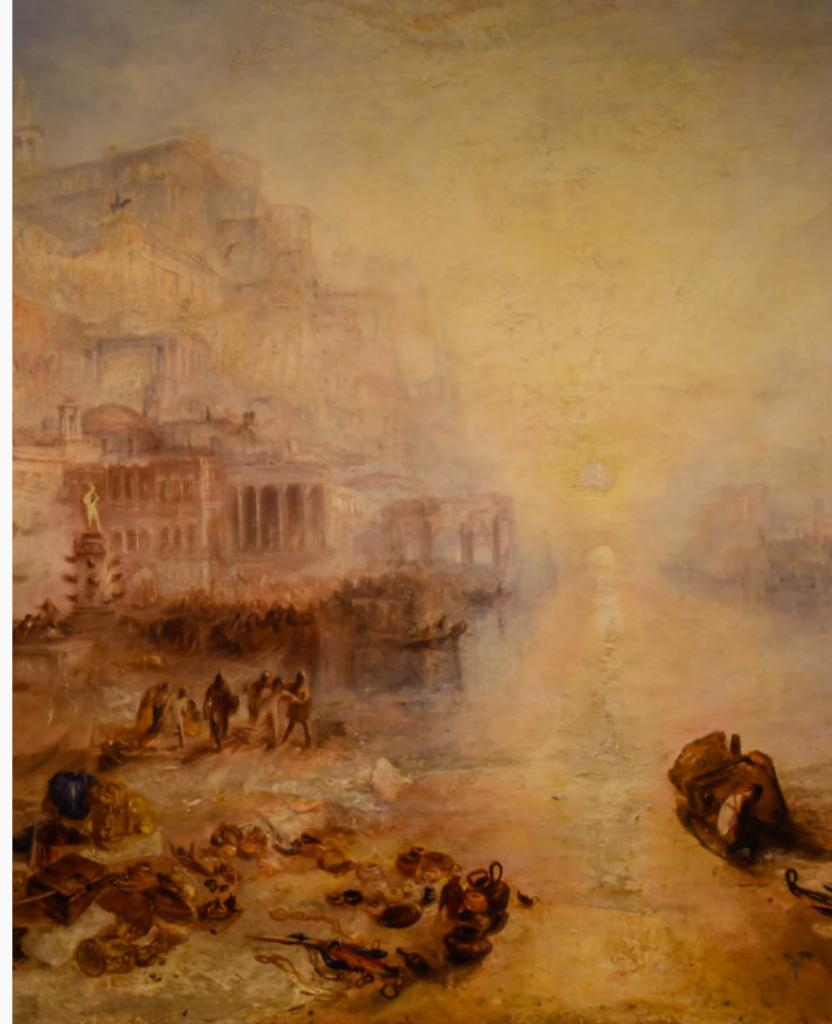
A Quantitative Investigation
of the Pirenne Thesis

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What caused the End of Antiquity?

- Antiquity: Roman and Greek civilizations centered around the Mediterranean
- End of antiquity circa 7th-8th Century AD:
 - Economic activity shifts away from the Mediterranean.
 - Rise of Northern Europe (Charlemagne).

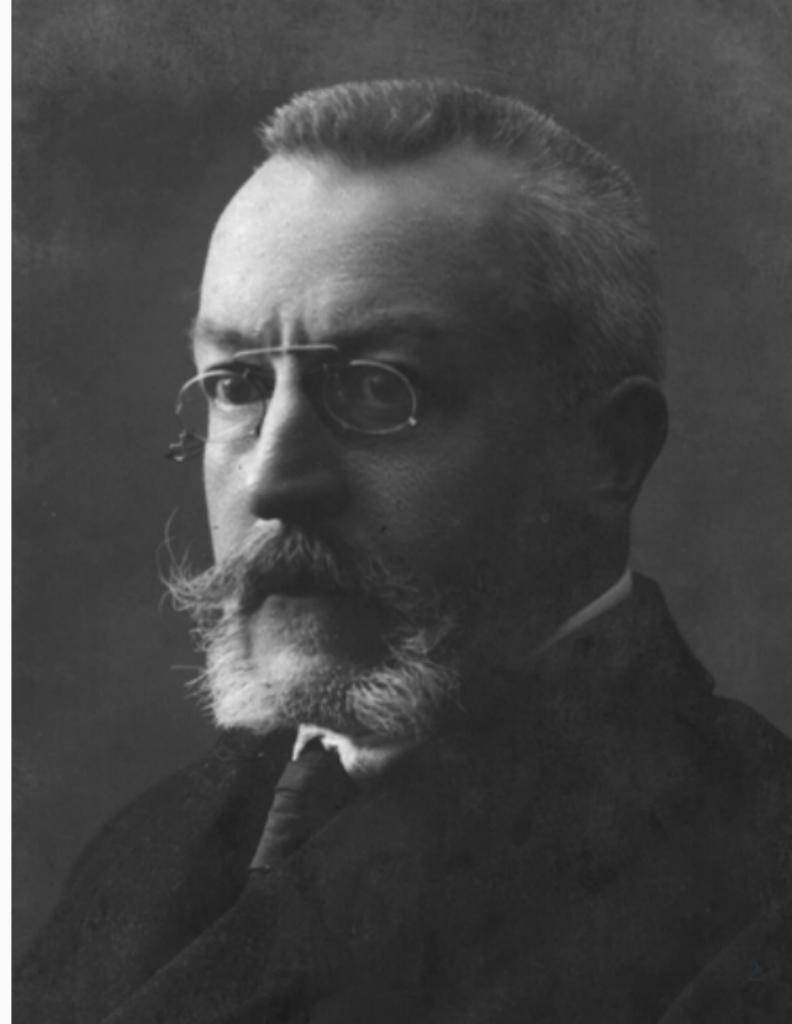
→ *Question:* What caused the End of Antiquity?

- Discussed, among others, by Montesquieu (1734), Voltaire (1756), Gibbon (1789)

Pirenne Hypothesis

Henri Pirenne (1937), “*Mahomet et Charlemagne*”

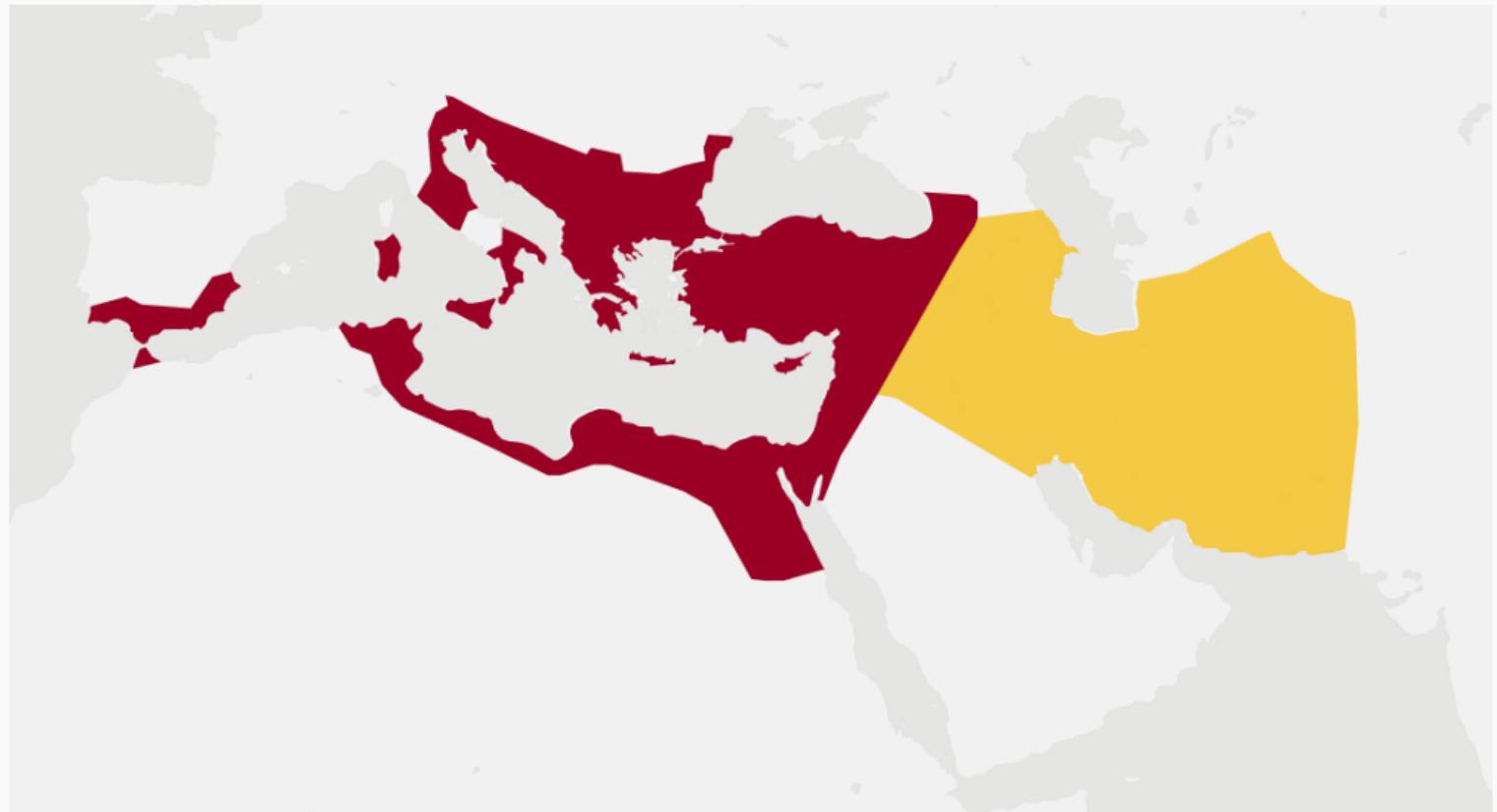
- Rise of the Islamic Caliphate disrupts Mediterranean trade/exchanges.
- Causes a shift of economic activity away from the Mediterranean.
- Rise of the Carolingian Empire in Northern Europe.



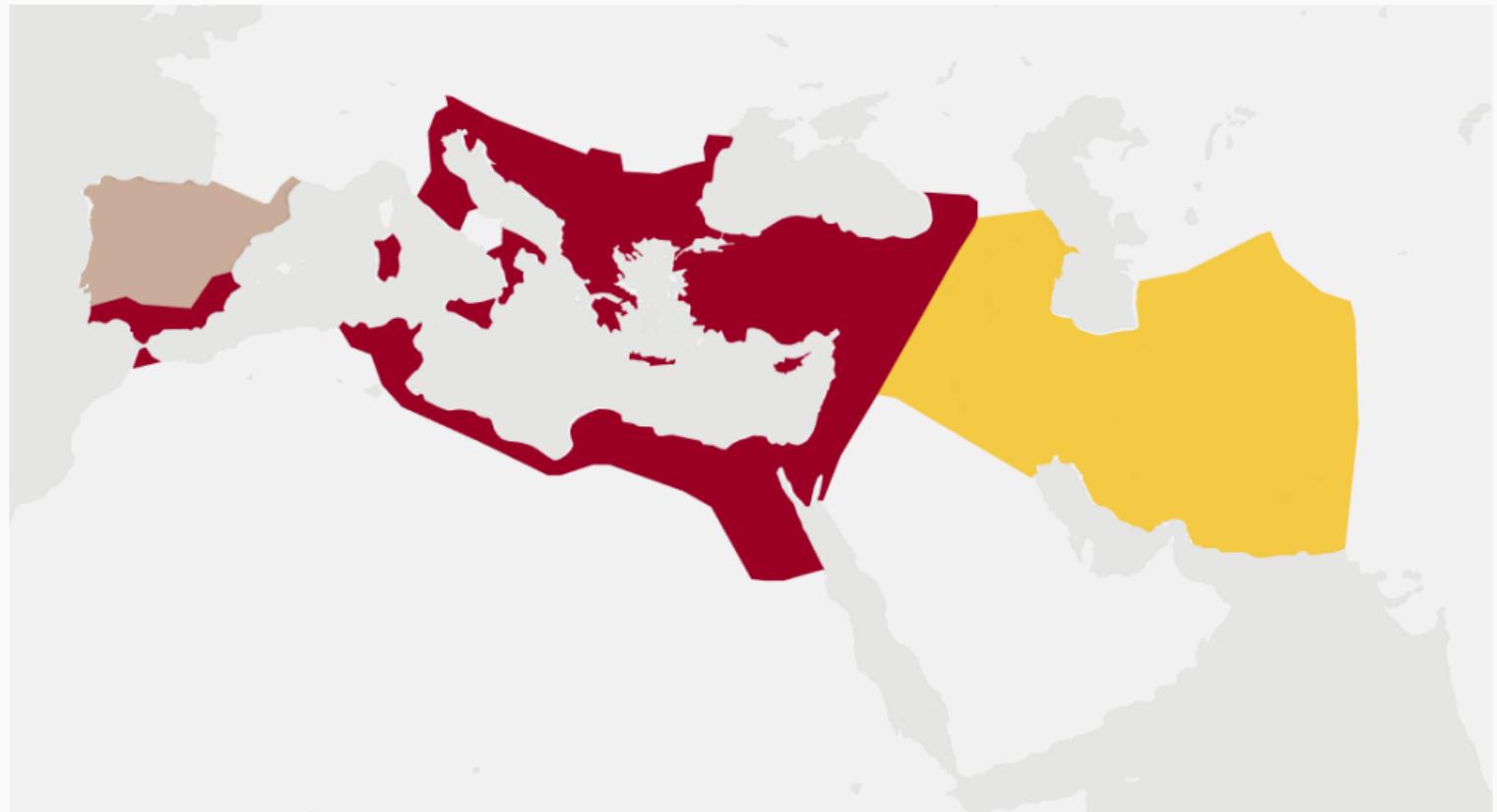
Political changes in the Mediterranean: 600 AD



