The Effect of the TseTse Fly on African Development

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Overview

- This paper explores how an endowment affects agricultural productivity and long-run development
- TseTse is an insect that is unique to Africa and causes disease in livestock and humans
- This paper provides support for the hypothesis that the TseTse hindered the ability of precolonial Africans to adopt agricultural technologies, leading to low population density and weak/extractive institutions
- There is also evidence that TseTse continues to affect modern African development through its effect on historical institutions

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    - Institutions$\rightarrow$ labor coercion (Hopkins) and weakened state development (Herbst)
- The role of TseTse has not been empirically investigated

TseTse: Hypothesized Role

- "It seems reasonable to suppose that for hundreds of years, the tsetse dictated that the economy of the African be based on the hoe and the headload, a dictatorship which he is now being freed by the petrol engine and the railway locomotive." *T.A.M. Nash (1969)*

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- "though the argument about the tsetse fly is obviously relevant, it can only be a very partial solution to the puzzle" *Chaves Engerman & Robinson (2010)*

Contribution

- First empirical examination of the effect of the TseTse fly on historical African development
- How did the TseTse affect precolonial (circa 19th century) Africa?
  - Agricultural Technologies (domesticated animals, plow use)
  - Subsistence Patterns (hunting and gathering, animal husbandry, extensive vs. intensive farming)
  - Urbanization (population density, cities)
  - Institutions (political centralization, coerced labor)
- Does the TseTse fly still affect economic outcomes today?

Outline

- Biology of the Fly
  - Identification (Insect Physiology$\rightarrow$ *TSI*)

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  - Placebo test
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  - Placebo test
  - Simulation
- Data and Empirics for Modern Africa

TseTse Fly

- Blood-sucking insect vector
  - **Only in Africa**
- Manifestations of *Trypanosomiasis*
  - Untreated, fatal to domesticated animals (*nagana*) and humans (sleeping sickness)
  - Livestock more affected than humans ▸ Ox Bait
  - Habitat is in fertile areas ▸ Habitat

Identification Strategy

- Develop a TseTse suitability index (TSI)
  - based on laboratory experiments on the fly
  - specific relationships between TseTse survival and temp/humidity
  - standard exponential population growth model with density dependent mortality→steady state fly population at ethnic group level
  - historical climate data
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- TSI is therefore interaction of specific nonlinearities in climate
- Placebo test to show TSI is not correlated with same outcomes in the Tropics outside of Africa

Model of TseTse Fly Population Growth

▸ Insect Physiology

- Λ : constant exponential growth in the absence of competition

$$\Lambda = B - M$$

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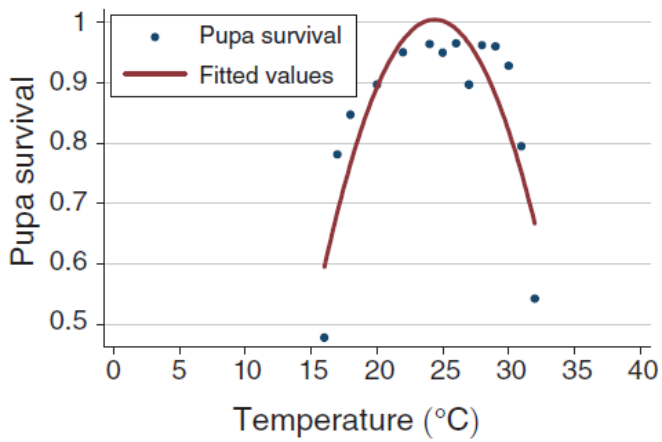
- Parameter values from May et al., (1974): $(0 < \psi < 2)$

