

Malaria's Last Mile and Liberalism

Byron Carson

bcarson@hsc.edu

Hampden–Sydney College

Justin Isaacs

Hampden–Sydney College

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Abstract

Liberal political and economic institutions shorten anti-malaria campaigns, which can reduce morbidity and mortality. Following the economic literature on institutions and public health, liberal institutions allow individuals to acquire more desirable private and public goods, which hastens elimination—a problem some refer to as malaria's *last mile*. With data on time-to-elimination, various measures of institutions, and relevant covariates, we develop Cox proportional hazard models and robustness checks assessing whether liberal political and economic institutions shorten malaria's last mile. These results indicate liberal institutions have discernable effects on fighting malaria, effects that complement on-going, concerted efforts to eliminate the disease.

Keywords: malaria, liberalism, economic freedom, democracy, survival analysis

JEL Codes: I15, I18, P50

List of Abbreviations

WHO, World Health Organization
V-Dem, Varieties of Democracy
EFW, Economic Freedom of the World
GMEP, Global Malaria Elimination Program
GMCS, Global Malaria Control Strategy

“Progress towards malaria-free status is a continuous process and not a set of independent stages. Countries, subnational areas and communities are situated at different points along the path towards malaria elimination, and their rate of progress will differ depending on the level of investment, biological determinants (related to the affected populations, the parasites and the vectors), environmental factors, strength of health systems, and social, demographic, political and economic realities.” Global Technical Strategy for Malaria 2016-2030 | 2021 Update, p. 5

I Introduction

Many scholars note the difficulties of eliminating malaria. Aside from underlying ecological, climatological, and biological factors, people influence mosquito breeding habitats and might also alter their exposure to mosquitos and malaria in various ways. While some people might easily alter their exposure at local levels like through migration or home improvement, eliminating malaria at higher levels like through collective action is often more challenging. Advancing a nation-wide anti-malaria program requires technical expertise, consistent funding, and, just as important, economic and political conditions that encourage private and public efforts. Moreover, scholars note how the final stages of elimination create additional problems related to ambivalence that slows or lengthens anti-malaria efforts (Lover et al. 2018).

National elimination programs attempt to successfully eliminate malaria, but it is not clear why some programs succeed while others fail. The U.S. successfully eliminated malaria in the early 1950s after a coordinated spray campaign along with other social and economic changes throughout the early 20th century, e.g., military led anti-malarial operations and increasing real wealth. Some countries, like Venezuela, also experience resurgence where malaria is eliminated but subsequent outbreaks occur. Analyzing the economic and political determinants of elimination might help practitioners and public health scholars better understand whether elimination campaigns will be successful and whether they can be sustained.

This paper develops a survival analysis on Malaria’s “last mile”, or more broadly the time it takes a country to successfully eliminate malaria. Survival analysis is commonly used in medical research and public health scholarship to examine likely determinants of survival, e.g., life expectancy after diagnosis (Lee and Go 1997). Recently, survival analysis was used to examine the risk factors associated with Covid-19 mortality in Mexico (Salinas-Escudero et al. 2020). Survival analyses on malaria, for example, examine the determinants of survival for children with malaria (Jumi et al. 2025); the effects of supervision when taking antimalarial medications (Dinelly et al. 2021); and clustering effects like when patients arrive at hospitals at similar times (Omaku, Braimah, and Correa 2024).

Specifically, we develop a stratified multivariate Cox proportional hazard model to explore the effect institutions might have on the hazard rates associated with country-level anti-malaria operations. Such a model allows us to examine the baseline hazard associated with the duration of anti-malaria programs, along with relevant time variant (and invariant) covariates. We measure duration as the number of years between 1947—the year that marked the first World Health Organization (WHO) Expert Committee on Malaria—and when the WHO certifies a country is free of malaria.

Our approach advances previous examinations of malaria in important ways. Using breakpoint regression analysis, for example, Cohen et al. (2022) estimates the timing of national anti-malaria operations, which implies an average duration of 12 years from the start of national anti-malarial operations to the first year of zero cases. While this study notes some of the factors that influence successful elimination like whether the country received WHO certification, it does not fully explain why such breakpoints occurred or which determinants influenced the last mile. As this study also only examines cases of successful elimination, the results also suffer from

survivorship bias. Using cross-country data Datta and Reimer (2013) examines correlates of malaria cases and accounts for larger endogeneity concerns. Our Cox model of malaria's last mile advances the model found in Datta and Reimer (2013) to examine the phenomenon pointed to in Cohen et al. (2022). We advance this research by including a larger sample of countries that have and have not eliminated malaria. We also examine the effects different determinants might have. Consistent with previous studies, our study indicates that political and economic institutions help to decrease the time it takes to obtain WHO certification.

Our survival model also contributes to the growing literature on the complex relationships between (liberal) institutions and public health (Troesken 2015; Geloso and Bologna Pavlik 2020; Candela and Geloso 2021; Geloso, Hyde, and Murtazashvili 2021, Forthcoming; Geloso 2021; Furton 2023; Carson 2025; Ogilvie 2025). Generally, we find that countries are more likely to receive WHO certification with higher levels of some economic freedom scores and with better quality democratic political institutions. There might be less severe tradeoffs between liberalism (as represented by economic freedom and various democratic political institutions) and public health. Similarly, countries can advance their institutions to facilitate economic and political development without a loss in public health, at least as it relates to malaria.

II Malaria Elimination and Liberalism

2.1 Mosquito Control and Malaria Elimination

Following the WHO's Global Technical Strategy for Malaria 2016-2030, 2021 update, there are several commonly accepted ways to eliminate malaria (also on the epidemiology of malaria, see Molineaux 1988). Focusing on vector control, people can develop ways to control

mosquito populations like through indoor residual spraying and the provision of insecticide treated bed nets. Focusing on humans as hosts of malaria parasites, chemoprophylaxis like quinine and other antimalarial drugs can limit the interactions between malaria parasites, mosquitos, and other people. Such medicines also provide treatment, which can alleviate symptoms and limit transmission. Improving the effectiveness of diagnostics, testing for individuals, and case detection for public health bureaus also encourage elimination.

Once a country's representatives believe they have eliminated malaria, they may apply to the WHO Director-General for certification. This process can take years as it involves initial assessment, review by the Technical Advisory Group on Malaria Elimination and Certification, field visits, and subsequent evaluations. Online Appendix I lists the countries that have received WHO certification.

2.2 Liberalism and Economic and Political Institutions

There are several reasons liberalism might have a positive effect on the timing of anti-malaria campaigns. As people develop better quality democratic political institutions, they might be better able to use democratic institutions and public funds to address social and public health problems like malaria. The Varieties of Democracy (V-Dem) project—which we use below—breaks democracy into five general dimensions: electoral, liberal, participatory, deliberative, and egalitarian. *Electoral* democracy measures whether democratic political institutions are responsive to citizens; whether suffrage is widely available; whether political and social organizations are free to operate; and whether elections are free, fair, and actually influence the executive branch. *Liberal* democracy refers to how protected individual rights are and, similarly, how protected individuals are from abuses of (tyrannical) states. *Participatory* democracy measures how widespread people

participate in the many forms of democratic governance. *Deliberative* democracy refers to the use of reason in political discourse, and the focus on genuine discussion of public wants rather than emotional appeals. Finally, *egalitarian* democracy measures how well democratic political institutions achieve equality.

These definitions of democracy indicate several pathways through which democratic political institutions might shape malaria and anti-national campaigns. Electoral democracy, for example, might be important if people want greater public support for anti-malaria operations. The desires of citizens to lower their exposure to mosquitos and malaria—expressed through electoral politics—might encourage public health bureaus to address the problem (see, Sen 2000, for a similar argument related to famine). Liberal democracy encourages myriad economic and social interactions by protecting property rights, some of which might facilitate anti-mosquito operations in intended and unintended ways. The more people want to limit their exposure to mosquitos and malaria, areas with higher participatory democracy scores might have more people using different bodies of government to advance their interests. Such competition between and across governmental agencies and levels—and from organizations in the private sector and in civil society—encourage a polycentric approach that helps to resolve public goods problems and encourages relevant innovations (Ostrom 2010). Ogilvie (2025) also indicates that areas with more diverse institutional responses—likely to occur in liberal environments—are better able to respond to and control infectious diseases. Deliberative democracy might be helpful for anti-malaria operations as the provision of such goods can be easily justified and advanced through political discourse; malaria can affect anyone and anti-mosquito operations are often appropriate means to address such problems. Egalitarian democracy might also be helpful in that malaria limits the abilities some people might have to advance their own goals, let alone participate in myriad

economic, social, and political activities. Areas with higher egalitarian democracy scores would rightly seek to redress such problems, likely seen as a kind of injustice often remedied by public health improvements.

Economic freedom might also positively influence people's ability to fight malaria. Generally, economic freedom refers to the freedoms people have to make their own choices, wherein such freedoms are derived from policies and institutions in a country. Such freedoms—as measured by the Economic Freedom of the World (EFW) Index—are often associated with higher rates of exchange, entrepreneurship, innovation, and economic development (Hall and Lawson 2014). This index groups aspects of economic freedom according to the following areas: the size of government (Area 1); legal system and property rights (Area 2); sound money (Area 3); freedom to trade internationally (Area 4); and regulation (Area 5). Area 1 includes measures like government consumption, transfers and subsidies, the top marginal tax rate, and state owned property, to indicate that larger governments can discourage private efforts. Like V-Dem's liberal democratic score, Area 2 measures the quality of a country's judicial system—whether judges are independent of the political process—property rights, contracts, military interference, and aspects of policing and crime to examine how well legal rules are generally enforced. Area 3 refers to the capacities people have to develop plans based on stable units of currency, which include various entrepreneurial projects as well as personal financial plans. This area includes variables on the growth rate of a country's money supply and the rate of inflation, e.g., the standard deviation in the annual rate of inflation over the last five years. Area 4 captures the freedoms people have to engage in international commerce, which includes tariff revenue as a share of international trade, non-tariff regulatory barriers to trade, black market exchange rates, and capital controls. Finally, Area 5 specifically measures domestic regulations, e.g., whether credit markets are heavily

regulated, whether labor markets are heavily regulated, and whether business formation is heavily regulated.

All of these conditions can theoretically influence how people limit their exposure to mosquitos and malaria, which can facilitate or burden anti-malaria campaigns. While larger governments (Area 1) might be better able to coordinate public health services, which include anti-mosquito operations and related anti-malaria campaigns, governmental programs might also crowd out private and local efforts. Governmental programs might also be dysfunctional and come with a host of public choice concerns that indicate governmental programs are less efficient producers of malaria elimination. The more people expect property rights and rules of law are well-protected (Area 2), the more they might engage in entrepreneurial endeavors—small and large—which might be geared towards eliminating mosquitos and malaria (see, for example, Carson 2016, 2020, 2023b, 2023a). Relatedly, the more people have an ability to make plans based on stable currencies (Area 3), which improves the ability to engage in economic calculation and determine the profitability of plans, the more they might engage in private and local mosquito operations. We might expect that the more access people have to international trade and capital (Area 4), people should have greater financial resources and/or lower costs associated with acquiring capital. Moreover, the more contact people have with foreign peoples, ideas, and practices, the more they might improve domestic efforts to control mosquito populations (see, for example, Bauer 2000). Finally, we might also expect that when people face fewer regulations, e.g., in credit and labor markets and when starting businesses, they might be better able to pursue profit opportunities, which might include controlling mosquito populations and providing anti-malaria services (see, for example, Carson 2023b).

While some recognize institutions that encourage economic freedom can negatively influence public health, e.g., Troesken (2015), there are other relevant positive effects (Geloso and Bologna Pavlik 2020; Candela and Geloso 2021; Geloso, Hyde, and Murtazashvili 2021; Geloso 2021). In the context of malaria, people might be better able to advance private methods of mosquito control, form firms in the private sector, and form organizations in civil society when underlying institutions encourage economic freedom (Carson 2023a).

III Data and Method

We develop a Cox proportional hazard model to assess the progression of elimination, as well as the effects of political and economic institutions. To advance this analysis, we divide countries into two groups; countries have either eliminated malaria and received WHO certification, or they have not.

We define our model with Equation 1 as follows:

$$\boxed{h(t|X_1, \dots, X_\rho) = h_0(t)^{\sum_{i=0}^{\rho} b_i X_i}} \quad (1)$$

where

- t represents the number of years between 1947 and when the WHO certified a country free of malaria.
- $h(t|X_1, \dots, X_\rho)$ is the hazard function as a function of X_ρ covariates.
- The X_ρ covariates include real GDP per capita in 2011 dollars, foreign direct investment net inflows (as a share of GDP), precipitation (average mm per year), population living under sea level (the share of people living below 5 meters as a share of total population), the number of physicians per 1,000, and different measures of institutions, i.e., democratic political institutions, the rule of law, and economic freedom. To scale GDP per capita and precipitation, we logarithmically transform them.

We use the five democracy indices, published by V-Dem, to measure democratic political institutions. Our measures of economic freedom area scores come from the Fraser Institute's 2024 report. The remaining covariates all come from the World Bank Development Indicators.

We selected these covariates out of a concern for parsimony and to minimize multicollinearity. There are many factors that influence how a country eliminates malaria and our model includes some of the primary determinants. GDP per capita, for example, indicates how people might allocate private and public resources to fight malaria. Foreign direct investment net inflows helps to capture how interested foreigners are in a country's economy, which might aid private and public efforts against malaria. Precipitation and population below sea level are common measures indicating how likely people are to come into contact with mosquitos. The number of physicians per 1,000 people provides some information about a country's healthcare. There are other measures of these factors, but the ones selected are a parsimonious attempt to develop this survival model.

All models include and report robust variance terms. All models are clustered at the country-level unless otherwise stated.

