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# PRIVATELY PREVENTING MALARIA IN THE UNITED STATES, 1900-1925

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*This article explores the collective action problem of disease prevention by developing the conditions under which people engage in private means of mosquito control and malaria prevention. People are more likely to overcome problems related to collective action and free riding when they face financial rewards or when they lower transactions costs related to monitoring and enforcement. These conditions hold especially when they can tie the collective good of prevention with complementary private goods, and when they can form associations and firms that encourage prevention. These conditions are developed with reference to the American experience with malaria in the early twentieth century, and, in particular, private efforts to eliminate mosquitos and lower malaria prevalence rates. The persistence of malaria in the southern United States supports this logic too, as the private benefits of prevention there were lower than the costs. This study shows that the scope for individual responses to changing prevalence rates is wider than typically assumed.*

"But with mosquito work, what is everybody's business is nobody's business, and the result is that in many localities everyone submits to the mosquito evil." (Leland Ossian Howard 1902, 162)

**Introduction**

When individuals prevent the spread of a communicable disease, other people are better off through a lower probability of infection. Following Paul Samuelson's (1954) logic on public goods, disease prevention

exhibits problems related to non-excludability and non-rivalry. Individuals cannot exclude others from the benefits of prevention once provided, and one person's consumption does not preclude another from consuming the same goods. The well-known free rider problem poses the core of this problem, collective action (Mancur Olson 1965), which leads to the underprovision of disease prevention. While every individual in a group benefits from the preventative behaviors of others, everyone is also better off by decreasing their preventative behavior, especially when prevention is privately costly. The problem of collective action and disease prevention worsens as transactions costs rise, uncertainty looms, and property rights are unclear (Azarmee Jamasji-Pavri 2006; Jennifer Roberts 2006).

This article complements the standard logic on public goods and disease prevention by developing the conditions under which individuals choose to produce mosquito control and malaria prevention *privately*. Private mosquito control and malaria prevention dominate when the net gains are positive and higher than alternative forms of control and prevention. While the primary benefits of control and prevention relate to improvements in health and the primary costs relate to the costs of production and transactions costs, these benefits and costs are not immutable. Individuals can change the calculus they face so as to maximize wealth and lessen the burden of mosquitos and malaria. This is especially when they can lower transactions costs, for example, the costs of excluding free riders and monitoring subordinates.

Multiple cases of private mosquito control and malaria prevention from the United States during the early twentieth century demonstrate how individuals change their incentives. In particular, individuals change their incentives by tying the collective good of mosquito control with private goods, by forming local associations, and by forming firms in the private sector. Their efforts to lessen transactions costs successfully controlled mosquito populations and lowered malaria prevalence rates. The persistence of mosquitos and malaria in the southern United States during the first half of twentieth century, however, remains puzzling. Still, the focus on the incentives individuals face and their ability to alter transactions costs provides a useful explanatory framework. The private benefits of mosquito control often outweighed the transactions costs of mosquito control.

These cases of private mosquito control conflict with theoretical presumptions that malaria prevention is underprovided in voluntary settings. For example, Gordon Tullock (1969) recognizes private actors can provide mosquito control and malaria prevention, but he assumes they succumb to free rider problems (also, see Tullock 1970). Jeffrey Hammer (1993, 12) states that, "For some antimalarial operations, such as mosquito control, the service provided is a pure public good—if the public did not provide it, it would not get done at all." Finally, Kara Hanson (2004) recognizes that common means of malaria prevention like insecticide treated bed nets and indoor residual spraying are neither public nor private goods, but she concludes that government coordination is the primary means of resolving the problems of non-exclusion and non-rivalry.[1] These scholars ignore how individuals alter the benefits and costs they face related to mosquito control and malaria prevention, especially when those individuals lower transactions costs by changing the organization of mosquito control and prevention.

Furthermore, the conditions of private mosquito control and malaria prevention support the theoretical, historical, and experimental work showing how private actors resolve problems related to externalities and free riding (James Buchanan 1965; Tyler Cowen 1985; Mark Lichbach 1994; Elinor Ostrom 1990, 2005; Todd Sandler 1992 and 2015) so as to facilitate the provision of public goods (Terry Anderson and Peter Hill 2004; Dan Bogart 2005; David Beito, Peter Gordon, and Alexander

[1] The scope for private disease prevention, in general, seems even smaller at the international level where nation-based institutions, private foundations, NGOs, and multilateral organizations are some of the primary providers of global public goods related to disease prevention (Pauline Allen and Bronwyn Croxson 2006; Inge Kaul, Pedro Conceicao, Katell Le Goulven, and Ronald Mendoza 2003; Inge Kaul, Isabelle Grunberg, and Marc Stern 1999; Todd Sandler and Daniel Arce 2002, 2003; Richard Smith and Landis MacKellar 2007; Richard Smith, David Woodward, Arnab Acharya, Robert Beaglehole, and Nick Drager. 2004). Scott Barrett (2007) argues that eradicating smallpox, a pure public good, was due to a subset of privileged countries that valued the collective good of eradication more than the costs (also, see Barrett, 2004, and Barrett and Michael Hoel 2007).

Tabarrok 2009; Earl Brubaker 1975; Rosolino Candela and Vincent Geloso 2018, 2019; Steven Cheung 1973; Ronald Coase 1974; Richard Cornes and Sandler 1996; Harold Demsetz 1970; Fred Foldvary 1994; Glenn Harrison and Jack Hirshleifer 1989; Daniel Klein 1990; Franklin Mixon and Robert Bridges 2018; Kuniyoshi Saito 2019; Emily Skarbek 2014; Vernon Smith 1980; Edward Stringham 2002, 2003). The application of these insights to mosquito control and malaria prevention remains underexplored with few exceptions. Byron Carson (2016, 313-316) develops one framework exploring the role financial incentives and property rights play in the provision of mosquito control and malaria prevention among firms in the private sector.[2]

**Collective Action and the Costs and Benefits of Disease Prevention**

Collective action forms the core economic problem related to disease prevention, mainly because prevention is complex and prohibitively costly for individuals to provide on their own (Roberts, 2006). While standard arguments observe externalities, free riding, and collective action problems—which then supports calls for public coordination—the default presumption about individuals should be that they can find ways to resolve their problems (Roy Cordato 1992, and Ostrom 1990) and they respond to externalities along multiple margins (see James Buchanan and William Stubblebine, 1962, for a discussion on inframarginal externalities). These factors suggest individuals are less likely to succumb to collective action problems. While collective action is more likely when individuals alter the costs and benefits they face, their ability to lower transactions costs is especially important. That is, individuals obtain the benefits of collective action when they lower transactions costs.[3] Furthermore, people alter the transactions costs they face along multiple margins depending on their ability to engage in different kinds of economic calculation (Ennio Piano

[2] Firms in the private sector often provide public health services, from sanitation (Price Fishback 1992) and clean water (Sebastian Galiani, Paul Gertler, and Ernesto Schargrodsky 2005) to HIV prevention (David Bloom, Lakshmi Bloom, Paul De Lay, Fiona Paua, Richard Samans, and Mark Weston 2007). Also, see David Bloom and Jaypee Sevilla (2005).

[3] I thank a reviewer for making this point clearer.

and Louis Rouanet, forthcoming).[4] The costs of excluding free riders and monitoring the behavior of subordinates are particularly important factors influencing when and where individuals resolve these collective action problems.

In the context of mosquito control and malaria prevention, individuals lower transactions costs and encourage the private provision of mosquito control and malaria prevention when the following conditions are met: when individuals tie the collective good of prevention with a private good, and when individuals can form organizations like associations or firms. With tying, individuals search for goods to bundle and adjust the price of a private good until the marginal private benefit equals the marginal private cost of the private and collective goods. Tying lowers the costs of excluding free riders because the main beneficiaries must pay a price, i.e., the price of a private good. For example, a person selling land is more interested in producing mosquito control because they can charge a higher price for the land. Tying is most relevant when individuals can easily tie private and collective goods, or when the costs of tying are negligible.[5] When those costs are high—when there are few bundling opportunities or when the degree of complementarity is low—individuals will find tying to be a less relevant means of excluding free riders.

People can also lower transactions costs and produce mosquito control and malaria prevention via cooperation. The formation of two or more people into a group or association—dedicated to a particular goal—enhances the division of labor, but those gains come with additional costs related to monitoring (Yoram Barzel 1997). For example, whereas individuals living around a lake might not eliminate mosquitos due to the private costs of production, a group effort lowers those costs by dividing

[4] Piano and Rouanet (forthcoming) argue economic calculation associated with production and the organization of production depends on the establishment of private property over the means of production.

[5] The extent to which tying resolves collective action problems also depends on the degree of complementarity between the collective and private goods; the costs associated with producing the bundle declines with the degree of complementarity (Yannis Bakos and Erik Brynjolfsson 1999; Cornes and Sandler 1992; Daniel Klein 1987; and Stan Liebowitz and Stephen Margolis 2009).

labor and/or pooling resources. Dividing the lake and assigning each person to a particular portion of the lake—to ensure it is free of mosquitos—lowers the costs of abatement for each person. Tullock (1969) develops this logic via the example of a town-funded aerial spray campaign; the private costs of the campaign fall when everyone contributes. Of course, free riding is now a problem; the group must now devote some of its resources to monitor the behavior or contribution of its members. Thus, the extent to which groups lower the cost of producing the collective good—mosquito abatement in this case—depends on whether they can lower the costs of monitoring and the costs of excluding potential free riders. For example, groups with the ability to exclude members, for example, to revoke membership or to evict residents, have more of an ability to adopt and enforce rules that require contributions or a particular preventative behavior. A private residential community faces lower exclusion costs—relative to an open neighborhood—as the private community can expel members who do not make adequate contributions or do not follow the rules.

