Labour Scarcity and Productivity: Insights from the Last Nordic Plague

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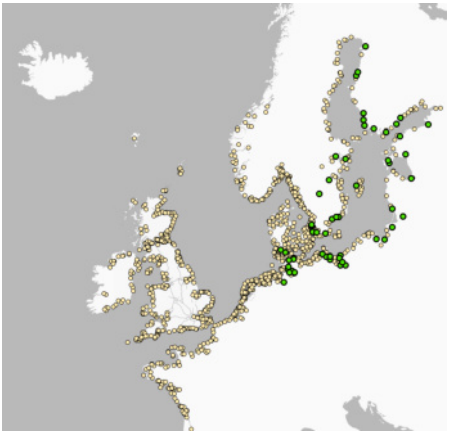
Research Question

- What determines long-run growth rates?
- Understanding productivity growth is key.
  - Labour scarcity may trigger growth by spurring productivity-enhancing innovation.
  - However, in current debates, it is considered an obstacle to growth.
- I provide empirical evidence supporting the prior by exploiting a natural experiment.
- Using a 1710s plague outbreak as an exogenous shock and port-level data, I find:
  - The share of capital-intensive exports rises by 10pp (pre-plague mean: 6.6%).
  - Destination market shares rise by 1pp (pre-plague mean: 0.9%).
  - In a Ricardian model, I trace this shift to productivity growth driven by capital deepening.
  - I find long-run changes in comparative advantages beyond population recovery.

Literature & Contributions

- Labour Scarcity & Productivity:
  - Habakkuk, 1962, Allen, 2009, Acemoglu, 2010, Voth, Caprettini, and Trew, 2024
  - **Contribution:** Exogenous mortality shock instead of endogenous migration or fertility; first open economy version of Habakkuk thesis.
- Path Dependence in Comparative Advantages:
  - Krugman, 1987, Juhász, 2018, Allen and Donaldson, 2020
  - **Contribution:** I provide evidence from an exogenous shock instead of endogenous policies.
- Recovery after Shocks:
  - Davis and Weinstein, 2002, Jedwab, Johnson, and Koyama, 2024
  - **Contribution:** This paper stresses active adaptation instead of mechanical forces.
- Economic Effects of the Plague:
  - Voigtländer and Voth, 2012, Alfani and Murphy, 2017, Dittmar and Meisenzahl, 2019,
  - **Contribution:** Most granular analysis of post-plague trade, including non-homotheticity.

The Great Northern War Plague Outbreak (1708-1712)



- Sweden (incl. parts of Northern Germany and Baltics) fought Russia (1700-1721). Armies spread plague. Army Movements
- 55 plagued regions. Pop. recovery by 1750.
- Danish toll data. 594 regions trading in 227 goods, 1668-1857. Sources Top 30 Goods
- Mortality comparable to 14th c. Black Death (36% vs 40%). Most trading partners unaffected.

Labour Scarcity & Trade

- Two potential adjustments to labour scarcity:
  - *within* sectors: K/L ↑ if factor prices not equalised; unobserved.
  - *across* sectors: observable shift into capital-intensive goods.
    - ⋆ Capital-intensive: pastoral farming; metal works and ship building.
    - ⋆ Labour-intensive: arable farming; textiles. Goods & Sectors
- Identification concerns: plague endogenous to trade or urban growth?
  - Spread not by traders but by armies.
  - To-be-plagued cities do not differ in population and trade volumes & composition.
  - Event studies on trade show almost no significant pre-trends at any margin.

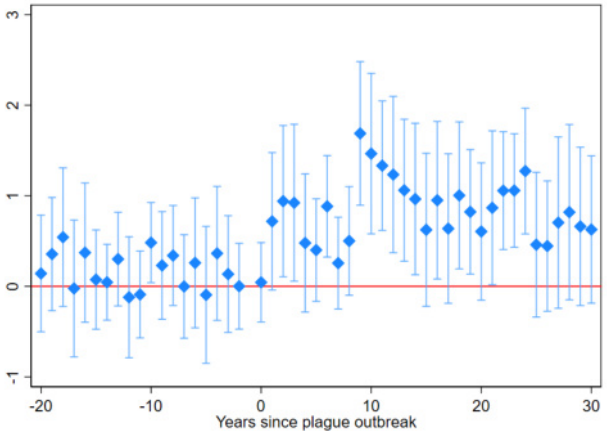
Event Study for Export Composition

- The first event study estimates the plague's effects on exports:

$$T_{ikt} = \alpha_{ik} + \alpha_{kt} + \sum_{l=-20\setminus -1}^{30} \beta_l^f \cdot \mathbb{1}(K_{it} = l) + \gamma_f x_{it} + \epsilon_{ikt}, \tag{1}$$

- where i are origin ports, k is one of 5 sectors, f is factor intensity (capital- or labour-intensive), and t are years. T_{ikt} are (log) exports.
- α_{ik} are origin-sector f.e., α_{kt} sector-time f.e., K_{it} is the time difference to the plague shock, x_{it} are annual growing season temperatures.
- The following figure shows the difference between β_l^C and β_l^L. Throughout, standard errors clustered at the origin-level.

Fact #1: Capital-intensive exports increase more than labour-int. exports



Notes: Alternative Assignment | DiDiD | Armies & Sieges | By good | Sectoral | Borusyak | Long run

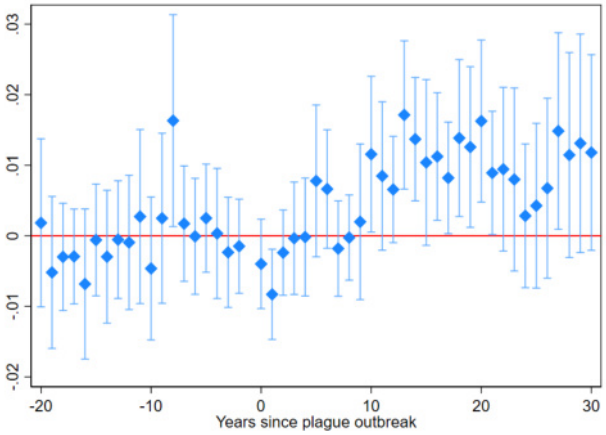
Event Study for Trade Flows

- The second event study estimates the plague's effect on bilateral trade:

$$T_{ijt} = \alpha_{ij} + \alpha_{jt} + \alpha_{at} + \sum_{l=-20\setminus -1}^{30} \beta_l \cdot \mathbb{1}(K_{it} = l) + \gamma x_{it} + \epsilon_{ijt}, \tag{2}$$

- where α_{ij} are pair f.e., α_{jt} are destination-time f.e., K_{it} is the time difference to the plague shock, and x_{it} are geographic controls.
- α_{at}: area-time f.e., e.g. states of Germany and voivodeships of Poland.
- T_{ijt}: i's market share in j (or export volume to j).

Fact #2: Plagued regions capture larger shares of destination markets



Notes: Volume | By good | Sectoral | Factor | 30 year pre-period | Borusyak | Long run

Further Results & Robustness

- Export Variety: Extensive margin ↑; Innovation: New exports ↑
- Effect heterogeneity: stronger for larger exporters, but significant even for smallest. Interaction with siege never significant.
- Evidence against mechanical explanations: local demand drop & export reallocation.
- Robustness: Borusyak, Jaravel, and Spiess, 2021, Chaisemartin and D'Haultfoeuille, 2022, sectoral gravity, indirect effects of plague across Europe.
- Example: Karlskrona

Overview of Ricardian Model

- Labour L_{ik}, mobile across sectors but immobile across regions; capital K_{ik} and investment capital I_{ik}, perfectly mobile. I assume that land was abundant in the Baltics.
- Productivity (TFP) is drawn for each (i, k, ω) from a Fréchet distribution:

$$F_{i,k}(z) = 1 - exp(-A_{i,k} z^{-\theta}), \tag{3}$$

- where $A_{i,k}$ is fundamental productivity and θ reflects intra-industry heterogeneity.

Sectors & Spatial Separation

Production Function | Serfdom

		Labour-intensive		Capital-intensive
Region	City	Labour-int. manufacturing (LM)	$\eta_{LM} < \eta_{CM}$	Capital-int. manufacturing (CM)
	Hinterland	Labour-int. agriculture (LA)	$\eta_{LA} < \eta_{CA}$	Capital-int. agriculture (CA)

Notes: η_k denotes the capital share in each sector k.

- Trade costs; policies (Magnusson, 2007); institutions (Klein and Ogilvie, 2015).
- Reference sector: unclassified goods (U).

Trade & Productivity

Preferences | Prices | Market Access | Wages

- Trade follows the gravity form:

$$X_{ijk} = \frac{\chi_k A_{ik} (w_{ik})^{-\gamma_k \theta} d_{ijk}^{-\theta}}{CMA_{jk}} \alpha_k Y_j. \tag{4}$$

- I estimate on a balanced panel using PPML:

$$X_{ijkt} = exp(\alpha + \delta_{ijt} + \delta_{jkt} + \delta_{ikt}) \times \epsilon_{ijkt}, \tag{5}$$

- where δ are fixed effects and ϵ_{ijkt} is the error term. Recover δ_{ikt}. Details
- I correct for climate warming at the end of the Little Ice Age.

Overview of Mechanism

- Within this model, I suggest a three step mechanism:
  - Step #1: The plague induces labour scarcity
  - Step #2: Production becomes more capital-intensive Skip
  - Step #3: Productivity grows more in high β_k sectors Skip
- I provide empirical evidence from trade and other data supporting each step. I also discuss serfdom as a historical factor mobility friction.
- Finally, I present evidence against alternative mechanisms: directed technical change, venting out, market power, and non-homotheticity.

Investment-led Productivity Growth FOCs

- I view A_{ik} as fundamentals of the model and project them on observables (Chor, 2010).
- General form: $A_{ik} = g\left(\left(\frac{I_{ik}}{L_{ik}}\right)^{\beta_k}, H_{ik}, x_i, x_k, x_{ik}\right)$. Focus on *ikt* by including fixed effects.
- In the long run, past shocks may affect productivities via H_{ik}.
- Producers take $A_{ik}(\omega)$ as given. For specific short-run form, I suggest A_{ik} follows:

$$A_{ik} = \left(\frac{I_{ik}}{L_{ik}}\right)^{\beta_k}. \tag{6}$$

- Differences in β_k: Technology limited in arable farming (Gallardo and Sauer, 2018, Coleman, 1956) and labour-intensive manufacturing (Atack, Margo, and Rhode, 2019).
- Possible microfoundations: Bustos, 2011, Krugman, 1987, Hausmann and Rodrik, 2003, Loecker, 2013

Step #1: The Plague Induces Labour Scarcity

- Theory: 36% mortality increases sectoral wages by 5.7% ($\gamma_k = 0.5$ and $\theta = 5$).
- Empirics: Real wages in England and Spain dropped after the Black Death for two years (Jedwab, Johnson, and Koyama, 2024). Shorter in 1710s (Alfani and Murphy, 2017).
- Historical population data too sparse. Proxy: # of captains in a region (Marczinek, Maurer, and Rauch, 2024). 50% drop in captain population and 15 year recovery period.

Step #2: Production Becomes More Capital-Intensive Empirics

- Unobserved adjustment *within* sectors if factor prices not equalised.
- **Observable Effect** across sectors, predicted by Rybczynski theorem:

$$\frac{X_{ijCM}}{X_{ijLM}} = \xi w_{iM}^{-\theta(\gamma_{CM}-\gamma_{LM})} w_{iM}^{\beta_{CM}-\beta_{LM}} \frac{CMA_{jLM}}{CMA_{jCM}}. \tag{7}$$

- Capital-intensive sectors have smaller labour share γ.
- Higher I/L increases productivity more in capital-intensive manufacturing.
- Relative price of capital-intensive goods in j decreases. Controlled for in event study.
- Empirical Evidence: Innovation. Significantly more new exports in capital-intensive sectors.

Step #3: Productivity Grows More in High β_k Sectors Empirics

- Two assumptions: $\gamma_k = \gamma \forall k$ & serfdom varies by area, not region. Details Data on 1668-1749 to focus on short run.
- I estimate the association between the plague and productivity growth:

$$\text{productivity growth}_{ikt} = \delta_k \textit{plague}_{it} + \alpha_{ik} + \alpha_{akt} + \epsilon_{ikt}, \tag{8}$$

- where the LHS is recovered from trade data, α are fixed effects and ϵ_{ikt} is the error term.
- Plugging in the wage increases documented by Jedwab, Johnson, and Koyama, 2024, I calculate $\beta_{CM} - \beta_{LM} = 2.57$ and $\beta_{CA} - \beta_{LA} = 3.24$.

Productivity Growth after the Plague

Conley SE | Long run

	Agriculture				Manufacturing			
	Labour-intensive		Capital-intensive		Labour-intensive		Capital-intensive	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Plague Dummy	-0.078		0.805***		-1.502***		0.236	
	(0.226)		(0.265)		(0.209)		(0.215)	
Mortality Rate		0.156		2.064***		-3.093***		0.898*
		(0.547)		(0.642)		(0.507)		(0.520)
Fixed Effects:								
– Region	✓	✓	✓	✓	✓	✓	✓	✓
– Area x Year	✓	✓	✓	✓	✓	✓	✓	✓
Observations	36,152	36,152	36,162	36,162	36,162	36,162	36,162	36,162

Notes: * p <0.10, ** p <0.05, *** p <0.01. The dependent variable is log sectoral productivity growth. The independent variable is a plague dummy or the (imputed) mortality rate. Denmark and Norway have been dropped from the sample as they reintroduced serfdom in 1733.

Factor Mobility Frictions: Serfdom Skip

- Serfdom severely limited labour mobility. Wage wedge: $w_{iM} = (1 + \phi_i) w_{iA}$. Evidence
- **Absolute labour scarcity:** migration equalises labour scarcity within a region.
- **Relative labour scarcity:** with serfdom rural workers cannot move to cities, so these additionally see *relative* labour scarcity.
- As cities are artificially scarce and hinterlands artificially abundant in labour, shift into capital-intensive exports is stronger in manufacturing and weaker in agriculture. Details

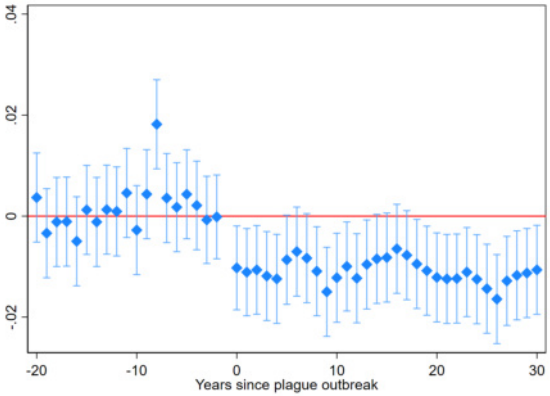
Overview of Alternative Mechanisms

- I discuss four alternative mechanisms that could induce an export boom:
  - directed technical change, which finds little historical support, Skip
  - venting out (Almunia et al., 2021), which cannot explain the long-run results, Skip
  - market power, which is inconsistent with plagued regions lowering export prices,
  - and non-homothetic preferences (Voigtländer and Voth, 2012, Fieler, 2011), for which I find no evidence in a test informed by a structural model. Skip I also find contrary evidence for the central empirical prediction of Voigtländer and Voth, 2012 for relative prices.

  Skip to Allen-Unger Skip to Soundtoll

Counterfactual Trade without Productivity Channel

- Shut down changes in $A_{i,kt}$ for approximated counterfactual market share. Details



Notes: Counterfactual export shares after the plague and observed export shares before the plague.

Conclusion

- This paper studies the relationship between labour scarcity and productivity growth. Plagued regions shift into capital-intensive exports and see a surprising export boom.
- In a Ricardian model, I argue that increased labour scarcity leads to productivity growth.
- Trade and comparative advantage patterns remain altered even after population recovery, supporting path dependence.
- Basic economic mechanisms operate under labour scarcity. This supports the role of our field in a discussion held increasingly politically.

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Army movements predict plague outbreaks

Back to Context Back to Identification

Back to Fact 1 by Army

Notes: Map of army marching routes between 1706 and 1714, when the plague was recorded to have spread across Eastern and later Northern and Central Europe. No distinction is made between armies, as both allied and Russian troops are known to have spread the plague. I base these routes on maps by Spruner and Menke, 1880 and Barraclough, 1997.

Population recovery based on Buringh, 2021

Back

	Population		Log Population	
	(1)	(2)	(3)	(4)
Plague x Year=800	0.0749	-0.0242	0.224	0.154
	(11.86)	(10.77)	(0.811)	(0.584)
Plague x Year=900	0.0715	-0.0998	0.141	0.0493
	(11.86)	(10.77)	(0.810)	(0.625)
Plague x Year=1000	0.251	-0.0178	0.0817	0.0286
	(11.86)	(10.76)	(0.737)	(0.531)
Plague x Year=1100	0.161	-0.232	0.112	0.0373
	(11.84)	(10.74)	(0.710)	(0.479)
Plague x Year=1200	0.424	-0.163	0.130	0.0898
	(11.82)	(10.72)	(0.697)	(0.469)
Plague x Year=1300	1.339	0.352	0.366	0.282
	(11.78)	(10.68)	(0.691)	(0.460)
Plague x Year=1400	1.772	1.043	0.460	0.468
	(11.74)	(10.64)	(0.690)	(0.458)
Plague x Year=1500	3.816	2.709	0.597	0.592
	(11.35)	(10.34)	(0.688)	(0.455)
Plague x Year=1550	4.758	3.489	0.622	0.637
	(11.24)	(10.23)	(0.686)	(0.454)
Plague x Year=1600	6.464	4.798	0.684	0.704
	(11.05)	(10.02)	(0.686)	(0.455)
Plague x Year=1650	7.789	5.332	0.783	0.747*
	(10.81)	(9.784)	(0.685)	(0.453)
Plague x Year=1700	9.645	6.381	0.800	0.737
	(10.52)	(9.499)	(0.687)	(0.455)
Plague x Year=1750	11.20	7.018	0.840	0.668
	(10.29)	(9.271)	(0.686)	(0.454)
Plague x Year=1800	14.78	8.766	0.954	0.697
	(9.583)	(8.657)	(0.687)	(0.454)
Plague x Year=1850	21.37**	10.64	0.844	0.692
	(8.999)	(8.147)	(0.687)	(0.454)
Plague x Year=1900	63.51***	44.93**	0.767	0.948**
	(19.85)	(18.64)	(0.691)	(0.460)
Plague x Year=1950	107.4**	87.99**	0.548	0.907*
	(42.88)	(38.62)	(0.695)	(0.465)
Plague x Year=2000	162.9***	153.2***	0.438	0.999**
	(59.85)	(54.14)	(0.694)	(0.467)
Fixed Effects:				
– City	✓		✓	
– Country x Year	✓	✓	✓	✓
– Year		✓		✓
Observations	22,470	22,489	17,027	17,059

Pre-plague balance checks

Back

	Log Exports	Export Growth	Log # of Exported Goods	Export Probability
	(1)	(2)	(3)	(4)
To be Plagued	0.588	-0.055	0.221*	0.090***
	(0.427)	(0.064)	(0.120)	(0.018)
To be Plagued x Capital-Int.	-0.437	0.080	0.043	-0.048***
	(0.367)	(0.063)	(0.107)	(0.006)
Fixed Effects:				
– Destination x Year	✓	✓	✓	✓
Years	1668-1708	1689-1708	1668-1708	1668-1708
Observations	15,826	47,160	31,604	496,920

Notes: Standard errors clustered at the origin level in parentheses. * p <0.10, ** p <0.05, *** p <0.01. The dependent variables are log export volumes (column 1), annual export volumes divided by total exports between 1668 and 1688 (column 2), the log number of exported goods (column 3), and a dummy for any exports (column 4). The independent variable is a plague dummy, equal to one for to-be-plagued regions, and this dummy's interaction with a dummy for a capital-intensive sector. Years are restricted to before 1708 to exclude any plague years. Additional controls are annual growing season temperature, latitude, and longitude.

Predicting mortality

Back

	Mortality rate
	(1)
Year of plague outbreak	-0.000
	(0.001)
Latitude	0.010
	(0.022)
Longitude	0.017**
	(0.007)
Distance to closest army	-0.062**
	(0.023)
East of the Sound	0.160**
	(0.055)
Observations	19

Notes: Standard errors in parentheses. * p <0.10, ** p <0.05, *** p <0.01. The dependent variable is the median urban mortality estimate. The independent variables are the year of the plague outbreak, latitude, longitude, distance to the closest army route between 1706 and 1714, and a dummy for the city being to the East of the Sound. The rationale for including army marching routes is that armies spread the plague.

Impact of plague on number of births in 59 Scania parishes

Back

	Births		Log Births	
	(1)	(2)	(3)	(4)
Post Plague	0.174	-0.376	-0.065	-0.104
	(0.725)	(0.735)	(0.068)	(0.083)
Fixed Effects:				
– Origin	✓	✓	✓	✓
– Year	✓	✓	✓	✓
Years	All	1647-1750	All	1647-1750
Observations	1,015	591	973	578

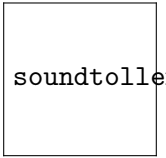
Notes: Standard errors in parentheses. * p <0.10, ** p <0.05, *** p <0.01. The dependent variable is a the (log) number of births per year and parish. The independent variable is a plague dummy, equal to one after the parish suffered a plague outbreak.

Overview of sources Back

- **Trade data:** Danish toll data. Toll introduced by the Danish King in 1429 on all ships entering or leaving the Baltic Sea at Helsingor.
  - Translate accounts of goods; identify and geocode ports. 227 goods; 594 regions.
- **Population data:** for 229 cities from Bosker, Buringh, and Zanden, 2013.
- **Mortality data:** Kroll, 2006 and Kroll and Grabinsky, 2007.
- **Climate data:** adjust agricultural productivity growth for effect of warming based on annual temperature grid by Luterbacher et al., 2004.
- **Serfdom:** I record regions' serfdom status based on Raster, 2023 and Peters, 2022.