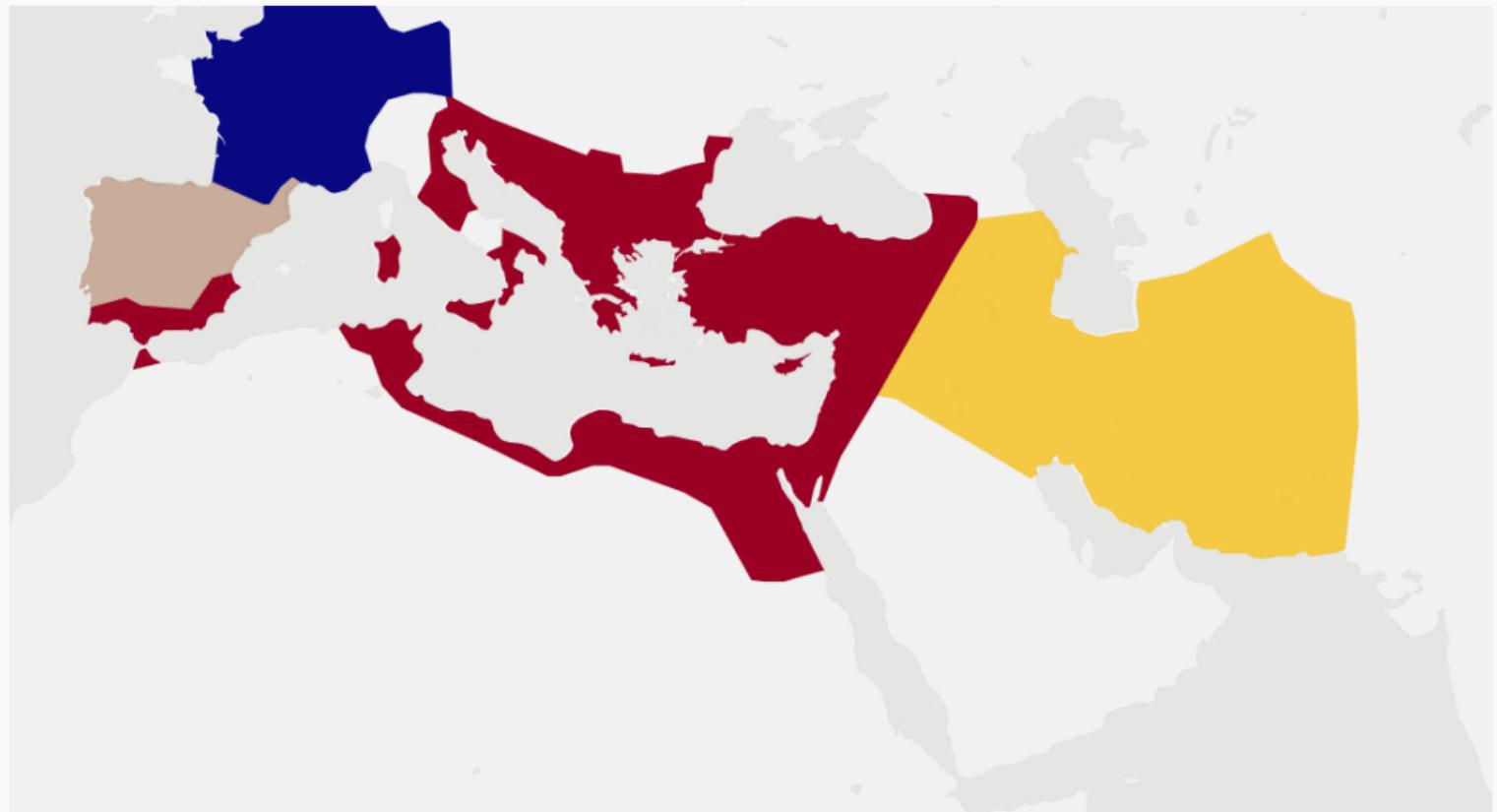
Political changes in the Mediterranean: 600 AD



Political changes in the Mediterranean: 600 AD



Political changes in the Mediterranean: 600 AD



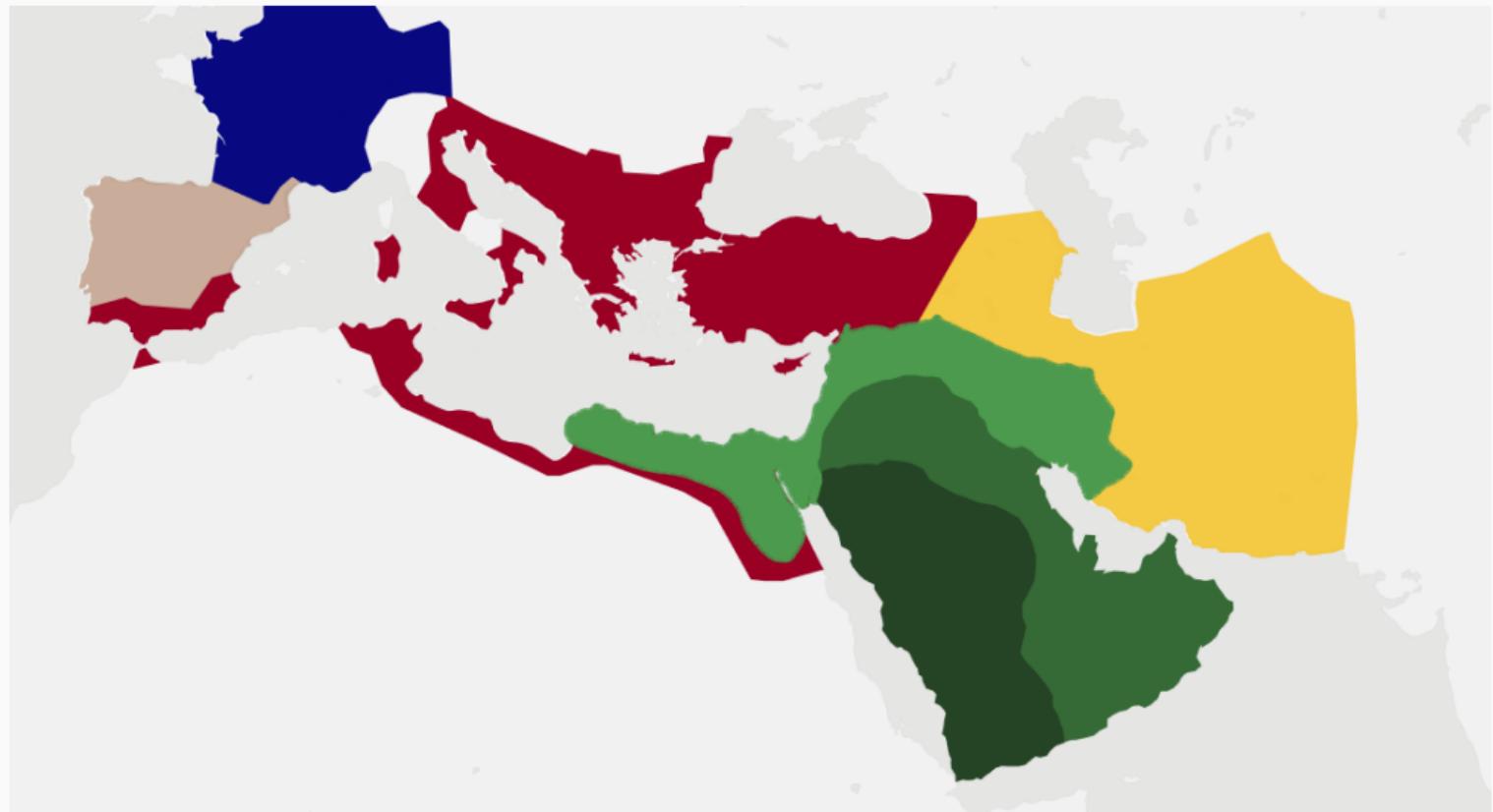
Political changes in the Mediterranean: 632 AD