Similarly, a firm might lower monitoring costs because of its comparative advantage in monitoring the production of its employees. Employees are already encouraged to perform, and owners and managers are already encouraged to monitor and enforce rules related to production. When a firm values the production of mosquito control, it can easily rely on its pre-existing hierarchy to organize mosquito control. In this way, a group of people cooperates to produce mosquito control, but the group faces lower monitoring and enforcement costs because the firm devotes its resources to monitoring the behavior of employees. Thus, associations and firms can lower transactions costs related to monitoring and enforcement; these kinds of groups are organizational solutions to free riding problems that encourage the private production of mosquito control and malaria prevention.

Overall, we should expect a fall in prevalence rates when individuals tie prevention with private goods and when they form into groups like firms or associations. Yet, there are three qualifiers related to the conditions of private disease prevention and their impact on prevalence rates. First, these conditions are not mutually exclusive categories. Associations and firms interested in malaria prevention can tie the

collective good with a private good, but they can also encourage prevention in ways that are unrelated to tying, like through a hierarchical structure that lowers the cost of monitoring preventative behavior. Second, people do not have to meet all of the conditions described above in order to obtain the desired amount of prevention. For example, the effect of tying prevention to a private good might be large enough to provide prevention, and it might be larger than the preventative efforts of a firm. The ultimate impact of these conditions—taken separately or any combination thereof—cannot be determined *a priori*. Finally, these conditions do not imply optimality. Once individuals meet these conditions, they face a larger incentive to prevent the spread of infectious diseases, for example, mosquito control and malaria prevention; this does not necessarily mean the optimal amount of disease prevention has been or will be achieved. The optimal amount of a public good is only relevant in a highly constrained setting where all of the costs and benefits facing every relevant individual are known and can be easily adjusted through a collective decision-making body.

## Mosquito Control and Malaria Prevention as a Collective Action Problem

*Why Malaria?*

Mosquito control and malaria prevention form a relevant case to analyze collective action problems associated with infectious diseases because of the externalities and potentially significant transactions costs.[6] The collective action problems related to mosquito control and malaria

[6] Malaria is a mosquito-borne disease that spreads primarily through infected female *anopheles* mosquitos, whereby the mosquito's saliva mixes with a person's blood. Once bitten malaria parasites enter the liver and reproduce. The incubation period, or time between an infected bite and the presentation of symptoms, can last from about one to two weeks. Typical cases of malaria involve periods of fever, followed by chills, and other flu-like symptoms; severe cases can cause organ failure and death. Relapses and reinfection are possible due to the nature of the disease and the different strains of malaria. Humans are most susceptible to the *falciparum* strain of malaria, while the *vivax*, *ovale*, and *malariae* strains are milder.

prevention have been recognized for some time, albeit underexplored (Howard 1902; Tullock 1969). The specific collective action problem considered here depends on how people disrupt the life-cycle of mosquitos, as these actions help to lower mosquito populations, lower the probability of infection, and emit external benefits. These actions include: wearing long-sleeved clothing, screening porches, implementing air conditioning, separating human and animal populations; draining or rerouting a body of water; introducing some species of fish into a lake; and spraying oil, gasoline, or kerosene into a body of water.

The transactions costs associated with mosquito control and malaria prevention further complicate this problem by raising the private costs of disease prevention for individuals (Jamasji-Pavri 2006). For example, it might be difficult to discover the source and location of mosquito breeding grounds, depending on flight ranges and wind conditions. These transactions costs relate to the physical production of mosquito control. It might also be difficult to negotiate a prevention campaign across larger groups of individuals, especially when some refuse to acknowledge the benefits of prevention or when free riding is possible. And it might be difficult to monitor and enforce contracts regarding a prevention campaign as there might be seasonal or year-long delays between anti-mosquito work and changes in mosquito populations and malaria prevalence rates.

The focus on mosquito elimination does not suggest other means of prevention are unimportant. Drainage, land reclamation, and innovations in agricultural techniques are commonly known to have significantly reduced people's exposure to malaria-carrying mosquitos (see, for example, Erwin Ackerknecht 1945; Robert Harrison and Walter Kollmorgen 1947; Margaret Humphreys 2001; Mary McCorvie and Christopher Lant 1993; Randall Packard 2007; US Census Bureau 1920). In particular, interior drainage projects in the United States probably had the largest impact on eliminating mosquito populations throughout the nineteenth century. However, the focus on anti-mosquito efforts remains justified because these were intentional projects. It is not clear whether individuals or governments intentionally pursued large-scale drainage projects as a means to lower the burden of malaria given the poor understanding between mosquitos and malaria throughout most of the

nineteenth century. That malaria prevalence rates declined during this time was a lucky byproduct.[7]

People have used antimalarial remedies and drugs, like quinine and artemisinin, in some form to alleviate the symptoms of malaria for centuries, but they have only recently been widely available or studied for the purposes of mass production. For example, the first licensed malaria vaccine, for example, *Mosquirix*, completed trials in the early 2010s (Kyle Wilby Tim Lau, Samuel Gilchrist, and Mary Ensom 2012), and was approved by European regulators for additional pilot programs in 2015. Since Ronald Ross's discovery of the link between mosquitos and malaria in 1897, however, mosquito elimination has been a more relevant, accurate means of prevention.[8]

While this study focuses on private means of mosquito control and malaria prevention, public efforts have dominated the history and public health work of malaria prevention. Armed with Ross's discovery in the early twentieth century, burgeoning public and private public health departments devoted greater attention and funds to mosquito elimination (also, see Alan Barreca, Price Fishback, and Shawn Kantor 2012; Carl Kitchens 2013a and 2013b; Daniel Sledge and George Mohler 2013). For example, the anti-mosquito work coordinated by various governments in and around the Panama and Suez Canals saved thousands of lives from the burden of malaria and yellow-fever. Malaria had long plagued Italy, but active steps by its fascist government in the early twentieth century dramatically improved health and revitalized its countryside, especially the Roman Campagna (Frank Snowden 2006). The Rockefeller Foundation, a private organization, even established an International Health Division in the early twentieth century to combat malaria and other public health problems in the United States and throughout the world (John Farley 2003).

[7] Reclaiming malarial areas might have been a primary concern for drainage efforts, according to McCorvie and Lant (1993, 25), but this rationale is not explored.

[8] Without a basic understanding of malaria transmission and its epidemiology, people blamed a variety of causes for malaria, from miasmas to dragons (William McNeil 1976; Terrence Ranger and Paul Slack 1992).

*Control and Prevention in the United States*

Mosquito control and malaria prevention in the United States during the early twentieth century is representative of control and prevention efforts in other areas because individuals faced similar conditions related to the burden of malaria, the irrelevance of public health departments, and the accurateness of mental models of transmission.

Malaria plagued most parts of the United States throughout the nineteenth century, despite its gradual decline around 1900, except in the southern United States (Marshall Barber 1929; Kenneth Maxcy 1923, 1924a, 1924b). *Vivax* malaria was a milder strain of malaria common in the upper South, whereas the *falciparum* strain was more virulent and more common in the lower South (Todd Savitt 1988). Explanations for the transition are primarily anecdotal as exact data on malaria prevalence rates in the early twentieth century are not available.[9] Henry Carter, surgeon general of the US Public Health Service, states: "In eastern North Carolina there is not now one-third of the malaria there was in the eighties. I think the same is generally true, though, perhaps, not to the same degree, in all of the cotton states. On the other hand, it has increased in some sections of these and other states" (Henry Carter 1919, 215). We should be cautious when interpreting malaria-specific mortality rates because of the incomplete quantitative record of malaria prevalence and morbidity, and because mortality misrepresents the full burden of malaria. That is, the burden is not just represented by mortality statistics as the disease was not often fatal; furthermore, mortality rates are also influenced by factors unrelated to the epidemiology of malaria. For example, malaria-specific mortality rates might be larger in the southern United States because of the depressed socio-economic conditions of black populations.[10] Figure 1

[9] Prior to Ross's discovery, physicians had not developed objective ways to diagnose malaria, let alone distinguish a case of malaria from similar diseases or the common cold; as a result, morbidity and mortality data associated with malaria prior to the 1920s were and remain imprecise.

[10] While malaria prevalence rates might have been similar across races, blacks were more likely to be impoverished, malnourished, and located in rural areas (on the conditions of blacks and mill workers, for example, see Edward Beardsley 1987). Indeed, these differences are

shows the distribution of mortality rates associated with malaria in 1890, reprinted from Melinda Meade (1980, 85), whereas Figure 2 shows the decline in malaria prevalence rates from 1920-1950.

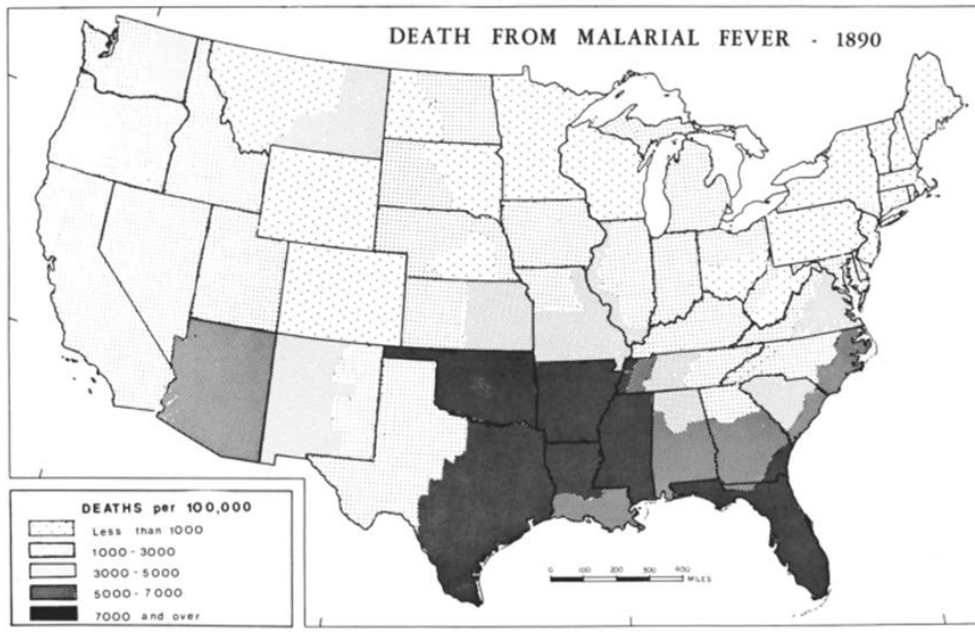
The second reason to focus on malaria prevention in the United States is that public health services were poorly financed; they often had little legal authority to coordinate malaria prevention, or were still developing. Table 1 shows the average annual expenditure of the largest public health departments, whereas Table 2 shows the size of public health department by region in 1890.

