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The impact of reduced incidence of malaria and other mosquito-borne diseases on global population☆

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ABSTRACT

Interrupting mosquito-borne disease (MBD) transmission was a 20th-century development. By exploiting a natural experiment hinging on the interaction between the probable onset of efforts to suppress MBD and the potential benefit to local communities' average health, this research finds that suppressing MBD explains at least 1.5% of the increase in global population growth since 1900. In Africa, estimates suggest 14% of growth is due to controlling MBD. Globally, the treatment effect is relatively uniform across the 20th century, while in Africa, population grew relatively faster after the widespread DDT spraying of the 1960s. Additionally, this research finds that different indices of historical malaria prevalence reveal complementary insights into the reduction of MBD and subsequent population growth. Robustness of the measured impacts are explored further using regional characteristics, such as topographic boundaries on the extent of Anopheles mosquitoes, as well as by controlling for other factors that could influence population growth.

1. Introduction

In 1898, scientists discovered that certain species of mosquitoes transmit malaria (Ross, 1923).[1] Recognizing the mosquito's critical role in disease transmission advanced public health technology, initiating mosquito-control (henceforth referred to as vector control) which interrupted the transmission cycle and reduced the incidence of all mosquito-borne disease (MBD) around the world.[2] The changing geographic extent of malaria over the 20th century is mapped in Fig. 1 (Hay et al., 2004; Packard, 2007). Vector control is an important part of modern global development and its effects have already attracted the attention of economists such as Cutler et al. (2010); Bleakley (2010), and Lucas (2013) have measured the benefits to individuals' health and education. The contraction of malarious regions, together with evidence of improved living standards, encourages broader analysis of aggregate welfare gains.

This research measures the portion of population growth during the 20th century that is now attributable to vector control. The interaction between geographic variation in historical malaria prevalence and the onset of vector control in 1900 identifies an exogenous source of variation. It is assumed that malaria prevalence serves as a proxy for all MBD prevalence and that population growth captures aggregate improvements in welfare due to reduced mortality and morbidity.[3] I use a difference-in-difference (DID) regression framework to investigate this quasi-natural experiment. The results suggest that vector control explains at least 1.5% of global population that lived since 1900 or close to 60 million people. The communities that benefited the most were in regions with moderately high malaria incidence. I find that 14% of population growth in Africa since 1900 is due to vector control. Globally, the treatment effect is uniform across the century, and in Africa the impact is larger in recent decades.

I use population data estimated by Historic Database of the Global Environment (HYDE) (Klein Goldewijk, 2001; Klein Goldewijk et al., 2010). HYDE population data offer three advantages that are unique among available historical data. First, HYDE population data are available at a spatially disaggregated unit, enabling the empirical analysis to exactly align changes in population with geographic variation in historical malaria prevalence. Second, HYDE provides the only population information for malarious regions of the world during the 19th century. Third, the backward projection procedure

☆ The views expressed here are those of the author and do not represent those of the U.S. Department of Agriculture or the Economic Research Service.
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[1] Please see Kiszewski et al. (2004) for a list of carrier-mosquito species.

[2] Vector control is a principle component of malaria prevention. Two core contemporary measures of vector control are long-lasting insecticidal nets and indoor residual spraying. In the beginning of the 20th century, vector control consisted of the destruction of mosquito larvae and breeding grounds, indoor fumigation, and installation of netting/screens. In the mid-part of the 20th century, between the early 1950s to the mid-1970s, the World Health Organization conducted extensive global DDT spraying initiatives around the world. DDT spraying focuses on killing adult mosquitoes.

[3] Endogenous fertility choices are discussed in the conceptual framework Section 2.

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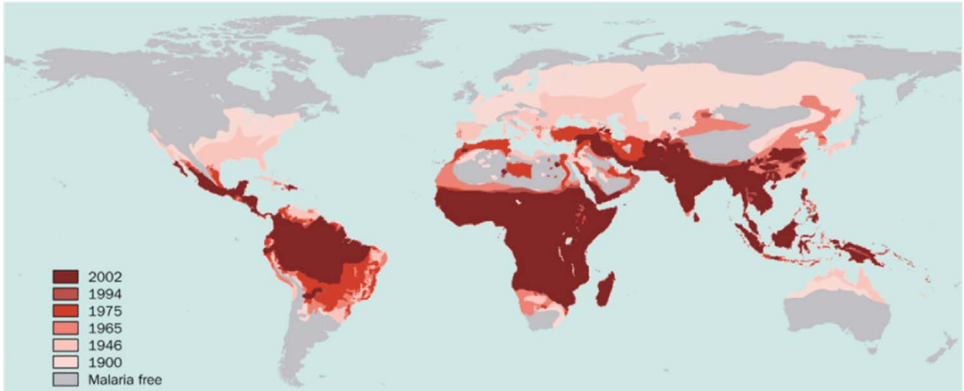

Fig. 1. Changes in the Global Distribution of Malaria Since 1900. *Note*: All-cause malaria distribution maps for the preintervention distribution (circa 1900) and for the years 1946, 1965, 1975, 1994, and 2002. Areas of high and low risk are merged to establish all-cause malaria transmission limits (Hay et al., 2004; Lysenko and Semashko, 1968).

used to create the HYDE data mitigates the likelihood of identifying an artificial break in the data, which is conducive to a valid DID empirical investigation.