Tables 1 and 2 present regional summary statistics for our measure of duration and institutions (Table 1) and for our covariates (Table 2). The WHO maintains a list of countries that have been certified free of malaria (reprinted in Online Appendix 1), along with the year in which they obtained that certification. They also include a list of countries that have been certified malaria free but where the disease never existed or it declined without specific measures. We focus on the list of malarial countries and exclude non-malarial countries. Among malarial countries, we take the difference between that year and 1947—the year of the first WHO Expert Committee on Malaria—to create our measure of duration.

Table 1: Summary Statistics - Duration and Institutions

Characteristic	N	East Asia & Pacific N=390 [/]	Europe & Central Asia N=1370 [/]	Latin America & Caribbean N=312 [/]	Middle East & North Africa N=624 [/]	North America N=78 [/]	South Asia N=78 [/]	Sub- Saharan Africa N=156 [/]
WHO Certification	3,008	60 (21)	46 (26)	59 (23)	75 (6)	23 (0)	69 (0)	52 (26)
V-Dem Electoral	2,672	0.41 (0.29)	0.49 (0.29)	0.45 (0.25)	0.13 (0.09)	0.79 (0.10)	0.55 (0.09)	0.50 (0.29)
V-Dem Liberal	2,617	0.35 (0.29)	0.38 (0.30)	0.32 (0.23)	0.10 (0.05)	0.71 (0.12)	0.39 (0.09)	0.44 (0.24)
V-Dem Participatory	2,672	0.24 (0.24)	0.30 (0.23)	0.29 (0.17)	0.06 (0.05)	0.55 (0.09)	0.29 (0.05)	0.30 (0.18)
V-Dem Deliberative	2,672	0.34 (0.28)	0.36 (0.30)	0.31 (0.23)	0.10 (0.08)	0.70 (0.12)	0.34 (0.09)	0.43 (0.25)
V-Dem Egalitarian	2,672	0.36 (0.24)	0.42 (0.25)	0.28 (0.21)	0.13 (0.05)	0.58 (0.15)	0.36 (0.06)	0.39 (0.23)
EFW Overall	1,114	7.10 (1.27)	6.75 (1.11)	6.33 (1.11)	5.52 (1.17)	8.23 (0.42)	6.11 (0.53)	7.11 (0.81)
EFW Area 1	1,021	6.41 (1.01)	6.46 (1.22)	7.76 (1.04)	5.53 (1.11)	7.18 (0.68)	7.95 (0.62)	7.20 (0.79)
EFW Area 2	1,055	6.78 (1.52)	5.87 (1.26)	4.49 (0.71)	3.58 (1.10)	8.23 (0.39)	4.72 (0.38)	6.01 (0.77)
EFW Area 3	1,019	8.50 (1.21)	8.02 (1.65)	7.46 (2.02)	7.43 (1.55)	9.48 (0.27)	6.07 (1.10)	8.11 (1.56)
EFW Area 4	940	7.77 (1.26)	7.84 (1.23)	6.56 (1.81)	5.96 (2.13)	8.41 (0.29)	6.02 (2.04)	7.21 (1.86)
EFW Area 5	1,029	6.97 (1.56)	6.40 (1.25)	6.02 (1.11)	5.39 (1.76)	8.45 (0.52)	5.92 (0.31)	7.00 (0.45)
[/] Mean (SD)								

Table 2: Summary Statistics - Covariates								
Characteristic	N	East Asia & Pacific N=390 [/]	Europe & Central Asia N=1370 [/]	Latin America & Caribbean N=312 [/]	Middle East & North Africa N=624 [/]	North America N=78 [/]	South Asia N=78 [/]	Sub- Saharan Africa N=156 [/]
GDP per capita	2,584	16,029 (16,181)	12,173 (9,267)	6,877 (4,142)	13,368 (15,435)	33,407 (13,256)	4,531 (3,024)	6,445 (5,446)
FDI	1,819	4.8 (6.4)	7.2 (31.5)	1.8 (2.1)	1.4 (2.9)	1.2 (0.8)	0.9 (0.6)	2.7 (2.9)
Precipitation	2,128	1,568 (959)	640 (191)	1,393 (571)	136 (80)	715 (0)	1,712 (0)	1,135 (910)
Population at Sea level	117	4 (4)	4 (12)	3 (4)	11 (13)	2 (0)	4 (0)	5 (3)
Physicians per 1,000	1,339	1.56 (0.84)	2.86 (1.17)	1.46 (1.24)	1.12 (0.63)	1.92 (0.73)	0.51 (0.33)	0.90 (0.63)
[/] Mean (SD)								

Table 1 indicates that of the 3,008 country-year observations for the time to receive WHO certification since 1947, the average time for countries in East Asia and Pacific was 60 years.

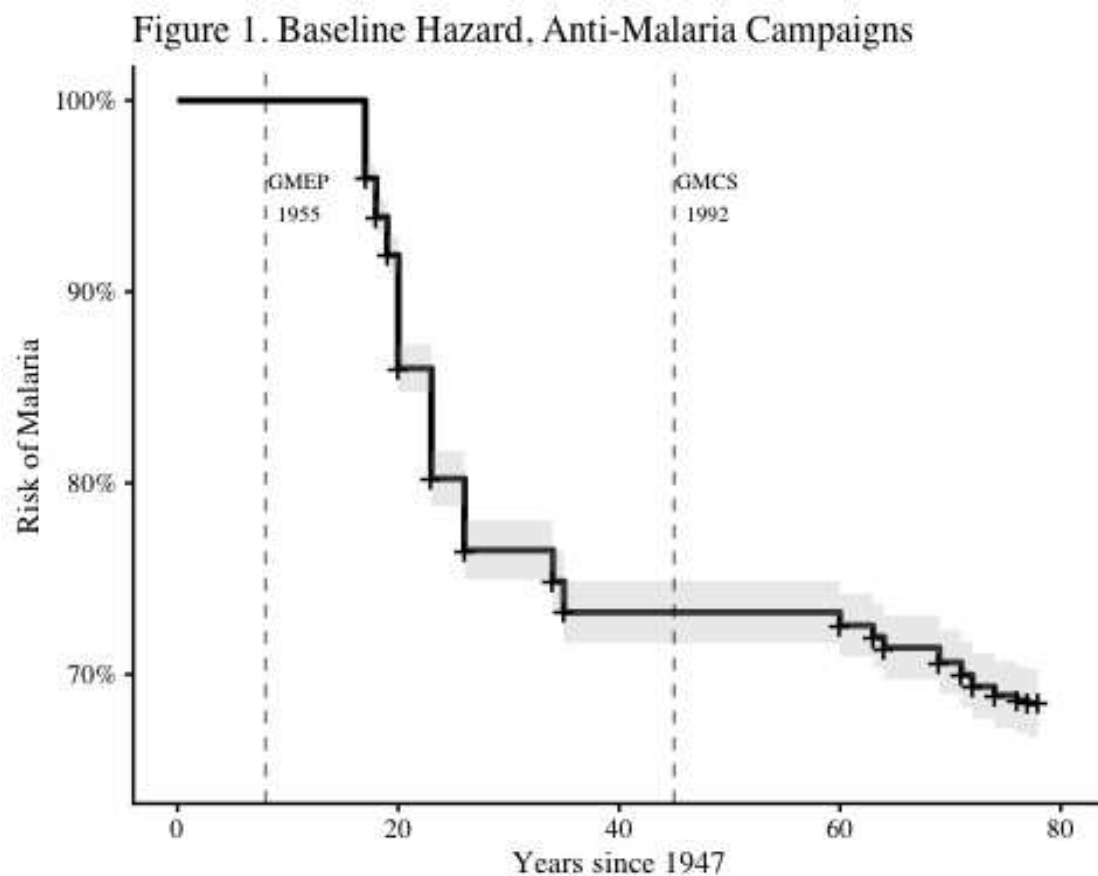
These summary statistics motivate a simple version of our argument. Countries in regions with lower V-Dem and Economic Freedom scores like the Middle East and North Africa should tend to have a more prolonged fight against malaria or, similarly, they should face a lower probability of receiving WHO certification. While not conclusive, these summary statistics indicate country-year observations in the Middle East and North Africa region face a longer average time to receive WHO certification (75 years since 1947).