Political changes in the Mediterranean: 634 AD

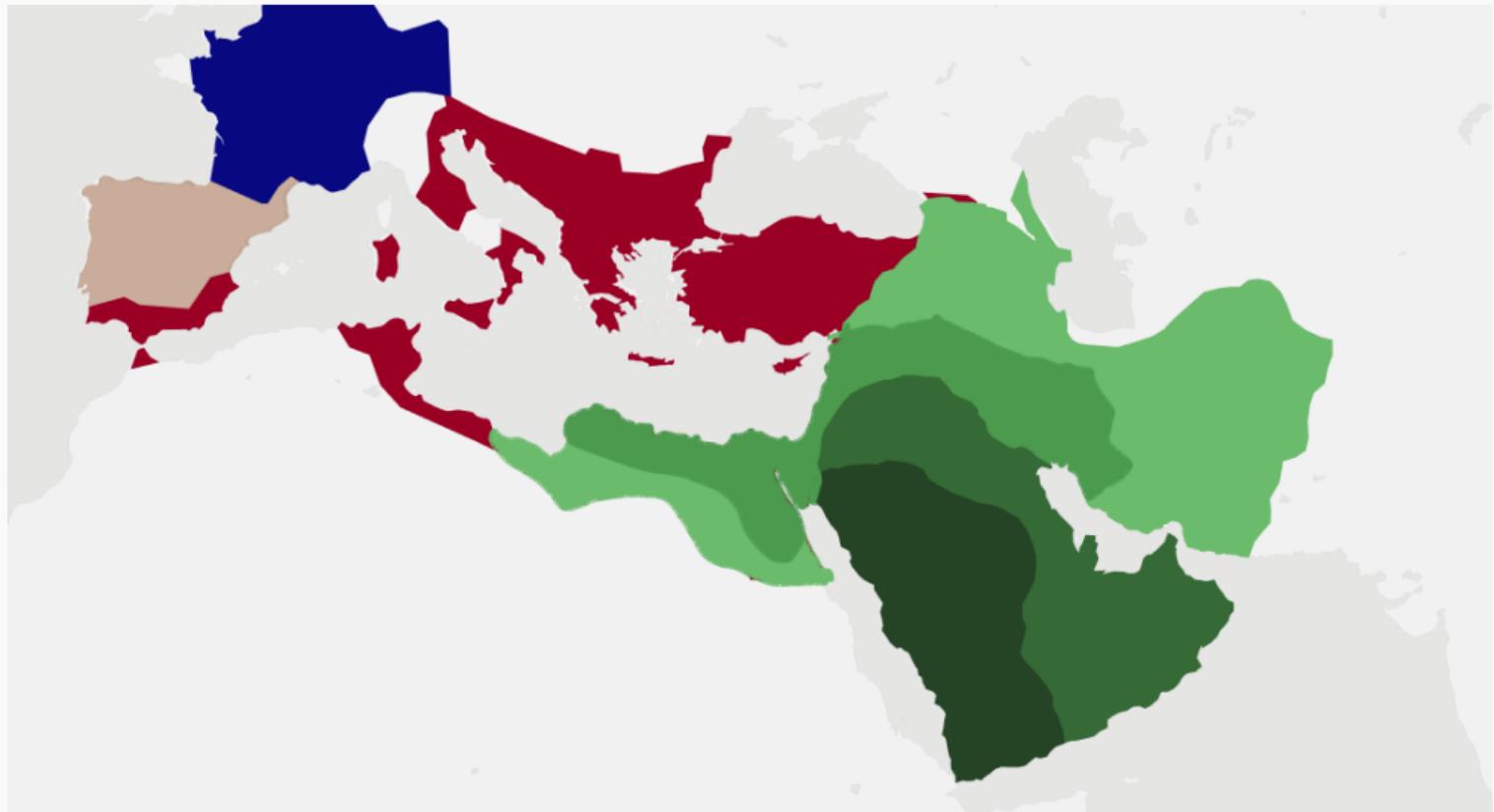


Political changes in the Mediterranean: 644 AD

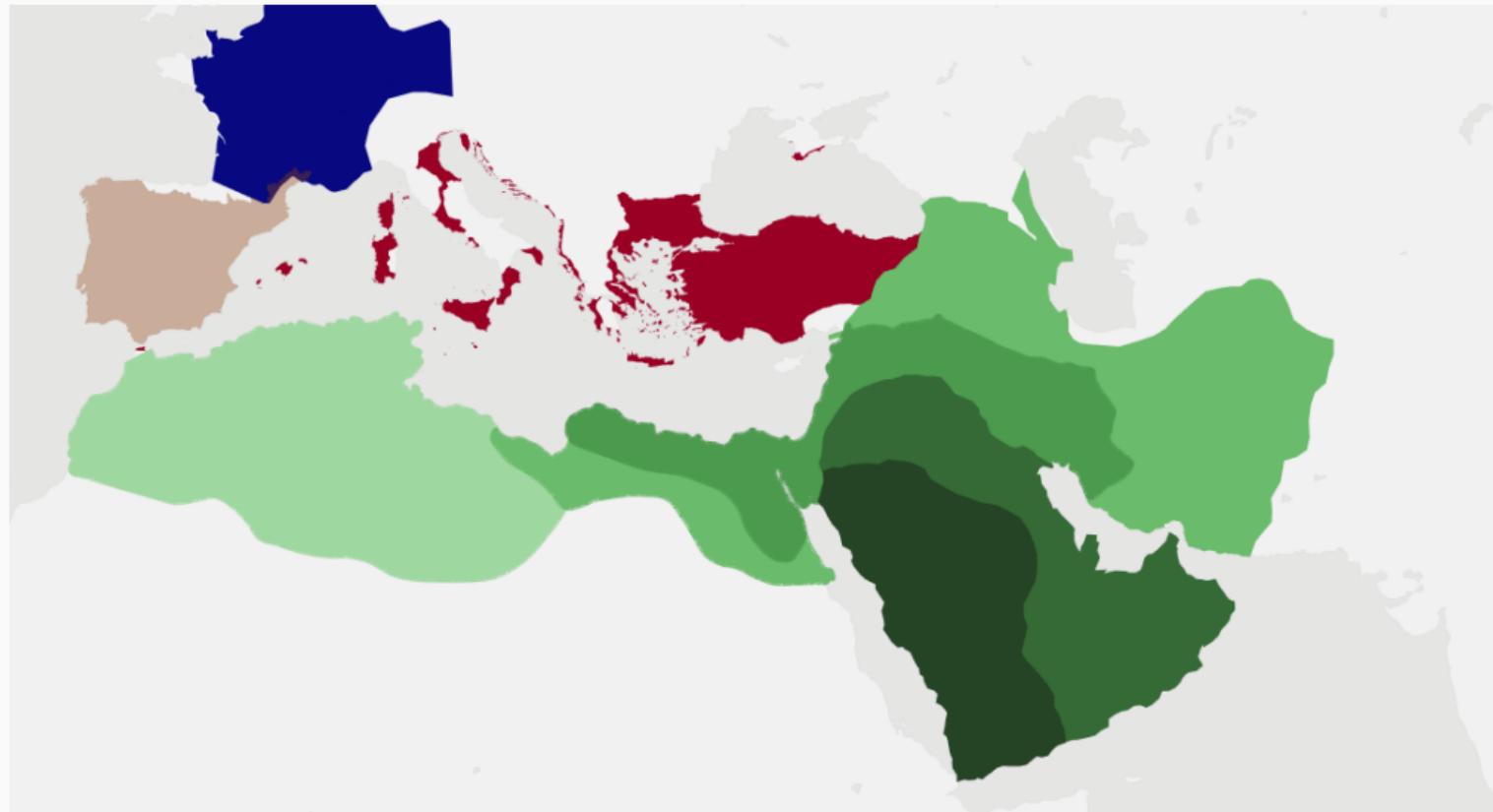


Political changes in the Mediterranean:

661 AD

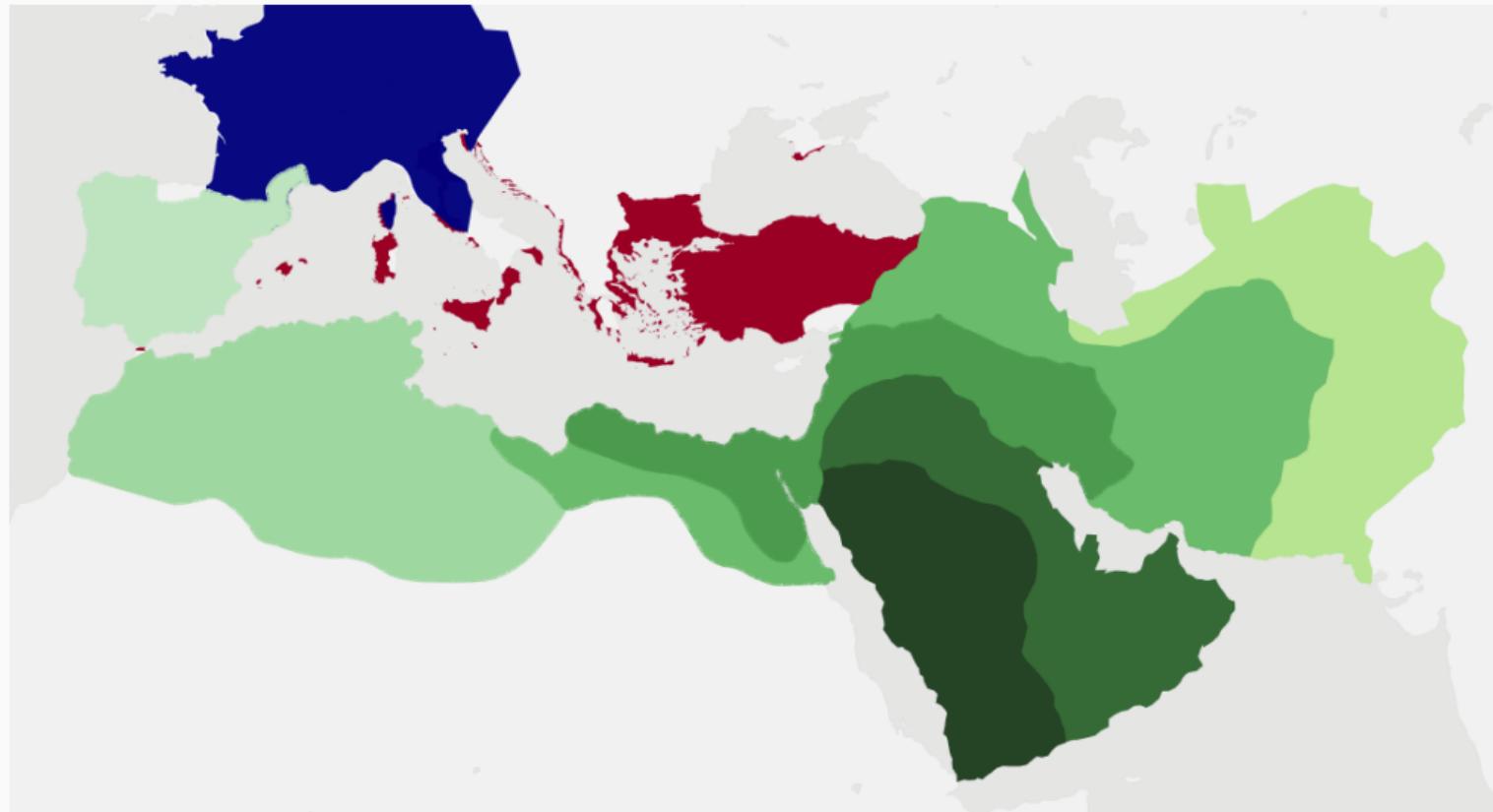


Political changes in the Mediterranean: 661-700 AD



Political changes in the Mediterranean:

750 AD



This paper

We use data on the movement of coins to study the changing economic geography during Late Antiquity.

- Coins are the main medium of exchange during Late Antiquity, particularly for long-distance trade → informative about trade
- Coins are well studied & documented by historians and numismatists
- Coins have features that help solve econometric identification problems

Roadmap:

1. Data description
2. Stylized facts / reduced-form evidence
3. Quantitative Model
 - Identification of trade shares from coin stocks
 - Identification of trade cost changes from origin/destination “sizes”
4. (Preliminary) quantitative counterfactuals to investigate the economic relevance of trade cost changes in the Mediterranean (→ Pirenne)

Outline

Data

Reduced form evidence

Model

Parameterization and Estimation

Data: Coins around the Mediterranean, AD 325 to AD 950

Assemble a large dataset of coin finds from around the Mediterranean

1. FLAME (2023) project:

- “Framing the Late Antique and Early Medieval Economy.”
- Collaboration of >60 historians and numismatists.
- ~200,000 coins with complete records from ~4,600 hoards
- Pre AD 725.

2. Hand-coded records from numismatic / archaeological literature:

- 797 coin finds.
- 100,478 coins.
- post AD 725.

Data covers most of published literature on hoard records (and more)

Coin hoard data: an example from al 'Ush (1972)

No.	MINT	DATE	DIAM.	WEIGHT	NUMB.
51	الأندلس	114	29.	2.93	4
52	"	115	29.5	2.92	1
53	"	116	26.5	2.92	3

Excerpt of an original publication on the Damascus silver hoard:

- record number (51)
- mint (al-Andalus) *
- mint date (year 114 of the Hijri calendar) *
- diameter (29mm)
- weight (2.93g)
- number of coins with these attributes (4) *

The issuing dynasty (Umayyad) is given in the table headings and the denomination and material (silver *dirham*) is stated in the text. * denotes required attributes

Coin dataset

- Each coin provides the following information:
 1. Mint location (“birthplace”): m
 2. Mint date (“birthdate”): τ
 3. Hoard location (“death place”): h
 4. Terminus post quem, tpq (“death date”): $T = \sup \tau$

Coin dataset

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 3. Hoard location (“death place”): h
 4. Terminus post quem, tpq (“death date”): $T = \sup \tau$
- 286,035 coins.
- Time:
 - Mint date > AD 325
 - tpq < AD 950.
- Space:
 - Western Europe.
 - Southern Europe.
 - Northern Africa.
 - Middle East++.

Spatial distribution: the (extended) Mediterranean



Figure 1: Region Definitions

Distribution of coin “death dates” (tpq)

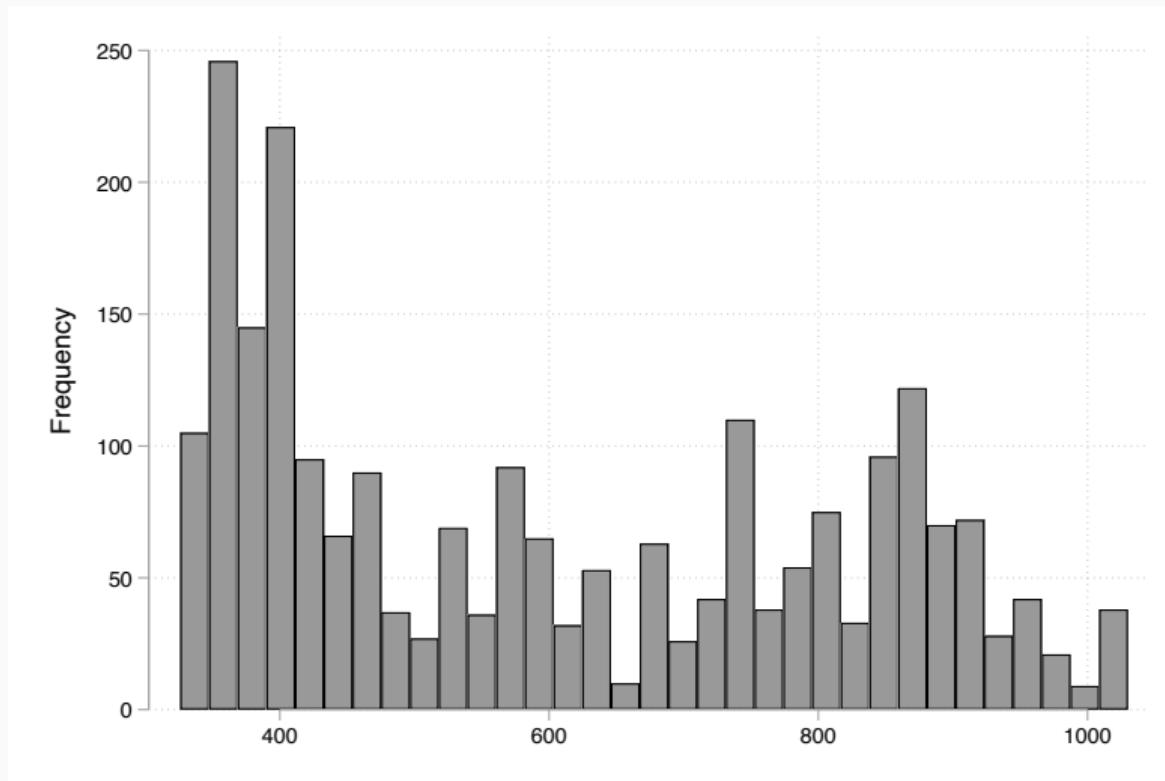


Figure 2: Terminus Post Quem (tpq) of hoards

Distribution of coin ages (tpq minus mint date)