Most state and federal government programs to eliminate malaria did not begin in earnest until the 1910s and especially during World War One, the Great Depression, and World War Two (for a history of federal anti-mosquito programs in the United States, see Carson 2016). Furthermore, governmental public health services had not developed systematic ways of collecting vital statistics.[11]

Malaria prevention in the United States in the early twentieth century is also relevant because knowledge about malaria and its prevention was still developing. Even though people began to associate standing bodies of water, wetlands, and marshy areas with malarial fevers in the mid-nineteenth century (Humphreys 2001, 37), accurate models of disease transmission and prevention were still debated throughout the 1900s. Without conclusive evidence regarding how malaria was transmitted, public and private efforts faced greater opposition from skeptics and people who did not know about the linkages between mosquitos and malaria.

consistent with the racial gap in infant mortality around 1920 (William Collins and Melissa Thomasson 2004a and 2004b).

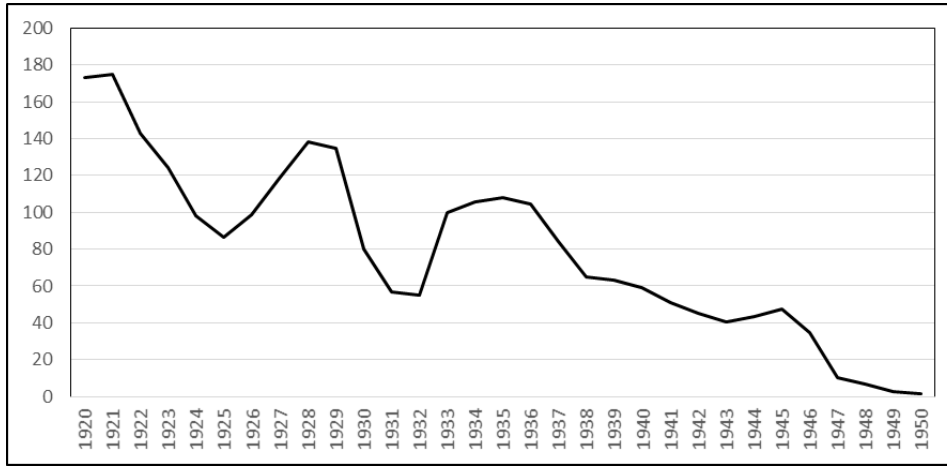
[11] The Connecticut State Board of Health is one exception, which began malaria surveys in the early 1900s. State funds were not allocated until later in the decade (Wilton Everett Britton 1904, 210; Britton 1905, 253).




*Source*: Meade (1980, 85).

**Figure 1**

Malaria Deaths in the United States, 1890




*Source*: US Census Bureau (1975, 77).

**Figure 2**

Reported Malaria Cases (per 100,000 people), 1920-1950

**Table 1**

The Largest Public Health Departments in the United States, 1890

| City | Number of Members | Number of Physicians | Average Annual Expenditures (in $) since 1880 |
|---|---|---|---|
| New York | 8 | 2 | 374,019 or 374,919 |
| St. Louis | 6 | 2 | 335,017 |
| Chicago | 3 | 1 | 207,174 |
| Boston | 3 | - | 105,319 |
| Philadelphia | 6 | - | 97,332 |
| Baltimore | 3 | 2 | 80,000 |
| Brooklyn | 1 | - | 77,329 |

*Source*: US Census Bureau (1890, 53-57).

**Table 2**

The Size of Public Health Departments by Membership and by Expenditures, 1890

| Geographical Divisions | Number of Cities | Population | Board of Health | | |
|---|---|---|---|---|---|
| | | | Membership | | Average annual expenditures since 1880 ($) |
| | | | Total | Physicians | |
| North Atlantic | 93 | 7,433,890 | 430 | 98 | 962,283 |
| South Atlantic | 17 | 1,104,810 | 101 | 31 | 215,162 |
| North Central | 85 | 4,575,845 | 435 | 96 | 803,984 |
| South Central | 14 | 769,061 | 77 | 22 | 81, 460 |
| Western | 8 | 142,754 | 33 | 14 | 12,638 |

*Source*: US Census Bureau (1890, 14).

**Private Malaria Prevention**

*Tying Mosquito Control to Property and Membership*

Individuals in the following cases mitigated the collective action problems associated with mosquito control and malaria prevention by lowering transactions costs specifically associated with excluding free riders. In the late nineteenth and early twentieth centuries, individuals tied mosquito abatement to the purchase of land, the construction of houses,

and the development of residential neighborhoods.[12] Referring to the problem of malaria in the United States, Howard (1902, 168) states that:

> … a mere passing thought shows the economic loss to a neighborhood in the prevalence of malaria. While the death-rate may not be high, the number of persons incapacitated for their full share of work is always great. Families suffer in one way or another, and the community, when the matter is considered in a broad way, is a great loser. Aside too, from malaria, it is perfectly obvious that a mosquito-ridden neighborhood is not a desirable place of residence. The very fact of the abundance of mosquitoes keeps real estate values at a depressed point.

Howard neatly captures the logic behind inframarginal externalities (Buchanan and Stubblebine 1962), but does not recognize that homeowners might be residual claimants who perceive profit opportunities from controlling mosquito populations.[13]

The following examples demonstrate particular instances of how single property owners face incentives to privately produce mosquito control. Henry Clay Weeks (1901, 20921-20922) describes a "well

[12] Howard (1902, 172) suggests that the publication of his experiment on kerosene facilitated mosquito control across the country. The report, published in the fifth volume of *Insect Life* (1892) demonstrates the effectiveness of kerosene as an insecticide, particularly useful for homeowners, and generated requests for additional information and articles, as well as further experiments.

[13] Similarly, speaking to the Fourth Annual Meeting of the New Jersey Mosquito Extermination Association in 1917, Assistant Surgeon General Carter asks,

> Has the presence of tuberculosis ever prevented a real estate transaction? I know of a deal involving the purchase of a large tract of land—about a half million dollars' worth—for colonization not consummated on account of the existence of malaria in that section, and there was not much either. You have not seen homes abandoned on account of either tuberculosis or typhoid. I have seen them abandoned on account of malaria. (NJMEA 1917, 83).

known" instance, at least to himself, of a "gentleman" who upon purchasing a "magnificent historic estate of some hundreds of acres" was informed mosquitos made the property uninhabitable during the summer months. The gentleman soon began to rid the property of water receptacles, added petroleum to bodies of water, and cleared drains of debris. Regarding a neighbor's pond that was the primary source of mosquitos, the gentleman obtained his neighbor's consent, added petroleum to the pond, and successfully eliminated the mosquito populations throughout the area. Furthermore, Mr. William Strong owned "a considerable stretch of marsh land" in or around the Shrewsbury River area of New Jersey that produced millions of mosquitoes (John Smith 1904, 445). Through his ditching efforts, however, he filled in the marshes and it is "doubtful whether anywhere on his estate a single mosquito can develop" (ibid.). Mosquito control made these homeowners and neighbors better off as there were fewer mosquitos, which eliminated a nuisance, potentially lowered the prevalence of diseases carried by mosquitos, and increased the value of nearby land and property. Because these properties were saleable and excludable, the owners could rely on their respective prices to assign a monetary value to mosquito control and exclude free riders.

The following report provides a specific example of tying mosquito abatement with the production and sale of summer homes in Stratford, Connecticut. Frederick Beech, an editor of the *Scientific American*, reported to Howard (1902, 208-209; 1910, 42) how the town became free of the "Stratford mosquito" in the 1890s:

> In the town of Stratford, Conn., where I have resided for the past forty-five years, we have been greatly plagued by swarms of mosquitos, so great in fact, that the 'Stratford mosquito' became a well-known characteristic of Stratford. We have in the southern part of our town, bordering on the sound, several acres of marsh-land or meadow, which would become periodically overflowed with water in the summer and a tremendous breeding ground for mosquitos, and this plague to the town continued until about 1890-91, when a party from Bridgeport, Conn., purchased a large section of the meadows and began to protect them by a dike, both on the north and south ends, which shut out the

> water. In addition to this, numerous drain ditches were made which helped to carry the water away. The result of this work made the land perfectly dry and spongy, so that after a rain no pools collected on the surface of the meadow and the creation of the mosquitos was prevented. The transformation was so remarkable that people outside the town would hardly believe that it had been effected, and a year or two later the town voted a special appropriation of $2,000 to the party who undertook to build the dike and render the meadows mosquito-proof. It had also the effect of placing on the market a large tract of land elevated from the sound, for residences, and as many as twenty-five summer residences have been built upon this land bordering on the sound, and the number is increasing each year. They are free from mosquitos, so that the operation shows the economy and the benefit that will result by using some means for eliminating the mosquito-breeding pools.

Transactions costs were low here as well because land was saleable and excludable via the local real estate market; the land improvement company purchased a portion of the meadow.[14] The company internalized the benefits of mosquito control, for example, they constructed dikes and built drainage ditches, because they owned the land that they expected to increase in value. This was especially the case as summer homes were built on the newly reclaimed land; subsequent homeowners are unable to free ride because home prices reflect the value of the anti-mosquito work previously performed. In this way, tying mosquito abatement with land and property aligns private and social incentives, which provide additional incentive to drain meadows and eliminate mosquito populations.[15]

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[14] Britton (1905, 303) suggests the party from Bridgeport was a land improvement company owned by W.R. Hopson.