IV Results

The figure below presents a baseline survival function, i.e., a Kaplan-Meier survival curve that estimates the probability a country receives WHO certification. This curve is based on 1) the

length of time between 1947 and one of two events (WHO certification or our cutoff of 2023 given data availability) and 2) whether a country received WHO certification in a particular year.

Similarly, and for simplicity, this survival curve describes the risk of continuous malaria transmission, as shown on the vertical axis. Between 1947 and 2023, most country-year observations “survived”, which in this case means they failed to receive WHO certification. In 1967, for example, Figure 1 suggests that about 85%-90% of country-year observations failed to receive WHO certification. By 2000, the risk of malaria decreased to less than 70%.



Intuitively, this graph corresponds with some of the major international efforts to eradicate malaria. None of the country-year observations received WHO certification until the mid 1960s, which coincides with the launch of the Global Malaria Eradication Program (GMEP) in 1955 and the

growing use of DDT. The WHO certified other countries during and after the 1990s, aided by the Global Malaria Control Strategy (GMCS) in 1992 and the Roll Back Malaria initiative in 1998. Online Appendix II provides additional Kaplan-Meier survival curves stratified based on whether countries have above average V-Dem liberal democracy scores, Economic Freedom Area 2 scores, and real GDP per capita. These curves indicate country-year observations have steeper survival curves when they have above average institutions and GDP. In this case, this indicates they are more likely to receive WHO certification.

Table 3 presents the estimated log hazard ratios of Equation 1 with the primary measures of political institutions from V-Dem and other covariates (robust standard errors are in parentheses). The inclusion of these variables show identifiable effects on the hazard—the risk of being certified malaria-free by the WHO. In all Columns, V-Dem coefficients are statistically significant and positive. Moreover, these results suggest that country-year observations with higher V-Dem scores tend to face substantially higher hazard ratios or risks associated with WHO certification. In Column 1, for example, increasing the V-Dem Electoral measure by one unit (one standard deviation) increases the log-hazard ratio by 3.773. Similarly, a one-unit change in the V-Dem electoral measure increases the hazard (of elimination) by a factor of 43.521. Tables 6 through 10 in Online Appendix III show the hazard ratios, confidence intervals, and p-values that correspond with the models in Columns 1 through 5 in Table 3.

Table 3. WHO Certification and V-Dem

	(1)	(2)	(3)	(4)	(5)
GDP (log)	0.441 (0.271)	0.283 (0.283)	0.426 (0.283)	0.350 (0.276)	0.274 (0.287)
FDI (%)	0.004+ (0.004)	0.005* (0.004)	0.005* (0.004)	0.004* (0.004)	0.004+ (0.004)
Precipitation (log)	0.101 (0.233)	0.156 (0.229)	0.187 (0.230)	0.131 (0.223)	0.135 (0.233)
Sea Level Population	-0.000 (0.012)	-0.002 (0.013)	0.001 (0.013)	-0.002 (0.013)	-0.003 (0.013)
Physicians per 1,000	0.019 (0.134)	0.047 (0.132)	0.015 (0.136)	0.053 (0.131)	-0.011 (0.136)
V-Dem Electoral	3.773*** (0.856)				
V-Dem Liberal		3.710*** (0.819)			
V-Dem Participatory			4.368*** (1.040)		
V-Dem Deliberative				3.633*** (0.821)	
V-Dem Egalitarian					4.420*** (0.944)
Observations	90	89	90	90	90
Nagelkerke R ²	0.459	0.461	0.448	0.450	0.470

+ p < 0.1, * p < 0.05, ** p < 0.01, *** p < 0.001

All of the primary V-Dem measures tend to increase the probability of WHO certification. These models include robust standard errors, and the results are unchanged when country weights are included. Such weights account for the potential for some country-year observations to be overrepresented in the data (results available upon request).

Figure 2 below compares the Kaplan-Meier survival curve, described above, and the survival curve based on the multivariate Cox proportional hazard model with the V-Dem electoral measure from Column 1 of Table 3. That these graphs are similar indicates similar hazard ratios.