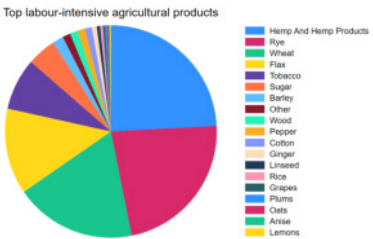
Original Data

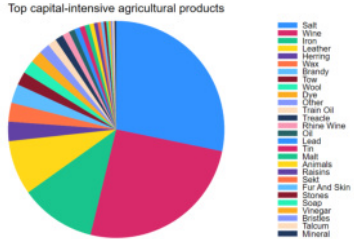
Back to Sources

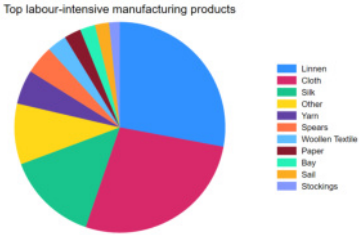


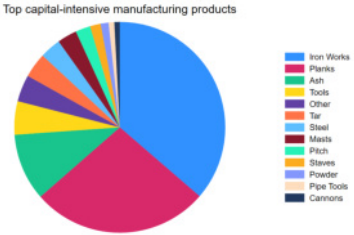
Goods by sector

Labour Scarcity & Trade | Data Overview









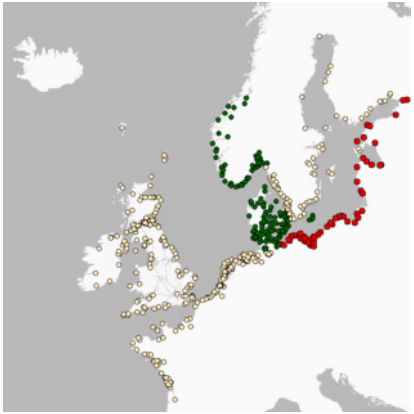
Top 30 goods by value

Back to GNW Back to Alt. Fact #1

Good	Sector	Share	Cumulative share	Rank
Hemp	Labour-int. Agriculture	11.25	11.25	1
Rye	Labour-int. Agriculture	10.57	21.82	2
Salt	Capital-int. Agriculture	9.75	31.57	3
Wine	Capital-int. Agriculture	8.84	40.42	4
Wheat	Labour-int. Agriculture	8.63	49.05	5
Flax	Labour-int. Agriculture	6.1	55.15	6
Iron Works	Capital-int. Manufacturing	4.31	59.46	7
Iron	Capital-int. Agriculture	3.9	63.36	8
Tobacco	Labour-int. Agriculture	3.68	67.04	9
Planks	Capital-int. Manufacturing	3.22	70.27	10
Leather	Capital-int. Agriculture	2.81	73.07	11
Sugar	Labour-int. Agriculture	2.05	75.13	12
Unclassified	Unclassified	1.32	76.44	13
Ash	Capital-int. Manufacturing	1.22	77.67	14
Goods	Unclassified	1.22	78.88	15
Linnen	Labour-int. Manufacturing	1.14	80.03	16
Cloth	Labour-int. Manufacturing	1.12	81.14	17
Herring	Capital-int. Agriculture	1	82.14	18
Wax	Capital-int. Agriculture	.97	83.12	19
Brandy	Capital-int. Agriculture	.97	84.09	20
Barley	Labour-int. Agriculture	.8	84.89	21
Tow	Capital-int. Agriculture	.69	85.58	22
Wool	Capital-int. Agriculture	.68	86.26	23
Dye	Capital-int. Agriculture	.63	86.88	24
Tools	Capital-int. Manufacturing	.61	87.49	25
Silk	Labour-int. Manufacturing	.58	88.07	26
Wood	Labour-int. Agriculture	.56	88.62	27
Pepper	Labour-int. Agriculture	.55	89.17	28
Cotton	Labour-int. Agriculture	.48	89.65	29
Train Oil	Capital-int. Agriculture	.45	90.1	30

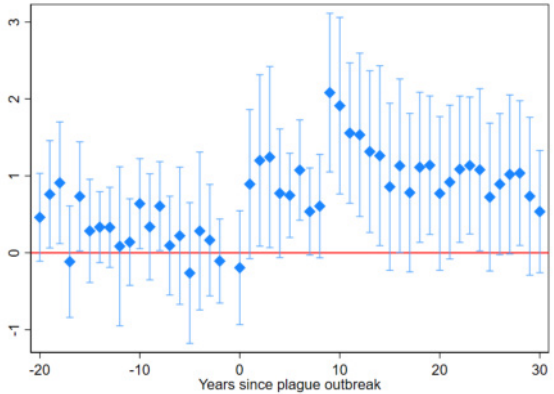
Regions by serfdom status

Back



Notes: This map classifies regions by their serfdom status according to the above discussion. Yellow regions did not feature serfdom before and after the plague, whereas red regions did. Green areas re-introduced serfdom in 1733.

Alternative assignment as capital-intensive: Fact #1 Back



Notes: Among the top 30 goods, I have reassigned four debatable goods (wine and tow from CA to LA, planks and ash from CM to LM) and find almost identical results.

Shift into capital-intensive exports as DiDiD

Back

	(1)	(2)	(3)	(4)
Post Plague	-0.980**	-1.151***	-0.471**	-0.563***
	(0.416)	(0.357)	(0.190)	(0.160)
Post Plague x Capital-Int.	0.970*	1.302***	0.451	0.840***
	(0.522)	(0.266)	(0.317)	(0.187)
Fixed Effects:				
– Origin x Sector	✓	✓	✓	✓
– Sector x Year	✓		✓	
– Year		✓		✓
Estimator	PPML	PPML	OLS	OLS
Observations	102,636	105,908	17,545	17,560

Notes: Standard errors clustered at the origin level in parentheses. * p <0.10, ** p <0.05, *** p <0.01. The dependent variable is annual exports by sector in levels (columns 1-2) and logs (columns 3-4). The independent variable is a post plague dummy, equal to one after the origin suffered a plague outbreak, and a dummy interacting the post plague dummy with a dummy for capital-intensive exports. Columns 1-2 show unweighted results, whereas in columns 3-4 the weight are exports in levels. Annual growing season temperatures are an additional control in all specifications.

Shift into capital-intensive exports by armies and sieges

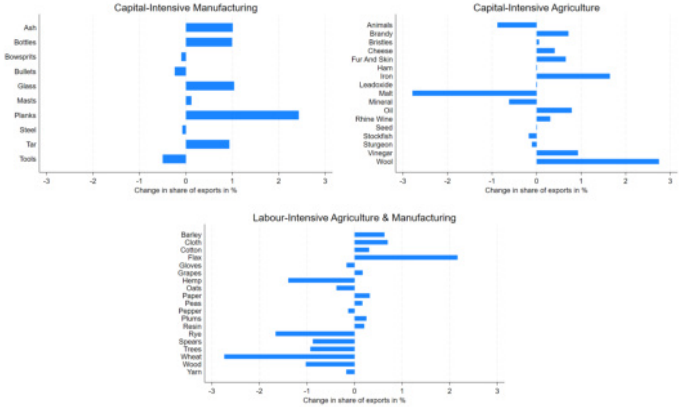
Sieges Armies Back

	PPML		OLS		PPML		OLS	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Army Distance x Post War	-0.060	-0.061	0.015	0.006				
	(0.071)	(0.057)	(0.031)	(0.025)				
Army Distance x Post War x Capital-Int.	0.061	0.047**	0.008	-0.002				
	(0.043)	(0.023)	(0.028)	(0.016)				
Siege x Post War					0.715***	0.750***	0.579***	0.607***
					(0.098)	(0.083)	(0.090)	(0.092)
Siege x Post War x Capital-Int.					0.335	0.309	0.007	0.007
					(0.273)	(0.315)	(0.229)	(0.239)
Post Plague	-1.136**	-1.256***	-0.424**	-0.545***	-1.156***	-1.321***	-0.615***	-0.709***
	(0.510)	(0.419)	(0.177)	(0.119)	(0.385)	(0.324)	(0.131)	(0.103)
Post Plague x Capital-Int.	1.132**	1.265***	0.514*	0.842***	1.109**	1.345***	0.573*	0.923***
	(0.530)	(0.270)	(0.308)	(0.193)	(0.563)	(0.340)	(0.329)	(0.216)
Fixed Effects:								
– Origin x Sector	✓	✓	✓	✓	✓	✓	✓	✓
– Sector x Year	✓		✓		✓		✓	
– Year		✓		✓		✓		✓
Estimator	PPML	PPML	OLS	OLS	PPML	PPML	OLS	OLS
Observations	100,530	103,750	17,353	17,368	102,636	105,908	17,545	17,560

Notes: Standard errors clustered at the origin level in parentheses. * p <0.10, ** p <0.05, *** p <0.01. The dependent variable is annual exports by sector in levels (PPML) or logs (OLS). The independent variable is a post plague dummy, equal to one after the origin suffered a plague outbreak, and a dummy interacting the post plague dummy with a dummy for capital-intensive exports. Additionally, in columns 1-4 I include the smallest distance any army had to a region during the Great Northern War, interacted with a post-war dummy (equal to 1 after 1721), and this interactions interaction with a capital-intensity dummy. The PPML columns show unweighted results, whereas in the OLS columns the weight are exports in levels. Annual growing season temperatures are an additional control in all specifications.

Fact #1: Shift into capital-intensive exports by goods

Back



Notes: Results from regressing a plague dummy on the share a good constitutes among origin-time exports, including origin and time fixed effects. Shown is a selection of point estimates that are significant at the 10% level.

The capital intensity of exports rose after the plague across sectors

Back

Table 1: Plague increases capital-intensive exports more than labour-intensive exports.

	Manufacturing		Agriculture	
	(1)	(2)	(3)	(4)
Post Plague	-1.491***	-0.547***	-1.136***	-0.566***
	(0.498)	(0.121)	(0.355)	(0.183)
Post Plague x Capital-Int.	1.267***	0.787***	1.507**	0.740*
	(0.235)	(0.142)	(0.647)	(0.379)
Fixed Effects:				
– Origin x Sector	✓	✓	✓	✓
– Year	✓	✓	✓	✓
Estimator	PPML	OLS	PPML	OLS
Observations	31,023	5,043	53,369	9,578

Notes: Standard errors clustered at the origin level in parentheses. * p <0.10, ** p <0.05, *** p <0.01. The dependent variable is annual exports by sector in levels (columns 2 and 4) and logs (columns 1 and 3). The independent variable is a post plague dummy, equal to one after the origin suffered a plague outbreak, and a dummy interacting the post plague dummy with a dummy for capital-intensive exports. Columns 1 and 3 show unweighted results, whereas in columns 2 and 4 the weight are exports in levels. Annual growing season temperatures are an additional control in all specifications.

Fact #1 using estimator in Borusyak, Jaravel, and Spiess, 2021

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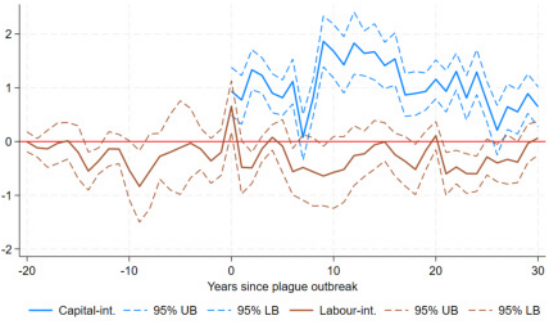
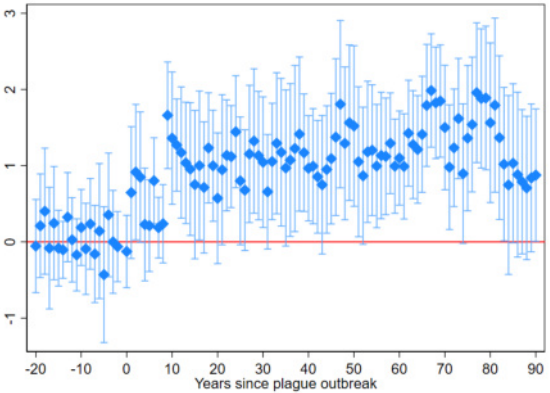


Notes: I estimate equation 1 by factor intensity using the imputation estimator in Borusyak, Jaravel, and Spiess, 2021. The package does not permit the estimation of pretrend heterogeneity, so these estimates are pooled across both factor intensities.

Fact #1 in the long run

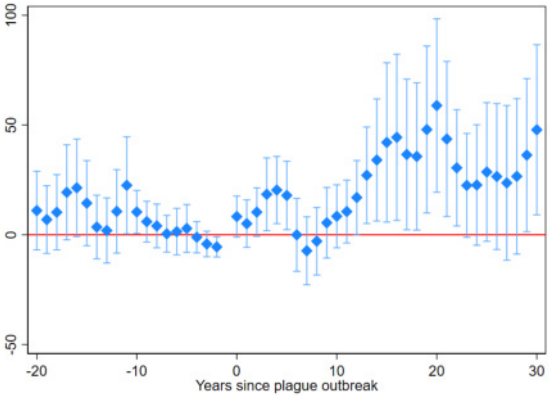
Back



Notes: I estimate equation 1 on long-run data.

Export volumes increased after the plague

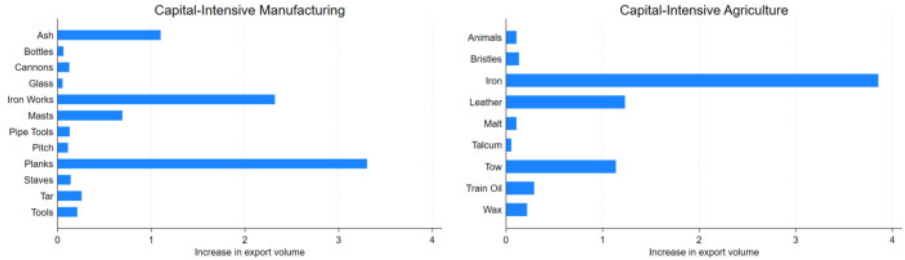
Back



Notes: Value of exports rather than export shares.

