The Journal of Private Enterprise 37(3), 2022, 1-24

Individuals and Externalities in Economic Epidemiology: A Tension and Synthesis

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Abstract
Both standard economic and public choice approaches to epidemiology ignore the role individuals play in disease prevention. Whereas the standard economic approach recognizes that people respond to changing prevalence rates, the standard public choice approach suggests they succumb to free-riding and collective-action problems. But the literature on collective action and the private provision of public goods suggests people can resolve collection-action problems in response to changing prevalence rates, especially when doing so lowers transaction costs. The insights of that literature suggest that decisions related to migration, housing, and community—and related markets that influence those decisions—influence mosquito control and, potentially, malaria prevalence rates.

JEL Codes: D70; H41; I15
Keywords: prevalence elasticity; externalities; transaction costs; malaria

> "By immunizing oneself against an infectious disease, one confers a small benefit on one's fellows, by slightly reducing the probability of their becoming infected. At the same time, the benefit to oneself is particularly great."
>
> —Richard Cornes and Todd Sandler

I. Introduction

Economists have generated distinctive insights on epidemiology and disease prevention, but the role individuals play in disease prevention and their degree of agency remain undertheorized. The more individuals have agency and the more they can avoid infection by altering their incentives, the weaker the case for public responses. To what extent do individuals have enough agency to alter these incentives?

* I thank Diana Thomas, Harry David, Edward Stringham, and an anonymous reviewer for their helpful comments. I also thank Art Carden, Peter Leeson, and William Shughart for their helpful comments on an earlier draft. All errors are my own.

Two approaches within economics examine this question, but remain in tension and arrive at different answers. According to the prevalence-elasticity literature, people respond to outbreaks and epidemics by altering the quantity and kind of their own preventative behavior (see, for example, Philipson and Posner 1993; Philipson 2000; Laxminarayan and Malani 2011; Agüero and Beleche 2017; Oster 2018).[1] And according to the epidemic-externalities literature, people succumb to free-riding and collective-action problems when preventative behaviors have external effects (Gersovitz and Hammer 2003, 2004). These approaches derive insights into how people respond to outbreaks, but it is not clear whether these insights contradict or complement one another. While the logic of prevalence elasticity suggests people increase their preventative behaviors as prevalence rates rise, the logic of collective-action problems suggests people decrease their preventative behavior when others provide disease prevention. Philipson (2000) notes that the timing of preventative behaviors affects which logic dominates; for example, people stop changing their behavior after they obtain their desired degree of exposure to a disease, which limits the benefits of subsequent public responses (for example, subsidies).[2] Regarding diseases for which people face private and collective incentives—that is, the amount of prevention depends on people's own behavior and the behavior of others—people might increase or decrease their preventative behavior depending on which incentives are stronger.

Whether people can resolve collective-action problems through a prevalence-elastic response is underexplored. Private and collective prevalence-elastic behaviors expand the scope for individual responsiveness to diseases, especially when they lower individuals' transaction costs. Mosquito control and malaria prevention constitute a context in which to examine the interplay between private and collective incentives and, perhaps, to develop a synthesis of the two approaches by focusing on conditions under which people lower transaction costs.[3] When people become more worried about

[1] Philipson (2000, p. 1764) states, "Central to the study of rational epidemics is thus the *prevalence-elasticity* of private demand for prevention against disease. It represents the degree to which prevention rises in response to disease outbreak."

[2] For example, administering an effective vaccine or a subsidy for that vaccine confers a negligible benefit to people who already took that vaccine, given their prior prevalence elasticity. Such measures will only influence the behavior of people who have not already engaged in a prevalence-elastic response.

[3] The current approach could also examine the consumption of antimalarial drugs and the emerging market for malaria vaccines that are under development. The

mosquitos and malaria (and similar vector-borne diseases), they face marginal private and collective incentives; that is, they have incentives to directly seek their desired amount of exposure and to free ride off the preventative behavior of others. Malaria is a parasitic disease that spreads through the interactions between mosquitos and humans, and mosquito control—in addition to taking antimalarial drugs or becoming vaccinated—is a common way to limit the spread of the disease (World Health Organization 2022).[4]

Previous research has examined the role transaction costs play in disease prevention, but the interplay between private and collective incentives remains underexplored. Exceptions include Carson (2016) and Carson (2020), which argue that when people alter the transaction costs they face, that changes how they—as individual homeowners and property owners or as participants in private firms or civil society associations—organize and produce mosquito control, which tends to internalize epidemic externalities. Meanwhile, many economists have examined the nature of what some consider externalities associated with COVID-19 transmission. For example, Leeson and Rouanet (2021) argue that while *cross-site* externalities remain because of the transaction costs associated with internalizing them, people often internalize *on-site* externalities given the information and expectations people derive from private property. Similarly, Carson (2021) develops a subjectivist approach to individual responsiveness and argues that people tend to internalize externalities—via innovation and by changing rules—according to their values. And Albrecht and Rajagopalan (forthcoming) argue that externalities related to COVID-19 vaccines are inframarginal given people's subjective values toward disease prevention, their local context, available technology, and institutional arrangements. Such insights indicate that people are likely to internalize the external benefits of vaccination and that Pigouvian subsidies are less effective. While many argue that externality arguments are overstated, they have not examined potential interactions between prevalence-elastic responses and collective-action

analysis could also examine other diseases for which people interested in prevention face private and collective incentives.