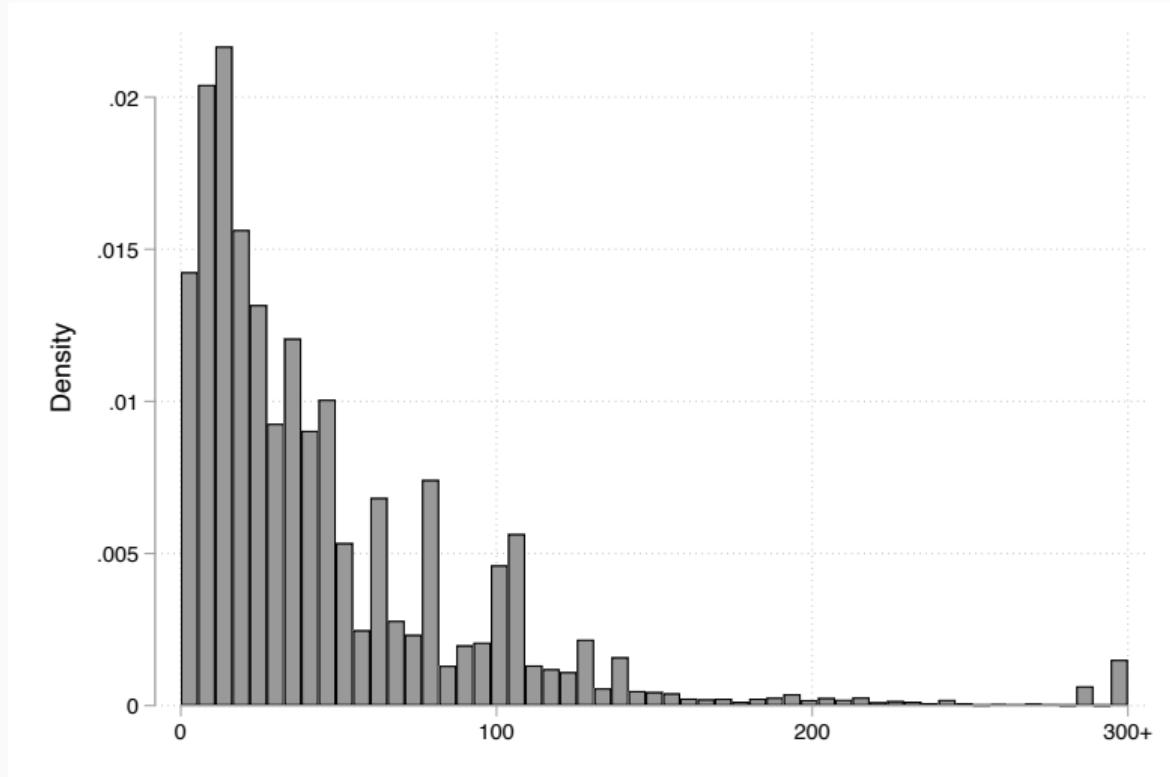


Figure 3: Coin age at time of deposit (tpq), in years

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Stylized facts

We document 3 main stylized facts:

1. Older coins travel further.
2. Distance *and* politics impede coin travels (gravity).
3. The Arab conquest disrupts Mediterranean crossings.

Fact #1: within a hoard, older coins have travel farther

Table 1: Within-hoard distance travelled and age of coin at deposit

Dependent variable: Log Distance between Mint and Hoard					
	(1)	(2)	(3)	(4)	(5)
Log Age of Coin	0.160** (0.050)	0.0942** (0.025)	0.0882** (0.031)	0.178** (0.049)	0.0623** (0.020)
Sample					No non-hoards No non-hoards
Hoard FE	Yes	Yes	Yes	Yes	Yes
Mint × 50-year-interval FE					Yes
Mint × 25-year-interval FE					Yes
R ²	0.762	0.863	0.869	0.775	0.899
Observations	287235	287018	286860	250133	249806

Standard errors in parentheses, clustered at the hoard level.

+ $p < 0.10$, * $p < 0.05$, ** $p < 0.01$

Age of coin = $tpq - \text{mint date}$

⇒ coins diffuse across space over time.

Fact #2: distance and political borders impede coin travels

Construct $1^\circ \times 1^\circ$ cells for mint and hoard locations and calculate flows count_{mdh}

Table 2: Gravity and Border Effects in Coin Flows

	Dependent variable: # Coins _{mdh}					
	(1)	(2)	(3)	(4)	(5)	(6)
Log Distance	-1.138** (0.12)	-1.002** (0.13)	-1.140** (0.10)	-0.955** (0.077)	-0.727** (0.10)	-0.694** (0.10)
Political border		-1.945** (0.62)		-2.073** (0.47)		-1.540** (0.41)
Hoard Cell FE	Yes	Yes	Yes	Yes	Yes	Yes
Mint × Empire Cell FE	Yes	Yes	Yes	Yes	Yes	Yes
Sample		Gold only	Gold only	Int. Marg. only	Int. Marg. only	
Estimator	PPML	PPML	PPML	PPML	PPML	PPML
Pseudo-R ²	0.766	0.778	0.809	0.825	0.737	0.744
Observations	216809	216809	57457	57457	6306	6306

Standard errors in parentheses, clustered at mint cell × empire and hoard cell level.

+ $p < 0.10$, * $p < 0.05$, ** $p < 0.01$

Estimating eqn: count_{mdh} = exp ($\gamma_1 \log \text{distance}_{mh} + \gamma_2 \text{withinBorder}_{dh} + \alpha_{md} + \alpha_h + \varepsilon_{mhd}$)

Fact #2: distance has a weaker impact on older coin flows

$\text{logcount}_{mth\tau} =$

$$\sum_{\tau' \in T} \beta_{\tau'} \log \text{distance}_{mh} \times 1(t - \tau = \tau')$$

$$+ \alpha_{mt} + \alpha_{h\tau} + \varepsilon_{mth\tau}$$

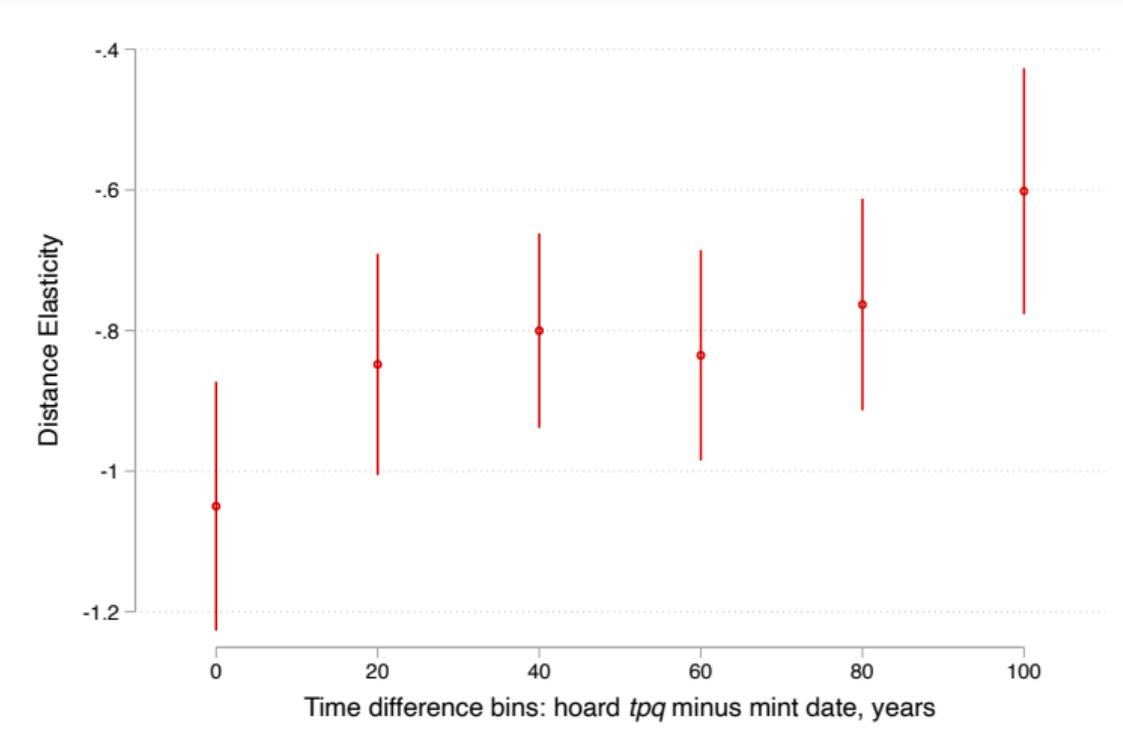


Figure 4: The distance elasticity declines as coins get older

Fact #3: Arab conquests disrupt Mediterranean trade

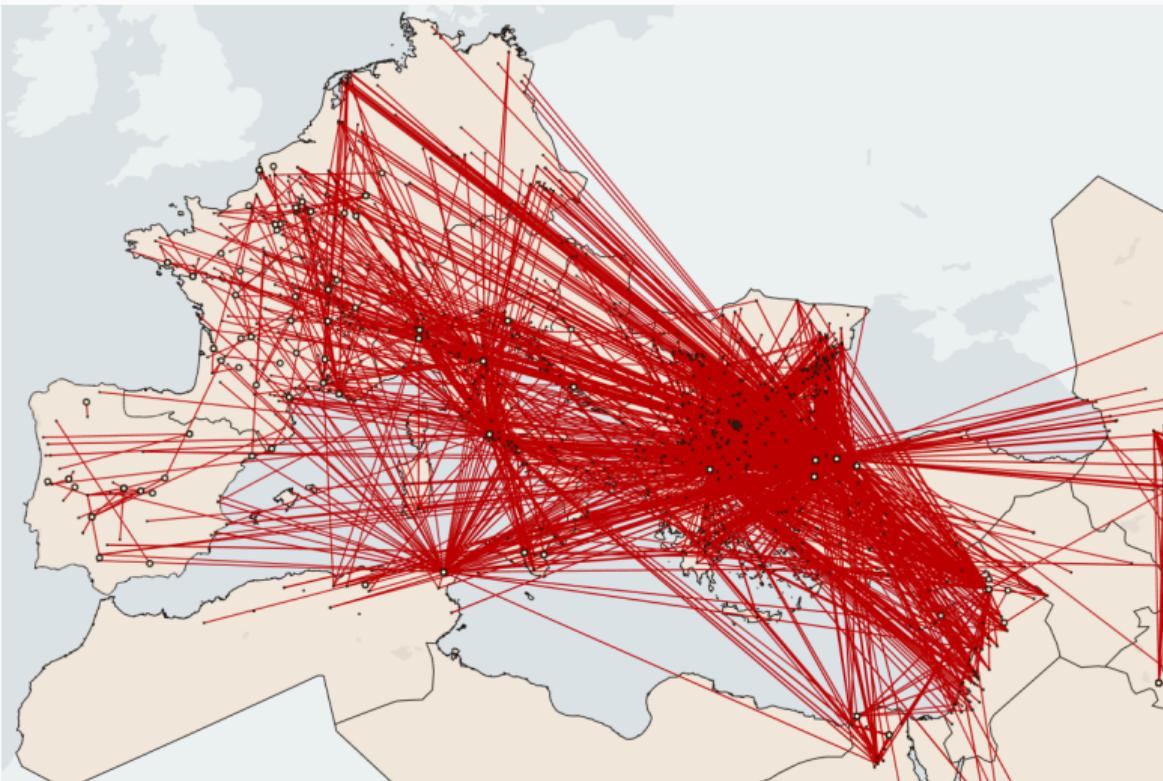


Figure 5: Before the Arab conquests: 450-630 AD

Fact #3: Arab conquests disrupt Mediterranean trade

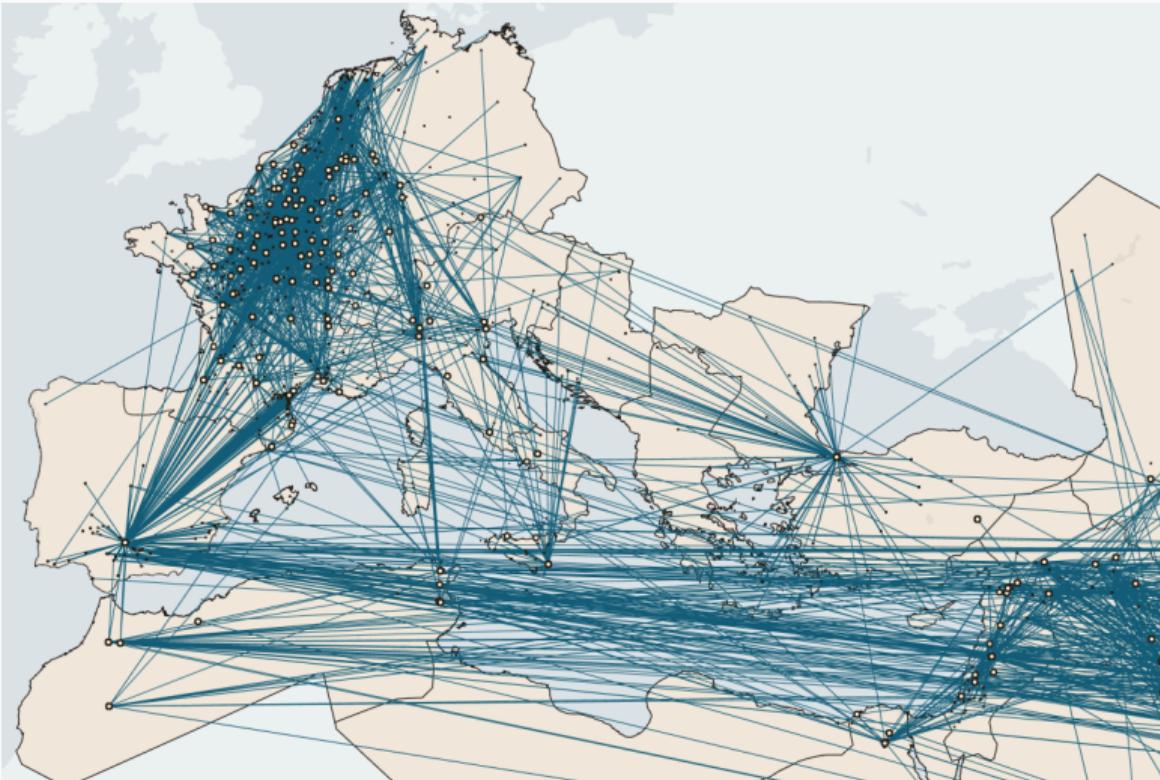


Figure 6: After the Arab conquests: 713-900 AD

Fact #3: Arab conquests disrupt Mediterranean trade

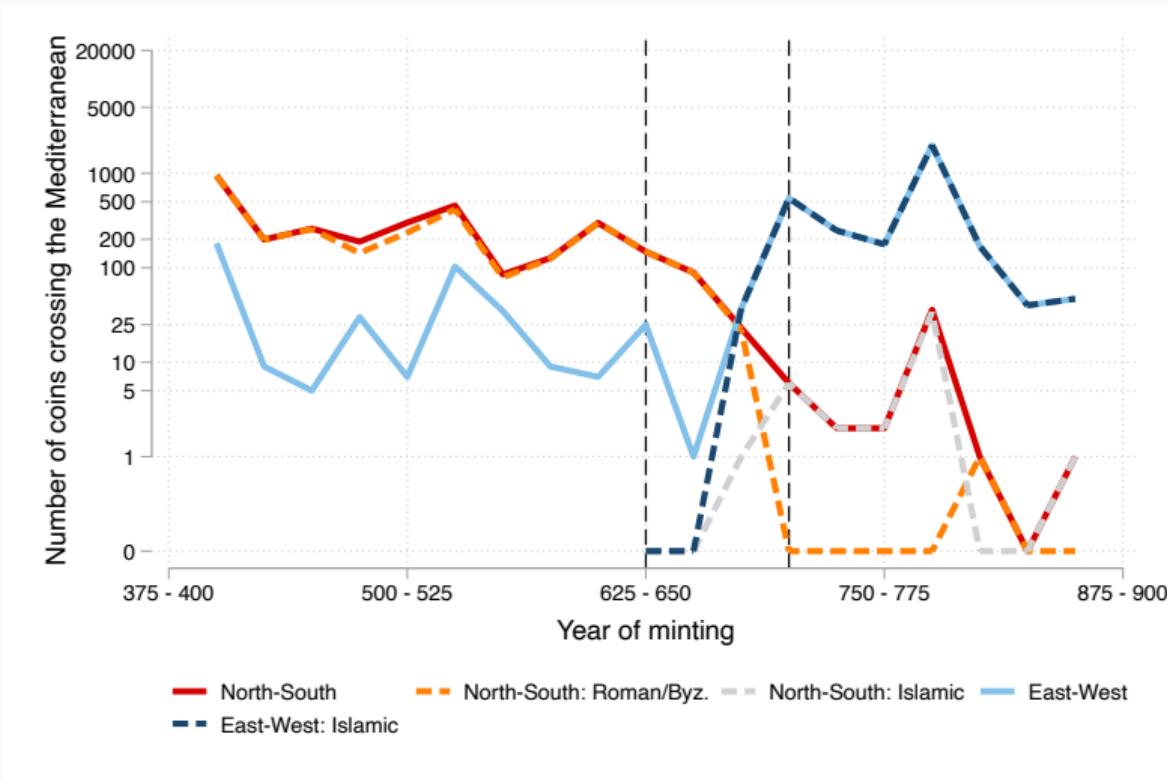


Figure 7: Number of coins flowing across the Mediterranean

Fact #3: Arab conquests disrupt Mediterranean trade

Table 3: The Mediterranean Before and After the Arab Conquest

	Dependent variable: Number of Coins			
	(1)	(2)	(3)	(4)
Crossing Mediterranean × After Conquests	-1.774** (0.46)	-3.141** (0.53)	-0.712 (0.66)	-1.751 (1.24)
Crossing Mediterranean × After Conquests × Islamic Coin		7.171** (0.91)	4.835** (0.97)	8.382** (1.15)
Crossing Mediterranean × After Conquests × Roman Coin			-3.108** (0.79)	-2.976** (0.71)
Mint Cell × Empire FE	Yes	Yes	Yes	Yes
Mint Cell × Hoard Cell FE	Yes	Yes	Yes	Yes
After Conquests FE	Yes	Yes	Yes	
Mint Cell × After Conquests FE				Yes
Hoard Cell × After Conquests FE				Yes
Estimator	PPML	PPML	PPML	PPML
Observations	10350	10350	10350	6023

Standard errors in parentheses, clustered at the hoard × era and mint × era level.

+ $p < 0.10$, * $p < 0.05$, ** $p < 0.01$

Estimating eqn: $\text{count}_{mdht} = \exp(\gamma_1 \text{mediterranean}_{mh} \times \text{after}_t + \dots + \alpha_{md} + \alpha_{mh} + \varepsilon_{mhdt})$

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Model

Parameterization and Estimation

Model

Objective:

Quantify impact of trade barriers (and other changes) on market access / trade / welfare

Approach:

Dynamic model of trade flows (gravity), where coins diffuse alongside trade and are thus informative about trade flows.

Key Assumption:

Traders are blind to coin types (mint location and date).

- ⇒ Coins diffuse in proportion to trade flows
- ⇒ Recover trade flows from stocks of coin types in hords in different locations/time periods.

Not used/needed for identification: total *quantities* of coins found

Setup

Location n , period t : homog. mass $L_n(t)$ of workers. Four sub-periods $t_{sub1}, t_{sub2}, t_{sub3}, t_{sub4}$

t_{sub1} Start with $S_n(t)$ coins saved from period $t - 1$

t_{sub2} A fraction $\lambda_n(t)$ of those saved coins is lost

$M_n(t) \geq 0$ fresh new coins are minted

t_{sub3} $X_n(t)$, expenditure on consumption

Budget constraint:

$$X_n(t) \leq (1 - \lambda_n(t)) S_n(t) + M_n(t)$$

t_{sub4} $L_n(t)$ workers produce and sell goods in exchange for coins

$w_n(t)$, competitive wage, $w_n(t)L_n(t)$, aggregate labor income

$S_n(t+1)$ coins saved for $t + 1$

$$\underbrace{(1 - \lambda_n(t)) \overbrace{S_n(t)}^{t_{sub1}} + M_n(t)}_{t_{sub2}} - \underbrace{X_n(t)}_{t_{sub3}} + \underbrace{w_n(t) L_n(t)}_{t_{sub4}} = \underbrace{S_n(t+1)}_{(t+1)_{sub1}}$$

Intra-temporal allocations

- Fraction π_{ni} of expenditure X_n allocated to goods from i :

$$\pi_{ni}(t) = \frac{T_i(t)(w_i(t)d_{ni}(t))^{-\theta}}{\sum_k T_k(t)(w_k(t)d_{nk}(t))^{-\theta}}, \quad (1)$$

as in Eaton and Kortum (2002).

Intertemporal preferences

- Intertemporal utility U_n , within period welfare W_n ,

$$U_n(t) = \mathbb{E} \left[\sum_{\tau \geq t} \beta^{\tau-t} \ln \left(\frac{x_n(\tau)}{p_n(\tau)} \right) \right],$$

$$\text{with } p_n(t) = \gamma \left(\sum_k T_k(t) (w_k(t) d_{nk}(t))^{-\theta} \right)^{1/\theta}$$

Dynamic optimization

- Optimal coin savings dynamics,

$$\max_{\{S_n(\tau)\}_{\tau \geq t}} \left[\sum_{\tau \geq t} \beta^{\tau-t} \ln \left(\frac{X_n(\tau)}{p_n(\tau)} \right) \right]$$

$$X_n(\tau) = w_n(\tau)L_n(\tau) + M_n(\tau) + (1 - \lambda_n(\tau))S_n(\tau) - S_n(\tau+1),$$

$$S_n(\tau+1) \geq w_n(\tau)L_n(\tau), \forall \tau \geq t,$$

$$\lim_{\tau \rightarrow \infty} \beta^\tau S_n(\tau+1)/X_n(\tau) = 0$$

- Dynamic equilibrium wages clear markets,

$$w'_i L'_i = \sum_n \pi_{ni}(T, d; w) [w_n L_n + M_n + (1 - \lambda_n) S_n - S'_n]$$

Savings $S_n(T, d, \delta, L, M; w)$ depend on parameters and wages, which depend on wages etc.

Optimal consumption/saving

Under log utility:

- price level $p_n(t)$ dynamics irrelevant (i.e. separates out)
- when unconstrained, consumption declines exponentially:

$$\frac{X_n(t+1)}{X_n(t)} = \beta(1 - \lambda_n(t)) < 1$$

- when constrained, consume as much as you can:

$$S'_n = w_n(t)L_n$$

Define *net saving*:

$$s_n(t) = \frac{(1 - \lambda_n(t))S_n(t) + M_n(t) - X_n(t)}{(1 - \lambda_n(t))S_n(t) + M_n(t)}$$

Steady state: zero net savings, $S_n(t+1) = S_n(t), \forall t$

- No motive for extra savings, $S_n = w_n L_n$. Hence $s_n(t) = 0$.
- Wages and trade shares jointly determined,

$$w_i L_i = \sum_n \pi_{ni} ((1 - \lambda_n) w_n L_n + M_n)$$
$$\pi_{ni} = \frac{T_i (w_i d_{ni})^{-\theta}}{\sum_k T_k (w_k d_{nk})^{-\theta}}$$

- Constant aggregate stock of coins in circulation,

$$\sum_n M_n = \lambda_n \sum_n w_n L_n$$

- Note: trade deficits as in Dekle, Eaton and Kortum (2007),

$$D_n = X_n - Y_n = M_n - \lambda_n S_n$$

Introducing and tracking coins of different vintages

Coin stocks $S_n(\tau)$ consist of coins of different vintage:

$$S_n(\tau) = \sum_{m=1}^N \sum_{t < \tau} S_{mn}(t, \tau)$$

Coin stocks start their life when minted: $S_{mm}(t, t) = M_m(t)$.

Traders are ‘blind’ to coin types, draw coins with equal probability:

$$S_{mi}(t, \tau + 1) = \sum_{n=1}^N (1 - \lambda_n(\tau)) (1 - s_n(\tau)) S_{mn}(t, \tau) \pi_{ni}(\tau) + (1 - \lambda_i(\tau)) s_i(\tau) S_{mi}(t, \tau), \forall \tau \geq t$$

In compact matrix form:

$$\mathbf{S}(t, T) = \mathbf{M}(t) \left(\prod_{\tau=t}^{T-1} (\mathbf{I} - \boldsymbol{\lambda}(\tau)) \left((\mathbf{I} - \mathbf{s}(\tau)) \boldsymbol{\Pi}(\tau) + \mathbf{s}(\tau) \right) \right)$$

Pitfall #1: medium of exchange vs store of value

- Dynamics with ‘saving-augmented’ trade shares,

$$S(t, T) = M(t) \left(\prod_{\tau=t}^{T-1} (I - \lambda(\tau)) \tilde{\Pi}(\tau) \right)$$

- Separate origin, destination, and bilateral terms,

$$\tilde{\pi}_{ni}(\tau) = \alpha_n(\tau) \beta_i(\tau) \delta_{ni}(\tau)$$

$$\alpha_n = \frac{1}{\sum_k T_k (w_k d_{nk})^{-\theta}}, \quad \beta_i = T_i (w_i)^{-\theta}$$

$$\delta_{ni} = (d_{ni})^{-\theta}$$

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$$\alpha_n = \frac{1}{\sum_k T_k (w_k d_{nk})^{-\theta}}, \quad \beta_i = T_i (w_i)^{-\theta}$$

$$\delta_{ni} = (d_{ni})^{-\theta} \times \begin{cases} (1 - s_n) & \text{if } n \neq i \\ (1 - s_n) + \frac{s_n \sum_k T_k (w_k d_{nk})^{-\theta}}{T_n (w_n d_{nn})^{-\theta}} & \text{if } n = i. \end{cases}$$

- $\frac{\delta_{nj}}{\delta_{ni}} = \frac{(d_{nj})^{-\theta}}{(d_{ni})^{-\theta}}, \forall n \neq i, j, \forall s_n \geq 0$: no impact on external trade

- $\frac{\delta_{nn}}{\delta_{ni}} > \frac{(d_{nn})^{-\theta}}{(d_{ni})^{-\theta}}, \forall s_n > 0$: net saving mimics home bias in trade!