This research also offers insights into the precision and accuracy of other metrics used to capture historical malaria prevalence. A number of recent articles in the development economics literature have used (Kiszewski et al., 2004) time-invariant malaria ecology index to measure historical disease environments (Alsan, 2014; Giuliano and Nunn, 2013; Henderson et al., 2012; Michalopoulos and Papaioannou, 2013). I find that malaria ecology precisely characterizes variation in malaria in Africa and propose that the ecology index's correlation with disease stability captures the likelihood of eradication of MBD. Additionally, I use a digitized version of Lysenko and Semashko (1968) malaria endemicity for 1900 which I find more accurately captures global MBD risk.

Section 2 provides a brief history of vector control and conceptual model for the relationship between vector control and population growth. Section 3 describes the historical malaria prevalence and population data and discusses how their features influence the efficacy of this study. Section 4 details the econometric framework, presents evidence of a valid pretreatment time period, and estimates of the global impact of vector control. Section 5 presents tests of sensitivity and robustness. Section 6 concludes with a summary of the results and implications.

2. Conceptual framework

Historical narratives provide evidence that vector control began immediately after 1898 and successful campaigns took place in Saharan and Sub-Saharan Africa, Central and South America, the Middle East and South Asia, and North America (Annett, 1902; Derryberry and Gartrell, 1952; Dutton, 1902; Kligler, 1930; Ross, 1900; Soper and Wilson, 1943). Prior to WWII, vector-control programs killed mosquito larvae by spreading oil on water surfaces, applying Paris Green insecticide, or draining known breeding sites. To kill adult mosquitoes, pyrethrum and sulfur sprays were used in localized fumigation (Packard, 2007). In the 1950s and 1960s, the World Health Organization (WHO) commissioned widespread outdoor DDT-spraying campaigns to target adult carrier mosquitoes. In recent decades, antimalaria public health efforts have used both larvicide and adulticide tactics. Since 2000, malaria in Africa has decreased (Bhatt et al., 2015).

The benefits of vector control increase with historical malaria prevalence. A 1954 United Nations study conducted by Pampana (1954) reports that greater improvements occurred in areas that had higher malaria prevalence at the start of the campaigns.[4] Their report concludes that spraying campaigns contributed to decreased morbidity and mortality rates in the local communities and had a negative impact on the crude death rate in these areas. Additionally, Bleakley and Lange (2009), construct their treatment in the assessment of benefits from DDT spraying following this concept.

Two concerns arise about the plausibility of the research question, “what is the impact of vector control on population growth?” First, it would be problematic if the implementation of vector control initiatives varied indirectly with historical malaria prevalence. An example would be if vector control in Africa did not start until the WHO DDT spraying campaign. There is evidence, however, the vector control was widespread since 1900.[5]

Second, despite being an increasing function of the initial malaria prevalence, the marginal benefit of vector control on population growth may diminish if a lower crude death rate provokes choices to reduce fertility. Lucas (2013) found evidence of a one-generation lag between the decrease in infant mortality and lower fertility rates when investigating the relationship between antimalaria efforts and fertility decisions, while Pampana (1954) did not document a change in the fertility rate. The theory of demographic transition states that, as a population transitions from a high-mortality, high-fertility state to a low-mortality, low-fertility state, the population goes through four stages (Raja, 2015; Bloom, 2001). I assume that the population growth due to vector control began with a reduction in mortality, followed by a continued decrease in mortality accompanied by a reduction in fertility, but the low-mortality, low-fertility steady has not yet been reached globally.

3. Data

In this section, I detail the two measures of malaria prevalence used to capture treatment intensity and assess the strengths and weaknesses of HYDE's population data.

3.1. Measuring the historical prevalence of malaria and other MBD

Obtaining an accurate account of the past MBD environment is challenging. I employ two indices of historical malaria prevalence that are void of anthropogenic influences: the malaria ecology index (Kiszewski et al., 2004) and the malaria endemicity index (Lysenko and Semashko, 1968), which serve as proxies for the prevalence of all MBD.[6,7]

[4] Please see the appendix for a brief overview of Pampana (1954) report.

[5] Please see the cited publication for explicit details about these early antimalaria campaigns. I have summarized a few of the historical initiatives in the online appendix.

[6] Examples of anthropogenic influences include any human efforts to destroy mosquitoes in order to reduce MBD incidence.

[7] Please see the original sources for maps of these indices.