[4] Mosquito control is neither necessary nor sufficient for lowering malaria prevalence rates, but it has been a useful method of combatting malaria for over a century. Mosquito control can lower prevalence rates if properly administered, but malaria might linger or mosquitos might import the disease into areas after mosquito control was provided. Further, there are ways to change prevalence rates—for example, antimalarial drugs—without mosquito control.

problems. This paper extends the logic of these papers and clarifies how prevalence-elastic behaviors provide additional conditions under which people internalize epidemic externalities.

The cases of mosquito control examined below highlight distinctively individualistic responses to the threat posed by vector-borne diseases. That is, they highlight how individuals—and not just governments—make marginal substitutions and decisions on multiple margins to lower transaction costs and resolve collective-action problems, especially in the area of housing. For example, people can improve the quality of a home, migrate to safer areas, and devise relatively formal rules to encourage mosquito control within their neighborhood. In making all of these decisions, people consider producing mosquito control, lowering transaction costs, and internalizing epidemic externalities as explicit goals.

Section 2 describes the tension in economic epidemiology in more detail and develops the transaction-cost logic that resolves the tension. Section 3 applies this logic to problems related to mosquitos and malaria. The first part of the section examines typical economic approaches to mosquito control and malaria to clarify the tension. The second part discusses various theoretical and real-world decisions related to housing and explains the conditions under which people can lower the transaction costs related to mosquito control. Section 4 discusses the implications of the scope for individual responsiveness for economic epidemiology and for the economics of collective action. Section 4 also concludes the paper.

II. A Tension and Synthesis in Economic Epidemiology

A. The Insights and Tension of Rationality in Economic Epidemiology

Prevalence elasticity is one of the first economic approaches to epidemiology—an approach explicitly grounded in rational choice theory. It suggests that people avoid potentially infectious behavior as prevalence rates rise (Philipson and Posner 1993; Philipson 2000). Prevalence elasticity connects the magnitude of a person's change in preventative behavior with a change in prevalence rates. A textbook model of prevalence elasticity also notes that prevalence rates and the opportunity costs associated with prevention influence behavioral responses (Bhattacharya, Hyde, and Tu 2018, pp. 449–53).

Scholars have applied the logic of prevalence elasticity to various kinds of infectious diseases and preventative behaviors. Goldstein et al. (1996) and Philipson (1996) examine the demand for measles vaccination, which increases with the prevalence of measles. Bennett,

Chiang, and Malani (2015) examine the demand for information about SARS, which increases with the prevalence of SARS. Agüero and Beleche (2017) examine how hygiene improved in response to the 2009 H1N1 epidemic, which explains the observed fall in diarrhea. More recently, Carson (2021), Droste and Stock (2021), and Sarkar (2022) examine individual responses to COVID-19—namely, possible mitigation measures such as social distancing, face masking, and vaccination—which, at certain times, rose with COVID-19 prevalence and mortality rates. These studies suggest that voluntary behavioral changes limit, but do not eliminate, the spread of infectious disease.

As with other kinds of elasticity, prevalence-elastic responses vary across individuals and circumstances (Dow and Philipson 1996). For example, people tend to be less responsive when the opportunity cost of prevention rises, when the value of remaining susceptible rather than being infected falls, when they believe they are already infected, and when they adopt a nihilistic attitude.[5] A person's expectation of the availability of a cure or other means of avoiding risk in the future can encourage them to engage in risky behavior in the present (Auld 2003; Lakdawalla, Sood, and Goldman 2006). Similarly, beliefs, myths, and superstitions influence responsiveness, as they cause people to over- or underestimate the probabilities of infection and transmission, which can encourage behaviors unrelated to prevention or even infectious behaviors (see, for example, Philipson and Posner 1993; Philipson and Posner 1995; and Oster 2012).

A second economic approach to epidemiology follows the literature on externalities, public goods, and collective-action problems (see, for example, Olson 1965; Sandler 1992, 2015; Cornes and Sandler 1996). This approach—also grounded on the presumption that individuals make rational choices according to marginal costs and benefits—suggests that people face incentives to free ride off other people's preventative behavior.[6] As more and more people free ride, fewer and fewer people engage in preventative behaviors, and diseases are more likely to spread.[7] Standard implications follow: (1) people in

[5] For example, Oster (2012) shows that condom usage declines when the prevalence of other diseases increases. For additional conditions under which people engage in prevalence-elastic responses, see Kremer (1996).

[6] