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Epidemic disease and innovation

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ABSTRACT

It is well-documented that the TseTse fly, which transmits an epidemic disease lethal to livestock, has precluded technology adoption in Africa. In this study, we systematically examine the impact of the TseTse fly on firm innovation in modern Africa. Exploiting newly georeferenced firm data across the world, we find that firms in places that satisfy the TseTse survival conditions are less likely to innovate, and this relationship is unique to Africa and more pronounced in industries with higher innovation intensity. Exploring the channel, we find that people hold more hostile attitude towards technology in historically heavily infested areas.

1. Introduction

Infectious disease is a key determinant of economic development in Africa.[1] In a recent study, Alsan (2015) examines the impact of the precolonial prevalence of the TseTse fly, which transmits an epidemic disease harmful to humans and lethal to livestock, on modern development in Africa. She documents a negative, economically significant relationship between the TseTse fly[2] and current economic performance, and argues that the operating channel through which the fly has exerted impact on Africa's development today is precolonial political centralization. While insightful, the analysis is restricted to political institutions in the precolonial period. Whether the TseTse fly has triggered a cultural change that helps explain Africa's development today remains a question.

In this paper, we contribute to this line of inquiry by examining the impact of the TseTse fly on people's attitude towards technology and firm innovation in modern Africa. Combining the TseTse suitability index (TSI) from Alsan (2015) with a newly georeferenced dataset on firm innovation and the World Value Survey (WVS), we investigate (a) whether the TseTse has triggered a culture of hostility towards technology in infested areas, and (b) whether such culture negatively affects firm's propensity to innovate today.[3] Given that innovation is one of the most important drivers of growth (e.g., Solow, 1957; Romer, 1990; Mokyr, 1992; Aghion and Howitt, 1992; Kogan et al., 2017), the TseTse fly may have affected African development through a culture of hostility towards technology and innovation.

Three influential lines of research frame our hypothesis of how the TseTse fly has shaped firm innovation in modern Africa. First, it

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[1] For example, see Bloom and Sachs (1998), Gallup and Sachs (2001), Sachs and Malaney (2002), Alsan (2015), and Lowes and Montero (2021).

[2] We use the TseTse fly, the fly and the TseTse interchangeably throughout the text.

[3] Since Africa is not at the technology frontier, firm innovation in Africa is mostly about imitation and technology adoption (see, e.g., Acemoglu, Aghion, and Zilibotti 2006; Ayyagari, Demirgüç-Kunt, and Maksimovic, 2011; Bircan and De Haas, 2020).

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is well-documented that the TseTse has affected Africa's ability to adopt technologies (e.g., Johnston, 1894; Law, 1977). For example, McPhee (1926) notes that the disease transmitted by the TseTse fly has prevented the use of draught animals and thus has impeded the adoption of more advanced transportation technologies, such as four-wheeled carriages and motorable roads. Nash (1969) documents that the TseTse has precluded the use of domesticated animals in agriculture and therefore has prevented the adoption of complementary technologies including the plough, harnessing, waterpower, and fertilizer.

The second line of research from cultural anthropology suggests that in the environment where the TseTse has severely impaired the ability of technology adoption, a culture of hostility towards technology may have evolved. As emphasized by Boyd and Richerson (1985, 1995), when information acquisition is imperfect, the use of heuristic decision-making, or what Nunn and Wantchekon (2011) call "rule of thumb", can yield optimal payoff. Relating this insight to our study, we argue that in places heavily exposed to the TseTse fly in the precolonial period, norms of being hostile towards technology likely yielded higher payoff than norms of being welcoming towards technology adoption.[4] As a result, the hostile norms towards technology over time would have become more prevalent.[5] An et al. (2022), using data from multiple sources, show evidence consistent with this hypothesis.

Lastly, an influential strand of economic literature stresses that culture, once formed, can be very persistent (e.g., Giuliano and Nunn, 2021). For example, Nunn and Wantchekon (2011) find that the transatlantic and Indian Ocean slave trades have triggered a culture of mistrust in Africa, which has persisted to today. Levine et al. (2020) and Pierce and Snyder (2018) discover that such culture still has large, negative ramifications on the function of modern financial markets. In addition, Alesina et al. (2013) show that the adoption of the plough centuries ago has generated a culture of gender inequality. They further show that such biased gender norms have persisted to modern society, with negative repercussions on female labour participation rates.[6] We thus conjecture that the TseTse fly may have caused a culture of hostility towards technology, and such culture may have persisted to today with a negative impact on firm propensity to innovate.[7]

To conduct our study, we firstly obtain data on the precolonial prevalence of the TseTse fly from Alsan (2015). Alsan (2015) provides d'ata on TSI for all ethnic locations in Africa, and those outside of Africa but within the Tropics of Capricorn and Cancer.[8] We then obtain firm-level information from the World Bank Enterprise Survey (WBES) and georeference firm locations to merge with ethnic location-level TSI. This allows the inclusion of country fixed effects in our analysis, which eliminate all country-level time--invariant confounding factors (e.g., the quality of institutions) that may influence firm innovation today (Donges et al., 2023). In some specifications, we are even able to control for ethnic location fixed effects, which help identify the impact of the TseTse fly on firm innovation independent of precolonial political centralization (measured at the ethnic location-level). This is important because Schapera (1967, 1970) argues that centralized societies are quicker in adopting Western technologies. To examine the relationship between the TseTse fly and people's attitude towards technology today, we link the ethnic-group level TSI index to World Value Survey (WVS) data by matching respondents' self-reported mother tongue from the WVS with ethnicities documented in the Ethnographic Atlas.

We summarize our results as follows. We find that the TseTse fly has had a negative impact on firm innovation. In particular, a one standard deviation increase in the TSI is associated with a 9.4 percentage points reduction in firm's propensity to introduce a new product to market, and a 10 percentage points decrease in the probability of introducing a new process, while the sample average probabilities of new product and new process introductions are 42% and 44%, respectively. These results are obtained when we include country and year fixed effects, and a large vector of firm covariates. We also find suggestive evidence that the TseTse fly has indeed changed people's attitude towards technology. Particularly, when asked about the extent to which they agree with the statement "the world is a better place with technology", respondents from high-TSI countries are less likely to give a high score (corresponding to a higher level of agreement), and such effect is mitigated by cultural discontinuity measured by climate instability (Giuliano and Nunn, 2021).

[4] For example, in the TseTse infested places, hunting and gathering yielded higher payoff in terms of the probability of survival than intensive agriculture because (a) large domesticated animals, which were essential for agriculture, could not be used, and (b) wild animals (for hunting) are largely immune to the TseTse fly due to wild game (Nash, 1969; Alsan, 2015). As another example, overland transportation by head porterage in the infested areas yielded higher payoff on average than large animals with four-wheeled carriage because large animals often fell ill and died before and during transportation (McPhee, 1926).

[5] In a related study, An, Hou, and Lin (2020) find that in historically TseTse-infested places, people are less likely to be prepared to learn new technologies to manage their finances.

[6] An (2020) finds that the biased gender norms generated by the adoption of the plough have distorted the function of informal financial markets today. He shows that manufacturing firms that hire a larger proportion of female employees have less access to trade credits when the biased gender norms are more prevalent.

[7] A related hypothesis arises from the medical camps sent by the colonial powers during the colonial period to cure and prevent the sleeping sickness, the disease carried and transmitted by the TseTse fly. Headrick (2014) documents that Africans who were treated by the medical campaigns were often forced to get injections at gunpoint. The treatment often led to severe, sometimes even lethal, side effects. Lowes and Montero (2020) find that such medical camps have triggered a culture of distrust towards Western medicines. If there were spillovers from distrust in Western medicine to distrust in technology, our results may partially reflect such impact. However, as discussed in Lowes and Montero (2021) in details, they did not find any spillover effects.

[8] In particular, the TSI is the standardized value (Z-score) of the fly's steady-state population derived from insect growth modelling, gridded climate data and geospatial data for each ethnic location. The exact functional forms linking TseTse fly birth and death rates to climate (e.g., temperature and humidity) are derived from controlled laboratory experimentation on the fly (Bursell, 1960; Rajagopal and Bursell, 1965; Mellanby, 1937).

Our results may be tainted by omitted variable and measurement error bias. For example, some other variables may have influenced both the precolonial prevalence of the TseTse fly and modern institutions that shape firm innovation. Additionally, the TSI may capture the effect of other confounding factors on firm's propensity to innovate, such as temperature and tropical climate related norms.

Guided by the literature (e.g., Alsan, 2015; An et al., 2022), we tackle the endogeneity issues by exploiting two unique features of the TseTse fly. First, the fact that the TseTse fly is restricted to the African continent due to geo-climate factors (e.g., climate change, continental drift, and glacier advances) permits a powerful placebo test where we replicate our baseline analysis in the Tropics of Capricorn and Cancer outside of Africa (i.e., the Americas and Asia Pacific). If the TSI only captures spurious effects of confounders associated with tropical climate, it should have the same explanatory power in firm innovation in other tropical areas outside of Africa. On the contrary, if it indeed measures the prevalence of the TseTse fly, then the index (TSI) should not have any predictive power in this set of tests. This is what we uncover: the TSI does not have explanatory power in firm's propensity to innovate outside of Africa.

We perform another set of placebo tests by exploiting the other unique feature of the fly. The survival of the TseTse critically depends on non-monotonic temperature requirements. This allows the manipulation of the temperature inputs in the formulas of the TSI in quantitatively trivial but physiologically important ways, which helps generate useful placebo indicators. In particular, if the TSI only captures a spurious effect of temperature, then perturbing the temperature input slightly up/downward should not change its power in predicting firm innovation. On the other hand, if the TSI is indeed capturing the effect the TseTse fly, then these placebo measures should lose their explanatory power. We find evidence that support the latter.

Next, we test whether the negative impact of the TseTse fly on firm innovation differs across industries in a theoretically predictive manner. This analysis helps us isolate the influence of the TseTse on culture and firm innovation from the effects of precolonial (political) institutions by allowing the inclusion of ethnic location fixed effects. In particularly, if the prevalence of the fly has shaped firm innovation today through altering people's attitude toward technology, then the relationship between the TseTse and firm propensity to innovate should be more pronounced for firms that have a higher innovation intensity. We test this prediction using the approach adopted by Moshirian et al. (2021) and find evidence consistent with our conjecture.[9] We identify the roles of foreign ownership and employees as key actors mediating the relationship between TseTse fly prevalence and innovation. The findings support the cultural transmission channel through which TseTse fly affects firm innovation. Lastly, we show evidence that our results persist even when account for the impact of firms' access to external finance, since finance plays an important role in firm innovation (Kerr and Nanda, 2015).

