You Reap What You Know: Observability of Soil Quality, and Political Fragmentation

Thilo R. Huning (Humboldt-Universität zu Berlin)
Fabian Wahl (University of Hohenheim)

Brown Bag Hohenheim
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Introduction and Overview

- We exploit political fragmentation (different size and type of states) in the late medieval Holy Roman Empire (HRE)
- **Research Questions:**
  1. Is observability of agricultural output connected to state capacity and hence can provide an explanation for different size and economic structure of states?
  2. Is it connected to the emergence of city states in during the medieval period?
- **Major contributions**:
  1. We theoretically propose a link between observability of agricultural output, tax capacity and the size of states as well as the emergence of city states.
  2. We do so by extending the principle-agent model of Mayshar et al. (2014) to capture proto-industry and warfare.
  3. Empirically, we show that differences in the observability (spatial variation) of soil quality among the territories of the HRE explain variation in political fragmentation in the HRE and the emergence of city states.

The Monstrum Germanicum: The Holy Roman Empire 1371

History: Political Fragmentation from Charlemagne to the Peace Treaty of Westphalia

- Carolingian Empire destabilized after the 9th century
- Additionally, events like the "Great Interregnum" and "Investiture Controversy" weakened central power
- Resulting high degree of fragmentation as a stable equilibrium from the 14th until the 17th century
- Innovations in military technology, overseas trade and colonialism changed the determinants of state capacity and lead to centralization tendencies (Gennaioli and Voth, 2015).

History: Political Fragmentation (Abramson, 2016)

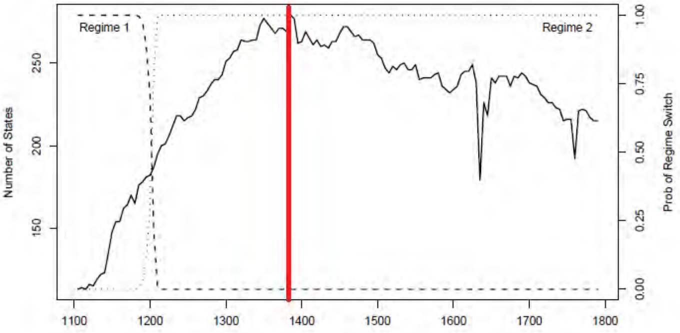

Figure II: The Number of Independent European States

Theory: Theoretical Background

- Builds on theoretical and empirical literature linking geography with institutions (Nunn and Puga, 2012; Bentzen et al., 2016), the emerge of territorial states (Tilly, 1975; Ang, 2015; Abramson, 2016) and cities (Bosker and Buringh, 2016)
- In particular, Mayshar et al. (2014) develop a micro-model of how taxation is constraint by the observability (their term: transparency) of agricultural output in a principal-agent setting

Theory: Theoretical Background

Our contribution:

1. The original by Mayshar et al. (2014) model is not testable. It only features H-L soil quality and there is no measurement proposed. We introduce a continuous theoretical variable with an empirical counterpart
2. Mayshar et al. (2014) thrive to explain differences in states' capacity to tax in Ancient times, neglecting a spatial dimension. We shift it to a highly competitive territory, aggregating the principal agent-problem on the macro-level to explain state size
3. We extend their model by explicitly modelling the emergence of cities and conflicts between states

Theory: Geography, Transparency, and Institutions

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- Mayshar et al. (2014): The state as a principal-agent problem
  - Rulers wish to extract all output from subjects
  - Soil quality is imperfectly observed, so peasants can cheat
  - The degree of observability (transparency) varies
  - Example: Egyptian Nile vs. Mesopotamian private canals
  - Bad observability allows peasants to move to cities, and cities to be defended

Theoretical Framework and General Assumptions

1. Two sector (agriculture and proto-industry) output model
2. Same technology used everywhere
3. Homogeneous military technology with no economics of scale
4. Model is static in agricultural and city (proto-industry) sector. Dynamics is introduced by waging of wars to gain new territories
5. Peasants cannot not save, while rulers optimize over an infinite time horizon
6. Population is assumed to be constant in the long-run and the only capital is soil