Figure 2. Baseline vs. Cox - V-Dem Electoral

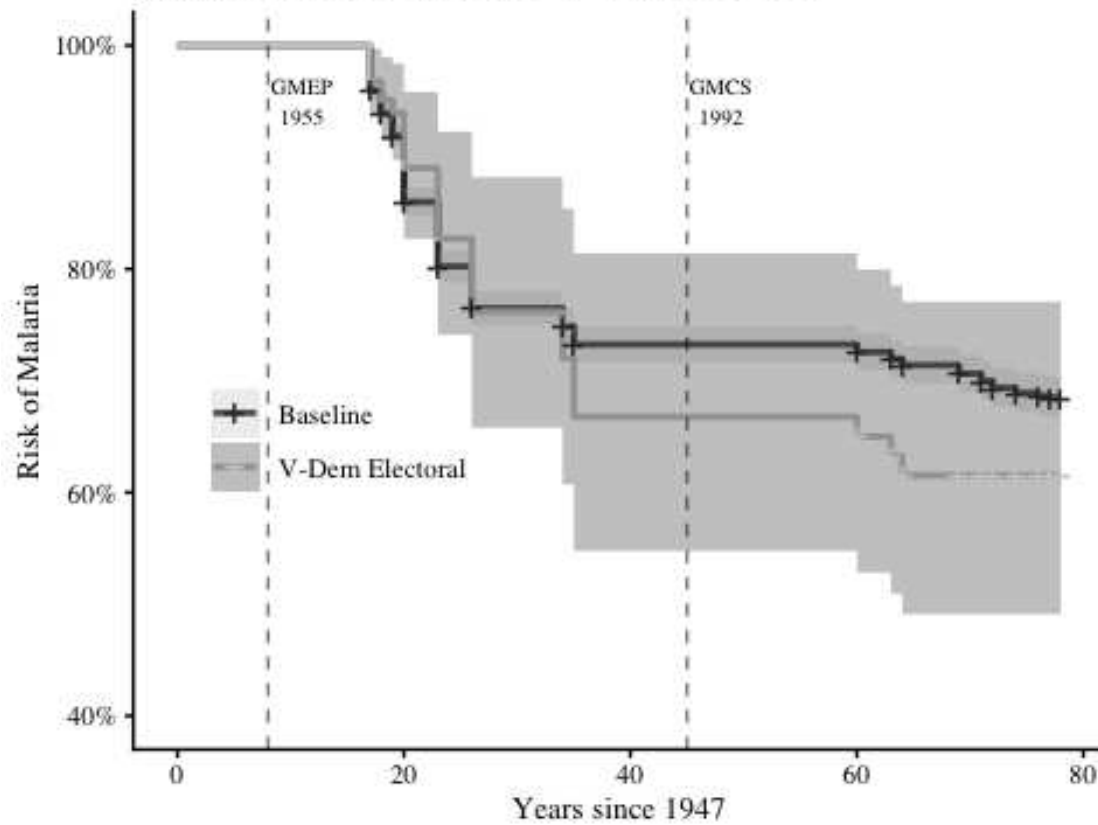


Table 4 presents the estimated log hazard ratios of Equation 1 with Fraser’s measures of economic freedom of the world representing liberal economic institutions. Columns 1 and 2 include overall measures of a country’s economic freedom, where Column 2 includes the standard deviation of economic freedom area scores, which provides more information about overall economic freedom (Bolen and Sobel 2020). The remaining columns each show different Area scores of economic freedom.

Table 4. WHO Certification and Economic Freedom

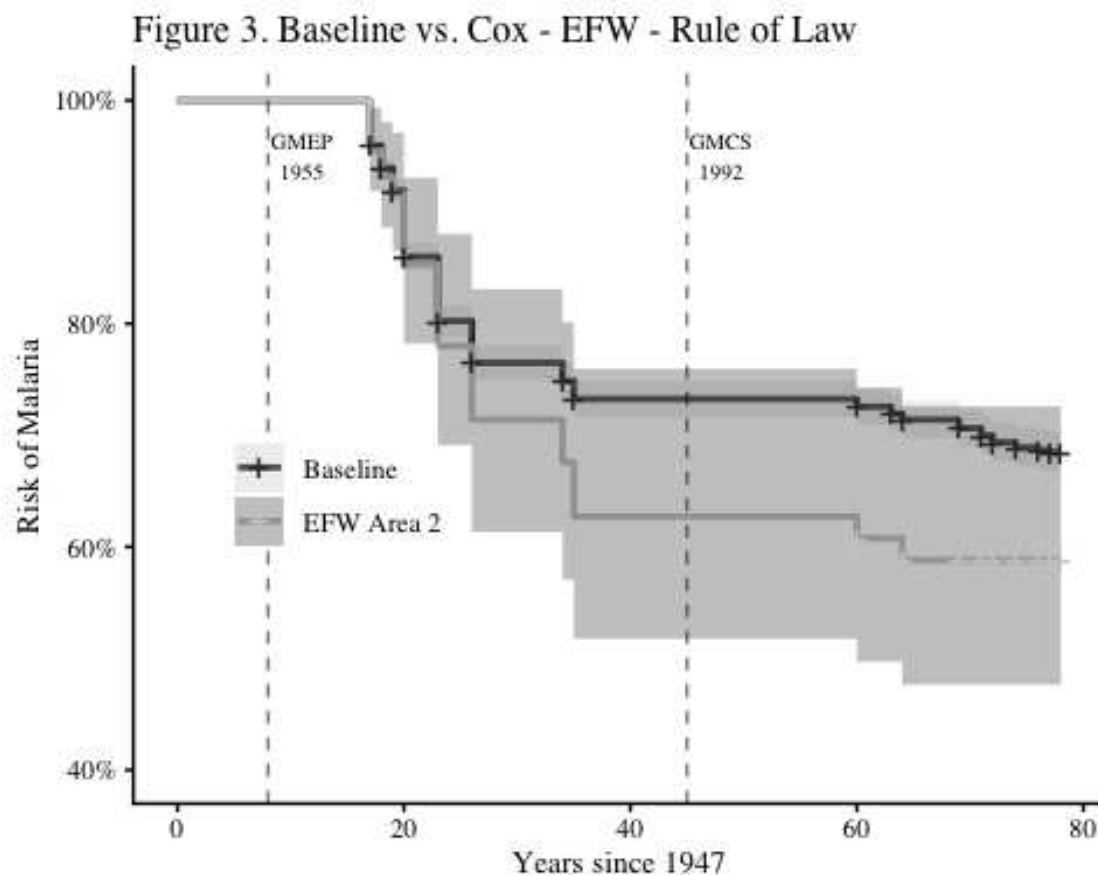
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
GDP (log)	0.606+ (0.283)	0.550 (0.290)	0.645* (0.223)	-0.037 (0.317)	0.790** (0.266)	0.485+ (0.269)	0.612+ (0.257)
FDI (%)	0.005* (0.005)	0.005* (0.005)	0.008*** (0.005)	0.006* (0.005)	0.006** (0.005)	0.005** (0.005)	0.005* (0.005)
Precipitation (log)	0.308 (0.213)	0.292 (0.214)	0.516* (0.198)	-0.001 (0.211)	0.397* (0.192)	0.330 (0.192)	0.314+ (0.190)
Sea Level Population	0.000 (0.014)	0.009 (0.017)	-0.008 (0.014)	-0.005 (0.013)	0.002 (0.014)	0.001 (0.014)	0.000 (0.014)
Physicians per 1,000	0.260 (0.123)	0.257 (0.122)	0.296+ (0.123)	0.186 (0.124)	0.281 (0.122)	0.297+ (0.117)	0.260 (0.120)
EFW	0.077 (0.214)	0.023 (0.214)					
EFW (s.d.)		-0.555 (0.543)					
Area 1			-0.366+ (0.179)				
Area 2				0.514*** (0.155)			
Area 3					-0.076 (0.117)		
Area 4						0.019 (0.125)	
Area 5							0.084 (0.158)
Observations	84	84	84	86	85	78	85
Nagelkerke R ²	0.261	0.270	0.297	0.363	0.269	0.244	0.268

+ p < 0.1, * p < 0.05, ** p < 0.01, *** p < 0.001

The area scores related to the size of government (Area 1) and legal systems and property rights (Area 2) are statistically significant but have different effects. Column 3 indicates that the Area 1 score is slightly significant and that increasing this score (countries with, for example, smaller government expenditures and lower rates of taxation) lowers the chances of receiving WHO certification; a one unit increase in the Area 1 score lowers the log hazard ratio by 0.366, which is a decrease in the hazard by 0.693. In Column 4, a one unit increase in the Area 2 score (areas with, for example, more secure property rights) increases the log hazard ratio by 0.514, an

increase in the hazard by a factor of 1.672. Online Appendix III shows Tables 11 and 12, which show the hazard ratios, confidence intervals, and p-values that correspond with the models in Columns 3 and 4 in Table 4.