Our analyses contribute to several strands of literature. First, in her influential study, Alsan (2015) finds that the TseTse fly has had a negative impact on modern development in Africa through precolonial political centralization. Our study offers novel evidence on another important channel, i.e., firm innovation, via which the TseTse has exerted deleterious effects on African development.[10] We also find that the fly has triggered a norm of hostility towards technology independent of precolonial political centralization, thus adding an important complement to the literature in understanding the impact of the TseTse fly. More broadly, our paper contributes to the literature that studies the economic consequences of disease environment (e.g., Acemoglu et al., 2001; Bloom and Sachs, 1998; Gallup and Sachs, 2001; Sachs and Malaney, 2002; Beck et al., 2003). While the literature mainly relies on cross-country correlations, our analysis exploits within-country variations in the distribution of the disease vector and the outcome variable. This helps isolate the impact of disease from the influence of all country-level, time-invariant confounding factors, such as climate and geography.

Our research also speaks to the literature on culture and innovation, which has been recently reviewed by He and Tian (2020). While the existing research focuses on religiosity (Bénabou et al., 2015), inclusive economic institutions, corruption (Ayyagari et al., 2014), and firm culture (e.g., Manso, 2011; Tian and Wang, 2014), our paper emphasizes the particular norm of being hostile towards technology triggered by an epidemic disease vector, the TseTse fly, centuries ago. Consistent with the social efficiency theory (e.g., Boyd and Richerson, 1985, 1995; Giuliano and Nunn, 2021), such norm has persisted to today with negative repercussions on firm's propensity to innovate.

The rest of the paper is organized as follows. Section 2 introduces the data. Section 3 examines the impact of the TseTse fly on firm innovation. Section 4 presents evidence on the relationship between the fly and people's attitudes towards technology and verifies the cultural transmission of the TseTse fly's impact. Section 5 discusses the role of external financing and institutions in the relationship between the TseTse fly and firm innovation. Section 6 concludes.

2. Data

In this section, we describe the data and variables used in examining the relationship between the TseTse fly and firm innovation in Africa, and the potential mechanism through which the TseTse fly influences firm's propensity to innovate. Our main data sources

[9] Although including ethnic location fixed effects help address omitted variable bias at the ethnic location level, we are concerned about potential omitted variables at the firm-level. To gauge the extent of such bias, we follow Oster (2019) to perform a bounding exercise. Using conservative parameters (i.e., setting maximum R-squared equal to 1), the result suggests that selection on firm-level unobservables needs to be implausibly large (ranging from 2.3 to 3.6 times of selection on observables) to "explain away" our baseline results.

[10] Our paper is also related to the literature that studies the deep roots of African development (see Spolaore and Wacziarg (2013) and Michalopoulos and Papaioannou (2020) for reviews). We find that social norm of being hostile towards technology, triggered by the TseTse fly centuries ago, can still negatively influence modern development in Africa. Since the extant research mainly focuses on (mis)trust, gender norms, kinship structure, our emphasis on preferences towards technology adds an important complement.

include Alsan (2015), the georeferenced World Bank Enterprise Survey (2019) and World Value Survey (wave 6). Table 1 provides detailed variable definitions and sources, while Table 2 presents the summary statistics.

2.1. Measures of the tsetse fly

We obtain the TSI, at the ethnic location-level, from Alsan (2015). Specifically, the index is calculated as the Z-score of the TseTse fly's steady-state population derived from insect growth modelling and geo-climate data. The functional forms that link climate to the fly's birth and death rates are derived from controlled lab experiments. The climate data that Alsan (2015) uses to construct the TSI is from the National Oceanic and Atmospheric Administration. She uses the temperature and humidity data from the earliest available year, 1871, in this database. In our study, we use the TSI as our main explanatory variable.

While Alsan (2015) provides TSI data for about 522 unique ethnic locations in Africa, our sample includes 81 of them after merging with firm-level information (and 39 after merging with the slave trade data obtained from Nunn and Wantchekon (2011)). As reported in Table 2, TSI ranges from −3.12 to 1.50 in our sample, with a considerable amount of cross ethnic location variations (standard deviation = 1.03).

We also obtain five alternative measures of the fly's prevalence from Alsan (2015). In particular, *Intrinsic rate of growth* is constructed as the difference between the birth and death rates of the fly in the experiment-derived steady-state population. To account for the negative skewness in the TSI, *Box-plot* is created as the fly's steady-state population with a box plot transformation. *Optimal conditions* is a dichotomous variable that equals to one if an ethnic location has better-than-average conditions for TseTse survival and zero otherwise. The data underlying TseTse survival conditions is obtained from Rogers and Randolph (1986). Pe*rturb TSI shift left* and *Perturb TSI shift right* are obtained by manipulating the temperature input in the original TSI formulas in quantitatively slight but physiologically important ways. Particularly, the temperature input is manipulated downward and upward by one standard deviation (about 3 °C) *in Perturb TSI shift left* and *Perturb TSI shift right*, respectively. As shown in Table 2, all five alternatives exhibit substantial variations.

2.2. Firm innovation indicators

We obtain firm-level data from the WBES, which reports information on firm locations at the survey cluster (mostly municipality) level. This allows us to georeference the firm locations on Murdock's ethnicity map using the centroid of the survey cluster. Because Alsan (2015) constructs the measures of the TseTse fly at the ethnic location-level, georeferencing the WBES enables us to exploit within country, cross ethnic location variations in the TSI and firm innovation. In total, 6579 firms are matched to 81 ethnic locations (which further reduced to 39 ethnic locations after merging with the slave trade data from Nunn and Wantchekon (2011)) in Africa for our main tests. We visualize the spatial distribution of the TseTse fly and WES sample in Fig. A1 in the online appendix. In Appendix Fig. A1, the black dots represent the locations of the sampled firms. The map indicates the prevalence of the TseTse fly at the ethnic group level, where a darker (red) color corresponds to higher prevalence. It shows that our sampled firms are relatively evenly distributed across regions with varying levels of TseTse fly prevalence. For our key placebo tests, we also georeference firms outside of Africa, but within the Tropics of Capricorn and Cancer.[11]

We construct three measures of new-to-firm innovations by following the literature on firm innovation in emerging markets (e.g., Ayyagaric et al., 2011). In particular, *New product* is equal to one if the firm has introduced a new product to market within the 12 months prior to the survey and zero otherwise. Similarly, *New process* is equal to one if the firm has introduced a new process in the year prior to the survey and zero otherwise. *Innovation* combines the information of the first two measures and equals to one if the firm has either introduced a new product or new process and zero otherwise. As reported in Table 2, about 54% of our sampled firms have either introduced a new product or new process in the year prior to the survey. In addition, all three measures exhibit substantial variations, with similar standard deviations of around 50%. Appendix Fig. A2 illustrates the temporal distribution of the firm samples, while Appendix Fig. A3 depicts the changing impact of the Tsetse fly on sampled firms over different years.

2.3. Ethnic location, firm, and industry variables

An influential line of research documents that many ethnic location-level characteristics have shaped the function of modern society in Africa through norms or institutions (e.g., An, 2020; An, Lin, and Tai, forthcoming). In examining the independent link between the precolonial TseTse fly and firm innovation across Africa, we control for these key factors. First, *Slave exports*, constructed by Nunn and Wantchekon (2011), is equal to the natural logarithm of the total number of slaves exported from each ethnic location between 1400 and 1900 in the transatlantic and Indian Ocean slave trades, normalized by land area. As emphasized by Lovejoy (2000), Nunn and Wantchekon (2011), Levine et al. (2020) and Pierce and Snyder (2018), the slave trades have triggered a culture of distrust in Africa, and distrust in turn harms the function of financial today. Since innovation is influenced by financial development (e.g., Hsu et al., 2014), we control for *Slave exports* in our analysis. We also include *Political centralization* in our analysis, which is found to be the

[11] Outside of Africa, only the centroids, not boundaries, of ethnic groups are mapped. Following the literature (e.g., Alsan, 2015), we use the centroids of ethnic groups outside of Africa to construct Thiessen polygons that approximate ethnic boundaries. This approach provides non-overlapping, and close-to real, ethnic boundaries, as shown by Alsan (2015) in a similar exercise in Africa. We then geo-match the firms in WBES to this newly constructed ethnicity map outside of Africa.

Table 1
Variable definitions.