Optimization of Rulers

- Rulers gain income from taxes in kind from agriculture, T^{Λ}, and cities, T^{Ξ}
- There is a state ruler (principal), and two types of subjects, peasants and citizens (agents)
- Rulers maximize the tax revenue of their state over an infinite time horizon applying a common discount factor δ

$$max\left(\sum_{t=0}^{\infty}\left(\frac{T^{\Lambda}+T^{\Xi}}{(1+\delta)^{t}}\right)\right). \qquad (1)$$

Agricultural Sector

Output Y of any plot m in period t is Cobb Douglas with constant returns to scale, common technology A, input factors labor L and soil S, the latter dependent on soil quality q and the weather in t, ω_t

$$Y_{mt} = AL_{mt}^{\alpha}S_{mt}^{(1-\alpha)} \tag{2}$$

$$S_{mt} = f\left(q_m, \omega_t\right) \tag{3}$$

The input factor soil S depends on exogenous soil quality q with

$$\frac{\partial\,\mathrm{E}(Y_{mt})}{\partial q_m} > 0. \tag{4}$$

Agricultural Sector: Variations in Observability

- Weather shocks ω_t (e.g. environmental variables, like exposure to sun or rain etc.) have ambiguous and complex consequences on one-period output
- However, ω is assumed to be perfectly observable by rulers and peasants
- Hence, variations in output due to weather are static, the long-run effect of weather is zero.

$$\frac{\partial \, \mathrm{E}(Y_{mt})}{\partial \omega_t} \lessgtr 0 \qquad \lim_{t^* \to \infty} \sum_{t=0}^{t^*} \frac{\partial \, \mathrm{E}(Y_{mt})}{\partial \omega_t} = 0 \tag{5}$$

Agricultural Sector: Variations in Observability

- Long-run differences in observability of agricultural output arise from variations in the signal of agricultural output $\eta = [0, \infty)$ that is due to, e.g. terrain characteristics and spatial variation in soil types of (and the interaction of these factors).
- At $\eta = 0$, both state rulers and peasants can perfectly predict agricultural output. A higher η implies a lower observability.
- Peasants learn about S as they go, but the signal of rulers S^*_{mt} is distorted

$$S^*_{mt} \sim \mathcal{N}\left(S_{mt}, \eta_m\right) \quad (6)$$

Soil, Effort and Taxation

- State planners tax output above subsistence s according to their signal

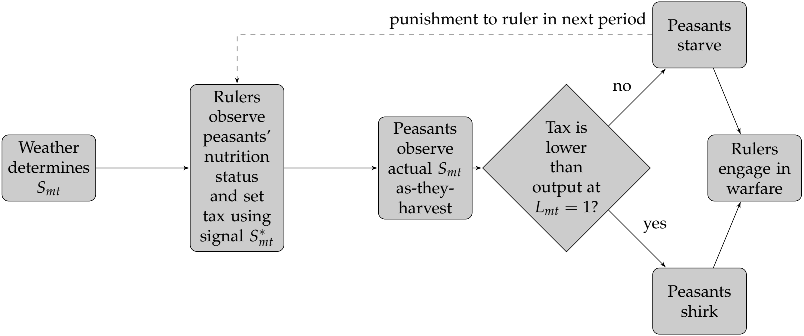
$$T_{mt} = A1^{\alpha} {S^{*}_{mt}}^{(1-\alpha)} - s. \tag{7}$$

- If peasants are undertaxed due to distortions of the noise, tax revenue is lower as peasants will shirk and reduce their efforts.

Soil, Effort and Taxation

- If peasants are overtaxed, they will starve. This is observed ex post and punished with a higher subsistence (to avoid starvation) in the next period what also will reduce the tax basis.
  $\Longrightarrow$ Combining under- and overestimation of taxable output it can be shown that a higher observability increases expected output.
  $\Longrightarrow$ States cannot benefit from a high quality of their soils if they cannot observe it.

Theoretical Framework: Graphical Representation



Cities, and City Taxes

- States can allow their subjects to move to cities and engaging in crafts.
- Crafts follow a CD production function and proto-industrial output is perfectly observable:

$$Y_{ct} = BL_{mt}, \tag{8}$$

- Transport of grain and purchases from agriculture sector come at cost $\tau > 1$
- Costs also allow grain storage and all taxes can be used to feed citizens if necessary. There is no starvation in cities and hence, taxable output is:

$$T_{ct} = BL_{mt} - \tau s_0 \tag{9}$$

Warfare

- States invest their tax income in waging wars with their neighbors
- States cannot borrow
- Each state i is geographically surrounded by a set of countries $J = \{j_1, j_2, ..\}$
- States are perfectly informed about the other states tax revenues
- Attacking any plot m comes with fix per-plot costs ψ, and variable costs Δ_m, depending on the budget of the defending state

Warfare

- State i's costs of an attack on plots M_{it} are therefore:

$$\mathrm{E}(\Psi_{M_{it}}) = \sum_{m \in M_{it}} \left[\mathrm{E}(\Delta_{mt}) + \psi_m\right] \tag{10}$$

- An attack is successful if the attacked state cannot bear the variable costs Δ_m.
- Because of perfect information, a state would only wage war over a plot m if this is the case and the war would result in the addition of m to i and a loss of j's territory.

Warfare

- The present value of attacking any plot m in t^* is

$$\sum_{t=t^*}^{\infty}\left[\frac{(\mathrm{E}(T_{mt})-\mathrm{E}(\Delta_{mt}))}{(1+\delta)^t}\right]-\frac{\mathrm{E}\left(\Psi_{mit}\right)}{(1+\delta)^{t^*}}. \tag{11}$$

WARFARE

War budget for state i under the assumption of no financial sector is given by

$$\forall t^* : \sum_{t=0}^{t^*} \Bigg[\underbrace{\frac{T_{it}}{(1+\delta)^t}}_{\text{Past income}} \underbrace{- \sum_{j \in J} \sum_{n \in N_{it} \cup M_{jt}} \left(\frac{\Delta_{jmt}}{(1+\delta)^t} \right)}_{\text{costs of past defences}} \underbrace{- \sum_{j \in J} \sum_{n \in N_{lt} \cup M_{it}} \left(\frac{\Psi_{jmt}}{(1+\delta)^t} \right)}_{\text{Costs of past attacks}} \Bigg] +$$

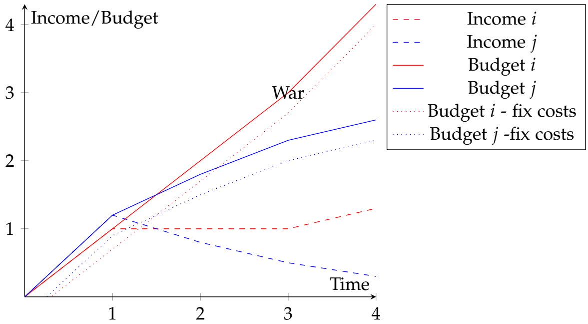
$$\underbrace{\sum_{t=t^*}^{\infty} \sum_{m \in N_{it} \cup M_{it^*}} \left(\frac{\mathrm{E}(T_{mt}) - \mathrm{E}(\Delta_{mt}))}{(1+\delta)^t} \right)}_{\text{Expected income}} - \underbrace{\frac{\sum_{t=t^*}^{\infty} \sum_{m \in M_{it}} \mathrm{E}(\Psi_{mit})}{(1+\delta)^t}}_{\text{Expected costs of defence}} \geq 0. \tag{12}$$

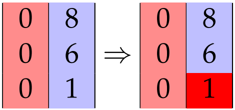
Warfare

- Optimal conquest strategy is a trade-off of between expected return of any conquered field, the neighbor's budget (expected cost of defense when conquering), and the observability of the conquered field (probability of loosing future war).
- Crucially, this implies that the expected defense cost depend on the probability of any plot being part of the conquest strategy of a neighbor j so that:

$$\frac{\partial \, \mathrm{E}(\Delta_m)}{\partial q_m} > 0 \tag{13}$$

WARFARE—ILLUSTRATION





Theorems

Theorem 1 (Observability of Soil Quality, and Capacity to Tax)

The observability of soil quality determines states' capacity to tax agricultural output

Proposition 1 (Observability of Soil Quality, and Cities)

In regions with lower soil quality, and lower soil quality observability, there will be more cities, centeris paribus.

Proposition 2 (Observability of Soil Quality and Agricultural States)

Territorial states with a higher observability of soil quality are geographically larger, ceteris paribus.

Empirical Analysis: Dependent Variable

- Dependent variables are the number of states and the borderlength (in km) per 2,500km^2 grid cell
- To be able to compute this variable we digitized a map of the territories of the HRE in 1378 from Wolff (1877).
- This maps is overlaid with the grid cells what enables to count the number of territories and the border length in each grid
- Map also contains information about the type of the territory (city state, ecclesiastical state, territorial state)
- All other control variables are also aggregated on grid cell level

Empirical Analysis: Dependent Variable

Empirical Strategy: Number of Territories

Empirical Strategy: Caloric Observability Index

- Our Caloric Observability Index is based on:
- Pre-1500 Caloric Suitability Index developed by Galor and Özak (2014, 2015)
- Robustness: Present day's Soil Suitability Index (higher spatial resolution) by Zabel et al. (2014)

Empirical Strategy: Caloric Observability

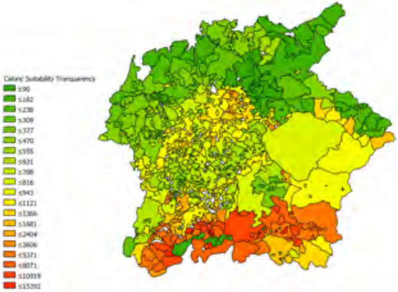
Caloric observability is computed as

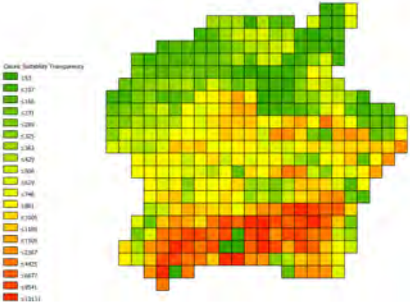
$$\sqrt{\sum_{i=r-1}^{r+1}\sum_{j=c-1}^{c+1}(s_{ij}-s_{rc})^2}, \quad (14)$$

- Proxies observability (the higher the index the lower the observability)
- Derivative of Riley et al. (1999), therefore implemented in GIS software

(r-1,c-1)	(r-1,c)	(r-1,c+1)
(r,c-1)	(r,c)	(r,c+1)
(r+1,c-1)	(r+1,c)	(r+1,c+1)

Empirical Strategy: Caloric Observability





Empirical Strategy: Estimation Approach

- Cross-sectional estimation of this equation using OLS and Poisson regression:

$$Political\,Fragmentation_{ic} = \alpha + \beta ln(COI_{ic}) + \gamma' \mathbf{X_{ic}} + \delta_c + \epsilon_{ic} \quad (15)$$

- Where X_{ic} is a vector of control variables and δ_c are 250,000 km^2 grid cell fixed effects.

Baseline Results

Dep. Var.	Number of Territories					
	(1)	(2)	(3)	(4)	(5)	(6)
ln(Caloric Observability)	0.330***	0.306***	0.391***	0.339***	0.5174***	0.4737***
	(0.103)	(0.118)	(0.115)	(0.117)	(0.0966)	(0.107)
Longitude			-0.002	-0.0019	0.0006	0.0005
			(0.000)	(0.000)	(0.000)	(0.000)
Latitude			-0.0000	0.0015	0.0012	0.0016
			(0.000)	(0.000)	(0.000)	(0.000)
Elevation				0.00542***	0.00403***	0.00476***
				(0.001)	(0.001)	(0.001)
Terrain Ruggedness				-0.0127***	-0.0129***	-0.0130***
				(0.003)	(0.003)	(0.003)
Roman Roads (km)					0.00536	0.00521
					(0.004)	(0.004)
Rivers (km)					-0.00401	-0.00387
					(0.003)	(0.003)
Ecclesiastical States					1.659***	1.656***
					(0.119)	(0.120)
Battles					0.462	0.463
					(0.535)	(0.539)
ln(Caloric Suitability (Pre-1500))						0.583
						(0.710)
500 km Grid Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Observations	385	385	385	385	385	385
R^2	0.014	0.302	0.306	0.337	0.614	0.615

Empirical Strategy: Predicting City States

- Test whether caloric observability significantly predicts city states we estimate the following equation:

$$City_{ic} = \alpha + \beta ln(COI_{ic}) + \gamma' \mathbf{X_{ic}} + \delta_c + \epsilon_{ic}, \tag{16}$$

- $City_{ic}$ being either a “City State” dummy or the “Number of City States” variable.