Pitfall #2: stocks vs flows (steady state math)

- SS: no net saving ($s = 0$), only age (a) matters, not time (t),

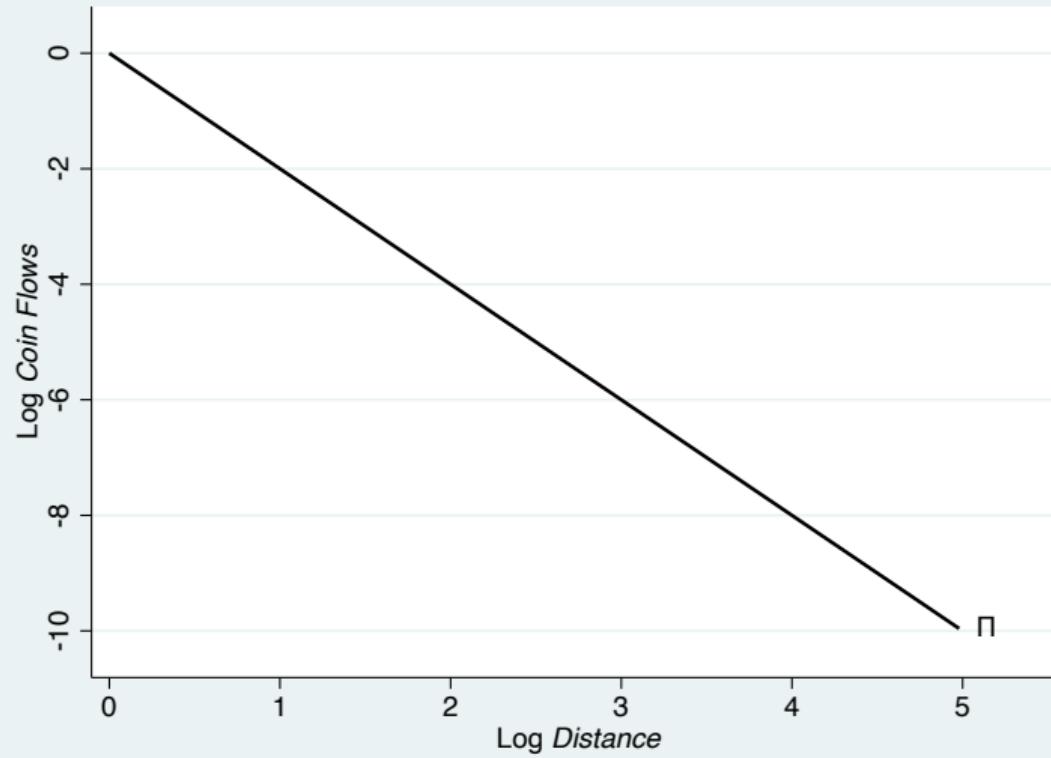
$$S(t, t+a) = S(a) = M \left((I - \lambda) \Pi \right)^a, \forall t$$

- Sum of different vintages (stocks by origin-destination),

$$\sum_{a=0}^A S(a) = M \left(\sum_{a=0}^A \left((I - \lambda) \Pi \right)^a \right) \underset{A \rightarrow +\infty}{=} M (I - (I - \lambda) \Pi)^{-1}$$

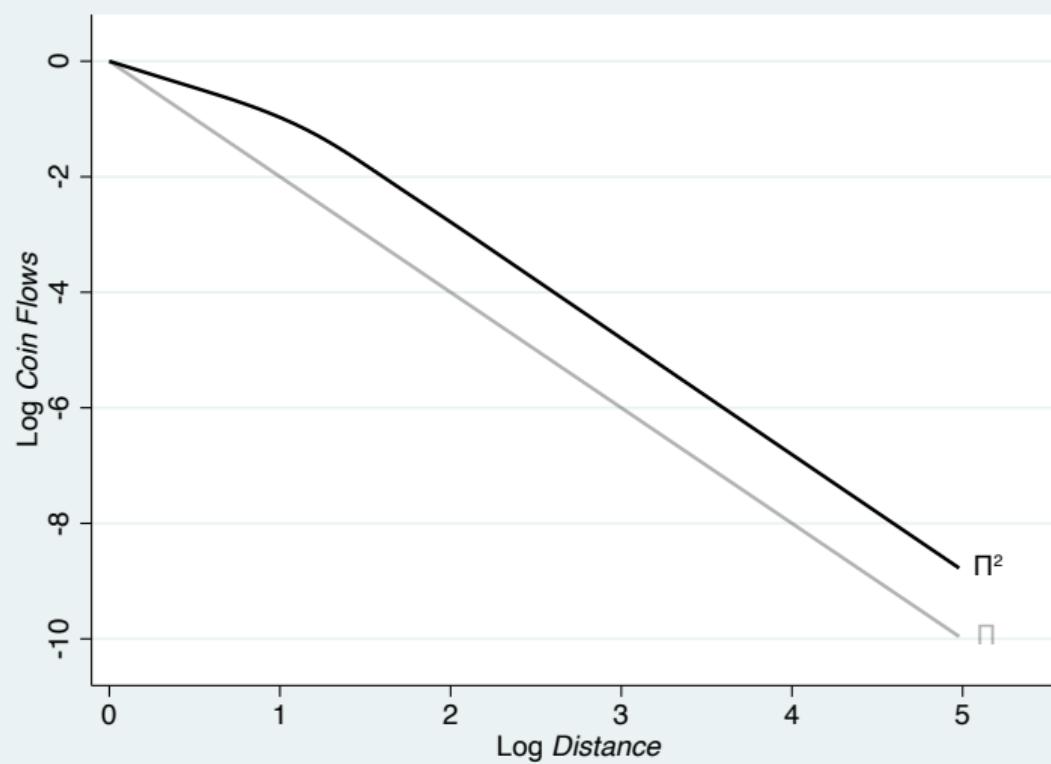
- Naive gravity on stocks gives Leontief inverse of trade shares!
⇒ inconsistent estimates of trade elasticities/border effects due to model misspecification

Pitfall #2: stocks vs flows (numerical example)



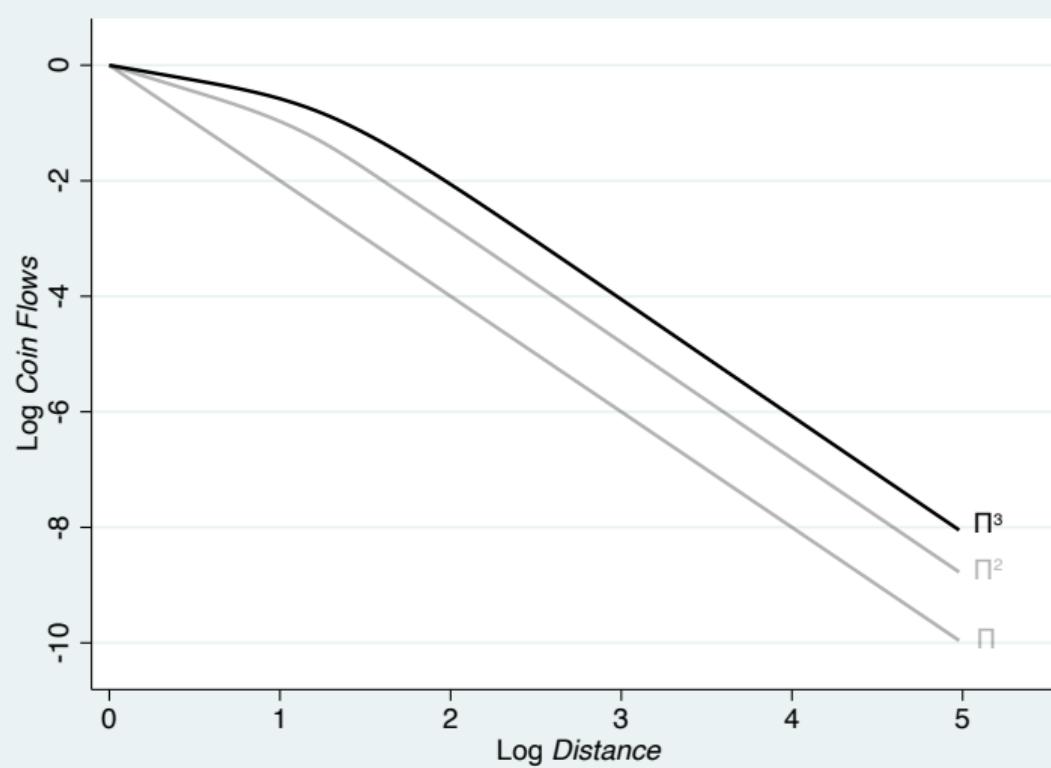
- Flow of coins: age 1 (same as trade flows Π)

Pitfall #2: stocks vs flows (numerical example)



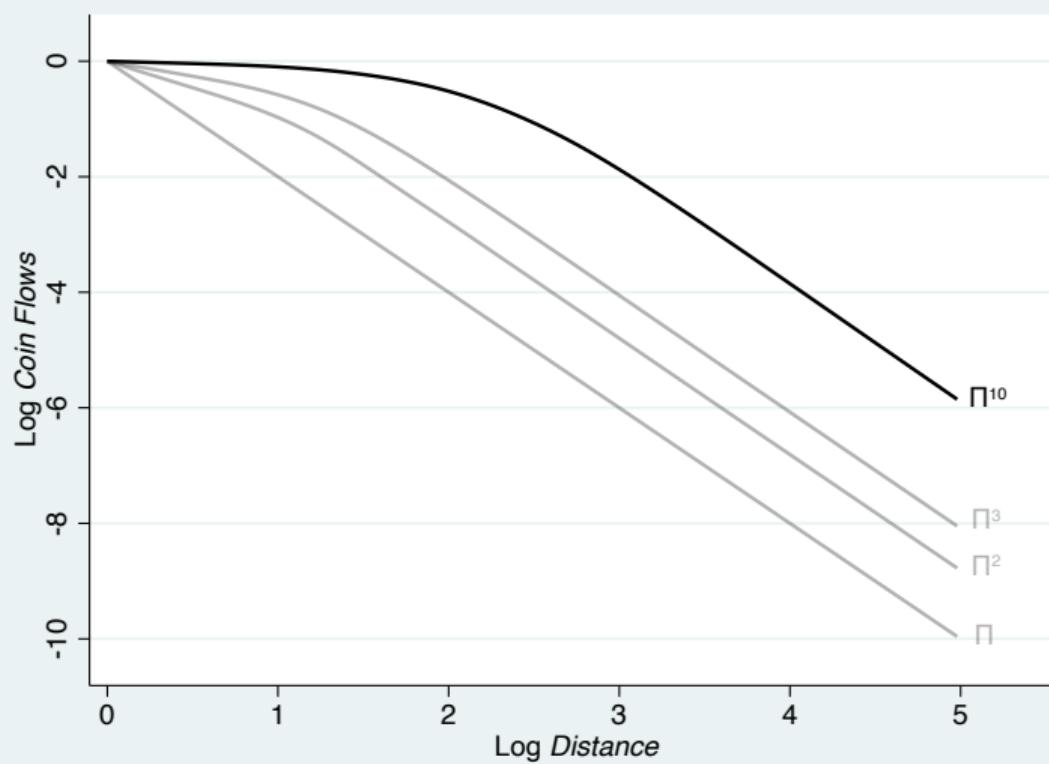
- Flow of coins: age 1, age 2

Pitfall #2: stocks vs flows (numerical example)



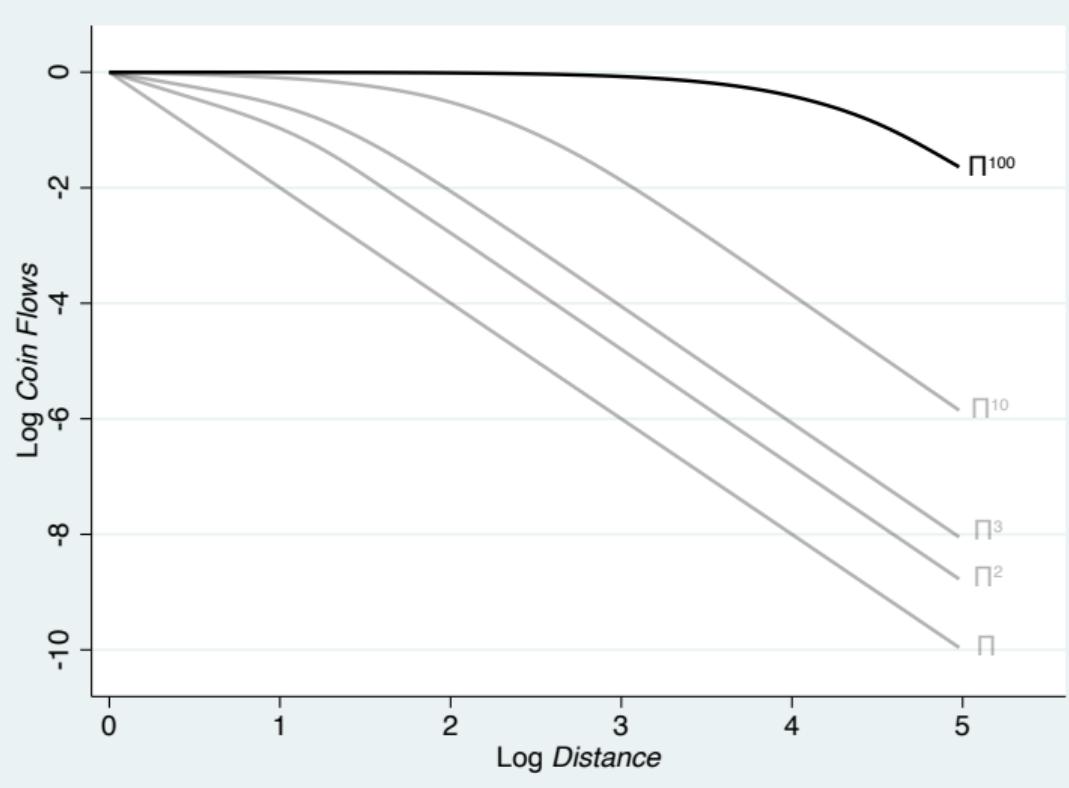
- Flow of coins: age 1, age 2, age 3

Pitfall #2: stocks vs flows (numerical example)