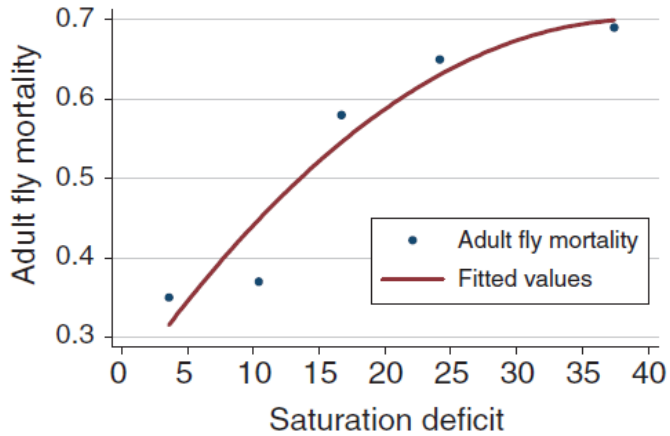
TseTse Physiology

▸ growth

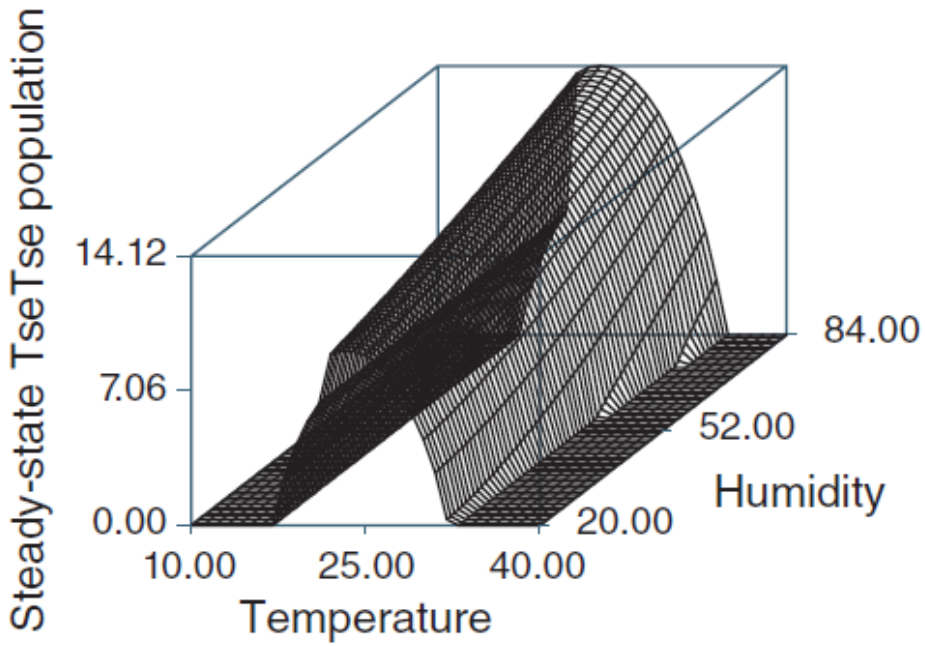
Panel A. Pupa survival and temperature



Panel B. Adult fly mortality and saturation deficit



TseTse Steady State Population



- TSI (TseTse Suitability Index)=Z-score of the fly population

Historical TSI

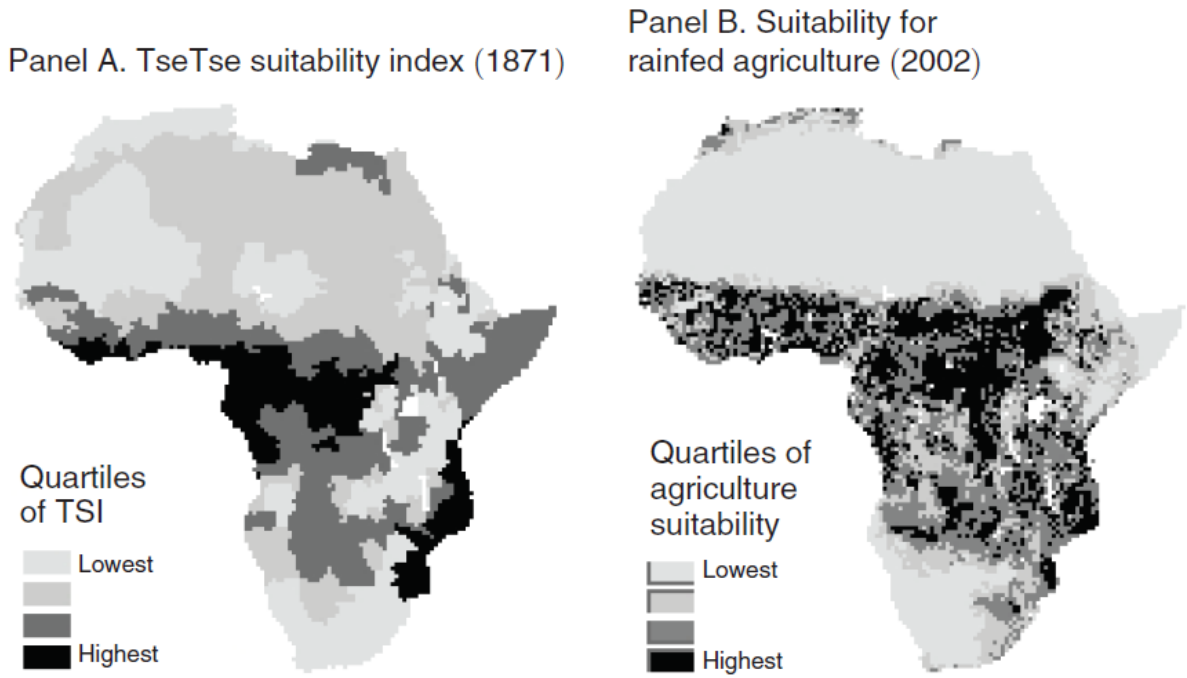


FIGURE 3. TSETSE SUITABILITY INDEX AND THE SUITABILITY FOR RAINFED AGRICULTURE

Notes: Panel A shows the historical TseTse suitability index created using climate data from NOAA's 20th Century Reanalysis for the year 1871. Panel B shows the suitability for rainfed agriculture (FAO 2002).