Fact #2: Export growth by goods

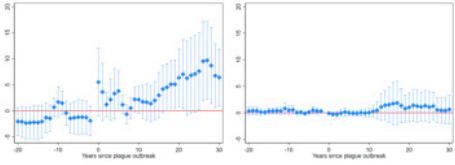
Back



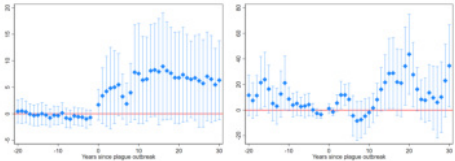
Notes: Results from regressing a post plague dummy on i's market share in j in good g in annual data, controlling for area x year, origin x destination, and destination x year fixed effects. Shown are only point estimates that are significant at the 5% level.

Intensive margin: Export volumes by sector

Back



(a) Capital-int. man. (b) Labour-int. man.

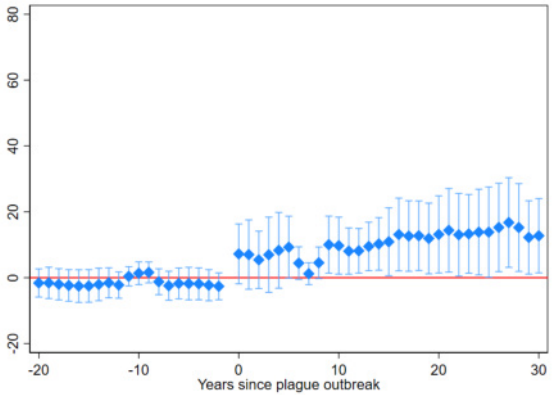


(c) Capital-int. ag. (d) Labour-int. ag.

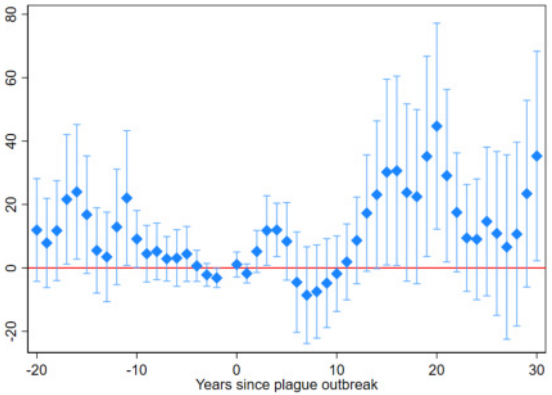
Notes: Export volumes by sector.

Intensive margin: Export volumes by factor intensity

Back



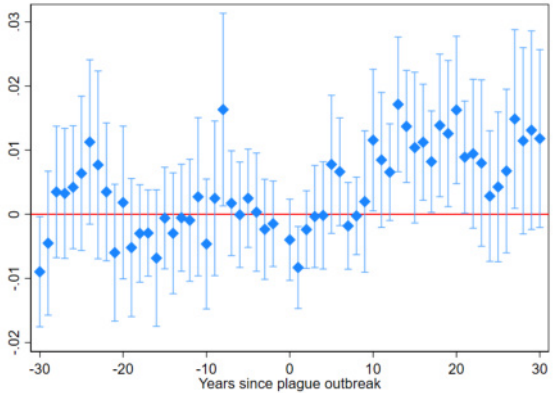
(a) Capital-intensive sectors.



(b) Labour-intensive sectors.

Pretrends over 30 years before the plague

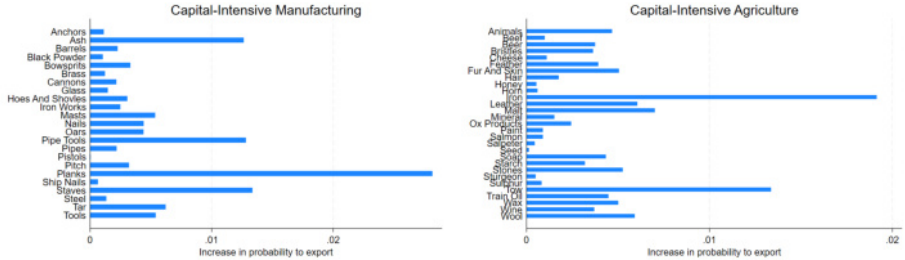
Back



Notes: Export shares, extending pre-period to 30 years.

Extensive margin expansion by goods

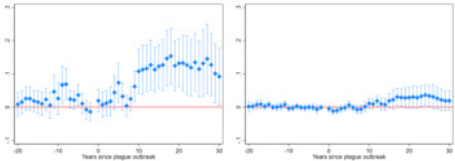
Back



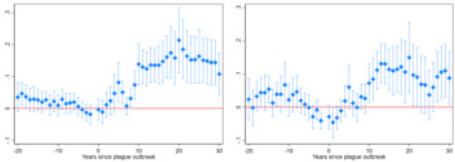
Notes: Results from regressing a post plague dummy on a dummy for positive exports of good g from i to j in annual data, controlling for area x year, origin x destination, and destination x year fixed effects. Shown are only point estimates that are significant at the 5% level.

Extensive margin expansion, by sector

Back



(a) capital-int. man. (b) labour-int. man.



(c) capital-int. ag. (d) labour-int. ag.

Extensive margin expansion, by factor

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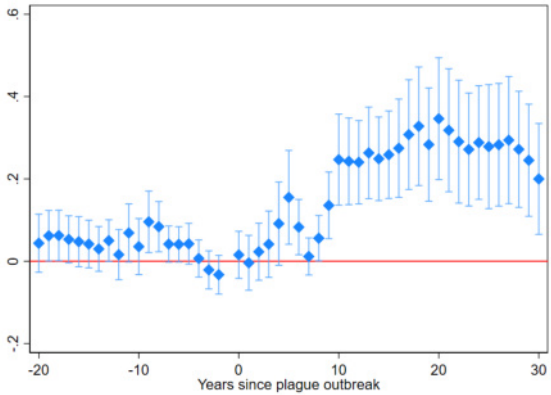
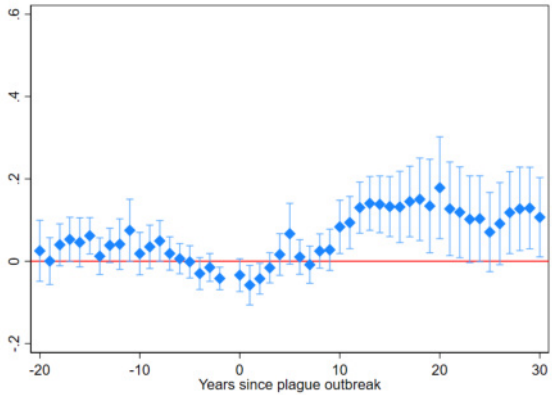


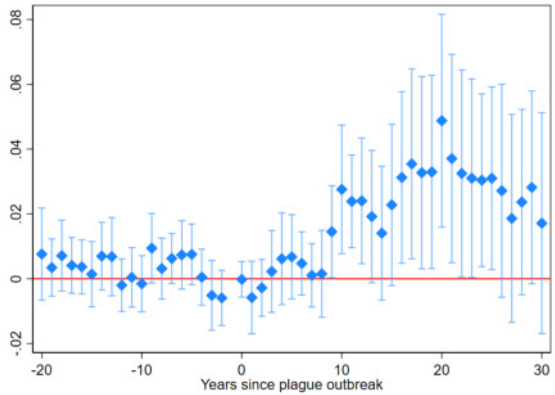
(a) # exported capital-intensive goods.



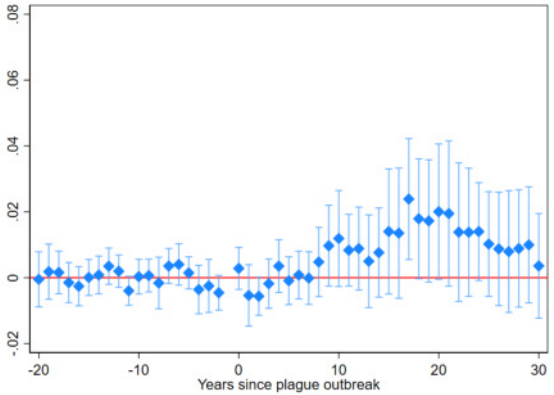
(b) # exported labour-intensive goods.

New exports at the extensive margin, by factor intensity.

Back



(a) # new goods, capital-intensive sectors.

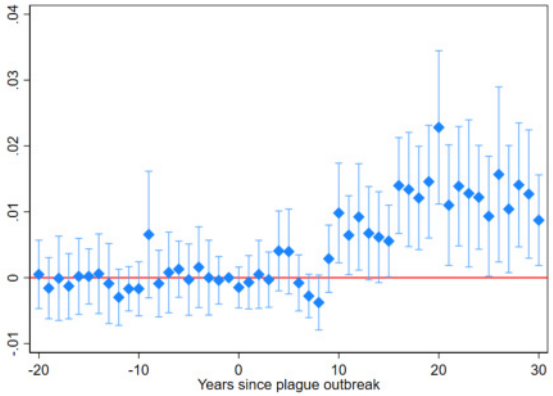


(b) # new goods, labour-intensive sectors.

New exports at the extensive margin, difference by factor intensity.

Back

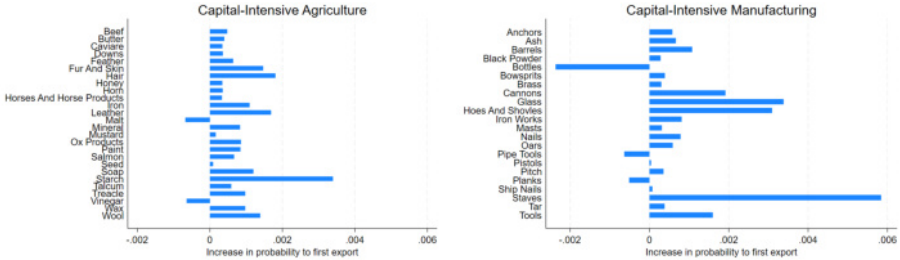
Back to Mechanism



Difference between capital- and labour-int. sectors.

Increased probability of exporting a good for the first time

Back



Notes: Results from regressing a post plague dummy on a dummy for a new export of good g from i to j in annual data, controlling for area x year, origin x destination, and destination x year fixed effects. A new export is a good not exported before the plague. Shown are only point estimates that are significant at the 5% level.

New exports at the extensive margin, by sector

Back

Table 2: Impact of plague on number of goods never exported before, by factor intensity.

	Overall	Labour-intensive ag.	Capital-intensive ag.	Labour-intensive man.	Capital-intensive man.
	(1)	(2)	(3)	(4)	(5)
Post Plague	0.962***	1.011***	0.413	1.349***	0.919***
	(0.242)	(0.325)	(0.280)	(0.266)	(0.321)
Fixed Effects:					
– Area x Year	✓	✓	✓	✓	✓
– Origin x Destination	✓	✓	✓	✓	✓
– Destination x Year	✓	✓	✓	✓	✓
– Controls	✓	✓	✓	✓	✓
Estimator	PPML	PPML	PPML	PPML	PPML
Observations	74,452	17,270	40,554	4,140	14,185

New exports at the intensive margin, by sector

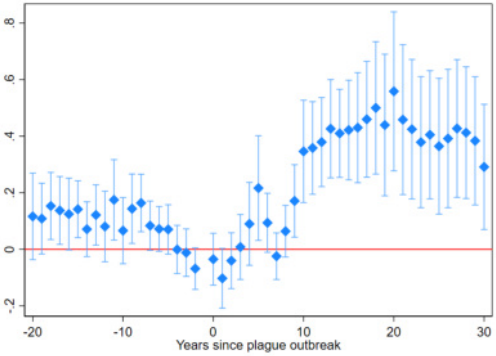
Back

Table 3: Impact of plague on volume of goods never exported before, by factor intensity.