[15] In the early 1900s, Connecticut state entomologists surveyed the mosquito problem throughout Connecticut and reported the following:

> The problem of getting rid of the salt marsh mosquito breeding places in Stratford township is practically solved. The community is entitled to congratulation on the excellent work done to exterminate

The Montowese House, a summer hotel in Branford, Connecticut, is another example where private and collective interests aligned. Once the owners, William Bryan Jr. and son W.A. Bryan, learned how to eliminate mosquitos around 1900, they applied oil to pools of water where mosquitos bred and drained the marshlands surrounding the hotel (Britton 1905, 303).[16] The Montowese House eventually became a popular resort during the first half of the twentieth century.[17] The Bryans tied mosquito abatement to hotel sales, which helped internalize the benefits of abatement. They faced lower transactions costs of tying because they owned the hotel and surrounding land, but also because they were able to attract customers from which they could charge for rooms and other hotel services that reflected the value of mosquito abatement.

Tying mosquito abatement to other kinds of property, for example, agricultural commodities, is also a way to lower transactions costs. Farmland could be developed, for example, if only the bodies of water that supported mosquito populations could be drained.[18] While N.S. Shaler (NSIA, 1902, 71-74) and Howard (1910, 10) discuss the profitability of draining marshland to produce cranberries, asparagus, and onions, it is not clear whether people actually developed fertile farmland as a means of malaria prevention. For instance, Shaler estimates that one acre of cranberries yields $100 per year, which is deemed to be an adequate incentive to eliminate mosquitos (NSIA 1902, 73). Yet, mosquito abatement and farming remain theoretical examples of complementary

mosquitoes. August 16 and 17h, 1904, the Stratford territory was examined. Nothing very serious was found. (Britton 1905, 292)

[16] Britton (1905) suggests Bryan received aid from neighbors and from the Branford Board of Health; the kind aid received is not specified. Additional efforts of the public health board and the Improvement Association of Pine Orchard also helped to reduce the burden of mosquitos throughout Branford.

[17] For a history of the Montowese House see the 2003 documentary narrated by Nancy Coykendall, the granddaughter of W.A. Bryan: https://vimeo.com/124312144, last accessed on February 2, 2020.

[18] Weeks (1901) suggests this is a plausible explanation behind the development of agricultural yields in Green Harbor, Massachusetts, particularly for asparagus.

goods, which would encourage tying and the private production of mosquito abatement.

Mosquito abatement can also be tied with club membership. For example, Howard (1902, 208) describes the success of a country club in New Jersey:

> In the work which was done by the Richmond County Club of Dongan Hills, New Jersey, under the leadership of Mr. W.C. Kerr … considerable drainage of fresh-water swamps above the seacoast bluffs was carried on with great success and at a minimum of expense. This work, together with the use of kerosene upon larger pools, resulted in complete relief from the attacks of the fresh water mosquitos, which during the early summer had always been numerous and ferocious …

Howard focuses on costs related to the production of mosquito control, for example, draining fresh-water swamps, but misses how the Richmond County Club faces lower transactions costs because of their ability to pool resources, monitor contributions, and explicitly select members. Mosquito control would have complemented the prestige of the club, lowered the annoyance of mosquitos, and solidified its attraction to prospective and existing members. Thus, tying abatement with the cost of membership, with entry fees, could have been a way for the club, its administrators, and members to internalize the benefits of abatement.

Individuals also internalized the benefits of mosquito abatement via the employment, matriculation, or association with an academic community. Princeton University competed with other schools by claiming that its relatively high elevation provided a healthier environment for students (Angus Deaton 2013, 98). For a more active approach to prevention, H.E. Weed treated with kerosene eleven large water tanks around the campus of the Mississippi Agricultural College (Howard 1902, 172), now Mississippi State University in Starkville, Mississippi. Similarly, Professor V.L. Kellogg of Stanford University experimented with kerosene and filling post-holes, which eliminated local mosquito populations (ibid.). These instances of mosquito abatement suggest academic communities internalize significant portions of the externalities

via the provision of relatively private goods and services related to malaria control from which they improve the health and well-being of their students, faculty, and staff, as well as the wealth and prestige of their respective schools.

*Anti-Mosquito Associations in New York and New Jersey*

The Twentieth Century Club, the North Shore Improvement Association (NSIA), and the associations of Monmouth and Rumson Neck demonstrate how associations in New York and in New Jersey encouraged prevention despite potential free riding problems.[19] Anti-mosquito associations lower the private costs of mosquito abatement, but they create additional problems related to monitoring and enforcement. In reference to drainage as a means of prevention and potential free riding problems, Weeks—an engineer hired by one of the associations—states that:

> There are many causes which militate against reclaiming marshes, which must be done before the largest factor in the spread of mosquitoes is eliminated. Generally they are held in small tracts by a number of owners, and the more the owners, the more the difficulty of action. (Weeks 1901)

*The Twentieth Century Club*

One of the first associations to engage in a concerted effort to control mosquitos during the summer of 1900 was the Twentieth Century Club

[19] On additional associations in the area, see Thomas Headlee (1921); on the South Orange Improvement Association, see Headlee (1945); on the New Jersey Mosquito Extermination Association, see the Proceedings of the Annual Meeting of the New Jersey Mosquito Extermination Association (NJMEA 1914). Associations also encouraged mosquito abatement in Connecticut. For example,

> The Improvement Association of Pine Orchard in the town of Branford has systematically drained considerable marsh area during two seasons, expending nearly $300 each season on the work. Oil has also been used, especially on the inland swampy areas. (Britton 1905, 303)

(TCC) of Richmond Hill, Long Island (Martha Claghorn 1901). Given the TCC's goal of promoting order, cleanliness, and beauty throughout the town, the Civics Committee of the TCC soon placed mosquito elimination under its purview once they realized the connection between malarial fever and mosquitos. The chairman of the committee, perhaps Claghorn herself, found by happenstance a report on mosquito elimination, "consular report No 693, dated April 2, 1900" from the Liverpool School of Tropical Medicine. Without adequate drains and sewers in Richmond Hill, the TCC decided to pursue mosquito elimination by applying kerosene to stagnant pools of water throughout the area.

The full record of what the TCC did to eliminate mosquitos and their ultimate influence is not well known, but there is suggestive evidence from Claghorn's report. To encourage cooperation the TCC issued cards to homeowners in Richmond Hill that read:

> The civics committee of the Twentieth Century club of Richmond Hill earnestly invite the help of the householders of Richmond Hill in a united effort to exterminate mosquitoes. To effect this it is requested that each household puts into its cesspool a gallon, more or less, of kerosene oil early in April, repeating the dose two or three times during the summer. This, it is said, will prevent the mosquitoes breeding in the cesspools, and thus cut off a large part of the supply. (Claghorn 1901, 373)

The TCC also distributed a circular containing further explanation of the anti-malaria plan, as well as a plea for sympathy, good will, and contributions. Claghorn (1901) suggests that subscriptions of twenty-five cents per month were asked for and received. The TCC used these funds to purchase kerosene from a public-spirited individual (for fifty cents), and they also hired one worker to distribute a pint of kerosene every week to the thirty-eight catch basins in Richmond Hill.[20]

[20] The TCC paid the worker one dollar per week, which lasted from May 28 to November 9, and cost the TCC about thirty-four dollars (in 1900); they paid a similar amount in 1901 (NSIA 1902, 123).

The organized collection of funds and the purchase of anti-mosquito materials and labor by the TCC lowered the private costs of mosquito abatement. The purchase of kerosene and the hiring of a worker to distribute kerosene were both essential components of the TCC's mosquito abatement efforts, and were aided by markets in those respective goods. These purchases lowered costs related to the production of abatement. However, the TCC could not easily deal with unwilling or resistant neighbors, and they could not compel their fellow neighbors to purchase kerosene and place it in mosquito breeding sites. Transactions costs remained high on some margins, especially in the form of enforcing rules related to mosquito control. Thus, the TCC relied solely on the voluntary contributions of residents.

Despite this vulnerability to potential free riding the TCC was ultimately successful. The swarms of mosquitos that usually plagued the area were barely noticeable after the campaign. After the first year's work was finished, one letter to the TCC read:

> This is my twenty-sixth year at Richmond Hill. Now at the end of July we are still practically free from mosquitoes. Nothing like this has ever happened before. … I shall deem it an honor to be counted on as ready to support your good work to the extent of my power. I enclose five dollars and will send twenty-five more if so much is my share. (Claghorn 1901, 373)

Claghorn later writes that the TCC was unable to raise funds to expand the work in the summer of 1901, but the same amount of work continued into 1901 and the area continued to be relatively free of mosquitos (NSIA 1902, 123).

*The North Shore Improvement Association*

Another association to focus on mosquito control was the NSIA, founded to enhance the quality of life on Long Island. Its mission was stated as follows:

> The objects of the North Shore Improvement Association are to secure co-operation in movements for good roads, protecting the water front,

> preventing and abating nuisances, securing capable and effective town government, and generally promoting such measures as will tend to protect the territory as a desirable residential region (NSIA 1902, xi).

With these goals in mind, the NSIA developed its anti-mosquito campaign by 1) surveying the magnitude of the problem and demonstrating the feasibility of mosquito abatement, 2) seeking experts in fields like entomology and marine ecology, 3) acquiring the means of prevention, and 4) coordinating and financing an elimination campaign.

Led by William Matheson, Treasurer of the NSIA, members of the association realized the feasibility of an elimination campaign in the summer of 1900:

> The subject has been brought to the attention of the residents of the North Shore of Long Island with special force, because one of the first and most important practical demonstrations of the feasibility of the plans proposed for exterminating mosquitoes was made at Lloyd's Neck, on Cold Spring Harbor, in the summer of 1900, by Mr. W. J. Matheson, under the direction of Prof. L. O. Howard, Chief of the Division of Entomology of the United States Department of Agriculture. It was there demonstrated in a single season that a locality previously infested by mosquitoes to an unusual degree could be almost entirely freed of the pest by measures at once simple and inexpensive. (NSIA 1902, 11)[21]

The executive committee of the NSIA readily supported these efforts:

> The Executive Committee of the North Shore Improvement Association accordingly determined that they could in no way more effectively advance the Association's policy of devising measures calculated to benefit the entire community than by inaugurating a plan

[21] Howard (1902, 211) also discusses this story; Howard (1910, 9) states that the work was "thoroughly done and was most successful" and that there were now "no mosquitoes breeding where they had previously swarmed to such an extent as to render the localities uninhabitable."