Variable	Definition	Source
Firm-level variables		
Innovation	Indicator that equals to one if a firm has introduced either new products or new processes of production, and zero otherwise.	Enterprise Survey, World Bank
New product	Indicator that equals to one if a firm has introduced new products and zero otherwise.	
New process	Indicator that equals to one if a firm has introduced new processes of production and zero otherwise.	
Bank financing	Proportion of working capital financed by banks.	
Line of credit	An indicator that equals to one if a firm has at least a line of credit and zero otherwise.	
Trade credit	Proportion of purchases of inputs and materials paid after delivery.	
Firm size	Tertiles of the number of employees in a firm.	
Firm age	The difference between the survey year and the first year when a firm started its operations.	
Sales growth	The median value of firms' sales growth within an industry in each year.	
State ownership	Percentage of government ownership.	
Foreign ownership	Percentage of foreign ownership.	
Export	Percentage of sales made as direct export.	
Profit	Firm's profit margin.	
CEO experience	Number of years of experience a CEO has in the industry.	
Business group	An indicator that equals to one if a firm belongs to a business group formed by other firms and zero otherwise.	
Access to finance	An indicator ranges from zero to four, representing no obstacle in access to finance (0), minor obstacle (1), moderate obstacle (2), major obstacle (3) and very severe obstacle (4).	
Obstacle educated	Firms rate the question "How much of an oobstacle: inadequately educated workforce?", on a scale from 0 to 4, where higher values represent greater difficulty.	
High school rate	The percentage of full-time workers who have completed high school	
Training	An indicator which takes a value of 1 if a firm's answer yes to the question "Are there formal training programs for permanent, full-time employees in last fiscal year?", and 0 if no.	
Ethnicity location variables		
TSI	This index measures the TseTse fly suitability for an ethnicity location. TseTse fly suitability index is constructed as the standardized value (Z-score) of the TseTse fly steady-state population in each ethnicity location derived using insect population growth modelling, gridded climate data, and geospatial software. The exact functional forms relating TseTse birth and death rates to climate are derived from the experimental data.	Alsan (2015)
Longitude	Longitude of the centroid of an ethnic location	
Latitude	Latitude of the centroid of an ethnic location	
SI	The agriculture suitability index that measures the average land quality for cultivation within an ethnicity location. The index is the product of two components capturing the climatic and soil suitability for farming.	
Malaria index	An index representing the contribution of regionally dominant vector mosquitoes to the force of transmission of malaria in ethnic location. The key temperature inputs were based on data draw from the period of 1901–1990.	
Intensive agriculture	Indicator variable equal to one if an ethnic location had intensive or intensive, irrigated agriculture in precolonial period and zero otherwise.	
Political centralization	Indicator variable equal to one if an ethnic location had political centralization that is equal or higher than two levels of hierarchy above the local authority in precolonial period, and zero otherwise.	
Large animals	Indicator variable equal to one if an ethnic location had large animals in precolonial period and zero otherwise.	
Temperature	The average of daily mean temperature in1871 in quantiles.	
Perturb TSI shift left	This index is constructed by manipulating the temperature inputs in the TseTse suitability index formula by one standard deviation (about 3 °C) to the right.	
Perturb TSI shift right	This index is constructed by manipulating the temperature inputs in the TseTse suitability index formula by one standard deviation (about 3 °C) to the left.	
Intrinsic rate of growth	It equals to the birth minus the death rate of the TsTse fly. The exact functional forms relating TseTse birth and death rates to climate are derived from the experimental data.	
Box-plot	It is the box plot transformation to the variable *Intrinsic rate of growth,* since the TseTse suitability index has a negative skew.	
Optimal conditions	It equals to one if an ethnic location meets the optimum environment for the survival of the TseTse fly, as defined in Alsan (2015). The optimum climatic conditions for the fly's survival are obtained from field research by Rogers and Randolph (1986) and are transformed into this binary indicator.	
Slave exports	Natural logarithm of the total number of slaves exported from each country between 1400 and 1900 in the four slave trades normalized by land area.	Nunn and Wantchekon (2011)
Cultural instability	A measure of the cross-generational climatic instability that was experienced by the group's ancestors.	Nunn and Wantchekon (2011)
Industrial-level variables		
Intensity	An index of industrial average propensity to innovate, calculated over 1981–2008 based on U.S. firms	Moshirian et al. (2021)

(*continued on next page*)

Table 1 (*continued*)

Variable	Definition	Source
Individual-level variables from World Value Survey		
World better off with technology	Indicator that ranges from one to ten, with larger value representing higher degree of agreement with the statement that the world is a better place with technology	World Value Survey, Wave 6
Gender	Indicator that equals to one if the respondent is a female and zero otherwise.	
Edu high	Indicator that equals one if the respondent's highest education level is higher education	
Edu sec	Indicator that equals one if the respondent's highest education level is secondary school	
Edu pri	Indicator that equals one if the respondent's highest education level is primary school	
Income high	Indicator that equals one if the respondent's income level is ranked as high	
Income medium	Indicator that equals one if the respondent's income level is ranked as medium	
Age	The respondent's age.	
Age square	The respondent's age squared	

Table 2
Summary statistics.

Variable	N	Mean	SD	Min	P50	Max
Firm-level variables						
Innovation	6292	0.540	0.498	0	1	1
New product	6290	0.415	0.493	0	0	1
New process	6271	0.435	0.496	0	0	1
Bank finance	5987	7.385	15.210	0	0	50
Line of credit	6194	0.222	0.415	0	0	1
Trade credit	4962	53.804	52.666	0	40	180
Firm size	6292	1.731	0.772	1	2	3
Firm age	6292	21.309	16.491	1	17	212
Sales growth	6292	0.107	0.191	−0.156	0.049	0.667
Private ownership	6292	83.678	33.716	0	100	100
Foreign ownership	6292	10.066	27.101	0	0	100
Export	6292	5.378	12.235	0	0	40
Profit	6292	0.493	0.332	−0.048	0.488	1
CEO experience	6292	17.436	9.935	3	15	35
Business group	6292	1.786	0.410	1	2	2
Access to finance	6223	1.852	1.337	0	2	4
Obstacle educated	6472	1.086	1.130	0	1	4
High school rate	5509	64.250	36.868	0	80	100
Training	6492	0.301	0.459	0	0	1
Ethnicity location variables						
TSI	81	−0.063	1.032	−3.119	0.125	1.495
Perturb TSI shift left	81	0.096	1.044	−2.650	0.222	1.925
Perturb TSI shift right	81	−0.113	1.056	−1.870	−0.195	1.461
Intrinsic rate of growth	81	0.414	0.166	0	0.437	0.679
Box-plot	80	39.891	21.543	3.693	40.555	79.059
Optimal conditions	81	0.358	0.482	0	0	1
Slave exports	41	0.571	1.002	0	0.038	3.656
Longitude	81	16.889	18.080	−17	16	42
Latitude	81	11.469	8.976	0	9	37
SI	81	0.514	0.197	0.092	0.550	0.838
Intensive agriculture	76	0.368	0.486	0	0	1
Political centralization	76	0.592	0.495	0	1	1
Large animals	76	0.711	0.457	0	1	1
Malaria index	81	12.198	9.732	0	11.926	31.149
Temperature	81	2.457	1.141	1	3	4
Cultural instability	80	0.200	0.048	0.108	0.204	0.314
Industrial-level variables						
Intensity	6292	2.355	0.784	0.180	2.220	3.890
Individual-level variables from World Value Survey						
World better off with technology	14,285	7.354	2.433	1	8	10
Gender	14,285	.516	0.500	0	1	1
Edu high	14,285	.156	0.363	0	0	1
Edu sec	14,285	.328	0.469	0	0	1
Edu pri	14,285	.287	0.453	0	0	1
Income high	14,285	.249	0.433	0	0	1
Income medium	14,285	.504	0.500	0	1	1
Age	14,285	35.586	13.815	16	32	99
Age squared	14,285	1457.232	1181.717	256	1024	9801

main channel that links the TseTse fly to modern economic development (Alsan, 2015). Following the literature, *Political centralization* is constructed so that it equals to one if the ethnicity had some forms of jurisdictional hierarchy, such as petty chiefdoms, petty states or large states, and zero otherwise (Michalopoulos and Papaioannou 2013, 2014).

In addition, we control for geographical factors that might potentially confound our results (e.g., Guo and An, 2022). As stressed by a number of researchers, natural endowment, such as geography, has a considerable impact on modern economic and financial institutions (Engerman and Sokoloff, 1997), which in turn may affect firm's propensity to innovate today. In particular, *Longitude* and *Latitude* correspond to the longitude and latitude of the centroid of an ethnic location; *SI* is the agriculture suitability index that measures the average land quality for cultivation; *Malaria index* measures the contribution of regionally dominant vector mosquitoes to the force of transmission of malaria in each ethnic location; *Temperature* is the average of daily mean temperature in 1871 divided into four quantiles; *Large animals* is an indicator that equals to one if the ethnic location had used large domesticated animals before colonization and zero otherwise; *Intensive agriculture* is a dummy variable that equals to one if the ethnic location had adopted intensive agriculture before colonization and zero otherwise.

We also control for a large vector of firm characteristics. Particularly, *Firm size* is an indicator that equals to one if the firm has below 20 employees, two if the firm has 20–99 employees, and three if above 100. *Firm age* equals the survey year minus the first year that the firm started operation; *Private* (*Foreign*) is the share of a company owned by private (foreign) parties; *Export* is the share of sales outside the country; *Sales growth* is the median value of firms' sales growth within an industry; *Profit* equals the firm's profit margin; *Business group* is coded so that it equals one if the firm is part of a larger company, and zero otherwise; and *CEO experience* equals the top manager's number of years of experience. *Access to finance* is an indicator that ranges from zero to four, representing "no obstacle in access to finance" (0), "minor obstacle" (1), "moderate obstacle" (2), "major obstacle" (3) and "very severe obstacle" (4).

We use *Intensity*, obtained from Moshirian et al. (2021), to measure innovation intensity when we examine whether the negative relationship between the precolonial prevalence of the TseTse fly and firm innovation varies across industries in a theoretically consistent manner. In particular, *Intensity* is constructed as the average number of patents held by a US firm in a three-digit ISIC industry in each year over 1981–2008. Given that our sample of African firms covers the period of 2011–2019, this is arguably an appropriate measure because (a) the time gap allows firms in Africa to imitate and adopt technologies from the frontier (Ayyagari et al., 2011); and (b) it is exogenous since it is constructed using the US data.

2.4. Measures of attitude towards technology

Our data on people's attitude towards technology is obtained from the World Value Survey (wave 6).[12] The survey asks respondents to what extent they agree with the statement "The world is a better place with technology." Answers to this question are then put on a Likert scale ranging from one to ten, with higher values indicating stronger degrees of agreement. Accordingly, we use *World better off with technology,* which equals to the respondent's answer (1–10), as our proxy of people's attitude towards technology. The survey also provides information on respondent's level of education, gender, age, and income levels. We control for these characteristics in our analysis.

To verify the role of the persistent culture hostile to technology as the primary mechanism of the impact of the TseTse fly on firm innovation, we link the World Value Survey data to the ethnic-group level TSI index. Using the methodology of Giuliano and Nunn (2021), we match respondents' self-reported mother tongue from the WVS with ethnicities documented in the Ethnographic Atlas. This refinement allows us to analyze individual-level variations within the same country by controlling for country fixed effects. This approach aligns with Gorodnichenko and Roland (2017)'s framework for examining the cultural influences on innovation.

3. The effect of the TseTse fly on firm innovation

In this section, we investigate the relationship between the precolonial prevalence of the TseTse fly and firm innovation across Africa. We begin by presenting our baseline results with country and year fixed effects. We then perform two sets of placebo tests that help mitigate the omitted variable and measure error bias. Lastly, we conduct a series of robustness checks including using alternative measures of the TseTse fly, various clustering strategies, and a heterogenous analysis where we can include ethnic location fixed effects.