Channels

1. influence subsistence patterns
   - population density, settlement structure, occupational specialization
2. $\uparrow$ transport/trade costs
3. $\downarrow$ labor productivity

Main Historical Data Source

- Precolonial Africa, few written records (indigenous writing systems)
- *Ethnographic Atlas*
  - 533 groups in Africa
  - Meant to capture indigenous characteristics of ethnic groups
  - Join with *Murdock's Map* of Africa (843 ethnic groups)
  - Observations mostly from 19th or early 20th century
  - Outcomes mainly binary
  - Population density estimates
- Chandler *Four Thousand Years of Urban Growth : An Historical Census*
  - Location of urban centers in 1800 with $\geq$ 20,000 inhabitants

Empirical Framework: Historical Analysis

$$y_j = \alpha_0 + \delta TSI_j + \mathbf{X}_j'\Omega + \varepsilon_j$$

- Unit of analysis is ethnic group (j)
- Focus on reduced form
  - comparability with outside of Africa (placebo)
  - lack of historical TseTse map
- $\mathbf{X}_j'$ vector of plausibly exogenous control variables that may explain African agricultural productivity
  - tropical climate: absolute latitude, proportion of land area in the Tropics
  - climate variables: rel hum, temp, first-order interaction
    ▸ Steady State
  - access to waterways: river & coast
  - altitude: free from insects, slave raiders and more rainfall
  - malaria: Sach's malaria ecology index
  - soil constraints: FAO ag suitability index ▸ Correlation

Baseline Historical Results: Overview

	(1)	(2)	(3)	(4)	Obs.	No. clusters	Sample mean
Panel A. Agriculture							
Large domesticated animals	−0.216*** (0.044)	−0.221*** (0.046)	−0.210*** (0.045)	−0.231*** (0.042)	484	44	0.626
Intensive agriculture	−0.092*** (0.028)	−0.079** (0.031)	−0.083*** (0.029)	−0.090*** (0.028)	485	44	0.320
Plow use	−0.052** (0.021)	−0.055** (0.023)	−0.052** (0.022)	−0.057** (0.023)	484	44	0.076
Female participation in agriculture	0.254*** (0.053)	0.226*** (0.053)	0.214*** (0.054)	0.206*** (0.060)	315	43	0.489
Panel B. Urbanization							
log population density (Murdock)	−0.880*** (0.272)	−0.828*** (0.256)	−0.802*** (0.244)	−0.745*** (0.229)	398	43	1.700
Panel C. Institutions							
Indigenous slavery	0.095** (0.040)	0.109** (0.043)	0.105** (0.043)	0.101** (0.040)	446	44	0.848
Centralization	−0.058 (0.035)	−0.076** (0.035)	−0.075** (0.035)	−0.075** (0.035)	467	44	0.334
Climate controls	Yes	Yes	Yes	Yes			
Malaria controls	No	Yes	Yes	Yes			
Waterway controls	No	No	Yes	Yes			
Geography controls	No	No	No	Yes			

Baseline Historical Results

Preferred Specification: Agriculture

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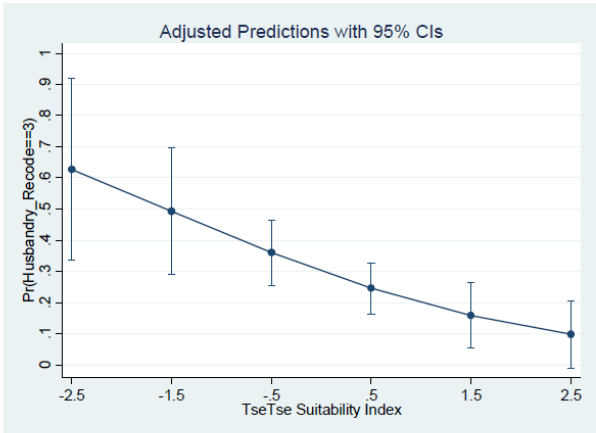
Subsistence Agriculture and TseTse Fly

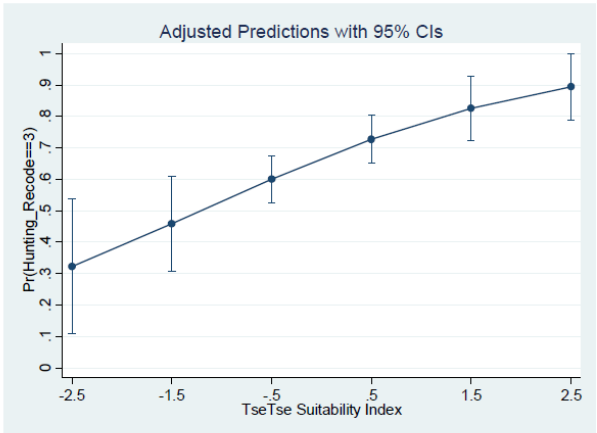
	Husbandry (1)	Hunting (2)	Gathering (3)	Agriculture (4)	Fishing (5)
TSI	−0.373**	0.216***	0.170**	0.046	−0.060
	(0.164)	(0.073)	(0.084)	(0.191)	(0.082)
Malaria ecology index	−0.005	−0.005	0.013	0.002	−0.005
	(0.019)	(0.006)	(0.009)	(0.020)	(0.014)
Observations	522	522	522	522	522
Number clusters	44	44	44	44	44
R^2	0.436	0.121	0.101	0.269	0.163