Figure 3 below compares the Kaplan-Meier survival curve, described above, and the survival curve based on the multivariate Cox proportional hazard model with the economic freedom Rule of Law (Area 2) measure. These curves also indicate similar hazard ratios.



V Robustness Checks

5.1 V-Dem

Model Assumptions

In this section we assess the validity of the proportional hazard assumptions for the V-Dem models in Table 3. Schoenfeld residual tests show that global p-values for the models used in Table 3 are less than 0.05, which indicates that the proportional hazards for some of the covariates vary across time (the results of these tests are available upon request). This is likely due to the GDP and V-Dem variables, as plots of their residuals show trends that are statistically different from zero and trends that vary across time.

We also recognize that our observations are not independent of each other. Country-year observations are likely dependent on other country-years observations. For example, people learn from past experience and from the experiences of other areas; once developed, mosquito control technologies are also available to different areas. While this is a violation of the Cox proportional hazard model, clustering allows the model to treat groups of country-years instead of individual country-year observations. The main results for V-Dem and EFW are robust to changing clusters, e.g., by country and by region (Results are available upon request).

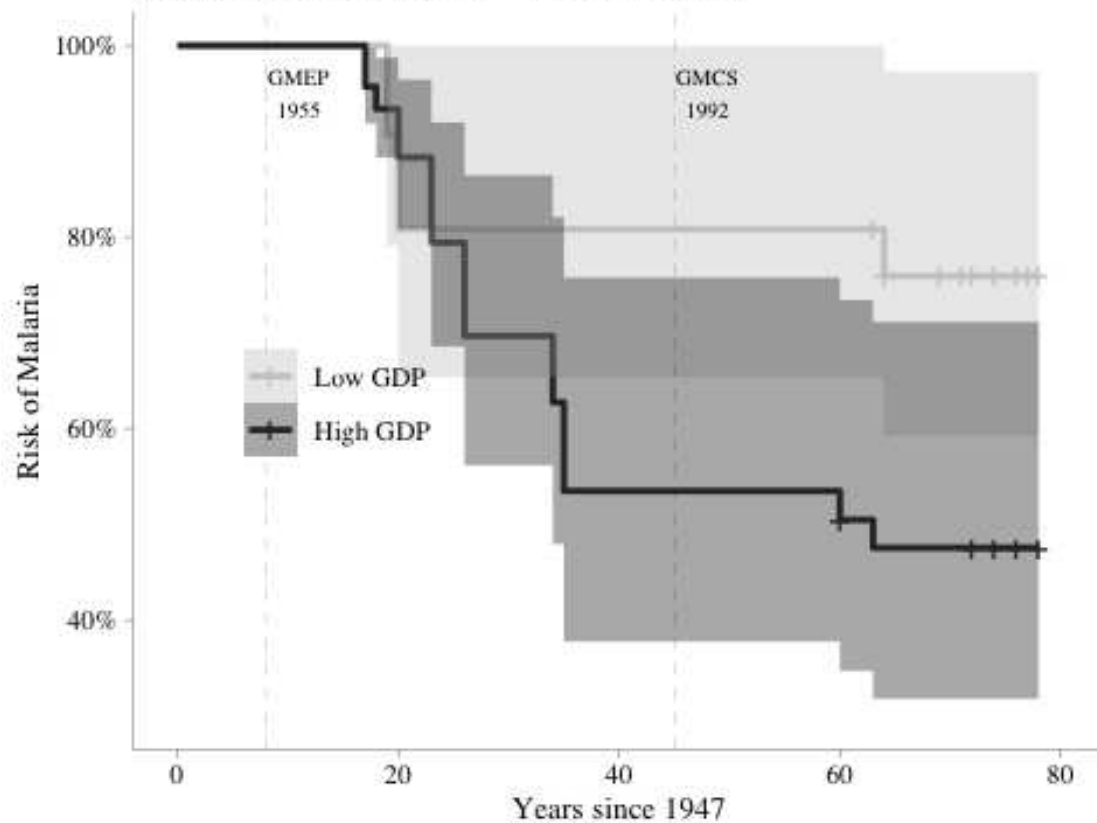
In terms of the linearity assumption, Martingale residual plots for all models in Table 3 indicate the continuous covariates are linearly related to the log hazard ratio. That is, confidence intervals for the covariates consistently overlap zero. Results available upon request.

Lastly, Cox proportional hazard models should account for multicollinearity to provide stable coefficient estimates. Variance inflation factors, however, indicate some multicollinearity—in the GDP, FDI, and population below sea level covariates. Dropping FDI to reduce multicollinearity does not change the main results, and it lowers all VIF scores. Results are available upon request.

Because some of the covariates do not have constant proportional hazards, we stratify these models to allow the non-proportional hazards to vary across strata. In particular, we stratify based on whether a country's GDP is above or below the mean GDP of all countries in a particular year. All of these stratified models show similar coefficients as Table 3, and now there are only 2 models that have global p-values that are less than 0.05. These are the models in Columns 1 and 3 of Table 3 (stratified regression results available upon request). These models also satisfy the Martingale residual tests.

Figure 4 shows the survival curves represented by one of the stratified models using the V-Dem liberal democracy measure—like the survival curve in Figure 2. Figure 4 indicates that areas with higher GDP tend to have steeper estimated survival curves. This result, of course, is also in addition to the effect higher V-Dem scores have, which is similar to the results above. As such, areas with above average GDP and above average V-Dem electoral scores are more likely to receive WHO certification.

Figure 4. Stratified Cox - V-Dem Liberal



Alternative Data

V-Dem also provides additional measures of the rule of law, which is an integral component of liberal political and economic institutions. These data allow for another examination between the effects liberal institutions and the timing and likelihood of WHO certification.

Table 5 shows the effect these alternative institutional measures might have on the log hazard ratio of receiving WHO certification. These results are similar to the other V-Dem coefficients in Table 3. For example, Column 3 of Table 5 shows that a unit increase in the estimated rule of law (Column 3) increases the log hazard ratio by 4.601. Similarly, a one unit increase in this measure raises the hazard ratio by 99.592. Tables 13 through 15 in Online

Appendix III show the hazard ratios, confidence intervals, and p-values that correspond with the models in Columns 1 through 3 in Table 5.