3.1. Baseline results

We start by examining the link between the TseTse fly and measures of firm innovation, using the following Ordinary Lease Squares (OLS) specification:

$$Innovation_{f,s,e,c} = \alpha + \beta TSI_e + \gamma X_e' + \delta X_f' + \Psi_c + \eta_s + \omega_y + \varepsilon_{f,s,e,c} \quad (1)$$

where the dependent variable, $Innovation_{f,e,c}$, is either *Innovation, New product*, or *New process* for firm *f*, in industry *s*, ethnic location *e* and country *c*. Our key interest variable is TSI_e, which measures the precolonial prevalence of the TseTse fly at the ethnic location level. β captures the impact of the TseTse fly on firm's propensity to innovate. X_e' includes a range of ethnic location-level control variables,

[12] Other waves of the World Value Survey do not contain the question that we use to construct our key attitude variable.

including *Slave exports, Political centralization, Longitude, Latitude, Large animals, SI, Temperature, Intensive agriculture*, and *Malaria index*. X_f' is a vector of firm characteristics, including *Firm size, Firm age, Sales growth, Private, Foreign, Exports, Profit, CEO experience, Business group*, and *Access to finance*. Since we are exploiting the within-country, cross ethnic location variations in the TSI and firm innovation, we include country fixed effects, Ψ_c, and survey year fixed effects, ω_y, as well as industry fixed effects (at the three-digit ISIC level), η_s. Standard errors are clustered at the ethnic location-level. All variables are defined in Section 2 and Table 1. We summarize our results in Table 3.

As reported in Table 3, TSI_e is strongly, negatively related to measures of firm innovation in Africa. The coefficients of TSI_e are significant at least at the five percent significance level. The results suggest that firms in places with historically high TseTse prevalence are less likely to innovate today, compared to otherwise similar firms but located in low prevalence areas. The economic magnitude of our coefficients is non-trivial. For example, consider the estimates in Table 3 column (2), where we condition the analysis on the full set of control variables. They suggest that a one standard deviation (1.032) increase the in TSI_e would reduce the probability of firms to introduce either a new product or a new process by about 9 percentage points (=1.032×0.087). This reduction represents 17% (=0.09/0.54) of our sample mean. Next, we perform several placebo tests and a series of robustness checks to push for a causal interpretation of this result.

3.2. Placebo tests in tropics outside of Africa

As a first step of addressing the concerns regarding omitted variables and measurement error, we leverage a unique feature of the TseTse fly: it is restricted to Africa due to exogenous reasons (e.g., climate change, continental drift and glacier advances). The fact that a large share of land areas covered by the Tropics of Capricorn and Cancer meet the TseTse survival conditions but the TseTse only exists in the African continent allows us to conduct a powerful placebo test. In particular, we replicate our analysis, using Eq. (1), for a sample of firms located outside of Africa but within the Tropics of Capricorn and Cancer (i.e., the Americas and Asia Pacific). The TSI is constructed in the same way as for within Africa analysis. However, because the TseTse is unique to Africa, we call this measure *Pseudo*

Table 3
The TseTse Fly and firm innovation.

	Innovation		New product		New process	
	(1)	(2)	(3)	(4)	(5)	(6)
TSI	−0.090***	−0.087***	−0.097**	−0.094**	−0.102***	−0.100***
	(0.027)	(0.027)	(0.037)	(0.037)	(0.027)	(0.028)
Firm size	0.054***	0.056***	0.072***	0.074***	0.047***	0.047***
	(0.011)	(0.011)	(0.010)	(0.011)	(0.012)	(0.012)
Firm age	0.000	0.000	0.000	0.000	−0.000	−0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Sales growth	−0.019	−0.023	−0.064	−0.062	−0.005	−0.009
	(0.065)	(0.066)	(0.083)	(0.085)	(0.053)	(0.053)
Private ownership	−0.000	−0.000	0.000	0.000	−0.000	−0.000
	(0.000)	(0.000)	(0.001)	(0.001)	(0.000)	(0.000)
Foreign ownership	0.000	0.000	0.000	0.000	0.000	0.000
	(0.000)	(0.000)	(0.001)	(0.001)	(0.000)	(0.000)
Export	0.002***	0.002***	0.003***	0.003***	0.001**	0.001**
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Profit	−0.026	−0.024	−0.036*	−0.036*	−0.021	−0.020
	(0.020)	(0.020)	(0.020)	(0.020)	(0.018)	(0.018)
CEO experience	0.001	0.001	0.001	0.001	0.001	0.001
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Business group	−0.055***	−0.057***	−0.051**	−0.054***	−0.053**	−0.053**
	(0.019)	(0.020)	(0.019)	(0.020)	(0.021)	(0.022)
Access to finance	No	Yes	No	Yes	No	Yes
Ethnic group controls	Yes	Yes	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes	Yes	Yes
Survey year FE	Yes	Yes	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	6579	6528	6597	6546	6560	6512
R-squared	0.198	0.197	0.136	0.136	0.279	0.278
# Ethnic groups	39	39	39	39	39	39

Note: This table reports OLS regression results for firm innovation in relation to historical TseTse fly prevalence. The explanatory variable, *TSI*, measures historical TseTse fly prevalence at the ethnic location level. *Innovation* is an indicator that equals one if a firm has introduced either new products or new production processes in the past three years and zero otherwise. *New product* and *New process* equal one if a firm has introduced new products and new production processes, respectively, and zero otherwise. Ethnic location-level controls include *Slave exports, Longitude, Latitude, SI, Temperature, Intensive agriculture, Political centralization, Large animals*, and *Malaria index*. Firm controls include *Firm size, Firm age, Sales growth, State, Foreign, Exports, Profit, CEO experience* and *Business group. Access to finance* is an indicator that ranges from zero to four, representing "no obstacle in access to finance" (0), "minor obstacle" (1), "moderate obstacle" (2), "major obstacle" (3) and "very severe obstacle" (4). Survey year, industry, and country fixed effects are included in all models. See Table 1 for more detailed variable definitions and data sources. Standard errors are clustered at the ethnicity location level and are reported in parentheses. *, **, and *** indicate significance at 10%, 5%, and 1%, respectively.

TSI.

We predict that the *Pseudo TSI* would still have strong statistical power in explaining firm innovation outside of Africa, if the measure only captures the impact of factors associated with the tropical climate (or other omitted variables) in Africa. On the contrary, if the TSI indeed captures the influence of the TseTse fly, we would then conjecture that the *Pseudo TSI* losses its power in explaining the variations in firm's propensity to innovate. We tabulate our results in Table 4.

Table 4 shows that the *Pseudo TSI* does not have a statistically significant relationship with measures of firm innovation in tropical regions outside of Africa. This evidence suggests that the TSI does not only captures the effects of factors associated with the tropical climate but also the prevalence of the TseTse fly. In other words, our baseline results are not fully driven by tropical climate and its associated factors.

3.3. Placebo tests within Africa

To further address the endogeneity concerns, we turn to another set of placebo tests within Africa. Particularly, we leverage another feature of the fly: its survival crucially relies on a specific, non-monotonic temperature requirement (Alsan, 2015). This feature suggests that if we perturb the temperature input in the TSI formula in a quantitatively trivial but physiologically important way, the resulting index will no longer capture the survival requirements of the TseTse. Consequently, the perturbed TSI will loss its predictive power in our measures of firm innovation. This prediction, however, is based on the assumption that the original TSI accurately captures the precolonial prevalence of the TseTse fly. If this assumption does not hold, i.e., the TSI only reflects some other confounding factors associated with temperature, then we would expect that the perturbed TSI still has explanatory power in variations of firm innovation.

We use Eq. (1) to assess these predictions. Particularly, we replace the TSI with two perturbed fly measures. *Perturb TSI shift left* is obtained by reducing the temperature input in the original TSI formula by one standard deviation (about 3 °C), while *Perturb TSI shift Right* is obtained by increasing the temperature input by one standard deviation. We present our results in Table 5. As evidenced in columns (1) and (2) of Table 5, neither of the manipulated TSI indices has a statistically meaningful relationship with measures of firm

Table 4
The TseTse Fly and firm innovation: placebo test from outside of Africa.

	Innovation		New product		New process	
	(1)	(2)	(3)	(4)	(4)	(6)
Pseudo TSI	−0.042	−0.039	0.040	0.041	−0.045	−0.042
	(0.046)	(0.045)	(0.042)	(0.042)	(0.041)	(0.039)
Firm size	0.094***	0.096***	0.075***	0.076***	0.093***	0.095***
	(0.015)	(0.015)	(0.010)	(0.010)	(0.015)	(0.015)
Firm age	−0.000	−0.000	−0.000	−0.000	−0.000	−0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Sales growth	0.103	0.118	0.139	0.146	0.034	0.042
	(0.123)	(0.124)	(0.130)	(0.131)	(0.136)	(0.136)
Private ownership	0.000	0.000	0.001	0.001	0.000	0.001
	(0.001)	(0.001)	(0.001)	(0.002)	(0.001)	(0.001)
Foreign ownership	0.000	0.000	0.000	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Export	0.000	0.000	−0.000	−0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Profit	−0.054**	−0.053**	−0.006	−0.002	−0.050**	−0.049**
	(0.024)	(0.023)	(0.018)	(0.018)	(0.024)	(0.023)
CEO experience	0.000	0.001	0.002*	0.002*	−0.000	−0.000
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Business group	−0.095***	−0.093***	−0.072**	−0.071**	−0.109***	−0.108***
	(0.023)	(0.023)	(0.031)	(0.031)	(0.026)	(0.025)
Access to finance	No	Yes	No	Yes	No	Yes
Ethnic group controls	Yes	Yes	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes	Yes	Yes
Survey year FE	Yes	Yes	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	12,099	11,985	12,134	12,018	12,084	11,970
R-squared	0.223	0.226	0.181	0.183	0.209	0.212
# Ethnic groups	25	25	25	25	25	25

Note: This table reports OLS regression results for placebo tests using firm-level data from Americas and Asia Pacific. The dependent variable is either *Innovation, New product,* or *New process*. The key explanatory variable, *Pseudo TSI*, is from Alsan (2015) and it is constructed with the same model as *TSI* but using inputs from Americas and Asia Pacific. Ethnic location-level controls include *Slave exports, Longitude, Latitude, SI, Temperature, Intensive agriculture, Political centralization, Large animals,* and *Malaria index*. Firm controls include *Firm size, Firm age, Sales growth, State, Foreign, Exports, Profit, CEO experience* and *Business group. Access to finance* is an indicator that ranges from zero to four, representing "no obstacle in access to finance" (0), "minor obstacle" (1), "moderate obstacle" (2), "major obstacle" (3) and "very severe obstacle" (4). Survey year, industry, and country fixed effects are included in all models. See Table 1 for more detailed variable definitions and data sources. Heteroskedasticity robust standard errors clustered at the ethnicity location level are reported in parentheses. *, **, and *** indicate significance at 10%, 5%, and 1%, respectively.

innovation. This suggests that the original TSI indeed measures the prevalence of the fly.