Subsistence Agriculture and TseTse Fly

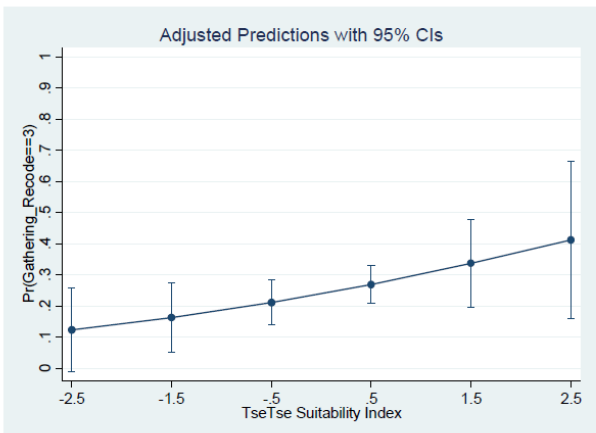
A. Husbandry



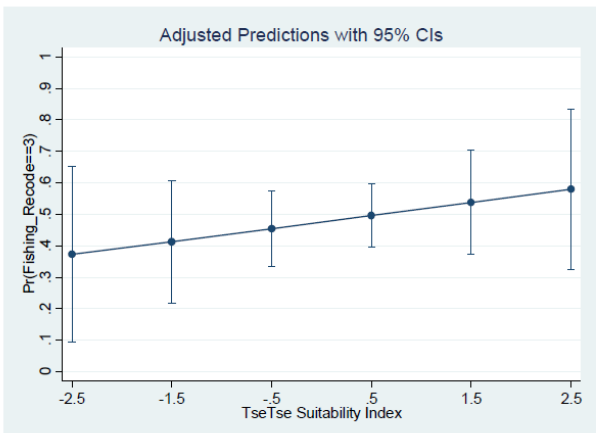
B. Hunting



C. Gathering



D. Fishing



Notes: These graphs show the relationship between TseTse suitability and subsistence patterns. The predicted probability that an ethnic group falls into the top quartile of dependence on a given subsistence strategy is plotted along with the 95 percent confidence interval after estimation using an ordered logit.

Baseline Historical Estimates: Robustness Tests

1. Perturbations to the TSI formula

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Baseline Historical Estimates: Robustness Tests

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4. Parameters in TSI - (sensitivity analysis)
5. Different Modes of Statistical Inference (Conley 10 lat/lon, cluster country, Multiway clustering)

Robustness Tests

	Alternative TseTse indices					Alternative clustering		
	Perturb TSI shift left (1)	Perturb TSI shift right (2)	Intrinsic rate of growth (3)	Box-plot (4)	Optimal TseTse conditions (5)	Conley SE (6)	SE clustered by country (7)	Multiway clustering (8)
Panel A. Agriculture								
Large domesticated animals	0.016	0.008	−1.392***	−0.009***	−0.367***	−0.231***	−0.231***	−0.231***
	(0.066)	(0.083)	(0.258)	(0.002)	(0.077)	(0.040)	(0.039)	(0.037)
Intensive agriculture	0.024	0.022	−0.567***	−0.004***	−0.127**	−0.090***	−0.090***	−0.090***
	(0.038)	(0.048)	(0.174)	(0.001)	(0.059)	(0.030)	(0.030)	(0.023)
Plow use	−0.021	0.013	−0.325**	−0.002***	−0.044**	−0.057*	−0.057*	−0.057*
	(0.013)	(0.035)	(0.142)	(0.0009)	(0.022)	(0.031)	(0.032)	(0.031)
Female participation in agriculture	−0.079	−0.055	1.241***	0.008***	0.265***	0.206***	0.206***	0.206***
	(0.055)	(0.070)	(0.363)	(0.002)	(0.060)	(0.041)	(0.047)	(0.058)
Panel B. Urbanization								
log population density (Murdock)	−0.293	−0.229	−4.479***	−0.029***	−0.663**	−0.745***	−0.745***	−0.745***
	(0.225)	(0.291)	(1.415)	(0.009)	(0.284)	(0.197)	(0.199)	(0.234)
Panel C. Institutions								
Indigenous slavery	0.020	0.029	0.619**	0.004**	0.100*	0.101**	0.101**	0.101**
	(0.040)	(0.055)	(0.242)	(0.002)	(0.054)	(0.039)	(0.040)	(0.040)
Centralization	0.029	−0.004	−0.464**	−0.003**	−0.004	−0.075*	−0.075**	−0.075**
	(0.060)	(0.084)	(0.214)	(0.001)	(0.058)	(0.043)	(0.036)	(0.035)