> for eliminating or minimizing the mosquito nuisance in the territory covered by the Association's activities (NSIA 1902, 12).[22]

The NSIA enlisted the help of engineer Weeks to conduct a survey of the area, and Weeks called upon the following individuals to aid in the survey: Charles Davenport, Professor of Entomology at the University of Chicago and head of the Cold Spring Biological Laboratory, F. E. Lutz, instructor of biology at the University of Chicago, N.S. Shaler, an eminent authority on marine marshes, and their respective assistants. With an expert team assembled, the NSIA began its survey work, which eventually included the area from Roslyn to Cold Spring and from "the Sound to the high range of hills which form the backbone of the island" (ibid., 12). The survey included finding the precise location of standing bodies of water, which included streams, ponds, and marshy areas, as well as holes in trees, animal footprints, and rain barrels. According to Weeks, marshlands developed around places like Frost Creek as tide levels changed, which revealed or covered new landmasses, and as soil, rocks, and other debris accumulated. With additional marshland came additional habitats for mosquitos to breed and thrive. Furthermore, the NSIA found about 150, 50, 40, and 30 water-filled barrels in Oyster Bay, Cold Spring Village, Locust Valley, and Bayville, respectively.

The NSIA and residents were now able to focus on anti-mosquito projects with information provided by the survey. For example, the NSIA drained the marshlands around Center Island, described in detail in NSIA (1902). This report describes specific kinds of mosquito abatement, as well as some of the features that encouraged and discouraged a successful campaign. While the campaign benefited from a few interested individuals and the "*carte blanche*" given to the engineer, they were not able to achieve full cooperation (NSIA 1902, 116-117). Indeed, eliciting the cooperation of homeowners was a central part of the NSIA's campaign:

[22] Governance of the NSIA is not discussed in the report on mosquitos, but there is a list of officers that includes a president, two vice-presidents, a treasurer, a secretary, and 20 directors. There is also a list of committees that includes an Executive Committee, a Committee on Village Improvement, and two committees on town government—one for Oyster Bay and one for North Hempstead.

"… their cooperation should be secured rather than by an attempt to treat them through regular visits of an agent of the Association" (NSIA 1902, 28).

By coordinating the survey, hiring experts and procuring materials, and then producing the actual abatement, the NSIA lowered the private costs of abatement. The NSIA survey is particularly important as it provided common knowledge about the extent of mosquitos and where they bred; this helped lower costs related to disagreeable neighbors. The hiring of perceived experts gave the NSIA survey and its work additional legitimacy, from which they could confront hesitant or unwilling homeowners. Furthermore, the NSIA and its members internalized the benefits of abatement as they—via their executive committee—decided which areas to survey. The size and extent of the survey was chosen to deliberately improve the quality of life of members of the NSIA, as well as the property values of homeowners of the NSIA.

Yet, the NSIA still faced potential free riding problems as they could not compel residents to contribute. However, their operations were deemed successful and spawned subsequent efforts at private abatement. Howard (1910) also suggests the NSIA's survey encouraged individuals like W. D. Guthrie of Lattingtown, to develop anti-mosquito measures. In the survey, Weeks describes a viable solution for Mr. Guthrie:

> The construction of dike and tide-gate here would not be difficult, physically speaking. This plan would redeem the whole of the 120 acres lying easterly from the bridge … When the area is dried out, its reduction for cultivation could be effected by levelling off, filling creeks, etc. The first cost of this is estimated at $2,975.00 … (NSIA 1902, 88)

Howard (1910, 10) reports that Guthrie did build the dike and sluice system, which drained about 75 acres of marsh, from which he began to grow cabbages, turnips, and celery by the end of the summer of 1902.

*The Associations of Monmouth and Rumson Neck*

With wealthy residents already familiar with privately providing public services, the resort communities of Monmouth Beach and Rumson

Neck of coastal New Jersey were well suited to engage in anti-mosquito efforts. According to Eugene Winship (Smith 1904, 438), these property owners "… pay for all improvements and sustain the running expenses by individual subscription. They also maintain a club house, country club, golf club and a church, water the roads and light the same. In addition to the above they pay for their own fire and police protection." Winship's use of "subscription" and his subsequent report on mosquito control suggests these funds were contributed voluntarily and not required by the associations.

In 1900, H.D. Cooke and William Barbour, homeowners in Monmouth Beach, observed the large mosquito populations and feared for a decline in tourism throughout the area, typically a summer beach resort. To mitigate these losses, which would also have lowered property values, the men asked their neighbors to help purchase oil and to pay for laborers to distribute the oil. Winship describes how the men and their neighbors developed an anti-mosquito plan in 1900:

> After obtaining all the information possible on the subject … they mutually agreed to inaugurate a crusade against the pests. Having adopted a plan, it was deemed advisable to commence operations at once. Circulars stating the object were printed and mailed to the property owners, requesting a subscription to commence the work. This was in the year of 1900. The response to the circular was not very generous; the majority of the residents ridiculed the idea and claimed that they had no money to throw away on such tom-foolery.
>
> However, enough funds were obtained to warrant the execution of the plan that had been adopted. It was decided that the spreading of oil upon the infected places would probably prove effective in exterminating the larvae, thereby decreasing the supply of adults. Oil was procured from the Standard Oil Company and a man engaged to spread the same in stagnant pools and salt holes on the meadows. In a small way the work was successful. The man engaged to spread the oil was conscientious in the discharge of his duties, and became quite proficient in finding and destroying the mosquito larvae. At this time the committee were badly handicapped. With only one man and a small quantity of oil, owing to the scarcity of funds, it was hardly to

> be expected that any great relief should be felt at Monmouth Beach. It was simply impossible under the above conditions to cover the territory that contained the breeding places. But the oil did its work and the larvae were destroyed in the pools, whether fresh or brackish, in which it was placed. The committee were not discouraged and determined to continue the crusade the following year … (Smith 1904, 438-439).

Similar to the cases above, this association lowered costs because it "procured" oil (ibid.) and hired a worker, both of which are relatively private and excludable goods.

The informal group of anti-mosquito crusaders continued their work the following year and received $390 from their neighbors.[23] In 1902, Cooke and Barbour enlisted the help of Eugene Winship and together they formed the Monmouth Beach Improvement Association (MBIA) with the aim of eliminating mosquitos in the area; Winship became the secretary and treasurer of the MBIA and the supervisor of all field work. The association organized a survey of the meadows and surrounding territory that located breeding places; they then divided the meadows into five districts with foremen in charge of the oiling and subsequent ditching efforts. The survey work here, like that of the NSIA, helped to create common knowledge about the location of mosquito breeding sites, which helps to lessen opportunities to shirk. Furthermore, the assignment of foremen to particular portions of the meadow lowered the costs associated with monitoring mosquito control.

While the MBIA faced some obstacles, they overcame them and ultimately helped to lower mosquito populations. Some of the problems they faced related to a lack of funds, as well as open ridicule from citizens and public health officials who remained unconvinced about the relationship between drainage efforts and mosquito populations. Winship states, however, that "… one by one, the different conditions were met and

[23] According to Winship, the MBIA paid Mr. Jerolaman, a boat-builder, and his nephew $343.54 to oil various bodies of water; while they suggest millions of larvae were killed, many areas remained untreated (Smith 1904, 439).

overcome, the subscription became more generous, the ridicule and active opposition ceased and the papers began to treat the matter seriously" (Smith 1904, 440).[24]

The formation of additional associations helped solidify the gains made by the residents of Monmouth. For example, residents formed the Monmouth Beach Protective Association (MBPA) in the fall of 1903. H. H. Brehme reports on the MBPA's drainage project that focused on a stretch of meadow about 250,000 feet along both sides of the Shrewsbury River (Smith 1904). With estimates of the work in hand by February, the MBPA contracted out the ditching work in March 1904 to Mr. Manahan; this work was finished by April 18. Such agreements are additional instances where individuals lower costs associated with producing mosquito control. Smith (1904) reports a similar story for the Rumson Neck community, separated from Monmouth Beach by the Shrewsbury River. The Rumson Neck Mosquito Extermination Association (RNMEA) was formed in 1903 and also hired Mr. Manahan; their ditching operations were finished by May 7.[25] The ditching efforts of the MBPA and RNMEA were deemed successful: whereas mosquitos continued to be unbearable in coastal towns of New Jersey, "Monmouth Beach and Rumson Neck did not have more than an occasional specimen, which usually came from an outside breeding place!" (Smith 1904, 445). Appendix One provides a circular sent on behalf of both associations from 1904, found in Smith (1904, 445-446).

[24] The amount of subscriptions seems to increase over time, but, the overall financial health of the MBIA is not clear as presented by Winship. While subscriptions change from $390, $380, and $425 between 1901, 1902, and 1903, respectively, yearly expenditures increase from $343.54, $522.72, and $657.54 between 1901, 1902, and 1904, respectively. Winship also claims that the MBIA spent a total of $1,770.26 over three years by 1904, and that through his position as Assistant Sanitary Inspector of Ocean township he was able to elicit subscriptions of $755.26 between July of 1902 and June 1903 (Smith 1904, 438-442).

[25] Most of these efforts preceded ordinances condemning all breeding places; the Duffield Amendment passed the New Jersey State legislature in March 1904, which defined standing water as a nuisance and gave public health boards the power to enforce nuisance laws regarding mosquitos.