Table 5. WHO Certification and V-Dem Rule of Law

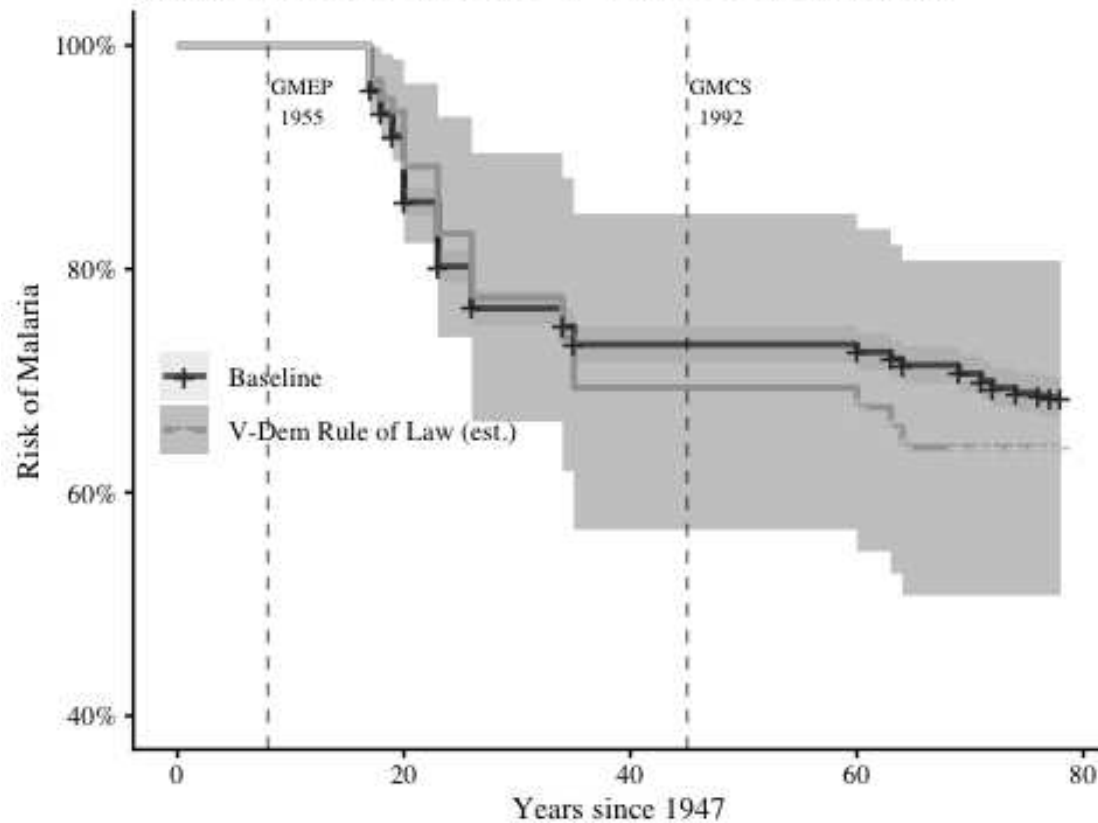
	(1)	(2)	(3)
GDP (log)	0.572 (0.426)	0.052 (0.425)	-0.176 (0.287)
FDI (%)	0.004 (0.005)	0.005* (0.005)	0.004+ (0.005)
Precipitation (log)	0.025 (0.318)	0.049 (0.220)	-0.040 (0.197)
Sea Level Population	-0.003 (0.021)	-0.014 (0.017)	-0.002 (0.013)
Physicians per 1,000	0.085 (0.214)	0.258 (0.148)	0.150 (0.112)
V-Dem Rule of Law	0.154** (0.066)		
V-Dem Equality		0.980** (0.412)	
V-Dem Rule of Law (est.)			4.601*** (1.044)
Observations	33	65	90
Nagelkerke R ²	0.371	0.363	0.462

+ p < 0.1, * p < 0.05, ** p < 0.01, *** p < 0.001

Of these models, Schoenfeld residual tests indicate that only the first two have global p-values above 0.05. Martingale residual tests indicate that all of the covariates are linearly related to the log hazard ratio. Variance inflation factors—to check for multicollinearity—are low.

Figure 5 compares the Kaplan-Meier survival curve, described above, and the survival curve based on the multivariate Cox proportional hazard model with the V-Dem Rule of Law (est.) measure. These curves also indicate similar hazard ratios.

Figure 5. Baseline vs. Cox - V-Dem Rule of Law (est.)



5.2 EFW

Model Assumptions

In this section we assess the validity of the proportional hazard assumptions for the models in Table 4 that show different measures of economic freedom. Schoenfeld residual tests show that most of the models (except the one in Column 7) have global p-values that are less than 0.05 (results available upon request). Plots of these residuals across time, however, indicate they are only slightly different from zero if at all. This suggests that the hazard ratios between country-year observations change (slightly) throughout the range of observation, which potentially violates the proportional hazard assumptions.

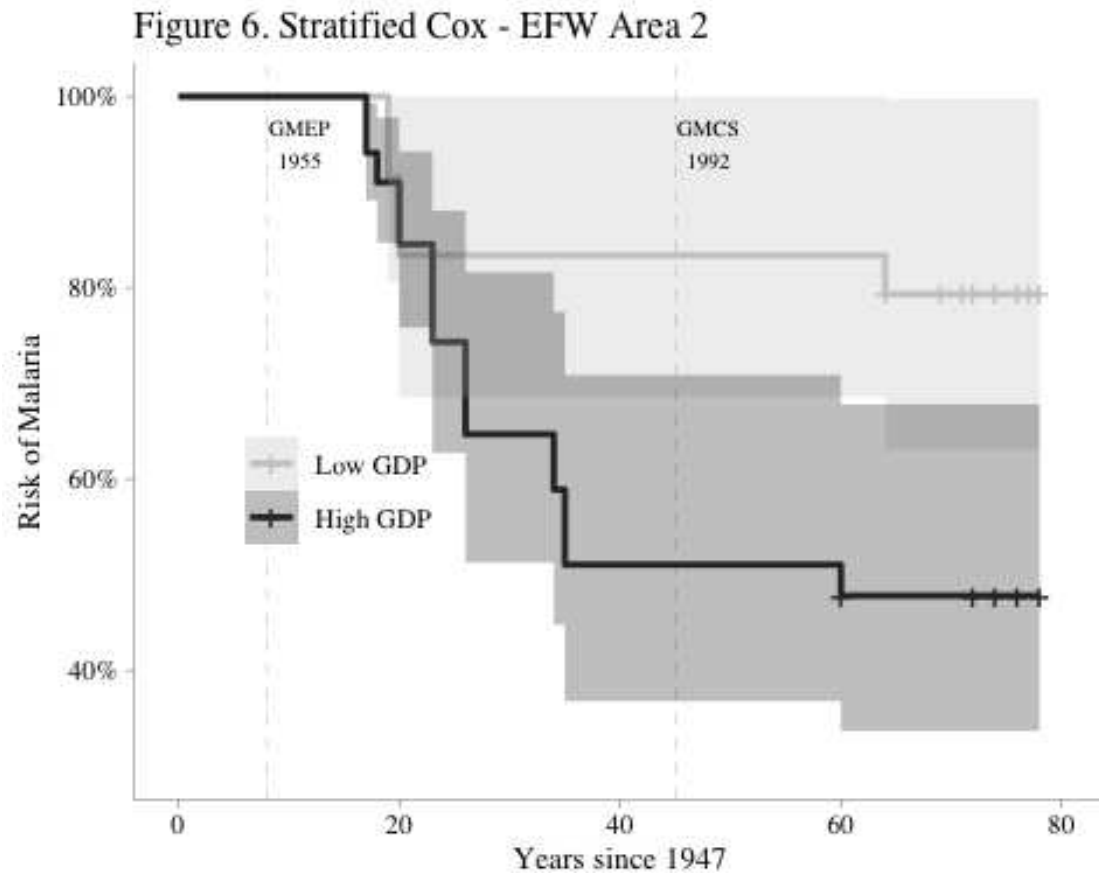
Our countries-year observations are not likely independent of each other as indicated above. Regional clusters are one way to group countries together so that they are more independent, which is less of a potential violation of the proportional hazard assumptions. The results in Table 4 show slightly different results with regional clusters. When regional clusters are used, the coefficient on the Area 2 subscore remains the same as in Column 4 of Table 4, but Columns 2 and 3 show different results. In Column 2, the standard deviation of area scores is now statistically significant and negative. This measure of the overall dispersion in economic freedom area scores indicates that the more different area scores are from the mean, the less likely a country is to receive WHO certification. Column 3 shows that the Area 1 score is now statistically insignificant. Results are available upon request.