Baseline Historical Estimates: Export Slavery

- Clearly trade between Europeans and Africans would have been a source of influence
- Export slave trade could have led to depopulation and war, decentralization
- Possible omitted variable bias can be corrected by including estimates of number of slaves exported as a control

Dependent Variable	Export Slave Trade
Urbanization	
Log Population Density	–0.741***
	(0.224)
Institutions	
Indigenous Slavery	0.100**
	(0.042)
Centralization	–0.075**
	(0.036)

Placebo

- TseTse only in Africa; so TSI, conditional on same variables, should not make similar predictions in the Tropics outside of Africa
- Challenge is that map with ethnic group boundaries only exists for Africa

Ethnographic Atlas Centroids

Thiessen Polygons

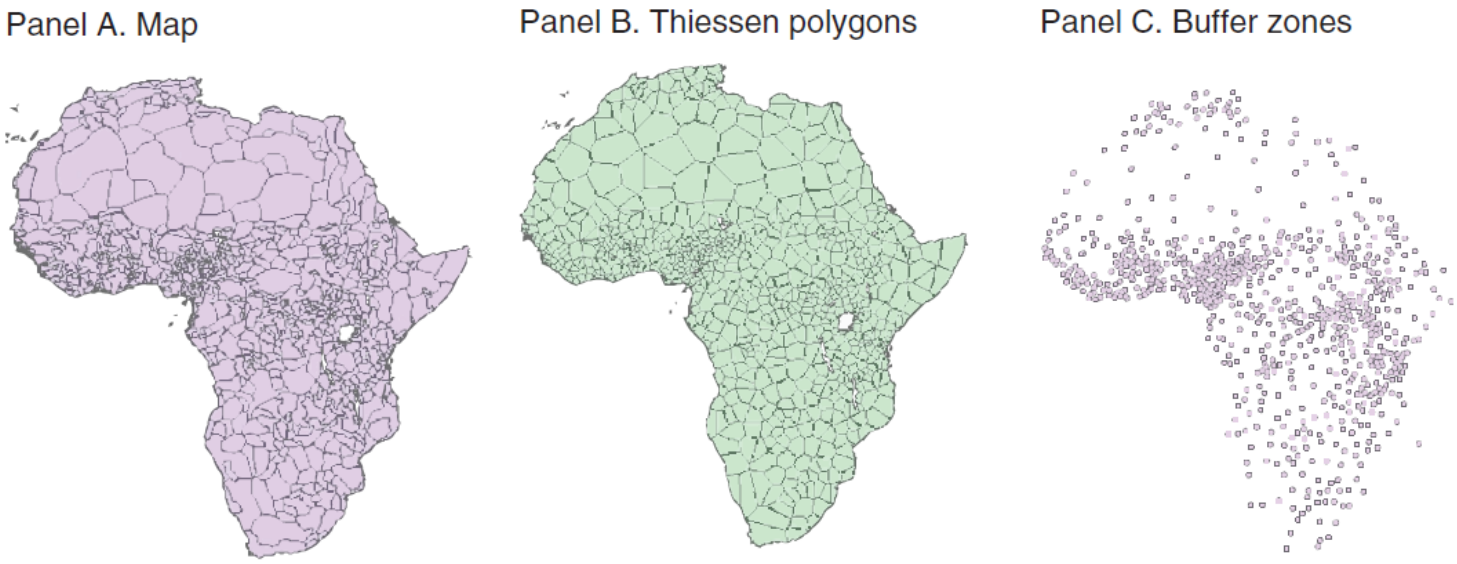


FIGURE 5. THIESSEN POLYGONS

Note: This figure compares the Murdock (1959b) map of ethnic groups in panel A with the constructed Thiessen polygons in panel B and with the buffer zone approach in panel C.

Map vs. Polygon Coefficient

TABLE 4—COMPARISION OF MURDOCK MAP AND THIESSEN POLYGON COEFFICIENTS
(*Tropics only*)

	Map (1)	Polygon (2)	Difference (3)
Panel A. Agriculture			
Large domesticated animals	−0.269***	−0.177***	−1.260
	(0.048)	(0.055)	
Intensive agriculture	−0.114***	−0.090**	−0.451
	(0.034)	(0.041)	
Plow use	−0.034	−0.0007	−1.020
	(0.021)	(0.025)	
Female participation in agriculture	0.230***	0.208***	0.230
	(0.064)	(0.071)	
Panel B. Urbanization			
log population density (Murdock)	−0.519**	−0.429**	−0.321
	(0.212)	(0.183)	
Panel C. Institutions			
Indigenous slavery	0.096**	0.102**	−0.094
	(0.040)	(0.050)	
Centralization	−0.091**	−0.106**	0.244
	(0.043)	(0.044)	