*Firm-led Malaria Prevention*

Three cases of anti-malaria campaigns within industrial firms in the private sector demonstrate another way individuals lower transactions costs related to abatement and encourage private prevention: the Tennessee Coal, Iron and Railroad Company (TCI) in Alabama, the cotton mills of Roanoke Rapids (RR), North Carolina, and the St. Louis Southwestern Railroad (SSW) in eastern Texas (Carson 2016; Rudolf Ezdorf 1916; H.W. van Hovenberg 1918 and 1919; Iron and Steel 1916).[26] Firms engage in mosquito control and malaria prevention when the health

[26] These are the cases with the most available information, but there are others. For example, the Crossett Lumber Company in Arkansas also conducted anti-malarial operations in the 1910s, according to interviews with former workers (Doogie Darling and Don Bragg 2008, fn. 46). George Bradley (1966) cites a newspaper report from 1935 on the anti-malaria work of a lumber mill in Pretoria, Georgia where J.M. Barnett was responsible for the campaign in the early 1900s. The campaign successfully screened houses, distributed quinine, drained bodies of stagnant water, and oiled larger bodies of water (Ackerknecht 1945). Also, the National Emergency Council Report (1938, 30) states that,

> In reports obtained in 1935 from 9 lumber companies, owning 14 sawmill villages in 5 southern States, there was agreement that malaria was an important and increasing problem among the employees. During the year 7.6 percent of hospital admissions, 16.4 percent of physician calls, and 19.7 percent of dispensary drugs were for malaria. The average number of days off duty per case of malaria was 9, while days in the hospital for the same cause were 5. Ten railroads in the South listed malaria as an economic problem and a costly liability. Four utility companies had full-time mosquito-fighting crews at work during the year. The average case admitted to a company hospital lasted 3 days and the average number of days off duty because of malaria was 11. Each case of malaria was said to cost the companies $40.

The Missouri Pacific Railroad, the Central of Georgia Railway, the Illinois Central Railroad, and the Louisiana Central Lumber Co., might be additional cases of firm-led malaria prevention.

of their workers and local communities is at stake; specific incentives include lowering turnover rates and healthcare costs, which increase productivity and profit. These goals become more obtainable when firms lower transactions costs related to excluding free riders and monitoring the provision of mosquito control. Firms are particularly capable of lowering those transactions costs because of their pre-existing hierarchical structure of production.[27]

The purchase of relatively private goods is one of the ways these firms excluded free riders and provided prevention. The TCI developed its own anti-malaria campaign in 1913. Led by Lloyd Noland, the company doctor, the campaign instructed sanitation workers of the company to drain swamps, backwater pockets on streams in the surrounding area, and to clean ditches and lake shoreline. They constructed drip barrels and other equipment to administer oil and larvicide throughout drainage ditches and other smaller areas where mosquitos bred. To address the problem of the company-owned Bayview Lake, believed to have caused a rise in malaria cases to 398 in 1915, the sanitation division hired a 24-foot motor boat and circled the lake every day. Ultimately, the campaign helped to reduce the prevalence of malaria within the company camps from about 4,840 cases in 1912 to 370 in 1913; 30 cases of malaria were reported in 1917 (see Noland's speech to the 1915 meeting of the American Iron and Steel Institute, Iron and Steel 1916, 257-275; Marlene Rikard 1983). From the purchase of the motorboat to the hiring of Dr. Noland, these inputs into mosquito control were all relatively private goods and services. The saleable and excludable nature of these inputs suggests that problems related to free riding could have been easily resolved.

The cotton mills in Roanoke Rapids financed anti-malarial work in January 1914, which included draining and straightening streams, oiling ponds, and clearing underbrush for a total annual expenditure of

[27] These firms were not required or regulated to engage in mosquito control and prevent infection. In some cases, individuals used liability law to encourage industrial firms to prevent malaria (Polly Price 2010), but this rationale was not explicitly mentioned in the following cases.

$3,683.61.[28] These firms purchased relevant materials, equipment, workers, and supervisors to produce abatement. For their efforts, the people of RR (about 2,000 individuals in 1913) observed a 67 percent reduction in the incidence of malaria by October 1914 (Carson 2016). The cotton mills benefited as their workers were less likely to have malaria: workers were more productive, more attentive, and more abundant. For example, the Roanoke Mills Company experienced an increase in the production of cloth by about 26 percent because of the anti-malaria campaign. Furthermore, the treasurer claimed workers were sent away due to the overall improved health conditions, whereas they had too few prior to the campaign. The relatively private inputs of mosquito control—including the firm's ability to select workers—helped to lower transactions costs related to excluding free riders.

Similarly, the SSW helped to reduce the incidence of malaria by 97 percent from 1917 to 1925. The private inputs of prevention include a financial trust that helped pay for the anti-malaria campaign, as well as the hiring of public health experts and sanitation engineers. Beginning in the fall of 1916, Edwin Gould, the SSW president, opened a trust to finance an anti-malarial campaign, which was eventually supported by contributions from other individuals and local communities alongside the railroad. Gould's trust is a novel way to lower the costs associated with free riders, as he could have refused access to the fund. The SSW then used those funds to create a sanitation department to coordinate the field work necessary to eliminate mosquito populations. Quinine dispensaries were established for workers and local towns, which helped to alleviate malaria symptoms. Whereas the average number of malaria cases in the company hospital was 602 between 1913 and 1916, the average number of cases fell to 251 between 1917 and 1920 (Carson 2016). The railroad benefited by improving the health of its workers and by increasing the productivity of partnering firms, like the San Augustine County Lumber Company.

[28] Beardsley (1987) suggests that cotton textile mills in Rockingham and Lumberton, both in North Carolina, provided similar responses to malaria.

The second feature that lowered transactions costs—particularly the costs associated with monitoring the behavior of subordinates and laborers—was that these firms maintained a comparative advantage in organizing the labor and materials required for prevention, as well as monitoring their performance and effectiveness. Each of the firms gave primary responsibility for the campaign to one individual, either a physician, public health expert, or sanitation engineer. Dr. Noland (physician), Dr. Long (physician), and H.W. van Hovenberg (sanitary engineer) coordinated the campaigns in TCI, RR, and SSW, respectively. Given the charge of eliminating mosquitos and preventing malaria, they became the residual claimants; these men then hired workers and materials to eliminate mosquitos.[29] Part of the ease in monitoring comes from the informational feedback inherent with malaria prevention. That is, if some of the workers shirked their tasks in a particular section or even if a ditch was dug incorrectly, it would eventually become known albeit with a seasonal or year-long lag.

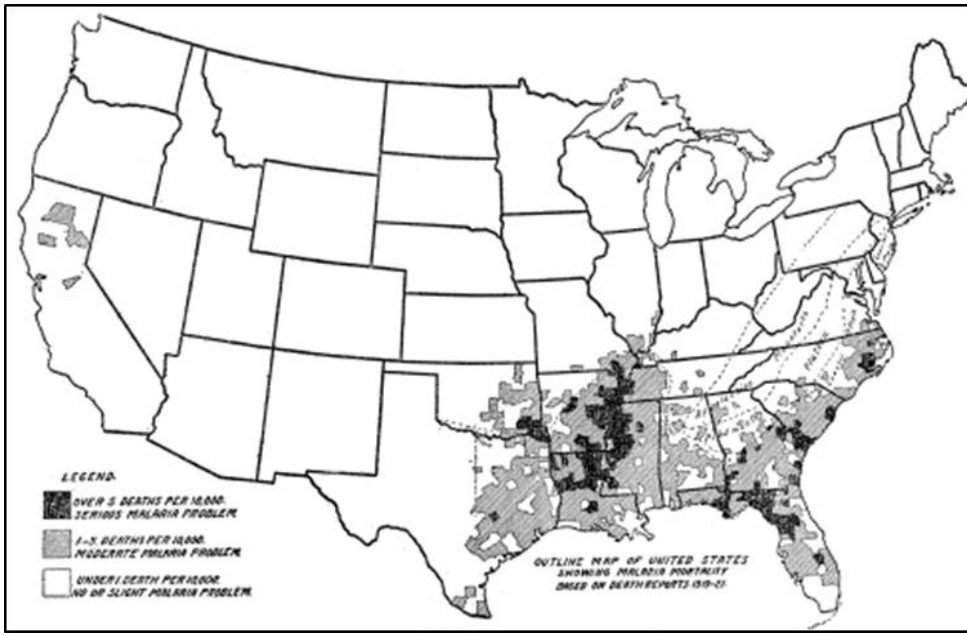
**Private Malaria Prevention in the South**

Tying and associations were common means of eliminating mosquitos in places like New Jersey, Long Island, and Connecticut in the early 1900s, but not in the southern United States. Referring to malaria prevention in the early twentieth century, John Duffy (1988, 46) states that, "In the South some gestures were made, but the old combination of apathy and poverty prevented any real headway." The lack of tying and associations to eliminate mosquitos and prevent malaria is puzzling given the persistence of malaria in the South, especially after the turn of the twentieth century. From 1919-1923, Maxcy (1923, 1924b) reports an increase in the number of malaria deaths in Alabama, Arkansas, Georgia, Mississippi, and Tennessee. With the caveat regarding interpreting malaria-specific mortality rates in mind, Figure 3 shows the distribution of malaria deaths

[29] Referring to how public bureaucracies respond and adapt to outbreaks, Jamasji-Pavri (2006, 274) states that, "fiat is the main instrument to which bureaux have access." Importantly, having a single individual or department in charge of a prevention campaign applies to public and private bureaucracies.

in the United States from 1919-1921.[30]

The lack of tying and forming associations as a means of prevention remains puzzling especially given the potential profit opportunities throughout the southern United States. Even before people knew how




*Source*: Maxcy (1923: 1127).

**Figure 3**
Average Malaria Mortality in the United States, 1919-1921

malaria spread, they recognized the connection between malaria, productivity, and profit. For example, S.H. Dickson read the following statement before the State Agricultural Society of South Carolina in November 1843 (SASSC 1846):

In the low country there are few plantations which admit of permanent

[30] Maxcy (1923) also shows that malaria is not generally distributed throughout the southern states. For example, the Mississippi delta region experienced endemic malaria, but malaria in other areas in Mississippi was sporadic.