	Overall	Labour-intensive ag.	Capital-intensive ag.	Labour-intensive man.	Capital-intensive man.
	(1)	(2)	(3)	(4)	(5)
Post Plague	1.583***	2.106***	1.260*	1.038**	1.217
	(0.467)	(0.624)	(0.749)	(0.522)	(0.853)
Fixed Effects:					
– Area x Year	✓	✓	✓	✓	✓
– Origin x Destination	✓	✓	✓	✓	✓
– Destination x Year	✓	✓	✓	✓	✓
– Controls	✓	✓	✓	✓	✓
Estimator	PPML	PPML	PPML	PPML	PPML
Observations	50,472	13,365	30,255	3,284	12,149

Plagued regions export a larger variety of goods

Back

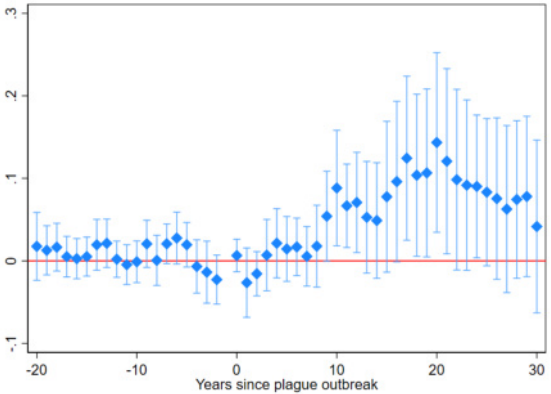


Notes: # of exported goods. Mean number of exported goods: 0.43.

By good By sector By factor

Exports of new products increase

Back to Robustness Back to Mechanism



Notes: # goods first exported within 20 years on either side of the plague.

By good By sector By factor Diff. by factor Intensive Margin

Mechanical Explanations Back

- Reallocation of exports from within the Baltic Sea to the North Sea.
  - Possible, but then plagued regions became competitive in new and further away markets, overcoming higher trade costs. I then underestimate the trade expansion.
  - Simulate productivity increase and find no bias in trade expansion estimates from observed vs. full sample.
- Alternatively, if harbours see a local demand drop, they might export more.
  - Plague came from hinterlands and disrupted production there, too.
  - Heterogeneity: results hold for smallest exporters, too; imports also went up.

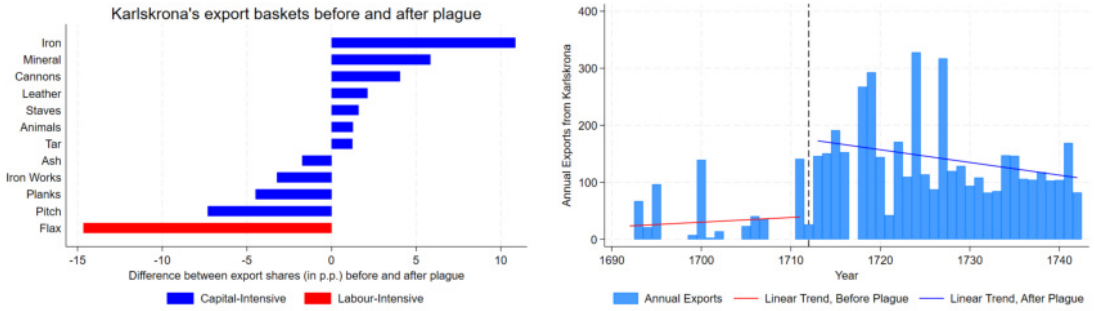
Robustness Back

- Robust to using the imputation estimator by Borusyak, Jaravel, and Spiess, 2021.
- Chaisemartin and D'Haultfoeuille, 2022: no negative weights on ATEs.
- Results continue to hold on cleaned underlying value. Holds as sectoral gravity model.
- Reducing trade to extensive margin, plague significantly increases probability to export at all.
- I discuss serfdom (Raster, 2023), venting out (Almunia et al., 2021) and non-homothetic demand (Fieler, 2011, Voigtländer and Voth, 2012) below.

Karlskrona

Back

Figure 12: Karlskrona after the plague.



Notes: Plagued between 1710 and 1712. Share of capital-intensive exports rises from 86% to 96%. New exports: tools in 1713, tow in 1714, staves in 1720, brass in 1728, oars in 1731, anchors in 1734. 1717: Polhemsdockan. Rise in export volumes from avg. 61 dalers per year to 140 daler.

Controlling for Indirect Plague Treatment

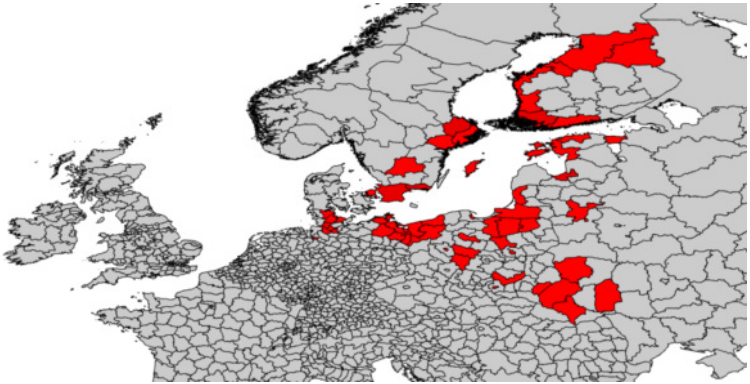
Map Back

	Plague (continuous treatment)				Plague (only accounting for distance)			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Own Plague	70.19260	0.01037***	0.19819***	0.07497**	68.78410	0.01087***	0.20180***	0.07387**
	(48.95880)	(0.00285)	(0.05970)	(0.03609)	(53.02448)	(0.00295)	(0.06222)	(0.03699)
Plague in Hinterland	-0.02843	-0.00000	-0.00002	-0.00006				
	(0.02638)	(0.00000)	(0.00010)	(0.00004)				
Own Plague x Capital-Int.	1.3e+02				1.6e+02			
	(1.2e+02)				(1.4e+02)			
Plague in Hinterland x Capital-Int.	0.01858*							
	(0.01089)							
Plague in Hinterland, Only Distance					-5.6e+01*	-0.00387**	-0.03760	-0.03447
					(31.34625)	(0.00196)	(0.09991)	(0.02659)
Plague in Hinterland, Only Distance x Capital-Int.					-3.4e+01			
					(49.50306)			
Fixed Effects:								
– Origin x Sector	✓				✓			
– Year	✓				✓			
– Area x Year		✓	✓	✓		✓	✓	✓
– Origin x Destination		✓	✓	✓		✓	✓	✓
– Destination x Year		✓	✓	✓		✓	✓	✓
Estimator	246,095	489,617	489,617	489,617	246,095	489,617	489,617	489,617

Plague in Hinterland is constructed as: $plague_{it}^{cont} = plague_{it}^{own} + \Sigma_j \frac{Population_j}{Distance_{ij}} plague_{jt}$, where j are NUTS 3 regions, area proxies for population, distance is a straight line, and a NUTS 3 region is counted as plagued if at least one location in it is recorded as plagued. Plague in Hinterland, Only Distance is constructed by dropping population.

Map of Plagued NUTS 3 regions

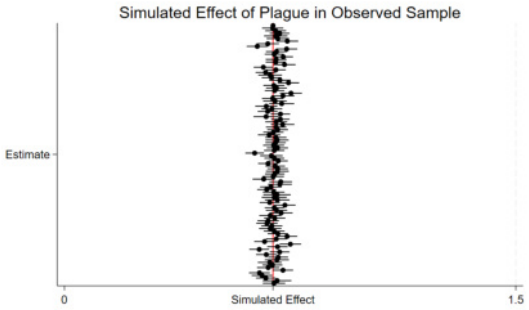
Back



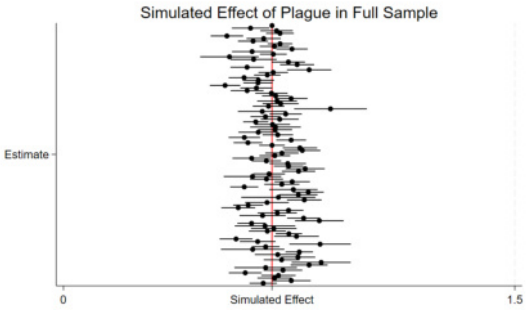
Notes: A map of plagued hinterlands based on Table **??**. Red colour indicates 1 or more plagued locations within a NUTS 3 region.

Simulated trade in observed vs. full sample

Back



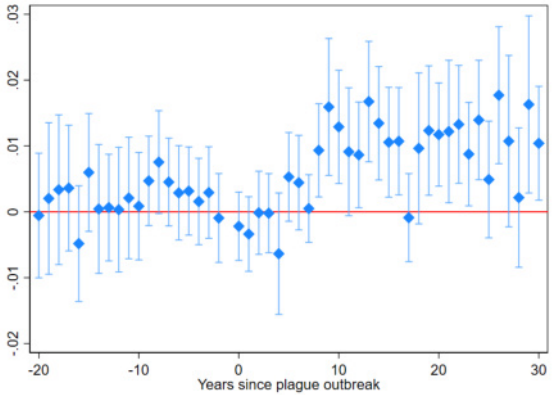
(a) Observed sample; origin-destination and destination-time fixed effects.



(b) Full sample; origin-destination and destination-time fixed effects.

No local demand contraction

Back to Mech. Exp.



(a) Import shares of plagued cities.

Heterogeneity of trade findings by pre-plague export levels. Back

	Export Volume		Export Share		# Exported Goods		# New Exported Goods	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Post Plague	-0.98035050**	-0.57260670	0.01024532***	0.00405861	0.19697625***	0.11466535**	0.06830435**	0.02939703
	(0.41571542)	(0.44376456)	(0.00274101)	(0.00311360)	(0.05694356)	(0.05151306)	(0.03415583)	(0.02897934)
Post Plague x Cap-Int.	0.96971886*	1.14320257***						
	(0.52203372)	(0.41610229)						
Post Plague x Pre-Plague Exports		-0.00000115***		0.00000006***		0.0004342*		0.00002052**
		(0.00000037)		(0.00000001)		(0.00002343)		(0.00000889)
Post Plague x Cap-Int. x Pre-Plague Exports		-0.00000154***						
		(0.00000042)						
Fixed Effects:								
– Origin x Sector	✓	✓						
– Sector x Time	✓	✓						
– Area x Year			✓	✓	✓	✓	✓	✓
– Origin x Destination			✓	✓	✓	✓	✓	✓
– Destination x Year			✓	✓	✓	✓	✓	✓
Estimator	PPML	PPML	OLS	OLS	OLS	OLS	OLS	OLS
Observations	102,636	102,636	491,277	491,277	491,277	491,277	491,277	491,277

Notes: Standard errors clustered at the origin level in parentheses. * p <0.10, ** p <0.05, *** p <0.01. The dependent variable in columns 1-2 is the volume of exports by capital intensity. In columns 3-4, it is the market share origin i captures in j. In columns 5-6, it is the number of exported goods. In columns 7-8, it is the number of new exported goods. The independent variables for all four dependent variables are first a post plague dummy and then additionally its interaction with the level of exports before 1709 (number of exported goods) for columns 1-4 (5-8). In columns 1-2, the independent variables also include a post-plague x capint dummy and its interaction with pre-plague exports.