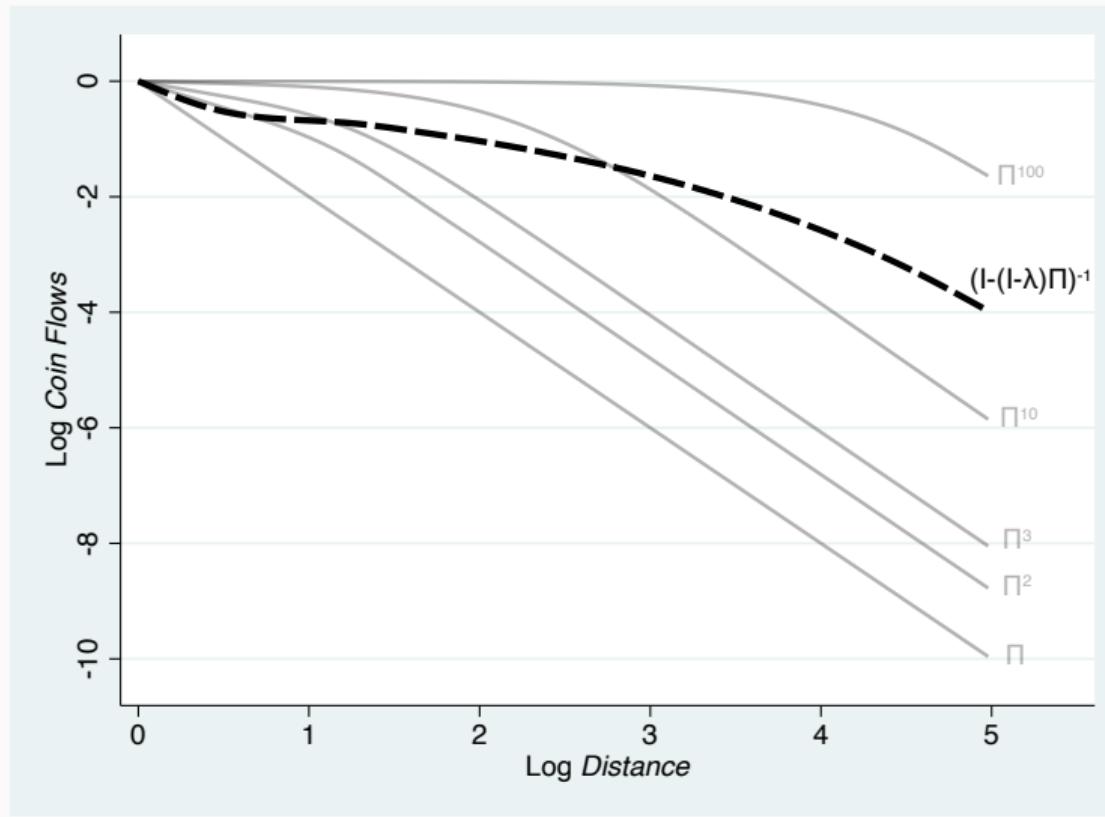
- Flow of coins: age 1, age 2, age 3, age 10

Pitfall #2: stocks vs flows (numerical example)



- Flow of coins: age 1, age 2, age 3, age 10, age 100

Pitfall #2: stocks vs flows (numerical example)



- Flow of coins: age 1, age 2, age 3, age 10, age 100, all ages

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Data generating process

- In n at t , a fraction $\eta_n(t)$ of the coins in circulation $S_n(t)$ is lost and subsequently found by archaeologists

Assumption: η small enough, does not affect model choices.

⇒ For coin shares within a hoard, the η 's cancel out. $\eta_n(t)$ not used in our identification!

Taking the model to the data

- 21 regions around the Mediterranean ▶ details
- 20-year time intervals
- Assume constant λ and estimate as exponential decay parameter in within-hoard age distribution:

$$\hat{\lambda}_{20y} = 0.3$$

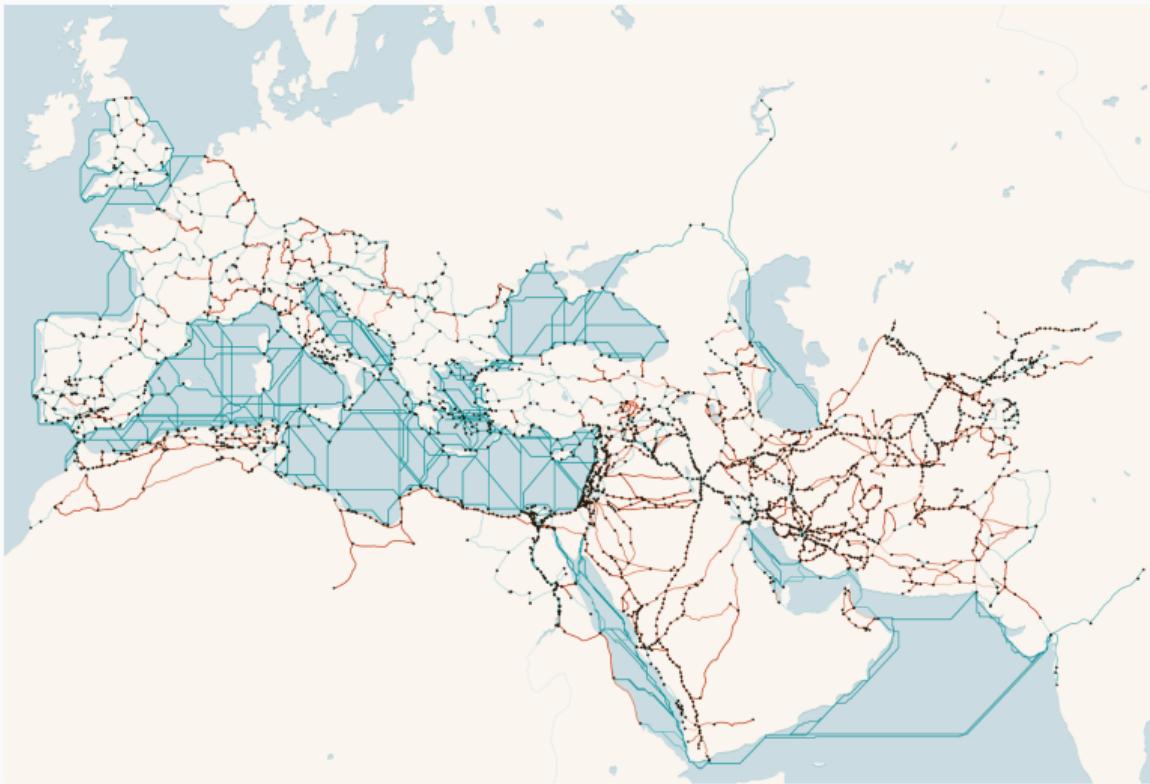
- Parameterize trade frictions,

$$d_{ni}(t)^\theta = \exp(\gamma_0 + \zeta \ln(\text{TravelTime}_{ni}) + \kappa_1 \text{PoliticalBorder}_{ni}(t) + \kappa_2 \text{ReligiousBorder}_{ni}(t))$$

if $n \neq i$ and $d_{nn}(t) = 1$.

- How to split domestic trade vs saving? Calibrate $\bar{s}_n(t) = 1.5\%$ (Scheidel, 2020).
- For counterfactuals, assume $\theta = 4$ (Simonovska and Waugh, 2014).

Trade costs *only* depend on travel times (and politics/religion)



Note: Combined geospatial models from Orbis (Scheidel, 2015) and al-Turayyā (Romanov and Seydi, 2022).

al-Maqdisi

Maximum likelihood estimation

Assume coins in our data are a random sample of coin types in each location \times time.

- Multinomial distribution of coin types,

$$P(\dots, X_i^{(m,\tau)}(T) = x_i^{(m,\tau)}, \dots) = \frac{N_i(T)!}{\prod_{(m,\tau)} x_i^{(m,\tau)}!} \prod_{(m,\tau)} [p_i^{(m,\tau)}(T)]^{x_i^{(m,\tau)}}$$

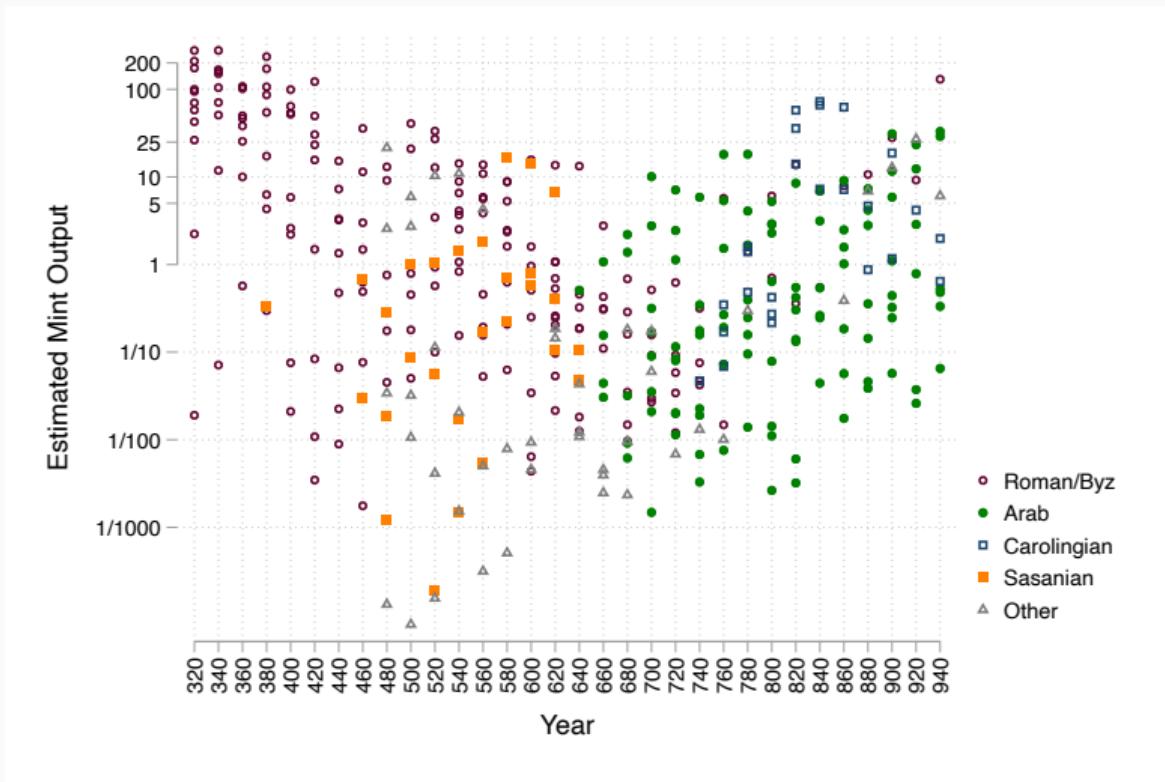
with the probability of drawing a coin of type (m, τ) ,

$$p_i^{(m,\tau)}(T) = \frac{S_i^{(m,\tau)}(T)}{\sum_{(m',\tau')} S_i^{(m',\tau')}(T)} = \frac{S_i^{(m,\tau)}(T)}{S_i(T)}.$$

- Likelihood of observing a sample of coins given parameters θ ,

$$\ell(X; \theta) = \sum_i \sum_T \sum_{(m,\tau)} x_i^{(m,\tau)} [\log S_i^{(m,\tau)}(T; \theta) - \log S_i(T; \theta)] + \text{constant}$$