3.4. Alternative measures of the fly and clustering strategies

In this section, we perform a range of robustness checks with alternative measures of the TseTse fly and different inference assumptions about the variance-covariance matrix. In particular, we consider three alternative measures of the TseTse fly. *Intrinsic rate of growth* is constructed so that it equals the difference between the birth and death rates of the TseTse fly in a steady-state population. *Box-plot* is constructed as the box plot transformation of the steady-state population of the fly since the original TSI is negatively skewed. *Optimal conditions* is coded so that it equals one if an ethnic location has an above-average condition for the fly's survival and zero otherwise (Rogers and Randolph, 1986). We expect *Intrinsic rate of growth, Box-plot* and *Optimal conditions* to have the same sign and similar statistical power in explaining the outcome variables to the TSI. The results are tabulated in columns (3)-(5) of Table 5, respectively.

We also cluster our standard errors in three alternative ways. First, following Conley (1999) to account for spatial correlations, we cluster the standard errors with cut-offs of 10° latitude and 10° longitude. Second, we allow the standard errors to correlate with each other within a country by clustering at the country level. Finally, using the method developed by Cameron et al. (2011), we cluster the standard errors at both the country and the ethnic location level. This is viable in Africa since some ethnic groups are divided by national borders. The results are shown in columns (6)-(8) in Table 5. As we expected, all the estimates from these tests have the same sign as the TSI, and they are statistically significant at least at five percent significance level.

3.5. Differentiating by innovation intensity

To further address the omitted variable concern, we next assess whether the negative impact of the TseTse fly on firm innovation varies across sectors in a theoretically predicable manner. This strategy permits us to add ethnic location fixed effects in our analysis, thus eliminating the impact of any ethnic location-level, time-invariant factors that may have jointly affected the TSI and firm innovation today. We conjecture that if the TseTse fly has influenced firm's propensity to innovate through altering people's preference to adopt new technologies, then such influence should be more pronounced in industries that have a higher innovation intensity for exogenous reasons.

Following the literature (e.g., Moshirian et al., 2021), we measure innovation intensity (*Intensity*) as the average number of patents held by a US firm in a three-digit ISIC industry in each year over 1981–2008. Since our sample spans from 2011 through 2019, this measure offers two advantages: (a) the time gap allows firms in Africa to adopt technologies from the frontier (Ayyagari et al., 2011); and (b) it is constructed using the US data so that it is arguably exogenous to African firms.

To assess whether the impact of the TSI on firm innovation varies with industry innovation intensity, we use the following OLS specification:

$$Innovation_{f,s,e,c} = \alpha + \beta TSI_e * Intensity_s + \delta X_f^{'} + \Psi_c + \theta_e + \eta_s + \omega_y + \varepsilon_{f,s,e,c} \qquad (2)$$

where the dependent variable, $Innovation_{f,e,c}$, is one of the three measures of firm innovation (*Innovation, New product* or *New process*), for firm *f*, in industry *s*, ethnic location *e* and country *c*. The key explanatory variable is the intersection term between TSI_e and $Intensity_s$. $X_f^{'}$ includes the same set of firm control variables as in Eq. (1), including *Firm size, Firm age, Sales growth, Private, Foreign, Exports, Profit, CEO experience, Business group*, and *Access to finance*. θ_e represents ethnic location fixed effects. Country fixed effects are denoted by Ψ_c. Survey year fixed effects, ω_y, and industry fixed effects (at the three-digit ISIC level), η_s, are also included. Due to the inclusion of ethnic location and industry fixed effects, TSI_e and $Intensity_s$ are subsumed. We cluster the standard errors at the ethnic location level. Results are tabulated in Table 6.

As reported in Table 6, the relationships between the TseTse fly and measures of firm innovation do vary across industries in a manner that is consistent with our conjecture. In particular, $TSI_e * Intensity_s$ enters all regressions with a negative, and statistically meaningful coefficient, regardless of which innovation measure we use. This implies that the negative impact of the TseTse fly on firm's propensity to innovate is particularly strong in industries that have a higher innovation intensity. This is consistent with our hypothesis that the TseTse fly has had an enduring, negative impact on economic development today through innovation.

4. The cultural transmission of the tsetse fly's impact

Culture tends to persist over time, often evolving slowly or remaining unchanged. Due to path dependence (Mahoney, 2000), early conditions play a critical role in shaping long-term outcomes. In this section, we present suggestive evidence on the relationship between the TseTse fly and people's attitude towards technology. To do so, we use household-level OLS regressions specified as follows:

$$Attitude_{i,e} = \alpha + \beta TSI + \Gamma X_e^{'} + JIX_i^{'} + \varepsilon_{i,e} \qquad (3)$$

where the dependent variable, $Attitude_{i,e}$ is the answer to the question of *Is the world better off with technology* for household *i* in ethnic group *e. World better off with technology* is an indicator that ranges from one to ten, with higher value corresponding to stronger belief in that "The world is a better place with technology." TSI_e, measures the precolonial prevalence of the TseTse fly at the ethnic location

Table 5
TseTse fly and firm innovation: robustness checks.

	Alternative TseTse indices					Alternative clustering		
	Perturb TSI shift left	Perturb TSI shift right	Intrinsic rate of growth	Box-plot	Optimal TseTse conditions	Conley SE	SE clustered by country	Multiway clustering
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Innovation	0.004	0.002	−0.611***	−0.006***	−0.194***	−0.087***	−0.087**	−0.087***
	(0.032)	(0.027)	(0.172)	(0.001)	(0.028)	(0.032)	(0.032)	(0.032)
New product	−0.025	−0.000	−0.648***	−0.006***	−0.216***	−0.094***	−0.094**	−0.094**
	(0.026)	(0.020)	(0.235)	(0.002)	(0.043)	(0.031)	(0.043)	(0.042)
New process	0.019	0.010	−0.689***	−0.006***	−0.200***	−0.100***	−0.100***	−0.100***
	(0.040)	(0.033)	(0.173)	(0.001)	(0.027)	(0.020)	(0.031)	(0.031)

Note: This table reports a range of robustness checks on the average impact of the historical TseTse fly prevalence on firm innovation. The alternative measures of TseTse fly are *Perturb TSI shift left* and *Perturb TSI shift right* in columns (1) and (2). They are constructed by manipulating the temperature inputs by one standard deviation (3 °C) (to the left and right, respectively) in the construction of the original *TSI*. Column (3) replaces the TSI with the intrinsic rate of growth of the fly. Column (4) is a box-plot transformation of the steady-state number of flies. Column (5) uses an alternative measure constructed by Rogers and Randolph (1986). In column (6) we report results using Conley (1999) standard errors to account for spatial correlation with cut-offs of 10° latitude and 10° longitude. In column (7) we cluster standard errors by country. In column (8), we cluster standard errors at country and ethnicity location levels using a multiway clustering method developed by Cameron et al., 2011. In all regressions, our dependent variable is either *Innovation, New product* or *New process. Innovation* is an indicator that equals one if a firm has introduced either new products or new processes of production in the past three years and zero otherwise. *New product* and *New process* equal one if a firm has introduced new products and new processes of production, respectively, and zero otherwise. In all regressions, we include firm controls, such as *Firm size, Firm age, Sales growth, State, Foreign, Exports, Profit, CEO experience, Business group* and *Access to finance*, and ethnic location-level controls, such as *Slave exports, Longitude, Latitude, SI, Temperature, Intensive agriculture, Political centralization, Large animals,* and *Malaria index*. Survey year, industry, and country fixed effects are also included in all models. See Table 1 for more detailed variable definitions and data sources. Heteroskedasticity robust standard errors clustered at the ethnicity location level are reported in parentheses unless otherwise specified. *, **, and *** indicate significance at 10%, 5%, and 1%, respectively.

Table 6
TseTse fly and firm innovation: differentiating by industrial innovation intensity.

	Innovation		New product		New process	
	(1)	(2)	(3)	(4)	(5)	(6)
TSI*Intensity	−0.017***	−0.017***	−0.015**	−0.015**	−0.012*	−0.012*
	(0.006)	(0.006)	(0.006)	(0.006)	(0.007)	(0.006)
Firm size	0.052***	0.052***	0.068***	0.068***	0.047***	0.046***
	(0.011)	(0.011)	(0.013)	(0.013)	(0.010)	(0.010)
Firm age	0.000	0.000	0.000	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Sales growth	0.014	0.010	−0.020	−0.024	0.035	0.025
	(0.043)	(0.043)	(0.068)	(0.068)	(0.043)	(0.044)
State ownership	−0.001	−0.001	−0.001	−0.001	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Foreign ownership	0.000	0.000	0.000	0.000	0.001	0.001
	(0.001)	(0.001)	(0.000)	(0.000)	(0.001)	(0.001)
Export	0.002***	0.002***	0.002***	0.002***	0.001**	0.001**
	(0.001)	(0.001)	(0.001)	(0.001)	(0.000)	(0.000)
Profit	−0.013	−0.015	−0.019	−0.021	−0.006	−0.011
	(0.024)	(0.024)	(0.022)	(0.022)	(0.025)	(0.025)
CEO experience	0.001*	0.001*	0.001	0.001	0.002**	0.002**
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Business group	−0.049**	−0.051**	−0.045**	−0.046**	−0.036	−0.041*
	(0.024)	(0.024)	(0.019)	(0.019)	(0.022)	(0.023)
Access to Finance	−0.003	−0.002	0.003	0.004	−0.004	−0.003
	(0.006)	(0.006)	(0.008)	(0.008)	(0.008)	(0.008)
Country FE	No	Yes	No	Yes	No	Yes
Industry FE	Yes	Yes	Yes	Yes	Yes	Yes
Ethnicity location FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	6223	6223	6234	6234	6208	6208
R-squared	0.265	0.265	0.183	0.184	0.323	0.325
# of Ethnic groups	81	81	81	81	81	81

Note: This table reports OLS regression results on the heterogeneous impact of the historical TseTse fly prevalence on firm innovation. The dependent variable is either *Innovation, New product,* or *New process*. The key explanatory variables include an interaction term between *TSI* and *Intensity*. *Intensity* measures the industrial average propensity to innovate calculated over 1981–2008 in the US and is obtained from Moshirian et al. (2021). *TSI* is obtained from Alsan (2015) and measures the historical TseTse fly prevalence in each ethnic location. Firm controls include *Firm size, Firm age, Sales growth, State, Foreign, Exports, Profit, CEO experience, Business group* and *Access to finance*. Ethnic location, country, industry (at the three-digit ISIC level) and year fixed effects are included in all regressions. See Table 1 for more detailed variable definitions and data sources. Heteroskedasticity robust standard errors clustered at the ethnicity location level are reported in parentheses. *, **, and *** indicate significance at 10%, 5%, and 1%, respectively.

level, is our key explanatory variable. $X_e^{'}$ includes a range of ethnic location-level control variables, including *Slave exports, Political centralization, Longitude, Latitude, Large animals, SI, Temperature, Intensive agriculture*, and *Malaria index*. $X_i^{'}$ represents household-level control variables, including *Education, Income, Gender, Age* and *Age squared*. All variables are defined in Section 2 and Table 1. Our coefficient of interest is β, which measures the relationship between the TseTse fly and household attitude toward technology. Standard errors are clustered at the ethnic location level. We tabulate our results in Table 7.