Heterogeneity of trade findings by siege status

Back Sieges

	Export Volume	Export Share	# Exported Goods	# New Exported Goods
	(1)	(2)	(3)	(4)
Post Plague	-0.948**	0.004	0.128**	0.027
	(0.442)	(0.003)	(0.054)	(0.026)
Post Plague x Pre-Plague Exports	-0.000	0.000***	0.000*	0.000**
	(0.000)	(0.000)	(0.000)	(0.000)
Post Plague x Cap-Int.	1.436***			
	(0.434)			
Post Plague x Cap-Int. x Pre-Plague Exports	-0.000***			
	(0.000)			
Post Plague x Siege	0.471***	0.000	-0.061	0.010
	(0.147)	(0.003)	(0.087)	(0.026)
Post Plague x Cap-Int. x Siege	-0.085			
	(0.228)			
Fixed Effects:				
– Origin x Sector	✓			
– Sector x Time	✓			
– Area x Year		✓	✓	✓
– Origin x Destination		✓	✓	✓
– Destination x Year		✓	✓	✓
Estimator	PPML	OLS	OLS	OLS
Observations	102,636	491,277	491,277	491,277

List of sieges

Back to Heterogeneity by Siege
Back to Fact 1 by Siege

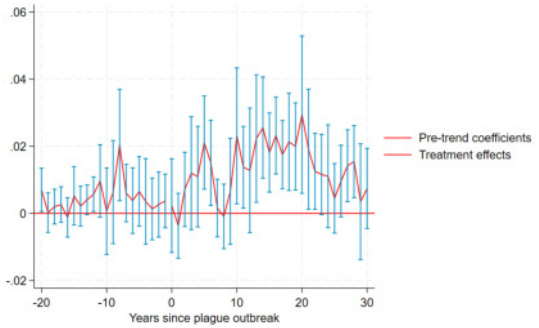
City	Modern Country	Siege
København	Denmark	1
Tönning	Germany	1
Hamburg	Germany	1
Halden	Norway	1
Gävle	Sweden	1
Härnösand	Sweden	1
Hudiksvall	Sweden	1
Piteå	Sweden	1
Söderhamn	Sweden	1
Umeå	Sweden	1
Södertälje	Sweden	1
Norrköping	Sweden	1
Nyköping	Sweden	1
Trosa	Sweden	1
Sundsvall	Sweden	1
Vyborg	Russia	1
Narva	Estonia	1
Riga	Latvia	1
Szczecin	Poland	1
Wolgast	Germany	1
Stralsund	Germany	1
Wismar	Germany	1

Notes: Six cities are both besieged and plagued. The six cities are Copenhagen (København), Narva, Riga, Stettin (Szczecin), Stralsund, and Wolgast. For Copenhagen and the first siege of Riga, there was no association with the plague, as these sieges occurred at the very beginning of the war in 1700 before the plague spread.

Imputation estimator for Fact #2

Fact #2 Robustness

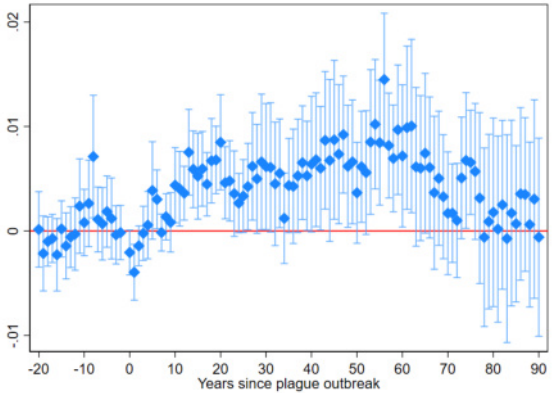
Figure 16: Imputation estimator in Borusyak, Jaravel, and Spiess, 2021 produces similar results.



Notes: This Figure shows results from estimating equation 2 with 20 pre-trends and 30 post periods using the imputation estimator by Borusyak, Jaravel, and Spiess, 2021.

Fact #2 in the long run

Back

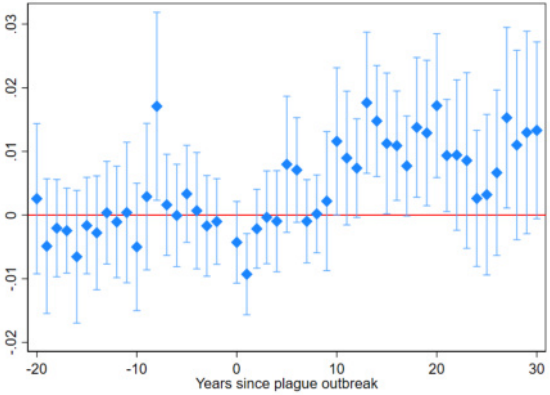


Notes: This Figure shows results from estimating equation 2 on market shares in the long run.

Trade event study on cleaned underlying value

Back

Figure 18: Trade regressions on underlying value



Trade results for bilateral dummy in sectoral gravity model

Back

	Overall	Agriculture		Manufacturing	
		Labour-intensive	Capital-intensive	Labour-intensive	Capital-intensive
	(1)	(2)	(3)	(4)	(5)
Post Plague	0.674*	0.718**	0.470*	1.232***	-0.602
	(0.372)	(0.356)	(0.279)	(0.454)	(0.682)
Fixed Effects:					
– Origin x Year	✓	✓	✓	✓	✓
– Destination x Year	✓	✓	✓	✓	✓
– Origin x Destination	✓	✓	✓	✓	✓
Estimator	PPML	PPML	PPML	PPML	PPML
Observations	505,415	49,887	69,106	26,141	40,514

Notes: Standard errors clustered at the origin level in parentheses. * p <0.10, ** p <0.05, *** p <0.01. The dependent variable is annual bilateral trade. The independent variable is a bilateral plague dummy, equal to one after either the origin, the destination, or both cities suffered a plague outbreak.

Plague increases probability to export at all

Back

	Marginal Effect		Average Marginal Effect			
	(1)	(2)	(3)	(4)	(5)	(6)
Post Plague	0.035***	0.007	0.032***	0.154***	0.057***	0.003
	(0.010)	(0.008)	(0.008)	(0.025)	(0.015)	(0.004)
Fixed Effects:						
– Origin		✓		✓		✓
– Year		✓		✓		✓
Estimator	OLS	OLS	Logit	Logit	Tobit	Tobit
Observations	502,980	502,980	502,980	502,980	502,980	502,980

Urban-rural wage differential in Copenhagen

Back to Model App. Back to Serfdom

Notes: Difference between urban and farm day wages divided by farm day wages. Data by Gary et al., 2022. The dotted line signifies the 1733 re-introduction of serfdom.

Factors and Sectors Back

- K_{ik} used in production. I_{ik} used to innovate and improve production processes.
- Permit each sector k to have a different labour share γ_k and capital share η_k:

$$P(L_{ik}, K_{ik}, I_{ik}) = A_{ik} L_{ik}^{\gamma_k} K_{ik}^{\eta_k} I_{ik}^{1-\gamma_k-\eta_k}. \tag{9}$$

- Productivity is therefore total factor productivity and not factor biased[1].
- I define a region as a city and its hinterland. Assume that hinterland size is fixed over study area[2].

[1] I discuss factor-biased technological change below.

[2] Until 1765, Swedish cities had trade monopolies over fixed surrounding areas (Magnusson, 2007).

Factors and Sectors Back

- In areas with serfdom, peasants could not move to cities, leading to a persisting wedge between urban and rural wages, ϕ_i[3]. Within agriculture and within manufacturing, workers continue to be mobile[4].

$$w_{iM} = \begin{cases} w_{iA}, & \text{without serfdom,} \\ (1+\phi_i)w_{iA}, & \text{with serfdom.} \end{cases} \tag{10}$$

- Supporting this, I show that an urban-rural wage wedge appeared in Denmark only after the re-introduction of serfdom.

[3] ϕ_i captures mobility, language, and labour market frictions.
[4] Serfs were not paid wages. Instead, I assume that their lords allocated them to equalise MPLs.

Investment & Productivity

Back

- Higher MPL raises both capital intensities:

$$\frac{I_{ik}(\omega)}{L_{ik}(\omega)} = \frac{(1-\gamma_k-\eta_k)}{\gamma_k i} w_{ik},$$
$$\frac{K_{ik}(\omega)}{L_{ik}(\omega)} = \frac{\eta_k}{\gamma_k r} w_{ik}.$$

- While producers take $A_{ik}(\omega)$ as given, I suggest that the distribution's scale parameters A_{ik} are a function of I/L[5].
- Drop ω for factor markets[6]. Factor adjustment *within* sectors.

[5] A time lag would complicate notation without providing unexpected insights.
[6] I/L rises overall, with $I_{ik} = \int_{\omega \in \Omega} I_{ik}(\omega)$.

Preferences Back

- The representative consumer in each region has a two-level utility function, where the upper tier is Cobb-Douglas and the lower tier is CES.
- α_k are the Cobb-Douglas weights in the upper tier and $\sigma_k > 1$ is the elasticity of substitution between differentiated varieties in the lower tier.
- Below, I will permit a specific form of non-homotheticity following Fieler, 2011 to test the hypothesis that plague-induced wage increases shifted demand into highly income-elastic luxury products (Voigtländer and Voth, 2012).

Prices

Back

- The marginal cost of production in sector k is given by[7]:

$$MC_{ik}(\omega) = \frac{(w_{ik})^{\gamma_k} r^{\eta_k} i^{1-\gamma_k-\eta_k}}{A_{ik}(\omega)}. \tag{11}$$

- Consumers in location j purchase a variety ω from its cheapest supplier location i:

$$p_{j,k}(\omega) = \min_{1 \leq i \leq I} c_{ij,k}(\omega) = \min_{1 \leq i \leq I} d_{ij,k} MC_{i,k}(\omega), \tag{12}$$

- where $c_{ij,k}(\omega)$ is as above, assumed to be strictly positive, and the outcome of perfect competition, $p_{ij,k}(\omega) = c_{ij,k}(\omega)$.

[7] I argue below that constant marginal costs are better suited to rationalise my findings than non-constant marginal costs (Almunia et al., 2021).

Market Access Back

- Following Redding and Venables, 2004 and Donaldson and Hornbeck, 2016, consumer market access for each sector in a location j is defined as the price index:

$$MA_{jk} = (P_{jk})^{-\theta} = \chi_k \Sigma_{i=1}^{I} A_{ik} (w_{ik})^{-\gamma_k \theta} d_{ijk}^{-\theta}, \quad (13)$$

$$FMA_{ik} = \chi_k \alpha_k \Sigma_{j=1}^{J} d_{ijk}^{-\theta} (CMA_{jk})^{-1} Y_j. \quad (14)$$

- where $\chi_k = \left(\Gamma\left(\frac{\theta+1-\sigma_k}{\theta}\right) \right)^{\frac{-\theta}{1-\sigma_k}} r^{-\eta_k \theta} i^{-(1-\gamma_k-\eta_k)\theta}$.

Wages & Labour Force

Back

- Within regions without serfdom, wages are equalised across sectors.

$$w_{ik} = \zeta_k \left(\frac{A_{ik} FMA_{ik}}{L_{ik}} \right)^{\frac{1}{1+\gamma_k \theta}}, \tag{15}$$

- Share of regional employment allocated to the most labour-intensive sector rises as other sectors switch away from labour: **labour cost channel**.
- Higher I/L increases productivities differentially. Additional shift of employment into sectors with high β_k: **productivity channel**.

Recovering productivity growth

Back to Gravity Back to Step #3

- From the gravity equation, I recover productivity growth as a three-way fixed effect. I first assume $d_{ijkt} = d_{ijkt'} \forall (ij, kt)$. The ikt fixed effect then recovers:

$$\frac{A_{ikt}A_{i'kt'}A_{ik't'}A_{i'k't}}{A_{ikt'}A_{i'kt}A_{ik't}A_{i'k't'}}\left(\frac{w_{ikt}w_{i'kt'}}{w_{i'kt}w_{ikt'}}\right)^{-\gamma_k\theta}\left(\frac{w_{ik't'}w_{i'k't}}{w_{i'k't'}w_{ik't}}\right)^{-\gamma_{k'}\theta}. \tag{16}$$

- Two assumptions are required to recover a productivity ratio. First, all sectors have the same labour share, $\gamma_k = \gamma \forall k$. Second, either there is no time variation in the labour mobility friction, $\phi_{it} = \phi_{it'}$ and $\phi_{i't} = \phi_{i't'}$. Or, the labour mobility friction does not vary within areas, such that $\phi_{ikt} = \phi_{jkt} \forall (k, t)$ and i,j within the same area.
- Unclassified goods will be the reference sector k', assumed to produce in the hinterland. Plugging in the assumption on wages and wages under serfdom, I show that δ_{ikt} identifies sectoral productivity growth compared to a reference region and unclassified goods for both agricultural sectors.