> residence; the whole region being pervaded by a pestilential infection, almost unfailing in the excitement of Fevers, Intermittent and Remittent, during the Summer and Autumn … Even in the middle country the risk is so great in many localities, and especially on the best lands, that scarcely any hope of return or actual profit to accrue from personal attention to his affairs, can indemnify him for the loss of health and comfort, and the decimation of his family by disease. Nay, in the immediate neighborhood of the mountains and at their very foot, the rich intervals which line the water-courses, and most fully repay the farmer of the upper Districts, are often afflicted, and in fatal violence, too, with the same or similar Endemics and Epidemics.

Dickson continues and even advocates for an inquiry into the feasibility of drainage projects that would improve the malaria situation in South Carolina. The relevant ties between mosquitos, malaria, stagnant bodies of water, and property values were explicitly recognized some decades later in the report to the Industrial Commission on Agriculture and Agricultural Labor (1901, cxcvii):

> Mr. Whitney says it is estimated that there are 168,000 acres of tide marshes along the Atlantic and gulf coasts…which, if protected from the tide and drained, would be of value in agriculture. Marshes have also an effect upon the value of adjacent land because of the prevalence of mosquitoes and disease … Malaria and similar diseases have contributed greatly to the discomfort of many of the Atlantic coast states, and in many cases areas and industries have been abandoned because of the unhealthfulness of the neighboring marsh lands. These causes have prevented to a large extent the settlement of some of the Southern States, and have caused the abandonment of other lands.

Agricultural census records also indicate agricultural properties remained a continuous source of wealth as the number and average size of farms increased from 1900-1920 (Ejigou Demissie 1990). Yet, as local and state health boards were still developing (Duffy 1988), little systematic anti-malaria work proceeded in the South until around 1912, except for the

work of the Rockefeller Foundation and the anti-malaria work of the private firms mentioned above.

Overall, individuals in the South did not expect the private benefits of mosquito control to be greater than the costs. Low prevalence rates and cheaper alternative means of mosquito control explain the lack of tying and the formation of association in the southern United States. Many southern areas actually faced lower prevalence rates, which indicates a lower benefit from prevention. For example, some rice farmers in Arkansas, Louisiana, and Texas adopted the agricultural practices similar to those of wheat farming in the Midwest. These measures included the use of labor-saving capital, for example, gangplows, seeders, discs, and steam-powered threshing machines, which limited exposure to malaria-infected mosquitos (Packard 2007, 76).

Others in the South used cheaper alternatives to tying and associations. In particular, the use of screening and mosquito nets, liability law, migration, and summer vacations were cheaper means of prevention than tying or forming associations. Despite drawbacks related to wear and tear, screening was a known prophylactic in the South. For example, mosquito nets and "catgut gause" had been in use by the early 1700s in South Carolina (Roy Merrens and George Terry 1984, 540). William C. Stubbs, testifying before the Industrial Commission on Agriculture and Agricultural Labor (ICAAL 1901, 778), and J.A. LePrince, in a speech to the First Conference of Sanitary Engineers directing antimalarial campaigns (CSE 1919, 28), indicate the extent to which tenant farmers, and black tenants in particular, relied on screening to prevent malaria.[31] Stubbs suggests that the property of most tenants is poorly maintained, but many used mosquito nets. LePrince states that,

> It has been stated time and time again that it is no use to screen the negro quarters on the plantations … [but] in Arkansas, in the rice-field towns, the negroes are not only living in effectively screened homes

[31] Stubbs is the director of the Louisiana Experiment Stations, farmer, and landowner in Alabama, Louisiana, and Virginia. LePrince is a sanitary engineer who helped eliminate mosquito populations throughout the early twentieth century.

> but they are paying for such protection themselves. The probable cost is 50 cents per yard, and balconies are being screened as well as doors and windows with 16-mesh galvanized iron screen. So the statement of the owner that it is no use to screen the negro quarters doesn't hold. In that locality the negroes are doing it themselves and paying for it. (CSE 1919, 28)

Given a choice between screens/mosquito nets or engaging in more extensive, private means of prevention, these southerners chose the former.

Southerners also used local and state supreme courts as a kind of malaria prevention because it was cheaper than private anti-malarial campaigns. Hydroelectric power, railroad, and other industrial firms that were common throughout the southern United States often engaged in activities that raised the prevalence of malaria. Local residents initiated legal proceedings once they realized the connection. The construction of hydroelectric dams in particular was associated with an "epidemic" of damage suits in North Carolina, South Carolina, and Alabama (T.H.D. Griffitts 1926, 368). Courts often helped to compensate plaintiffs or required firms to eliminate mosquito populations (Price 2010).[32] In 1916, for example, a circuit court in Marion County, Tennessee, ordered the Chattanooga and Tennessee River Power Company to pay a local resident $3,000 because he had been infected with malaria (William Doran 1968).

That individuals in the South resorted to courts and liability laws as a means of prevention, instead of direct negotiation, indicates significant transactions costs. Agreement between local residents and firms was too costly for individuals to pursue as a means of mosquito control; that is, residents would be hard pressed to demonstrate harm because of the particular actions of a firm. Resolving this disagreement, thus, requires the use of a higher level judicial system to arbitrate disputes. The case of

[32] Price (2010) references the following cases as some of the earliest legal proceedings dealing with liability and malaria: Godwin v. Atlantic Coast Line Railroad Co., 120 Ga. 747, 48 S.E. 139 (1904); Chesapeake & Ohio Railway Co. v. Whitlow, 51 S. E. 182 (Va. 1905); Towaliga Falls Power Co. v. Sims, 6 Ga. App. 749, 65 S.E. 844 (1909).

Spring Creek, Georgia demonstrates the extent of these costs (also, see the comments of Dr. M.A. Fort, in W.G. Smillie 1927). Between 1920 and 1926, residents of Spring Creek believed and claimed that the power company's construction and operation of a dam impounded a large pond, impeded the natural flow of Spring Creek, and created a hospitable habitat for mosquitos, which ultimately increased the prevalence of malaria. Residents pleaded with a power company for compensation and for preventative measures, but with little to show for it. Dr. Fort, resident of nearby Bainbridge, Georgia, claims there was "considerable friction" between the firm and local residents (Smillie 1927, 479).[33] Fort urged the company to eliminate mosquito populations but was not convincing, he presumes, because of changes in ownership and differences in medical opinions between local physicians. Local residents were successful in 1926 after they sued the company. Prior to the trial, "… attorneys and health officials" met and the company agreed to 1) hire an expert in anti-mosquito work, 2) empty the pond, and 3) spray the surrounding area with insecticide. The power company then hired experts on mosquito control and sprayed all parts of the lake with insecticide, which they expected to lower the prevalence of malaria.[34]

Another alternative to private mosquito abatement took the form of moving to areas with relatively low prevalence rates. This alternative represents the demand side of tying; whereas the home and property owners above produced mosquito abatement, people also consume abatement through the purchase of homes and land. Both landowners, in their decisions to locate a home, and workers, in their decisions to migrate, considered the deleterious effects of malaria, especially in the South. Regarding colonial rice plantations in South Carolina, for example, plantation owners were more likely to live near swampy areas before the

[33] Fort claims that 90 percent of residents had malaria in 1926, and that 90 percent of children examined had palpable spleens, an indicator of malaria; these percentages represent about 450 people (Smillie 1927).

[34] In correspondence with Smillie (1927), W.G. Stromquist, an engineer with the US Public Health Service, suggests that water power companies throughout the Atlantic and Gulf states had implemented malaria control campaigns on a larger financial scale than all other anti-malaria activities in the country.

mid-eighteenth century, but they moved to healthier areas as their exposure to mosquitos increased (Merrens and Terry 1984). For example, some planters built houses on pine ridges, located above areas infested with mosquitos (Jill Dubisch 1985).

Summer vacationing—another saleable and excludable good—was also a cheaper way to avoid malarial areas.[35] Seasonal migration patterns to avoid malaria had been established in South Carolina and Virginia at least by the early 1800s (Lawrence Brewster 1947; Dubisch 1985; Merrens and Terry 1984). Fleeing plantation owners added to the appeal of cities like Charleston and Savannah (Meade 1980). Rice planters in South Carolina had a variety of options to avoid mosquitos in the summer months by living in more hospitable areas like on Pawley and Sullivan islands. McPhersonville, South Carolina, Flat Rock, North Carolina, Saratoga Springs, and Newport, Rhode Island provided respite from mosquitos for many landowner-farmers, especially in the mid-1800s (Dubisch 1985; James Tuten 2010).[36]

Southern workers also faced little incentive to privately prevent malaria during the early twentieth century. White and black workers often were unable to pay for private prevention, given low incomes, indebtedness, and the lack of land ownership due to sharecropping and tenant arrangements (Robert Higgs 1987). The lack of ownership would have increased transactions costs related to mosquito control; accordingly, tenant farmers had little incentive to invest in long-term improvements like

[35] I thank a reviewer for the following point: the presence of property rights alone, for example rights over land, does not necessarily encourage private mosquito control and lower malaria prevalence rates. This is especially if landowners can go away for the summer. However, the incentives to provide mosquito control still remain; the improvements related to mosquito control are tied with property regardless of the owner.

[36] Dubisch (1985) indicates that the lack of large-scale cattle herding also influenced the relatively large burden of malaria in areas like South Carolina. Tuten (2010) suggests the practice of vacationing in healthy areas declined in the postbellum era because of the falling burden of malaria. Tuten also points to the decline in writing between planters and overseers as evidence for the decline of summer vacationing.

malaria prevention (Packard 2007, 71-73).[37] Black populations in particular comprised a significant portion of the population susceptible to malaria in the South (Beardsley 1987), but demographic and migratory evidence suggests this burden was in decline by the early 1900s. If black workers remained in southern states, they were more likely to move to urban areas where malaria was less burdensome. Higgs (1987, 24-32) suggests that despite a positive net migration towards northern states, many black populations remained stationary between 1865 and 1914 and/or migrated towards urban areas.[38] Furthermore, Beardsley (1987, 21) argues that the Rockefeller Foundation's International Health Board focused on larger urban areas in the South to gain popular support, which would have lowered the benefit of tying or the formation of associations in those areas (also, see Farley 2003).