In column 1, we show that the ethnic-level TSI index has a significant negative effect on individual beliefs regarding the statement “The world is better with technology.” The coefficient of TSI is −0.278, indicating that a one-standard-deviation increase in TSI (1.032) is associated with a 0.287 decline in agreement with this statement. This decrease is approximately 4% of the sample mean (7.354). Given that education level has a significant impact on attitudes toward technology and may also influence the transmission of traditional culture and beliefs to some extent, it is important to account for this variable when interpreting the results. In columns 2 and 3, we divide the respondents into two groups based on their education levels: a low-education group, consisting of individuals without higher education, and a high-education group, including those who have received some or full higher education. We find that the impact of TSI on attitudes toward technology is primarily concentrated in the low-education group. In this subsample, the coefficient of TSI is −0.435. In contrast, for the high-education group, the coefficient of TSI is −0.051 and is no longer statistically significant. This finding is intuitive, as modern education tends to make people more inclined to believe that “The world is a better place with technology.” The hostile attitude towards technology left by traditional views, as shaped by TseTse fly, is more likely to be prevalent among less-educated populations. In contrast, we expect such negative effects to be less pronounced among highly educated groups. The role of individuals’ educational background on people’s openness to technology has also inspired us to further test the influence of employees’ education level and training among employees on the relationship between TseTse fly prevalence and firm innovation (see Table 11).

Early attitudes toward technology, influenced by the TseTse fly, can adapt and persist across generations, though the continuity of such cultural traits may be eroded by certain factors over time. To further investigate the cultural channel, we incorporate Giuliano and Nunn’s (2021) measure of cultural instability. They argue that populations whose ancestors lived in environments marked by greater

Table 7
TseTse fly and attitudes toward technology.

	The world is better with technology				
	Full	Education		Cultural instability	
		Low	High	Low	High
	(1)	(2)	(3)	(4)	(5)
TSI	−0.278*	−0.435***	−0.051	−0.237***	0.077
	(0.141)	(0.155)	(0.226)	(0.026)	(0.299)
Individual Controls	Yes	Yes	Yes	Yes	Yes
Ethnicity Controls	Yes	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	Yes	Yes	Yes
Observations	14,285	12,062	2223	6152	6643
R-squared	0.104	0.105	0.096	0.119	0.053
# of Ethnic groups	53	53	38	7	45

Note: This table reports OLS regression results for household attitudes toward technology in relation to historical TseTse fly prevalence, using World Value Survey data. The dependent variable is *The world is a better place with technology*. It ranges from 1 to 10, with higher value representing higher level of agreement with the statement. The key explanatory variable, *TSI*, obtained from Alsan (2015) and measures the historical TseTse fly prevalence in each ethnic location. Education is low if an individual's highest level of education is below higher education, and high if they have received some or full higher education. *Cultural instability* is an indicator variable equal to 1 if the country-level temperature anomalies exceed the sample mean from Giuliano and Nunn (2021), and 0 otherwise. Individual controls include a gender indicator, age, age squared, incomes, and education. Ethnic location-level controls, such as *Slave exports, Longitude, Latitude, SI, Temperature, Intensive agriculture, Political centralization, Large animals*, and *Malaria index*, and Country fixed effects are included in all regressions. See Table 1 for more detailed variable definitions and data sources. Standard errors clustered at the ethnicity location level are reported in parentheses. *, **, and *** indicate significance at 10%, 5%, and 1%, respectively.

cross-generational instability tend to place less importance on maintaining tradition today, resulting in lower cultural persistence. In contrast, in more stable environments, cultural traits that evolved in earlier generations are more likely to remain relevant for subsequent generations. According to their framework, if the influences of the TseTse fly on firm innovations that we observe are indeed transmitted through the cultural channel, we would expect that in environments with less stable cultural transmission (as indicated by climatic instability), the persistence of TseTse fly-induced cultural traits into modern times would be weakened.

The empirical results presented in Table 7 columns (4) and (5) align with our predictions. Here, we divide the sample into low cultural instability and high cultural instability groups based on the mean value of the cultural instability indicator from Giuliano and Nunn (2021). The cultural instability index measures the cross-generational climatic instability experienced by the ethnic group's ancestors. Consistent with our expectation, for the group with low cultural instability in column (4), the coefficient of TSI is significant at −0.237, while the coefficient of TSI for the group with high cultural instability in column (5) is entirely insignificant. This indicates that in the high cultural instability group, the negative effect of TSI on modern attitudes toward technology is attenuated. This finding supports our conjecture that the influences of the TseTse fly on firm innovations are transmitted through the cultural channel.

To provide further evidence supporting the cultural channel of TseTse fly, we examine the relationship between ethnic-level attitudes toward technology from WVS and firm innovation using the WES firm sample. Ideally, the ethnic-level attitudes toward technology could predict firms' innovative activities. In Table 8, the three outcome variables are *Innovation, New product*, and *New*

Table 8
Attitudes toward technology and firm innovation.

	Innovation	New product	New process
	(1)	(2)	(5)
Better with technology	0.622**	0.381*	0.733***
	(0.204)	(0.192)	(0.187)
Access to finance	Yes	Yes	Yes
Ethnic group controls	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes
Survey year FE	Yes	Yes	Yes
Country FE	Yes	Yes	Yes
Observations	2154	2159	2151
R-squared	0.276	0.180	0.337
# of Ethnic groups	10	10	10

Note: This table reports the OLS regression results on firm innovation in relation to local attitudes towards technology. The explanatory variable, *Better with Technology*, stands for the statement, "The world is a better place with technology," which has been included in the World Value Survey. It ranges from 1 to 10, with a higher value representing a higher level of agreement with the statement. Ethnic location-level controls, such as *Slave exports, Longitude, Latitude, SI, Temperature, Intensive agriculture, Political centralization, Large animals*, and *Malaria index*. Firm controls include *firm size, firm age, sales growth, state ownership, foreign ownership, exports, profit, CEO experience*, and *business group affiliation*. Survey year, industry, and country fixed effects are included in all models. See Table 1 for more detailed variable definitions and data sources. Standard errors clustered at the ethnicity location level are reported in parentheses. *, **, and *** indicate significance at 10%, 5%, and 1%, respectively.

process, same with the outcome variables used in our baseline analyses. The independent variable is the ethnic-level "The world is better with technology" from the WVS. It ranges from 1 to 10, with higher values representing a higher level of agreement with the statement. Due to differences in country coverage between the WES firm sample and the WVS survey, only 2159 firms are matched with the ethnic-level measure of "The world is better with technology". In column 1, the coefficient of "The world is better with technology" is 0.622. This means that for every one-unit increase in the "The world is better with technology" index of the ethnicity where the company is located, the likelihood of the company's innovation increases by 62.2%. This increase is equivalent to 1.02 times the sample mean of our innovation variable, which is 61%. Similarly, the coefficients in columns 2 and 3 are 0.381 and 0.733, respectively, both of which are significantly positive. Our results indicate that the attitudes toward technology captured in the WVS data indeed reflect the likelihood of corporate innovation activities. This finding supports the cultural channel mechanism of the TseTse fly's influence.

We have identified that TseTse fly prevalence influences individuals' attitudes toward technology, and this pattern is primarily driven by respondents residing in countries with more stable cultural environments. It is reasonable to expect that the negative impact of the TseTse fly on firm innovation will primarily manifest in countries with a high degree of cultural transmission. Therefore, we examine the relationship between the TseTse fly and the three indicators of firm innovation in subsamples of firms divided based on the sample mean value of the cultural instability index. The results in Table 9 show that the effect of Tsetse fly prevalence on firm innovation is more negative in the low cultural instability group than in the high cultural instability group. The coefficient of TSI in Column 1 is −0.377, which is more than three times the coefficient of TSI in Column 2, at −0.111. This indicates that the negative impact of TSI on firm innovation diminishes in the presence of cultural instability. This finding also supports the cultural channel mechanism of the TseTse fly.

We further investigate the culture channel by testing the role of foreign ownership which acts as an external shock on the domestic culture in the relationship between TseTse fly and firm innovation. Local preferences can influence firm innovation activities through various corporate roles. For instance, Chen et al. (2014) find that local gambling preferences strongly drive innovative activity by affecting employee preferences at all levels of the organization, not only through top managers. To understand how TseTse fly affects firm innovation through specific company characteristics or key roles, we explore the influences of firm's foreign ownership. It's likely that foreign ownership plays a key role in diluting the influence of TseTse fly and its associated domestic culture on company strategic choices by bringing new thoughts and resources that unaffected by local traits. If the influences of the TseTse fly on firm innovations are indeed transmitted through the cultural channel, we expect that TseTse fly prevalence primarily affects firm innovation among samples with non-foreign ownership dominance.

We verify the role of foreign ownership by testing the relationship between the TseTse fly and the subsamples divided by foreign ownership dominance. A firm is classified into the foreign ownership dominant group if more than 50% of its ownership belongs to foreigners, and into the non-foreign ownership dominant group otherwise. The impact of TseTse fly prevalence on firm innovation is primarily observed in the non-foreign ownership dominant sample. We report the results in Table 10. Among the foreign ownership dominant group, the coefficients of TSI are not statistically significant (in Columns 1, 3, and 5). However, for the non-foreign ownership dominant group, the coefficients of TSI are significantly negative. For example, the coefficient of TSI in Column 2 is −0.093, indicating that a one-standard-deviation increase in TSI (1.032) is associated with a 0.1 decrease in the likelihood of innovative activities by firms. This decrease is approximately 15.73% of the sample mean (0.61). This finding is consistent with our

Table 9
TseTse fly and firm innovation: the role of cultural instability.