Recovering productivity growth Back

- For manufacturing, I find:

$$\delta_{ikt} = \frac{A_{ikt}A_{i'kt'}A_{ik't'}A_{i'k't}}{A_{ikt'}A_{i'kt}A_{ik't}A_{i'k't'}}\left(\frac{(1+\phi_{it})(1+\phi_{i't'})}{(1+\phi_{i't})(1+\phi_{it'})}\right)^{-\gamma\theta}. \tag{17}$$

- This is where I need the second assumption, on serfdom. I consider $\phi_{it} = \phi_{it'}$ and $\phi_{i't} = \phi_{i't'}$. While Raster, 2023 argues for increased serfdom after the plague in Northern Estonia, this is compatible if the degree to which this limits labour mobility is unchanged.
- Alternatively, if time variation in serfdom is at the level of areas, it will be absorbed by fixed effects later.
- Denmark reintroduced serfdom. The paper discusses ways to mitigate this. I also show that the reference region is irrelevant under the right set of fixed effects as only relative values are identified.

The Little Ice Age Back

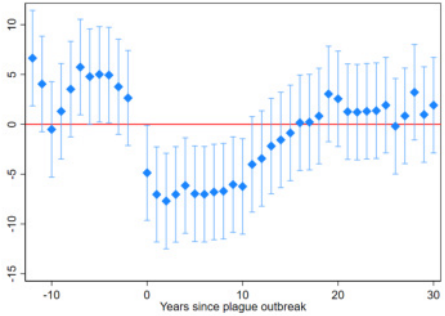
- Beginning in late Middle Ages, temperatures in Northern Europe decreased with significant spatial variation. I observe temperature increases after centuries of low temperatures.
- From Luterbacher et al., 2004, collect data on annual and growing season (spring and summer) temperature as the distance-weighted average over the four closest grid points.
- Assume that temperature growth is proportional to agricultural productivity growth:

$$\frac{A_{i',At}}{A_{i',At'}} = \left(\frac{temp_{i',t}}{temp_{i',t'}}\right)^{\epsilon_{At}}. \tag{18}$$

- Under the assumption that $\epsilon_A = 1$, I adjust recovered agricultural productivity growth for temperature change. Reasonable average across crops for Northern Europe (Liu, Mishra, and Ray, 2020).

Dynamics of population recovery after the plague: number of captains as proxy for population

Back



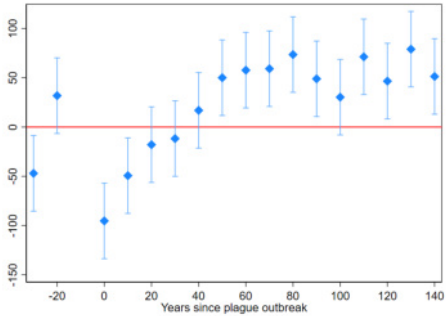
Notes: Event study with area-year and region fixed effects on the number of unique captains' last names living in a region. Captains with the same first and last name from the same region in the same year are assumed to be duplicates and thus dropped.

Empirics: Capital-intensity Back

- **Within sectors:** capital stocks drop less than sectoral employment.
  - Proxy: ship ownership (mobile piece of capital). K drops, but less than L.
- **Across sectors:** Swedish farms shifted into capital-intensive agriculture.
  - Reduced production of rye and barley and shifted into calves, as in England after Black Death (Clark, 2016). Details
  - Proximity to plagued cities associated with stronger shift into capital-int. agriculture. Details

Dynamics of capital accumulation after the plague: number of ships as proxy for the capital stock

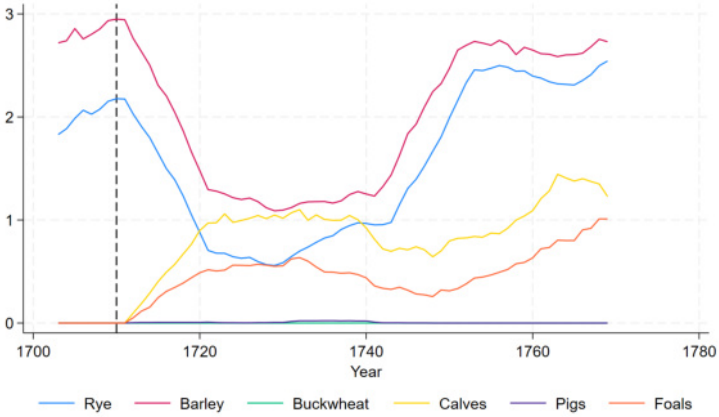
Back



Notes: Event study with area-time, region, and decade fixed effects on the number of ships registered in a harbour in levels. Decade -1 is omitted as the reference decade.

Agricultural production in Scania became more capital-intensive

Back



Notes: This Figure covers 119 farms and the composition of their production. Data by Olsson and Svensson, 2017.

Farm production and distance to plagued cities

Back

Table 4: Farm production and distance to plagued cities

	Calves	Pigs	Foals	Rye	Barley
	(1)	(2)	(3)	(4)	(5)
Plague Distance x Post Plague	-0.00656**	-0.000395**	-0.00521***	0.0182***	0.0355**
	(0.00281)	(0.000156)	(0.00171)	(0.00138)	(0.0031
Fixed Effects:					
– Year	✓	✓	✓	✓	✓
– Farm	✓	✓	✓	✓	✓
Observations	5,683	5,683	5,683	5,304	5,304

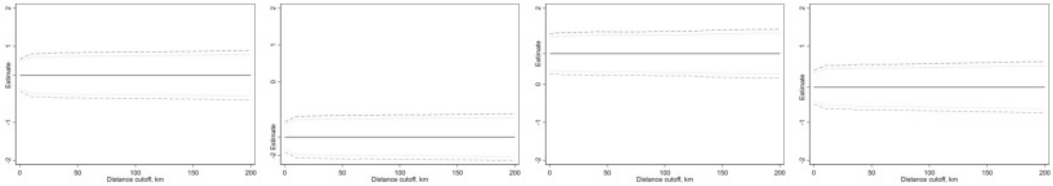
Notes: Standard errors clustered at the farm level in parentheses. * p <0.10, ** p <0.05, *** p <0.01. The dependent variables are farm's production of calves, pigs, foals rye, barley, and buckwheat. The independent variable is the sum of distances multiplied by a plague dummy over the four closest cities in Scania province. Both Ystad and Malmö suffered a

Empirics: Productivity Growth Back

- Agricultural output per capita expanded in Scania, also in England after BD (Clark, 2016).
- Adoption of agricultural machinery, e.g. metal ploughs, threshing machines and modern farm buildings (Magnusson, 2007).
- Scanian agriculture departed from strip farming in an overtly labour saving shift. Investments in drainage systems allowed farming fertile wet lands.
- Ship building: I show that the vast majority of Swedish ships and ship yards built after the plague years was built in previously plagued regions. They produced the largest and most productive ships, measured by # successful East Asia trips. Details

Productivity Effect by Sector, using Conley Standard Errors

Back



(a) Capital-int. man. (b) Labour-int. man. (c) Capital-int. ag. (d) Labour-int. ag.

Notes: These Figures repeat columns 1, 3, 5, and 7 of Table 19 with Conley standard errors and distance cut-offs between 0 and 200 km in steps of 10 km. Distance cut-offs are denoted on the x axis and point estimates (solid line), 95% confidence intervals (dashed lines), and 90% confidence intervals (dotted lines) on the y axis. Implemented using Stata packages by Baum-Snow and Han, 2024, Thiemo Fetzer, and Hsiang, 2010.

Productivity in the long run

Back

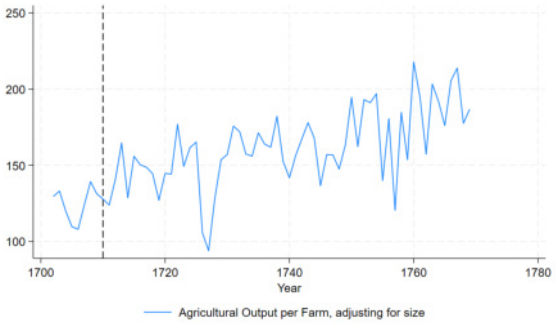
Table 5: Impact of plague on sectoral productivity growth in the long run.

	Labour-intensive ag.	Capital-intensive ag.	Labour-intensive man.	Capital-intensive man.
	(1)	(2)	(3)	(4)
0-9 Years Post Plague	-0.553**	0.457	-0.732***	-0.226
	(0.246)	(0.292)	(0.229)	(0.252)
10-19 Years Post Plague	0.165	0.360	-1.576***	0.178
	(0.246)	(0.292)	(0.229)	(0.252)
20-29 Years Post Plague	-0.141	1.026***	-1.395***	0.298
	(0.246)	(0.292)	(0.229)	(0.252)
30-39 Years Post Plague	-0.289	0.826***	-1.697***	1.131***
	(0.246)	(0.292)	(0.229)	(0.252)
40-49 Years Post Plague	0.248	0.550*	-1.328***	1.616***
	(0.246)	(0.292)	(0.229)	(0.252)
50-59 Years Post Plague	0.647***	1.639***	-1.694***	1.773***
	(0.246)	(0.292)	(0.229)	(0.252)
60-69 Years Post Plague	1.182***	1.558***	-1.125***	1.986***
	(0.246)	(0.292)	(0.229)	(0.252)
70-79 Years Post Plague	1.287***	1.717***	-1.587***	0.629**
	(0.246)	(0.292)	(0.229)	(0.252)
80-89 Years Post Plague	1.706***	1.816***	-1.641***	0.308
	(0.246)	(0.292)	(0.229)	(0.252)
90-99 Years Post Plague	1.074***	0.912***	0.110	1.295***
	(0.246)	(0.292)	(0.229)	(0.252)
Fixed Effects:				
– Region	✓	✓	✓	✓
– Area × Year	✓	✓	✓	✓
Observations	170,403	170,430	170,430	170,430

Notes: Standard errors in parentheses. * p <0.10, ** p <0.05, *** p <0.01. The dependent variable is log sectoral productivity growth. The independent variable is a plague dummy that equals 1 for plagued regions after the plague hit interacted with decade dummies after the plague. Denmark and Norway have been dropped.

Total value of agricultural production per farm, controlling for farm size

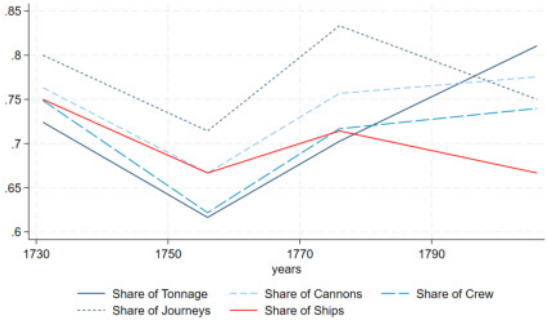
Back



Notes: This Figure covers all farms in Scania and their total output.

Share of Swedish Wharf Output by Plague Status

Back



Notes: Based on data on the production location of all ships (n=30) operated by the Swedish East India Company. Wharves founded in plagued regions after 1714 are classified as located in plagued regions. The y axis denotes the share of tonnage, journeys, cannons, crew and ships for four points in time produced in wharves founded after the plague in plagued regions.

Serfdom & Rybczynski

Back

- I put this prediction to the test and estimate:

$$T_{ift} = \delta_p plague_{it} + \delta_{ps} serfdom_i \times plague_{it} + \delta_{pf} factor_f \times plague_{it} + \delta_{pfs} serfdom_i \times plague_{it} \times factor_f + \alpha_{if} + \alpha_{ft} + \gamma x_{it} + \epsilon_{ift},$$

- where T_{ift} are exports by factor intensity, α are fixed effects, x_{it} are geographic controls, and ϵ_{ijkt} denotes the error term.
- δ are the coefficients of interest.
- Next slides: results and interpretation.

Serfdom & Rybczynski

Back Interpretation

Table 6: Impact of plague on shift into capital-intensive exports by sector & second serfdom.