Estimation results: Mint output



Estimation results: Determinants of trade costs

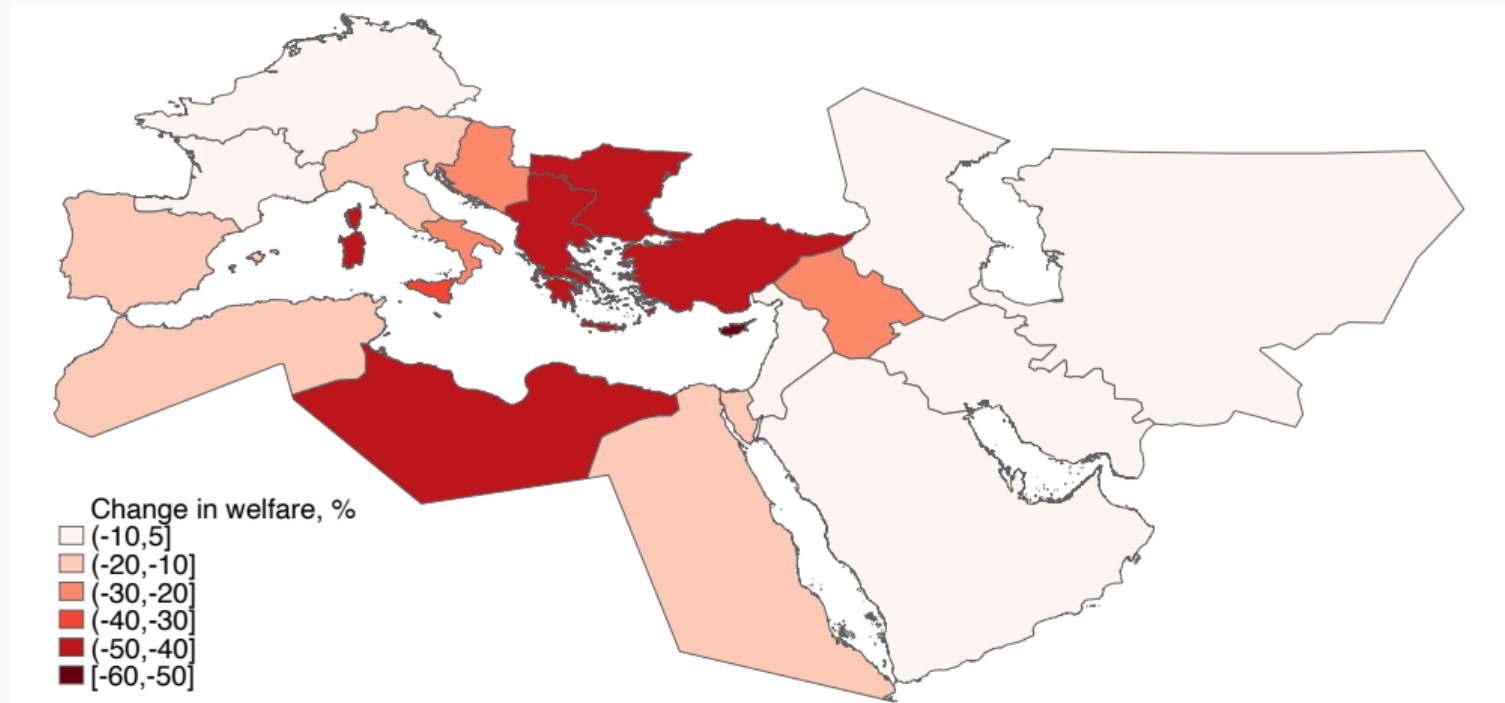
$$\ln((d_{ni}(t))^{-\theta}) = \text{constant} - 2.12 \underset{(0.08)}{\ln(\text{TravelTime}_{ni})} - 2.33 \underset{(0.52)}{\ln(\text{PoliticalBorder}_{ni}(t))} - 1.37 \underset{(5.30)}{\ln(\text{ReligiousBorder}_{ni}(t))}. \quad (2)$$

Holding fixed multilateral resistance term:

- removing a political border would increase a bilateral trade share by $\exp(2.33) - 1 \approx 928\%$
- removing a religious border would increase the same trade share by $\exp(1.37) - 1 \approx 294\%$

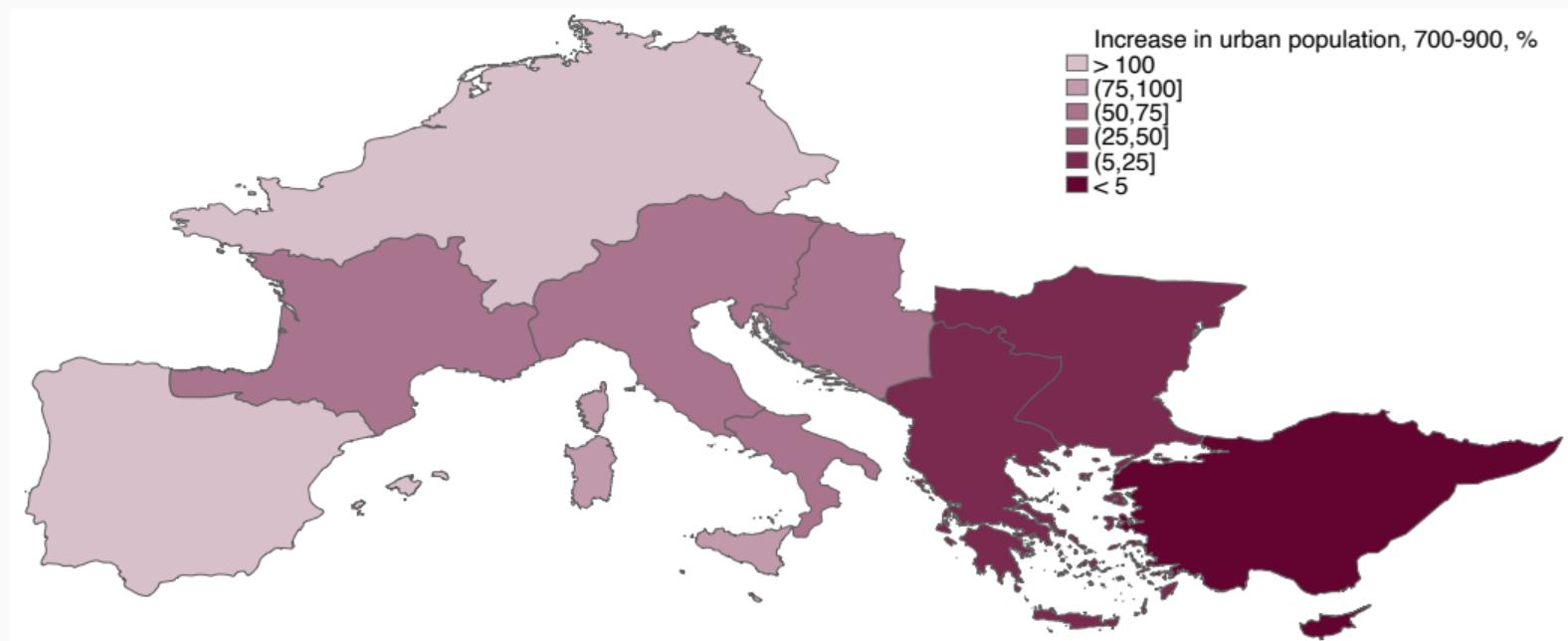
Changing pre-conquest trade costs to post-conquest: $(d_{ni}^{-\theta})^{pre} \rightarrow (d_{ni}^{-\theta})^{post}$

Holding fixed technology T_i , wages w_i , and mint output M_i at pre-conquest levels, and assume $\theta = 4$.



Compare to relative urbanization rates, 700–900 AD

Change in total urban population (urban: > 1k inhabitants), data from Buringh (2021)



Taking stock

- Clear pattern of change in economic geography before vs after conquest
- Trade disruption can account for the relative decline in the eastern Mediterranean
- Change in trade cost *alone* not able to account for urbanization in Muslim Spain, or in Carolingian empire
- Potentially in conjunction with changes in technology T_i (\rightarrow Spain) or mint output (\rightarrow Carolingian empire).

Conclusion

“Simply looking at the Mediterranean cannot of course explain everything about a complicated past created by human agents, with varying doses of calculation, caprice and misadventure. But this is a sea that patiently recreates for us scenes from the past, breathing new life into them, locating them under a sky and in a landscape that we can see with our own eyes, a landscape and sky like those of long ago. A moment’s concentration or daydreaming, and that past comes back to life.”

Fernand Braudel, Les Mémoires de la Méditerranée

THANK YOU!

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BACKUP SLIDES

References

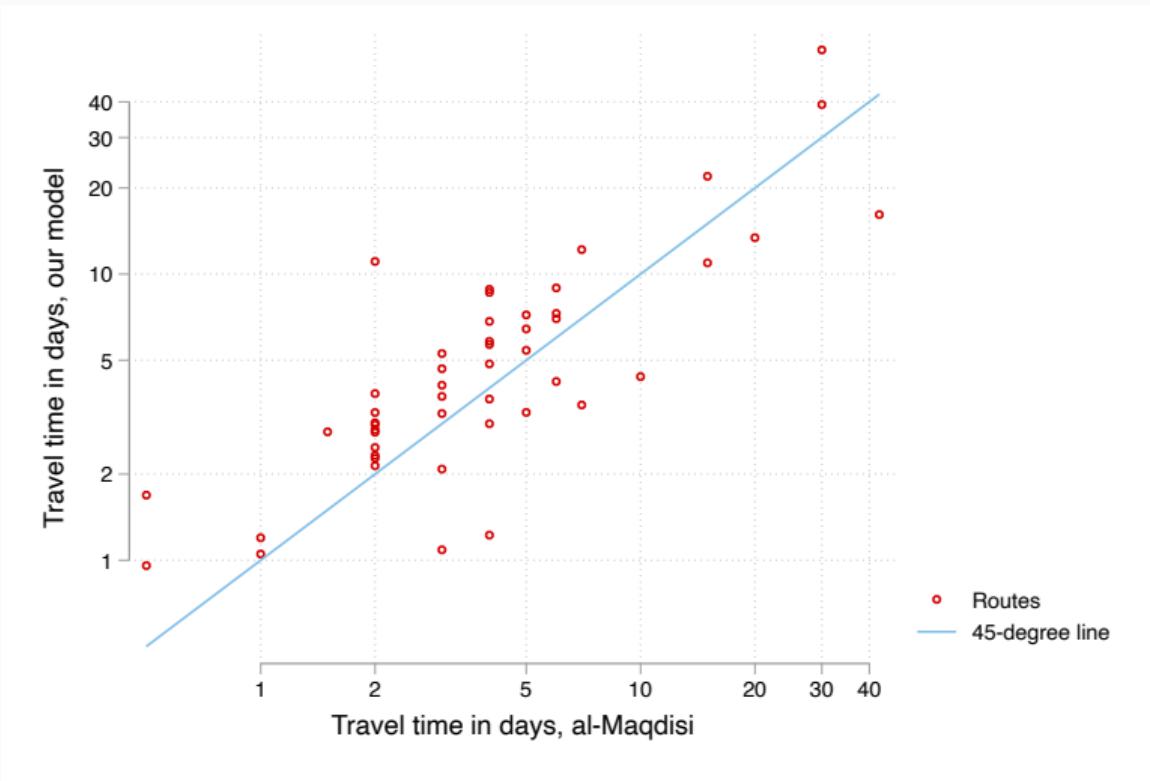
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Regions



Validating Travel Times

Al-Maqdisi (c. 945–991): *The Best Divisions for Knowledge of the Regions*



Unsolved problems (as of yet)

- Lucas critique #1: cost function does not minimize costs

$$\ln(\delta_{ni}(t)) = \min_{p \in paths(i \rightarrow n)} \left(\gamma_0 + \gamma_1 \ln(TravelTime_p(t)) + \sum_{pb: \text{ all political borders along } p} \gamma_2 PoliticalBorder_{pb}(t) + \sum_{rb: \text{ all religious borders along } p} \gamma_3 ReligiousBorder_{rb}(t) \right)$$

- Lucas critique #2: net saving (in δ_{nn}) depends on parameters.
- Fix for #2: location-specific intercepts ($\gamma_{0,n}$) and δ_{nn} 's.

For now: constant γ_0 , and $\delta_{nn} = 1$...

Fact #3: Arab conquests disrupt Mediterranean trade: Gold only

	Dependent variable: Number of Coins				
	(1)	(2)	(3)	(4)	(5)
Log Distance	-1.484** (0.13)	-1.512** (0.12)	-1.517** (0.12)	-1.159** (0.15)	-1.163** (0.16)
Crossing Mediterranean	0.157 (0.38)	0.172 (0.38)	0.187 (0.37)	-0.126 (0.29)	-0.114 (0.29)
Crossing Mediterranean × After Conquests	-1.565* (0.70)	-2.887** (0.73)	-1.701* (0.70)	-2.273* (0.98)	-3.067** (1.14)
Crossing Mediterranean × After Conquests × Islamic Coin		3.112** (0.77)	1.907* (0.77)		2.865* (1.24)
Crossing Mediterranean × After Conquests × Roman Coin			-1.766 (1.13)		
Mint Cell × Empire FE	Yes	Yes	Yes	Yes	Yes
Hoard Cell × After Conquests FE	Yes	Yes	Yes	Yes	Yes
Sample				Gold only	Gold only
Observations	167840	167840	167840	28895	28895

Standard errors in parentheses, clustered at the hoard × era and mint × era level.

+ $p < 0.10$, * $p < 0.05$, ** $p < 0.01$

Before: 400–630; after: 713–950