	Innovation Cultural instability		New product Cultural instability		New process Cultural instability	
	Low (1)	High (2)	Low (3)	High (4)	Low (5)	High (6)
TSI	−0.377***	−0.111**	−0.295***	−0.142***	−0.425***	−0.120**
	(0.020)	(0.045)	(0.029)	(0.037)	(0.022)	(0.050)
Access to finance	Yes	Yes	Yes	Yes	Yes	Yes
Ethnic group controls	Yes	Yes	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes	Yes	Yes
Survey year FE	Yes	Yes	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	3213	2487	3222	2495	3207	2478
R-squared	0.166	0.189	0.113	0.154	0.235	0.286
# of Ethnic groups	21	16	21	16	21	16

Note: This table reports the OLS regression results on firm innovation in relation to historical Tsetse fly prevalence, examining the role of cultural instability. The explanatory variable, *TSI*, measures historical TseTse fly prevalence at the ethnic location level. *Innovation* is an indicator that equals one if a firm has introduced either new products or new production processes in the past three years, and zero otherwise. *Cultural instability* is an indicator variable equal to 1 if the country-level temperature anomalies exceed the sample mean from Giuliano and Nunn (2021), and 0 otherwise. Ethnic location-level controls include *Slave exports, Longitude, Latitude, SI, Temperature, Intensive agriculture, Political centralization, Large animals*, and *Malaria index*. Firm controls include *firm size, firm age, sales growth, state ownership, foreign ownership, exports, profit, CEO experience*, and *business group affiliation*. Survey year, industry, and country fixed effects are included in all models. See Table 1 for more detailed variable definitions and data sources. Standard errors clustered at the ethnicity location level are reported in parentheses. *, **, and *** indicate significance at 10%, 5%, and 1%, respectively.

Table 10
TseTse fly and firm innovation: the role of foreign ownership.

	Innovation Foreign ownership		New product Foreign ownership		New process Foreign ownership	
	>50%	≤50%	>50%	≤50%	>50%	≤50%
	(1)	(2)	(3)	(4)	(5)	(6)
TSI	−0.048	−0.093***	−0.159	−0.090**	−0.014	−0.108***
	(0.091)	(0.027)	(0.097)	(0.036)	(0.080)	(0.026)
Access to finance	Yes	Yes	Yes	Yes	Yes	Yes
Ethnic group controls	Yes	Yes	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes	Yes	Yes
Survey year FE	Yes	Yes	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	712	5814	713	5831	710	5800
R-squared	0.294	0.194	0.216	0.135	0.403	0.271
# of Ethnic groups	37	39	37	39	37	39

Note: This table reports the OLS regression results on firm innovation in relation to historical TseTse fly prevalence, examining the role of foreign ownership. The explanatory variable, TSI, measures historical TseTse fly prevalence at the ethnic location level. *Innovation* is an indicator that equals 1 if a firm has introduced either new products or new production processes in the past three years, and 0 otherwise. Foreign 50% indicates whether a firm has over 50% ownership by foreigners. Ethnic location-level controls include *Slave exports, Longitude, Latitude, SI, Temperature, Intensive agriculture, Political centralization, Large animals*, and *Malaria index*. Firm controls include *firm size, firm age, sales growth, state ownership, foreign ownership, exports, profit, CEO experience*, and *business group affiliation*. Survey year, industry, and country fixed effects are included in all models. See Table 1 for more detailed variable definitions and data sources. Standard errors clustered at the ethnicity location level are reported in parentheses. *, **, and *** indicate significance at 10%, 5%, and 1%, respectively.

expectation. It lends additional support to our hypothesized cultural channel by introducing an external shock to local culture, while also indicating that ownership plays a critical role in mediating the relationship between TseTse fly prevalence and firm innovation strategies.

After identifying the role of ownership in the relationship between TseTse fly prevalence and firm innovation, we turn to examine the role of workforce in this relationship. Evidence suggests that employees' cognitive abilities, attitudes, creativity, and appropriate training for employees can influence firm innovation to some extent (Liu et al., 2017; Sung and Choi, 2018; Chaubey et al.,2022). In

Table 11
TseTse fly and firm innovation: the role of workforce.

	Innovation				
	Full	Obstacle educated		High school rate	
		Yes	No	Low	High
	(1)	(2)	(3)	(4)	(5)
TSI	−0.090***	−0.092**	−0.075**	−0.119***	−0.102***
	(0.027)	(0.037)	(0.030)	(0.031)	(0.030)
TSI*Training	0.022	0.045*	0.003	0.034*	0.001
	(0.014)	(0.027)	(0.016)	(0.018)	(0.017)
Training	0.164***	0.153***	0.163***	0.139***	0.157***
	(0.020)	(0.028)	(0.021)	(0.022)	(0.024)
Access to finance	Yes	Yes	Yes	Yes	Yes
Ethnic group controls	Yes	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes	Yes
Survey year FE	Yes	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	Yes	Yes	Yes
Observations	6492	1980	4449	2605	2876
R-squared	0.219	0.237	0.226	0.206	0.258
# Ethnic groups	39	39	39	39	39

Note: This table reports the OLS regression results on firm innovation in relation to historical TseTse fly prevalence, examining the role of workforce. The explanatory variable, TSI, measures historical TseTse fly prevalence at the ethnic location level. The dependent variable, *Innovation*, is an indicator that equals 1 if a firm has introduced either new products or new production processes in the past three years, and 0 otherwise. *Obstacle Educated* is "yes" if a firm rates the question "How much of an obstacle: inadequately educated workforce?" as less than 2 (on a scale from 0 to 4, where higher values represent greater difficulty); it is "no" if the rating is 2 or higher. *High School Rate* is defined as "high" if the percentage of full-time workers who have completed high school is above the sample mean; otherwise, it is defined as "low." *Training* is an indicator that takes a value of 1 if a firm's answer is "yes" to the question "Are there formal training programs for permanent, full-time employees in the last fiscal year?" and 0 if "no." Ethnic location-level controls include *Slave exports, Longitude, Latitude, SI, Temperature, Intensive agriculture, Political centralization, Large animals*, and *Malaria index*. Firm controls include *firm size, firm age, sales growth, state ownership, foreign ownership, exports, profit, CEO experience*, and *business group affiliation*. Survey year, industry, and country fixed effects are included in all models. See Table 1 for more detailed variable definitions and data sources. Standard errors clustered at the ethnicity location level are reported in parentheses. *, **, and *** indicate significance at 10%, 5%, and 1%, respectively.

Table 7, we have found that TseTse fly prevalence primarily affects the attitudes of local low-education populations toward technology, thus if employees play a role in the relationship between TseTse fly prevalence and firm innovation, we expect that TseTse fly's influences on firm innovation primarily show among firms with a higher proportion of low-education employees, and training for employees, as a supplement for low education, can mitigate the negative impact of TseTse fly prevalence on innovation.

Table 11 reports our results. The impact of TseTse fly prevalence on firm innovation is primarily observed in: (1) firms that report difficulties in finding educated employees, and (2) firms with a predominantly low-education workforce. Our first grouping criterion is firms self-reported *the extent of inadequately educated workforce.* Firms are classified into the high education group if this value is less than 2 (on a scale from 0 to 4, where higher values represent greater difficulty), otherwise they are in the low education group if the rating of obstacle is 2 or higher. The second grouping criterion is high school rate (in %), as reported in the WES dataset, which reflects the percentage of full-time workers who have completed high school. Firms are classified into the high education group if this value is above the sample mean; otherwise, they are classified into the low education group. In the high-education and low-education groups, we separately test the impact of TseTse fly prevalence on firm innovation and examine whether employee training could mitigate the negative effects of TseTse fly prevalence. Training is an indicator which takes a value of 1 if a firm's answer yes to the question "Are there formal training programs for permanent, full-time employees in last fiscal year?", and 0 if no.

The results in Table 11 show that the adverse effects of TSI on innovation are more pronounced in the low-education group (Columns 2 and 4). In the low-education group, training mitigates the negative impact of TseTse fly prevalence on firm innovation. In Column 2, the coefficient of *TSI* * *Training* is 0.045, indicating that for firms providing employee training, the negative effect of TSI on firm innovation is reduced, with the total TSI coefficient becoming −0.047. In contrast, for firms not offering training, the total TSI coefficient is −0.092, which in absolute value exceeds the TSI coefficient (−0.087) in our baseline results. In the full sample and the high-education group subsample, the coefficient of *TSI* * *Training* is not statistically significant, suggesting that the adverse effects of TseTse fly prevalence are larger among low-education employees. Furthermore, training these employees can alleviate these negative effects (see Table 7).

By conducting the above tests, we clarify how TseTse fly prevalence and the related attitudes impact firms' innovation behaviors through two specific organizational roles: ownership and workforce. The stronger effects of TseTse fly prevalence in firms not dominated by foreign ownership suggest that local traits primarily influence firms' innovation strategies through the perceptions and decisions of domestic owners. By observing that firms with a higher proportion of less-educated employees are more significantly affected by TseTse fly prevalence in terms of innovation, and that this negative effect can be mitigated through employee training, we demonstrate that TseTse fly prevalence also impacts firm innovation through the cognition and abilities of employees.

TTo more accurately identify the cultural transmission channel, we conduct an additional robustness check. The cultural transmission channel relies on intergenerational inheritance, which can be disrupted by population migration. To account for migrations that occurred between countries over the past 500 years, Gorodnichenko and Roland (2017) use a more stringent sample (restricted to

Table 12
TseTse fly, firm financing, and innovation.