	Manufacturing		Agriculture	
	(1)	(2)	(3)	(4)
Plague	1.232*	0.627	1.205*	0.850
	(0.707)	(0.398)	(0.681)	(0.529)
Plague x Serfdom	-2.498***	-0.930**	-2.187***	-1.325**
	(0.419)	(0.409)	(0.591)	(0.526)
Plague x Capital-Int.	-1.855***	-0.809	0.653	0.868
	(0.546)	(0.528)	(0.915)	(0.922)
Plague x Capital-Int. x Second Serfdom	2.544***	0.930*	-0.478	-0.715
	(0.539)	(0.525)	(0.849)	(0.911)
Fixed Effects:				
– Origin x Sector	✓	✓	✓	✓
– Sector x Year	✓	✓	✓	✓
Estimator	PPML	OLS	PPML	OLS
Observations	29,798	5,040	53,088	9,576

Notes: Standard errors clustered at the origin level in parentheses. * p <0.10, ** p <0.05, *** p <0.01. The dependent variable are sectoral exports in levels (columns 1 and 3) and logs (columns 2 and 4). In columns 2 and 4, values are weighted by exports in levels. The independent variables are a plague dummy, a second serfdom dummy, a capital-intensive sector dummy, and their interactions. I additionally control for growing season temperatures.

Empirics: Serfdom & Rybczynski Back

- With serfdom, significantly larger increases in the capital-intensity of manufacturing exports and insignificantly smaller increases in agricultural capital-intensity: *relative* labour scarcity.
- Interaction between factor proportions and serfdom behaves as expected. This framework is useful in examining factor mobility frictions.
- For productivity implications, I find no systematic evidence. Evidence
- Some historical evidence suggests agricultural productivity growth in Sweden (Magnusson, 2007) but not in Prussia and Russia (Broadberry and Korchmina, 2024).

Impact of plague on sectoral productivity growth, by second serfdom

Back

	Agriculture		Manufacturing	
	Labour-intensive	Capital-intensive	Labour-intensive	Capital-intensive
	(1)	(2)	(3)	(4)
Plague	-0.435	0.936***	-1.244***	0.196
	(0.296)	(0.347)	(0.274)	(0.281)
Plague & Serfdom	0.790*	-0.291	-0.571	0.090
	(0.423)	(0.496)	(0.391)	(0.401)
Fixed Effects:				
– Region	✓	✓	✓	✓
– Area x Year	✓	✓	✓	✓
Observations	36,152	36,162	36,162	36,162

Notes: Standard errors in parentheses. * p <0.10, ** p <0.05, *** p <0.01. The dependent variable is log sectoral productivity growth. The independent variable is a plague dummy that equals 1 for plagued regions after the plague hit interacted with a dummy for second serfdom. Denmark and Norway have been dropped from the sample as they reintroduced serfdom in 1733.

Directed Technical Change

Back

- Directed technical change can produce TFP and export growth (Alfaro et al., 2024).
- Acemoglu, 2002 shows that factor bias depends on price effect favouring scarce factor vs. market size effect complementing abundant factor.
  - In my model, production is C-D, so elasticity of substitution between factors is 1 and these channels cancel out.
- Few labour-saving machines in agriculture[9] until 19th century (Gallardo and Sauer, 2018, Coleman, 1956).
- Most labour-saving technological changes in manufacturing consolidated multiple hand tasks into a single machine task. This rarely came to bear before the 19th century (Atack, Margo, and Rhode, 2019).

[9] An early example of a crop harvesting machine that explicitly substituted labour for capital was the cotton gin by Eli Whitney, patented only in 1794.

Venting Out Back

- Almunia et al., 2021 propose variable marginal cost to explain Spanish export boom during domestic demand slump. Under constant MC, export markets cannot counteract negative local demand shock.
- Great setting to use exports to counteract local demand drop: most trade partners were not plagued! Reducing flexible inputs (e.g. day labourers) reduces MC and increases competitiveness.
- However, short-run MC changes unlikely to explain 30 year export boom. Need a channel that keeps MC from rising again, e.g. productivity growth.

Non-Homotheticity Back

- Voigtländer and Voth, 2012 tell a story of non-homotheticity. But need evidence that demand shares shifted into capital-intensive goods.
- Fieler, 2011: generalised model with non-homotheticity breaks down to EK if $\theta_k = \theta \forall k$:

$$X_{ijk} = \frac{\chi_k A_{ik} (w_{ik})^{-\gamma_k \theta} d_{ijk}^{-\theta}}{CMA_{jk}} X_{jk}, \tag{19}$$

- where I no longer assume $X_{jk} = \alpha_k Y_j$. First, note that finding on productivity growth still stands: δ_{jkt} still absorbs demand side changes.
- Prices support my story, but not non-homotheticity. Test for non-homotheticity: no evidence.

Testing for Non-Homotheticity: Price data Back

- Three types of prices: regional prices show relative drop in capital-int. goods prices. Consistent with productivity and labour cost channels. Unable to disentangle supply from demand.
- At Sound, construct bilateral prices from values and weights. Import prices do not show relative change: speaks against non-homotheticity.
- Export prices decline relatively for capital-intensive goods: speaks for productivity and labour cost channels.

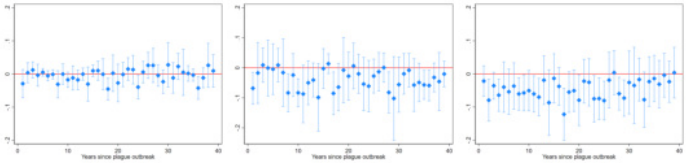
Testing for Non-Homotheticity: Trade data

Back

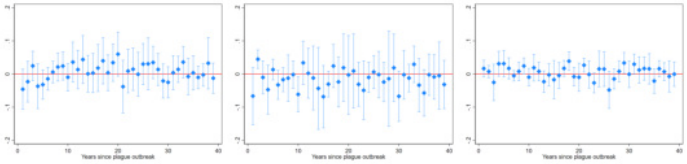
- I form a double ratio of the gravity equation between two sectors and between the pre-period (1700-1710) and any year after the plague. I assume $w_{ik} = w_{ik'}$ and $\gamma_k = \gamma_{k'}$.
- Only observe trade coming from unplagued North Sea regions: for observed trade, I see no relative import price effects. So consumer market access ratio is constant.
- In event studies on log of this ratio, origin-time FEs absorb productivity changes and destination FE absorbs baseline demand ratio.
- Results: no evidence supporting non-homothetic demand, under the caveat that this evidence relies on the specific framework used by Fieler, 2011.

Testing for plague-induced relative demand shifts

Back



(a) CM & LM (b) CM & LA (c) CM & CA



(d) CA & LM (e) CA & LA (f) LM & LA

Product-level prices by sector and year in Danzig and Amsterdam

Back to Alt. Mech. Back to Non-Homoth.

	Labour-int. Agriculture				Capital-int. Agriculture				Labour-int. Manufacturing
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Post Plague	10.53***	32.82	114.2*	702.0***	-41.24***	-59.72	-16.44**	4.615***	0.665***
	(3.15e-14)	(21.90)	(16.61)	(8.00e-12)	(6.44e-14)	(10.04)	(0.663)	(1.99e-14)	(3.70e-15)
Fixed Effects:									
– City	✓	✓	✓	✓	✓	✓	✓	✓	✓
– Year		✓	✓			✓	✓		
– Product			✓				✓		
– Product x Year				✓				✓	
Observations	4140	4140	4140	452	5116	5116	5116	248	191

Notes: Standard errors clustered at the city level in parentheses. * p <0.10, ** p <0.05, *** p <0.01. The dependent variables are prices of products by sector in Amsterdam and Danzig. The independent variable is 1 after the plague in Danzig in 1709. The second and third specification cannot be estimated for labour-intensive manufacturing due to lack of observations. No data on capital-intensive manufacturing products are contained in the data set.

Good-level logarithmic export prices.

Back to Alt. Mech. Back to Non-Homoth.

	(1)	(2)	(3)	(4)
Post Plague	0.526***			
	(0.185)			
Post Plague x Capital-Int.	-0.511**		-0.664**	
	(0.224)		(0.298)	
0-10 Years Post Plague		0.253**		
		(0.103)		
11-20 Years Post Plague		0.501***		
		(0.169)		
21-30 Years Post Plague		0.546***		
		(0.183)		
>30 Years Post Plague		0.548***		
		(0.205)		
0-10 Years Post Plague x Cap-Int.		-0.246		-0.375*
		(0.153)		(0.224)
11-20 Years Post Plague x Cap-Int.		-0.558***		-0.814***
		(0.203)		(0.296)
21-30 Years Post Plague x Cap-Int.		-0.639**		-0.801**
		(0.248)		(0.341)
>30 Years Post Plague x Cap-Int.		-0.505**		-0.657*
		(0.252)		(0.340)
Fixed Effects:				
– Area x Sector x Year	✓	✓	✓	✓
– Origin x Destination x Year			✓	✓
– Origin x Destination x Sector	✓	✓	✓	✓
– Destination x Sector x Year	✓	✓	✓	✓
Observations	118108	118108	73091	73091

Notes: Standard errors clustered at the origin level in parentheses. * p <0.10, ** p <0.05, *** p <0.01.

Good-level logarithmic import prices.

Back to Alt. Mech. Back to Non-Homoth.

	(1)	(2)	(3)	(4)
Post Plague	0.281***			
	(0.0597)			
Post Plague x Capital-Int.	-0.0997		0.0875	
	(0.116)		(0.136)	
0-10 Years Post Plague		0.143		
		(0.124)		
11-20 Years Post Plague		0.386***		
		(0.0832)		
21-30 Years Post Plague		0.493***		
		(0.0982)		
¿30 Years Post Plague		0.248***		
		(0.0703)		
0-10 Years Post Plague x Cap-Int.		0.0200		0.303
		(0.224)		(0.195)
11-20 Years Post Plague x Cap-Int.		-0.0243		0.0534
		(0.129)		(0.176)
21-30 Years Post Plague x Cap-Int.		-0.122		0.0776
		(0.123)		(0.138)
¿30 Years Post Plague x Cap-Int.		-0.107		0.0603
		(0.117)		(0.152)
Fixed Effects:				
– Area x Sector x Year	✓	✓	✓	✓
– Origin x Destination x Year			✓	✓
– Origin x Destination x Sector	✓	✓	✓	✓
– Origin x Sector x Year	✓	✓	✓	✓
Observations	132411	132411	89334	89334

Notes: Standard errors clustered at the destination level in parentheses. * p <0.10, ** p <0.05, *** p <0.01.

Details on Trade Counterfactual Back

- Export shares: $s_{ij,kt} = \frac{X_{ij,kt}}{\Sigma_i X_{ij,kt}} = \frac{A_{i,kt} w_{it}^{-\gamma\theta} d_{ij,kt}^{-\theta}}{\Sigma_i A_{i,kt} w_{it}^{-\gamma\theta} d_{ij,kt}^{-\theta}}$. Let PRE denote pre-plague, POST immediately after the plague, and t the number of years since the plague.
- Assume $\Sigma_i A_{i,kPOST} w_{iPOST}^{-\gamma\theta} d_{ij,kPOST}^{-\theta} \approx \Sigma_i A_{i,kPOST} w_{iPOST}^{-\gamma\theta} d_{ij,kPOST}^{-\theta}$. jkt fe absorb these.
- Write $s_{ij,kPOST} = \left(\frac{w_{iPOST}}{w_{iPRE}}\right)^{-\gamma\theta} s_{ij,kPRE}$. Plug in wage equation, shutting down the productivity channel, to get $s_{ij,kPOST} = \left(\frac{L_{iPOST}}{L_{iPRE}}\right)^{\kappa_2\gamma\theta} s_{ij,kPRE}$.
- Assume 40 years of recovery for regional population and exponential growth:

$$s_{ij,kt}^{c} = (1-m_i)^{\kappa_2\gamma\theta} \left(\frac{1}{1-m_i}\right)^{\frac{\kappa_2\gamma\theta t}{40}} s_{ij,kPRE} \tag{20}$$

$$= \left(\frac{L_{it}}{L_{iPRE}}\right)^{\kappa_2\gamma\theta} s_{ij,kPRE}. \tag{21}$$