Still, landowners had other reasons to forego private means of prevention. Drainage was sometimes too costly for any individual given the large distance separating homes. LePrince suggests that, "In the region where there are many cases of malaria, as a rule, the houses are not close together. There is not sufficient population to pay for extensive drainage measures" (CSE 1919, 28). Landowners are also reticent to eliminate mosquitos when tenants were quick to move away. For example, Maxcy (1924a, 1121) reports on a "recent" case in Montgomery County, Alabama where a farmer constructed a fishing pond and caused nearby tenants to become infected with malaria:

> In a well-drained hilly region, previously free from malaria, a farmer dammed a small stream to make a fish pond within immediate vicinity of which were six houses of tenant farmers. No trouble was experienced during the first summer, but during the second a 'sawmill hand' and his family (presumably carriers of malaria) moved into a house close by the pond. The father and three children came down

[37] Packard (2007) also notes that tenant farmers lived in overcrowded dwellings, their diets were poor, and they often suffered from other diseases like pellagra and hookworm.

[38] Trevon Logan (2009) argues that literacy and health are important co-determinants of this migration.

> with 'chills and fever,' and all except the mother were very ill. Following this there were cases of malaria in four out of five of the other families living within mosquito flight range of the pond. At the end of the season all of these families, except one that had escaped attack, moved away from the locality because it was 'unhealthy'.

As tenants and workers become relatively scarce, however, employers would face incentives to attract them by improving the quality of housing (Higgs 1987, 109). This suggests they might also have been interested in lowering the exposure to mosquitos to lower malaria prevalence rates, depending on the relative scarcity of tenants.

There were many charities and other kinds of voluntary associations in the South, but it is not clear how influential they were as it related to mosquito control and malaria prevention. The Samaritan Society, founded in 1837, and the Can't Get Away Club, founded in 1839, provided relief to victims of yellow fever and malaria, respectively, in Birmingham and Mobile, Alabama (Wayne Flynt 1989). Furthermore, the South Carolina Agricultural Society discussed the problem of malaria again in 1884, which they considered to be a "sleepless enemy from which man has been able to discover no refuge save in flight" (Tuten 2010, 78). Yet, there is little evidence on whether these associations coordinated efforts to prevent malaria in the early 1900s.

Black associations had the potential to coordinate malaria prevention, but due to their oppressed and marginalized status in the South during the early twentieth century, they faced larger costs associated with organizing in general, let alone malaria prevention. Many black churches took a conservative approach to social and political issues and might have been actively prohibited from organizing activities outside the church or faced the threat of abuse (Kendra Barber 2015). In the early 1900s, clubs like the Washington, DC, Colored YWCA and the Indianapolis Woman's Improvement Club focused on various health issues, but not on malaria; the Alpha Kappa Alpha sorority developed the Mississippi Health Project to provide healthcare for sharecroppers and helped to treat malaria but their efforts started in 1935 and ended in 1942 (Linda Gordon 1991).

**Conclusion**

The standard logic of disease prevention and collective action correctly predicts that voluntary cooperation falls prey to free riding and leads to an underprovision of prevention, but it mistakenly ignores when and where people lower costs related to monitoring and exclusion. Without this understanding, we exaggerate the burden of disease prevention and collective action, especially when people value tying and forming associations and/or firms.

Another implication is that property rights establish incentives to encourage mosquito abatement and malaria prevention. In all of the cases of private malaria prevention described above, property rights played some role in creating expectations over the future value of goods and services. These rights created incentives to produce and sell goods and services related to mosquito abatement, from goods like oil and kerosene to the sale of one's expertise and from draining a lake or meadow on one's property to the reorganization of a firm. This connection between property rights and mosquito abatement suggests a larger scope for private activity depending on the extent to which individuals have rights over private goods related to abatement and the extent to which they can tie or bundle private goods with abatement. Furthermore, this connection suggests an alternative approach to explaining when and where people face larger burdens of malaria. That is, economic and political institutions that protect property rights encourage specialization and the division of labor, which encourages the accumulation of wealth; these institutions also encourage private actors to control mosquito populations, which lowers the burden of malaria in addition to geographical and climatological factors. This connection between an area's property rights institutions and the burden of disease is consistent with Werner Troesken (2015), which shows an explicit connection between the political institutions of the United States and the cost of eliminating infectious diseases. Further study might attempt to explicitly highlight these connections between the quality of property rights, incentives to engage in mosquito abatement, and the burden of malaria.

Relatedly, the ease or difficulty of excluding free riders depends on the kind of group, club, or association people form, but this also depends on the kinds of rules people adopt within those organizations. Whereas the

associations above could not easily exclude residents for failing to contribute or for ignoring a rule, other kinds of associations like private, residential communities could more easily enforce rules relevant for mosquito control. The potential connection between private communities and mosquito control remains underexplored. Furthermore, firms in the private sector select particular workers and can exclude others; similarly, firms can more effectively monitor the behavior of workers and can enforce rules related to abatement. Thus, selecting and adapting different organizations and rules are inputs into mosquito abatement and malaria prevention.

The formation of such groups also depends on a country's set of economic, political, and social institutions. For example, American institutions of the early twentieth century were generally favorable to the formation of groups, which created incentives to engage in abatement; however, other people in other countries might face tougher barriers to the formation of such groups. Further study should explicitly examine whether the ease of association—particularly in developing areas with high rates of malaria—influences incentives to engage in abatement and prevention.

The cases above demonstrate the feasibility of private mosquito control and malaria prevention, but the complexity of mosquito abatement and malaria prevention suggest other factors remain important. The unique economic and geographical setting of the United States tempers claims of generality.[39] It seems that many of the individuals who owned property, who were homeowners, and who were members of the associations were relatively wealthy, which remains an important factor in their efforts to successfully control mosquito populations.[40] This seems especially

[39] Other factors in the decline of malaria, particular to the United States, relate to drainage associated with farming, the use of quinine, improved structure and screening of dwellings, the domestication of animals and livestock, a decrease in the virulence of malaria parasites, and increased wealth (Barber 1929). Packard (2007) also describes unique social and agricultural factors that influenced the decline of malaria in the United States. On the history and global burden of malaria, see Simon Hay Carlos Guerra, Andrew Tatem, Abdisalan Noor, and Robert Snow (2004).

[40] Aggregate measures of income indicate that people in the United States during the early twentieth century had a greater ability to finance

relevant for the residential communities and resort towns highlighted above from New York, Connecticut, and New Jersey. This wealth effect, however, is consistent with Olson's (1965) notion of privileged groups, which lessens collective action problems.

The production of mosquito abatement in these cases might have been relatively cheap depending on geographical, ecological, and climatological factors related to mosquito habitats. For example, if it only takes a few drops or gallons of insecticide to effectively control mosquito populations the marginal benefit of even a small amount of abatement might be quite large. Indeed, that mosquito-ridden areas of the United States had declined by the early twentieth century suggests that the private efforts described above were easier relative to what they might have been decades earlier. Such factors suggest that whether abatement is privately (or publicly) provided might be less important. However, focusing on the incentives to *privately* engage in mosquito abatement—and lower transactions costs—remains relevant as mosquito abatement might take multiple seasons or years to be effective. Furthermore, the resurgence of mosquito populations is a perennial problem (Justin Cohen, David Smith, Chris Cotter, Abigail Ward, Gavin Yamey, Oliver Sabot, and Bruno Moonen 2012; David Smith et al. 2013) regardless of the initial marginal unit of production; however, private efforts can encourage the monitoring and control of mosquito populations with the right set of incentives. Producing abatement might also require initial units with small marginal benefits, and private prevention is especially relevant for such cases. Still, future research that distinguishes between these relative effects would be most welcome.

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anti-malaria campaigns than many in developing areas do today. For example, Burkina Faso has one of the highest incidence rates of malaria in the world, at least between 2000 and 2015 according to the World Bank. Yet, the people of Burkina Faso have about one third of the income people in the United States had in 1900.

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## Appendix One: Circular on the Anti-Mosquito Work around the Shrewsbury River (Smith 1904, 445-446)

To all Householders:

The residents of Rumson Neck and Monmouth Beach, through committees, have begun a crusade against the pest of mosquitoes, and for several months have been actively at work ditching and filling in low spots on both shores of Pleasure Bay, under the direction and supervision of Prof. John B. Smith, of New Brunswick, State Entomologist. So far as this work is concerned, it has been so well and carefully done as to destroy the breeding grounds, but it is necessary to have the co-operation of every property-owner and householder of both sides of Rumson Neck, from the Seabright bridge to Red Bank, including Little Silver, and from the village of Seabright to North Long Branch and beyond on the shore, and inland from Monmouth Beach to Branchport, and incidentally this appeal is intended for the entire townships of Shrewsbury and Ocean. The co-operation is for each and every householder and property-owner to fill in all low spots where water would become stagnant, to do away with all barrels and cans of any kind holding water, as these are particularly objectionable as places for deposit of larvae and for breeding of mosquitoes. Further, that where the area is too large for filling in of low spots that ditches be dug of not more than eight inches and of such depth as to carry off the water and dispose of it in such manner as to remove the possibility of breeding grounds. With co-operation such as suggested the comfort and health of the community-at-large will be greatly benefited, as it has been definitely settled that mosquitoes are carriers of disease, and the value of property will be much enhanced. There has been 150,000 lineal feet of ditching on the shores of Rumson Neck and Monmouth Beach, besides filling in of low places, and it is supplemental to this that prompts this appeal by the chairman of the committees of Rumson Neck and Monmouth Beach, respectively, Messrs. William A. Street and Henry L. Thornell. June 10, 1904.