	Innovation			New product			New process		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
TSI	−0.078***	−0.081***	−0.131***	−0.091**	−0.084**	−0.144***	−0.089***	−0.093***	−0.149***
	(0.027)	(0.028)	(0.030)	(0.036)	(0.037)	(0.037)	(0.027)	(0.027)	(0.037)
Bank financing	0.002***			0.002***			0.002***		
	(0.000)			(0.000)			(0.000)		
Line of credit		0.095***			0.103***			0.091***	
		(0.021)			(0.021)			(0.020)	
Trade credit			0.001***			0.001***			0.001***
			(0.000)			(0.000)			(0.000)
Firm controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Ethnic group controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Survey year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	6457	6362	4601	6476	6380	4612	6441	6346	4585
R-squared	0.202	0.202	0.199	0.141	0.142	0.143	0.281	0.279	0.246
# Ethnic groups	33	33	33	33	33	33	33	33	33

Note: This table reports OLS regression results on firm innovation in relation to historical TseTse fly prevalence, conditional on various types of firm financing. The explanatory variable, *TSI*, measures historical TseTse fly prevalence at the ethnic location level. *Innovation* is an indicator that equals one if a firm has introduced either new products or new production processes in the past three years and zero otherwise. *New product* and *New process* equal one if a firm has introduced new products and new production processes, respectively, and zero otherwise. *Banking financing, Line of credit*, and *Trade credit* equal the share of working capital financed by banks, credit line issued by financial institutions, and trade credit, respectively. Ethnic location-level controls include *Slave exports, Longitude, Latitude, SI, Temperature, Intensive agriculture, Political centralization, Large animals*, and *Malaria index*. Firm controls include *Firm size, Firm age, Sales growth, State, Foreign, Exports, Profit, CEO experience* and *Business group. Access to finance* is an indicator that ranges from zero to four, representing "no obstacle in access to finance" (0), "minor obstacle" (1), "moderate obstacle" (2), "major obstacle" (3) and "very severe obstacle" (4). Survey year, industry, and country fixed effects are included in all models. See Table 1 for more detailed variable definitions and data sources. Standard errors clustered at the ethnicity location level are reported in parentheses. *, **, and *** indicate significance at 10%, 5%, and 1%, respectively.

countries with roughly the same ethnic composition as 500 years ago) to validate the relationship between culture and innovation. Following their approach, we use data from Putterman and Weil (2010) to identify and drop countries that experienced significant migration flows since 1500 (where the share of the indigenous population from 1500 in today's population is lower than 85%). Our results remain robust when we restrict our sample accordingly. In Column 1 of Table A1 in the online appendix, the coefficient of is −0.19 which is greater in absolute value compared to the coefficient of TSI (−0.087) in our baseline results.

5. TseTse fly and firm innovation: the role of external financing and institutions

Our main findings indicate that the TseTse fly influences firm innovation by shaping local attitudes toward technology. However, we acknowledge that, in addition to the cultural channel, the TseTse fly may also affect innovation through its impact on financing channels. There is a substantial body of literature examining the role of finance as a determinant of innovation (for a survey, see Kerr and Nanda, 2015). Moreover, An et al. (2022) demonstrate that the TseTse fly has had a significant negative impact on firm financing. Ignoring the financial channel may lead to an overestimation of the cultural channel's influence on innovation.

As mentioned before, we have included firms' self-reported financial obstacles, *Access to finance,* as a control variable in most of our models. This approach helps to partially isolate the impact of the financial channel, allowing us to more accurately identify the cultural channel's influence. In our baseline results, the coefficient for *Access to finance* is not statistically significant. Additionally, we control for the impact of major sources of external firm financing in our analysis. For example, we include various firm-level characteristics related to the ease of borrowing. At the ethnic level, we control for factors such as the extent of precolonial slave trade, malaria prevalence, and precolonial political centralization, all of which can influence local financial development through their impact on institutions (Acemoglu et al., 2001; Aslan, 2015; Pierce and Snyder, 2018).

In this section, we present the results of a series of robustness checks that account for firms' external financing, and differentiate the impacts of cultural and financial channels. Specifically, we re-estimate model (1) while incorporating various measures of external financing. These measures include *Banking financing, Line of credit*, and *Trade credit*, which represent the share of working capital financed by banks, credit line issued by financial institutions, and trade credit, respectively. Table 12 presents the results.

As shown in Table 12, the relationships between TseTse fly prevalence and measures of firm innovation remain qualitatively similar to our baseline findings. All three measures of firm external financing are positive and significantly different from zero, aligning with existing evidence from developing countries (Kerr and Nanda, 2015). These results suggest that the impact of TseTse fly prevalence on firm innovation persists even when accounting for local financial development, as noted in An et al. (2022).

Additionally, we group the sample firms into two categories: those with more access to finance and those with less access to finance. We analyze the impact of the TseTse fly on innovation in each group. This grouping method allows us to compare the impact of TseTse fly on innovation among firms with similar financial conditions. Moreover, by testing the influence of the TseTse fly on innovation among firms with no or minimal financial difficulties, we can more accurately quantify the standalone effect of the cultural channel. We present our results in Appendix Table A2. The estimation based on low financial obstacle group (at −0.077) primarily reflects the cultural channel of TseTse fly, as this subsample excludes firms with particularly high financial obstacles. It is slightly smaller in absolute value compared to the coefficient of TSI (−0.087) in our baseline results.

To investigate further, we incorporate an interaction term between TSI and *Access to finance* (a variable ranging from 0 to 4, representing increasing levels of financial difficulty) in our model. The results in Appendix Table A3 indicate that *Access to finance* itself have a negligible impact on innovation. These results suggest that the effect captured by TSI primarily reflects the cultural channel. Although a firm's financial obstacles do not directly affect innovation, this cultural influence is amplified as the severity of a firm's financial obstacles increases.

We further discuss the role of Fintech development in perpetuating the attitudes that shaped by TseTse fly prevalence. It's well documented that more developed financial markets can encourage firms to innovate by providing more accessible financial resources (Egger and Keuschnigg, 2015; Fombang and Adjasi, 2018; An and Rau, 2021). We conjecture that Fintech provides alternative financing channels that are less influenced by traditional cultural norms compared to traditional banking. Consequently, we expect that the negative influences of the TseTse fly will be less pronounced in countries with greater Fintech development. To test this heterogeneity, we investigate the impact of Fintech development by examining the relationship between the TseTse fly and firm innovation in subsamples divided by the sample mean of the Fintech development measure from Cornelli et al. (2023).

Appendix Table A4 presents our results, which reveal that more advanced Fintech development can offset the negative effect of TseTse fly on innovation. The significant reduction of the negative impact (from −0.359 to −0.093) highlights the transformative potential of Fintech in mitigating cultural barriers to firm innovation, reinforcing the importance of modern financial infrastructure, especially alternative financing channels that are less influenced by traditional cultural norms, in fostering a more innovation-friendly business environment.

Both formal and informal institutions play a crucial role in shaping innovation activities (Lee and Law, 2016; He and Tian, 2020). Finally, we discuss the role of formal institutions in perpetuating the attitudes that shaped by TseTse fly prevalence. Attitude is an informal institutional trait, and there is evidence suggesting that formal institutional traits such as the quality of legal systems can complement and interact with informal institutions (Roland, 2004; Fiori, 2018; Buggle and Durante, 2021). Specifically, we test the role of informal institutions including property rights protection, contract enforcement, and ease of doing business.

Property rights protection is the legal framework and enforcement mechanisms that safeguard individuals' and organizations' ownership of tangible and intangible assets. It ensures that owners have the authority to use, transfer, or benefit from their property without interference or expropriation by others, including the government. Stronger legal protections for property rights (including patents) may increase firms' willingness to invest in intangible assets, alleviating concerns about others misappropriating their technologies (Chen and Puttitanun, 2005; Fan et al., 2013).

Contract enforcement evaluates the process and mechanisms through which agreements or contracts between parties are upheld and disputes are resolved, ensures that the terms of a contract are legally binding and that parties are held accountable for fulfilling their obligations. Effective contract enforcement relies on a functioning legal system, including courts or arbitration bodies, that can address breaches of contract, interpret terms, and impose remedies such as damages or specific performance. Stricter contract enforcement ensures fairness in commercial and personal transactions, thereby protecting and incentivizing firms' innovation activities (Seitz and Watzinger, 2017).

A high ease of doing business ranking by the World Bank indicates a regulatory environment that is more conducive to the establishment and operation of local firms, as well as stronger protections of property rights. Innovation is inherently fraught with risk and uncertainty, which raises transaction costs. If these costs become too high, firms are likely to refrain from investing in innovation. A key function of law and regulation is to mitigate such risk and uncertainty (Van Waarden, 2001). When the regulatory environment is supportive of business activities, including R&D, firms are more willing to allocate resources toward innovation.

We expect that the negative impact of the hostile attitude toward technology caused by TseTse fly prevalence on firm innovation may be weaker in countries with higher formal institutional quality, by providing incentives through a better policy environment. Conversely, lower formal institutional quality may create an environment where firms lack incentives to innovate, thereby amplifying the impact of TseTse fly prevalence.

We divide the company sample into strong institutions and weak institutions groups based on the sample mean values of the three institutional quality indices mentioned above, and test the relationship between TSI and firm innovation in the divided subsamples. Appendix Table A5 presents our results, which are consistent with our expectations. The coefficients of TSI are more negative in the weak institutions group. These results suggest that strong institutional frameworks not only cushion the adverse effects of TSI but, in some cases, nearly eliminate them, providing a supportive environment for firms to overcome local cultural constraints. The results reinforce the notion that formal institutional quality plays a critical role in buffering against the adverse cultural effects associated with TseTse fly prevalence.

6. Conclusion

In her innovative work, Alsan (2015) finds that the TseTse fly has exerted a negative impact on economic development in modern Africa. She further traces the operating channel to precolonial political centralization. We contribute to this line of research by documenting evidence on another important mechanism through which the TseTse fly has influenced economic growth, i.e., firm innovation. We hypothesize and find that in places with high TseTse prevalence historically, firms are less likely to innovate. This result is only obtained in Africa, and is not fully driven by confounding factors associated with tropical climate and temperature, as well as country- and ethnic location-level time invariant factors. We further discover that in countries where the TseTse fly was more prevalent, people are less welcoming towards technology, which is consistent with view that the fly has triggered a culture of hostility towards technology and such culture continues to shape firm's propensity to innovate today.

Our findings can inform policies aimed at fostering innovation in Africa. Although the TseTse fly has created inherently disadvantageous natural conditions in certain African regions, these challenges can be mitigated through the development of cultural, financial, and legal systems. To address the hostile perception of technology influenced by the TseTse fly, efforts could focus on foundational education and media campaigns, as our study indicates that the TseTse fly's impact is more pronounced among individuals with lower education levels. Strengthening education systems to cultivate a workforce of skilled innovators, technical experts, and forward-thinking business leaders can promote innovation from a human capital perspective. Governments can also encourage companies to implement regular employee training programs, which we have found to be beneficial for fostering innovation within firms.

Additionally, providing affordable access to innovative technology guidance and financial incentives—such as tax breaks and subsidies for innovative firms—can enable businesses to acquire the knowledge and skills essential for innovation at manageable costs. Furthermore, our findings highlight that strong formal institutions can mitigate the adverse effects of the TseTse fly. Strengthening institutional frameworks, including legal and financial systems, could offset the inherent disadvantages posed by the TseTse fly's influence, creating a more conducive environment for innovation and economic growth.

Declaration of competing interest

All authors have nothing to declare.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.jebo.2025.106917.

Data availability

Data will be made available on request.

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