Placebo Test

- Expand sample to include outside of Africa
- TSI : main effect represents average effects across all geography
- $TSI \cdot I_j^{Africa}$: interaction, represents the differential effect of the TSI in Africa
- Include $I_j^{Africa}\mathbf{X}_j'$: Africa allowed to differ from the rest of the Tropics in many ways, not just the TSI

Placebo Test: Results

TABLE 5—PLACEBO TEST

	Main effect TSI (β) (1)	Africa interaction TSI (δ) (2)	Africa total TSI ($\beta+\delta$) (3)
Panel A. Agriculture			
Large domesticated animals	0.036	−0.214***	−0.177***
	(0.030)	(0.039)	(0.029)
Intensive agriculture	−0.015	−0.075*	−0.090***
	(0.041)	(0.043)	(0.022)
Plow use	0.069**	−0.070*	−0.0007
	(0.030)	(0.035)	(0.019)
Female participation in agriculture	−0.039	0.247***	0.208***
	(0.065)	(0.088)	(0.063)
Panel B. Institutions			
Indigenous slavery	−0.003	0.105**	0.102***
	(0.042)	(0.049)	(0.020)
Centralization	0.010	−0.116**	−0.106**
	(0.027)	(0.051)	(0.049)

Africa without the TseTse?

Great Zimbabwe *"peninsula in a sea of TseTse"* Garlake (1978)

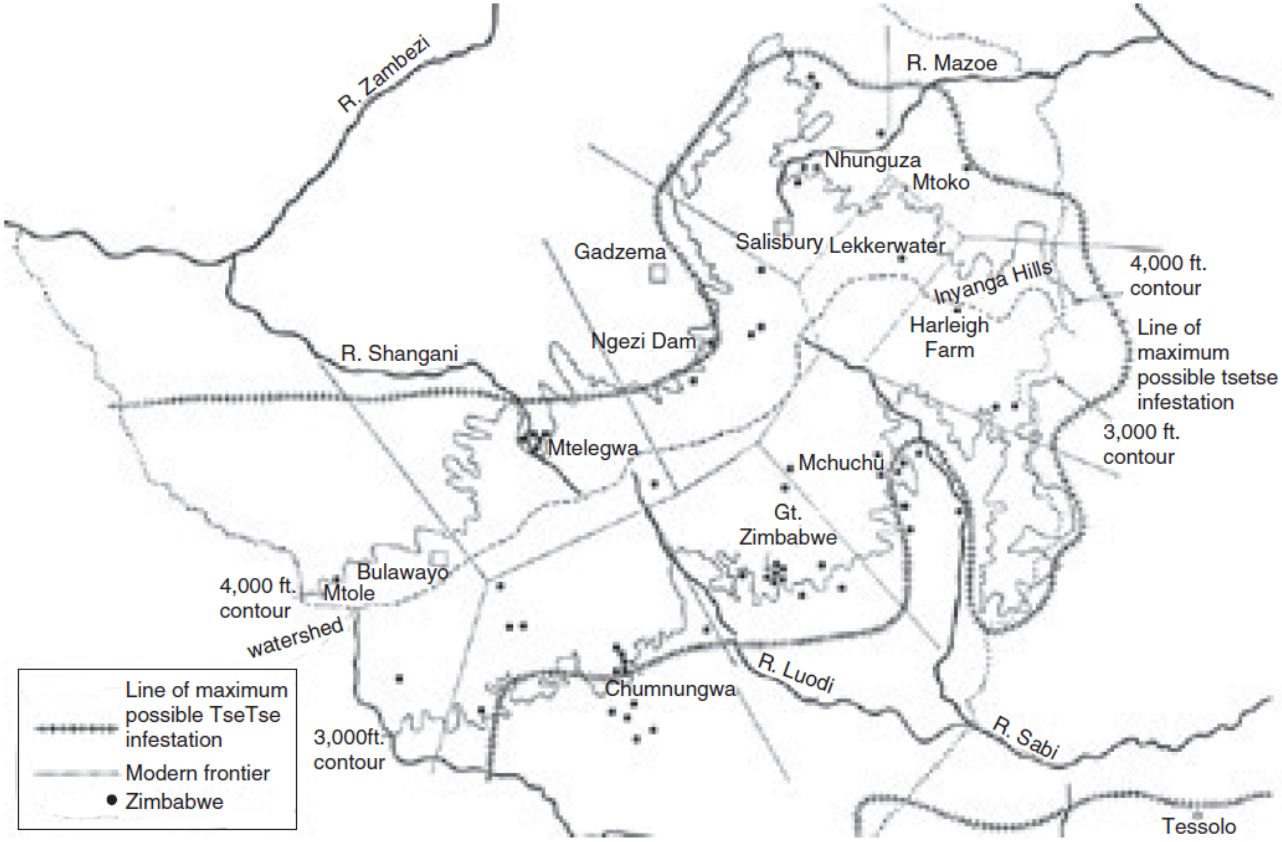


FIGURE 6. MAP OF GREAT ZIMBABWE

Notes: This figure demonstrates the overlap between the boundaries of Great Zimbabwe and the line of maximum possible TseTse infestation. The figure is used with permission from Garlake (1978). The hatched line indicates the line of maximum possible TseTse infestation as described by Oxford zoologists David Rogers and Sarah Randolph. The black dots represent the *zimbabwe*—stone enclosures indicative of human settlement.