In terms of the linearity assumption, Martingale residual plots for all models in Table 4 indicate the continuous covariates are not always consistently linearly related to the log hazard ratio. That is, confidence intervals for the covariates do not consistently overlap zero. When confidence intervals do not overlap zero, the differences are minor. In any event, these results indicate another potential violation of the proportional hazard assumptions.

To address some of these issues, we stratify these models like we did with the V-Dem models. That is, we stratify to allow the non-proportional hazards to vary across strata (high and low GDP). Regression results are largely the same as in Table 4. The Area 1 score is not significant, however, and the coefficient on the Area 2 score in Column has a smaller magnitude (0.383). Doctors per 1,000 people now is consistently significant and positive; a one unit increase in doctors per capita increases the log hazard ratio by 0.305 to 0.424. Results available upon request.

Figure 6 shows survival curves stratified by GDP. These curves indicate similar hazard ratios except when country-year observations have above the mean amount of GDP. Country-year

observations that have above average GDP and above average levels of economic freedom tend to have a higher probability of receiving WHO certification.



Still, Schoenfeld residual tests report that four of these stratified models have global p-values that are less than 0.05 (the models in Columns 1, 2, 4, and 5 of Table 4). Focusing on Model 4, the one with the Area 2 subcomponent of economic freedom, a plot of these residuals indicate that the Area 2 measure trends away from zero towards the later period of observation. Including a time interaction effect is another way to examine how the proportional hazard for a particular covariate might change over time and overcome the concerns related to violating the proportional hazard assumptions. Including a time interaction effect, i.e., the log of Area 2, in the stratified model indicates that the coefficient for Area 2 is -3.46, whereas the coefficient on the interaction effect

is 1.22. Together, these coefficients indicate that while increasing Area 2 might decrease the likelihood of receiving WHO certification in earlier periods of observation, it increases the likelihood in later periods. Results available upon request.

VI Discussion and Conclusion

Overall, these results suggest that economic and political institutions influence the timing and speed with which countries become certified free of malaria by the WHO. Climate, geography, and ecology are still relevant factors that influence the spread of malaria. Our results suggest that institutions are important too. Countries with higher V-Dem scores, with higher rule of law scores, and with higher Area 2 scores for Economic Freedom tend to face steeper survival curves, which in this case indicates a higher chance of WHO certification.

We advance the work of Cohen et al. (2022) which estimates that among the countries that have successfully eliminated malaria, anti-malaria campaigns take an average of twelve years. We extend this analysis by examining a larger set of countries—countries that have and have not eliminated malaria, which allows us to examine the effect of liberal economic and political institutions among other covariates. This extension allows for a deeper understanding of the determinants that influence the timing and speed of certification. Our results indicate that liberal institutions complement concerted efforts to control malaria. Datta and Reimer (2013) develops a similar model, but largely focuses on the endogeneity between malaria and economic development. We use similar covariates and other institutional measures to explain the risk of malaria and with our survival analysis how long it takes to receive WHO certification.

These results correspond to the well-known history of national anti-malaria campaigns. But they help articulate a novel way to combat malaria. Liberal, open-access, inclusive economic, legal, and political institutions increase the chances of acquiring WHO certification. Some of these relationships are understandable. People living in areas with more opportunities to use their electoral processes, might be better able to encourage their representatives to improve public health and provide mosquito control. People living in areas where the rights of individuals are more strongly protected (areas with higher V-Dem democracy and rule of law scores) might be better able to make plans to acquire their desired amount of mosquito control. The measure of participatory democracy, however, also accounts for participation in civil society and other aspects of governance. In this light, areas with higher participatory scores might indicate people are more encouraged to use such organizations to provide mosquito control and to monitor the behavior of others, all of which might encourage WHO certification. Deliberative democracy, moreover, might encourage genuine debate, more appropriate or tailor-made policies that can encourage mosquito control. Finally, WHO certification follows areas where people obtain a more equal distribution of rights, resources, and power. Mosquito control can be a local, regional, and national problem, so it is often a larger concern—one that can be addressed via egalitarian political institutions.

Throughout the 20th century, national governments, NGOs, and many other organizations have spent hundreds of millions of dollars and have developed myriad policies to combat malaria. Such responses are often beneficial, but our results suggest they have a marginal impact given the quality of institutions. Moreover, spending might go further in areas with better quality institutions. Such implications conform with our growing understanding of when and where foreign aid is effective, e.g., in areas with better quality institutions, where aid is less likely to go towards

corruption and more likely to go towards poorer areas (Easterly 2003; Easterly and Pfutze 2008; Ryan C. Briggs 2017; Ryan C. Briggs 2021).

Our models account for some of the unobserved, underlying conditions that also influence WHO certification. Our results are deficient, however, in that they do not control for the effects malaria prevalence and malaria specific development assistance for health might have on WHO certification. These are seemingly relevant factors influencing the last mile and WHO certification. While we have these data (mostly after 2000) and did examine our models with their inclusion, they substantially decreased the number of observations. In any event, malaria specific DAH leaves the V-Dem scores mostly statistically significant like in Table 3 and the EFW scores are similar to those results in Table 4. Results available upon request. Thus, we present our main results tentatively and as partial determinants of WHO certification, namely determinants related to economic and political institutions.

People in countries with higher GDP per capita might be better able to allocate private and public resources to provide mosquito abatement. Higher income, generally, encourages the consumption of normal goods, of which people often increase spending on health (Pritchett and Summers 1996). While we find that GDP does not consistently influence the chances of receiving WHO certification, there might still be interactions between GDP and economic and political institutions. Both Figure 5 and Figure 6—our stratified Cox models—suggest that people might be better able to respond to the burden of malaria, halt transmission, and receive WHO certification with additional income and with better quality institutions. There are myriad ways such effects might take place like through increased abilities to monitor malaria cases, to provide surveillance, and to alter mosquito habitats.

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Declaration of generative AI and AI-assisted technologies in the manuscript preparation process

During the preparation of this work the author(s) used ChatGPT in order to consider and assess the validity of our models. After using this tool/service, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the published article.

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