Results: Border Length

Dep. Var.	Border-Length (km)					
	(1)	(2)	(3)	(4)	(5)	(6)
ln(Caloric Observability)	15.16***	16.60***	19.67***	24.55***	20.18***	19.65***
	(5.215)	(6.244)	(6.308)	(6.411)	(5.305)	(5.635)
Longitude			-0.135*	-0.132*	-0.0227	-0.0240
			(0.072)	(0.069)	(0.0527)	(0.052)
Latitude			0.0982	0.167**	0.143**	0.147**
			(0.0748)	(0.0728)	(0.063)	(0.069)
Elevation				0.222***	0.158***	0.165**
				(0.063)	(0.049)	(0.069)
Terrain Ruggedness				-0.479***	-0.473***	-0.474***
				(0.161)	(0.131)	(0.132)
Roman Roads (km)					0.175	0.174
					(0.168)	(0.168)
Rivers (km)					-0.228	-0.227
					(0.162)	(0.163)
Ecclesiastical States					74.57***	74.54***
					(6.092)	(6.098)
Battles					37.17	37.18
					(22.66)	(22.70)
ln(Caloric Suitability (Pre-1500))						5.878
						(31.06)
500 km Grid Fixed Effects	No	Yes	Yes	Yes	Yes	Yes
Observations	385	385	385	385	385	385
R^2	0.013	0.250	0.263	0.287	0.537	0.537

Results: Agricultural Observability and City States

Dep. Var.	City State				Number of City States			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Method	OLS		Probit		OLS		Poisson	
Standard Errors	Robust	Clustered	Robust	Robust	Robust	Clustered	Robust	Robust
ln(Caloric Observability)	0.0344***	0.0344**	0.118***		0.0460**	0.0460**	0.453	
	(0.011)	(0.015)	(0.042)		(0.021)	(0.018)	(0.305)	
ln(LSA Observability)				0.0928*				0.447*
				(0.049)				(0.255)
500 km Grid Fixed Effects	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Full Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	385	385	318	318	385	385	385	385
R^2 or Pseudo R^2	0.275	0.275	0.252	0.269	0.278	0.278	0.314	0.339

Results: Robustness

Dep. Var.	Number of Territories			Border-Length (km)	Number of Territories			Border-Length (km)	Number of Territories
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Robustness Check	More grid fixed effects		Clustered Standard Errors		Poisson Regression	Alternative Transparency Measure			Accounting for Climate Change
Method	OLS				Poisson	OLS	Poisson	OLS	
ln(Caloric Transparency)	0.448***	0.448***	0.474***	25.92***	0.104***				0.450***
	(0.149)	(0.149)	(0.170)	(9.214)	(0.03)				(0.127)
ln(Soil Transparency)						0.178	0.135**	25.87**	
						(0.237)	(0.06)	(12.31)	
500km Grid Fixed Effects	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
200km Grid Fixed Effects	Yes	Yes	No	No	No	No	No	No	No
Full Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	385	385	385	385	385	385	385	385	385
R^2 Pseudo R^2	0.633	0.633	0.410	0.363	0.19	0.439	0.212	0.411	0.408

Conclusion

- We transpose the theoretical model by Mayshar et al. (2014) to aggregated outcomes, namely state size and extend it to capture warfare and proto-industry.
- Based on a uniquely detailed map of the HRE we construct a measure of observability of agricultural output to test the model
- Observability of agricultural output, via its impact on taxation capacity and political structure of states was an important determinant of state size in pre-modern Europe.

Conclusion

- Observability of agricultural output fostered the emergence and growth of city states and hence Europe's unique urban network.
- Results suggest an almost unexplored interaction between agriculture and geography in explaining political and economic outcomes.

Thank you!

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