TseTse and Current Development

- Approach
  - is there a correlation between TSI and current economic performance
  - if so, is this relationship robust to adding controls for historical institutions affected by the fly
- Outcomes
  - Satellite Light Density (2008)
  - Cattle Density (2005)

Modern TseTse: Empirical Framework

- Construct a district-level measure of the fraction of population whose ancestors practiced slavery or lived in a centralized ethnic group

$$\begin{aligned} Institution_c^i &= \frac{\sum_j L_{j,d,c} \cdot \mathbf{I}_j^i}{L_{d,c}} \\ i &\in \{centralization, slavery\} \end{aligned}$$

  - $\mathbf{I}_j^i$ is an indicator variable equal to one if ethnicity j was historically characterized by institution i and zero otherwise
  - $L_{j,d,c}$ is the number of inhabitants of country c in district d that are of ethnicity j
    - mapped groups to their current location using the *Ethnologue*

Economic Development and the TseTse

TABLE 7—REDUCED-FORM ESTIMATES OF THE RELATIONSHIP BETWEEN MODERN ECONOMIC DEVELOPMENT AND TSETSE SUITABILITY

	(1)	(2)	(3)	(4)	(5)
Panel A. Dependent variable is the log mean luminosity					
TSI	–0.480**	–0.441*	–0.744***	–0.452*	–0.296
	(0.236)	(0.234)	(0.228)	(0.252)	(0.246)
Historical centralization					1.083***
					(0.247)
Panel B. Dependent variable is the log number of cattle					
TSI	–1.270**	–1.172**	–1.491***	–0.639*	–0.648*
	(0.473)	(0.447)	(0.390)	(0.320)	(0.323)
Historical centralization					–0.060
					(0.319)
Climate controls	Yes	Yes	Yes	Yes	Yes
Malaria index	No	Yes	Yes	Yes	Yes
Other geographic controls	No	No	Yes	Yes	Yes
Country fixed effects	No	No	No	Yes	Yes
Observations	665	665	665	665	665
Number clusters	48	48	48	48	48

Conclusion

- Investigated the effect of the TseTse on historical African development
- Created a TSI using insect physiology and fly population growth model
- TSI correlated with "backward" agricultural technologies, low population density and extractive/weak institutions within but not outside of Africa
- Simulation and archaeological record suggests Africa would have been more similar to rest of Old World without the fly
- Economic development appears to be affected by the fly through the channel of precolonial centralization

Ox Bait

▸ fly

TseTse Suitability and Agricultural Suitability

fly

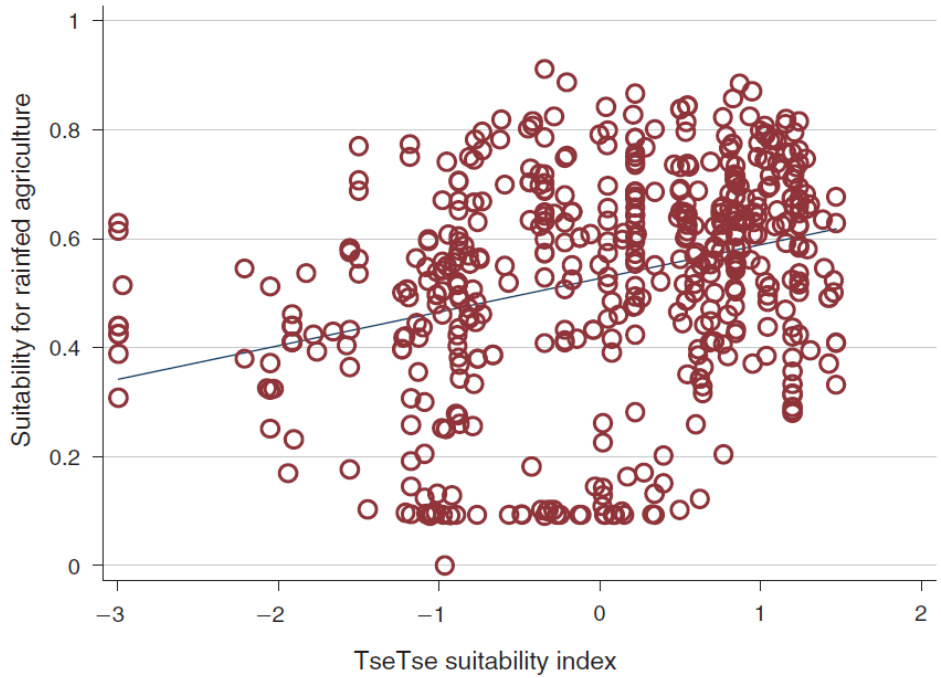
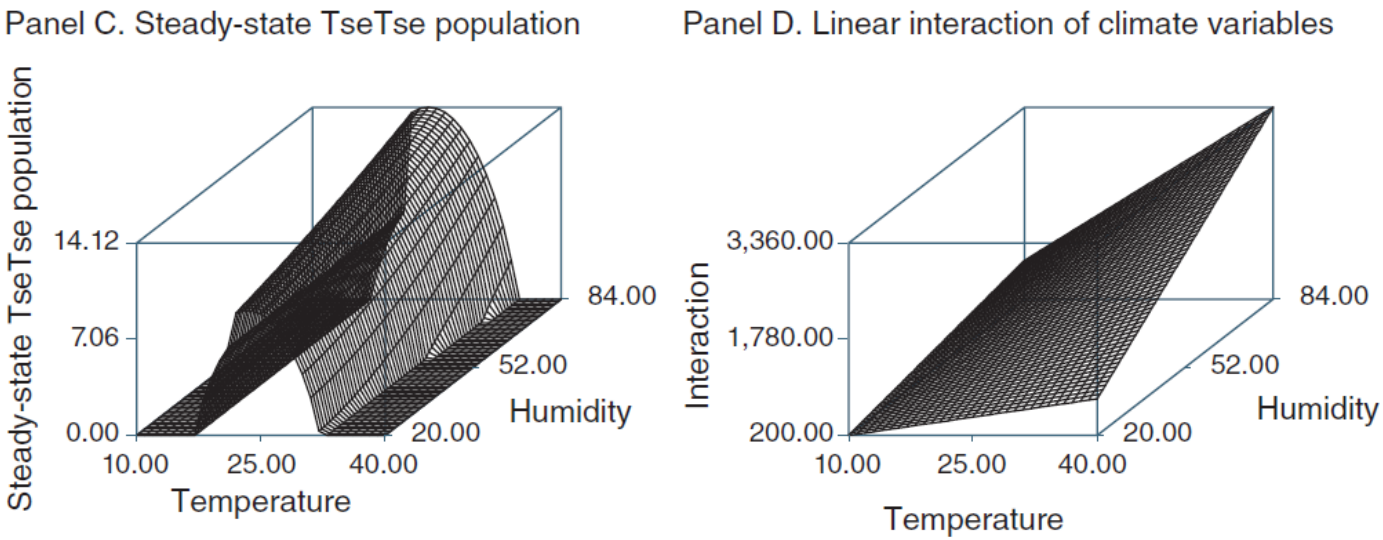


FIGURE 1. AGRICULTURAL SUITABILITY VERSUS TSETSE SUITABILITY (*African ethnic groups*)

Notes: This figure demonstrates the correlation between agricultural suitability and TseTse suitability. Data on agricultural suitability for rainfed crops are from the FAO Global Agro-Ecological Zones (2002). Details on the FAO methodology can be found in online Appendix B. The TseTse suitability index (TSI) is based on the author's calculations using climate data from the National Oceanic and Atmospheric Administration's (NOAA) 20th Century Reanalysis (1871). The equations for the TSI can be found in online Appendix C, Table C.I.

Steady State Fly Population

▸ empirics



Correlation

▸ empirics

	TSI	Temp	RH	Itx	Mal 1900	Mal Ecology	Abs Lat	Longitude	River	Coast	Alt	Ag Suit	Prop Tropics
Historical TSI	1.00												
Historical Temperature	0.38	1.00											
Historical RH	0.36	–0.45	1.00										
Interaction	0.67	0.04	0.87	1.00									
Malaria 1900	0.41	0.24	0.41	0.59	1.00								
Malaria Ecology Index	0.39	0.70	0.00	0.37	0.45	1.00							
Absolute Latitude	–0.40	–0.08	–0.52	–0.61	–0.52	–0.25	1.00						
Longitude	–0.21	–0.46	0.14	–0.10	–0.20	–0.38	–0.22	1.00					
River	0.10	–0.05	0.19	0.18	0.18	0.12	–0.11	0.03	1.00				
Coast	0.04	0.00	0.06	0.07	–0.12	–0.16	0.30	–0.21	–0.03	1.00			
Mean Altitude	–0.34	–0.53	0.00	–0.29	–0.26	–0.50	0.04	0.43	0.12	–0.19	1.00		
Agricultural SI	0.31	0.15	0.38	0.51	0.56	0.49	–0.43	–0.07	0.18	–0.15	–0.23	1.00	
Proportion Tropics	0.33	0.36	0.18	0.36	0.39	0.37	–0.77	0.09	0.08	–0.32	–0.10	0.36	1.00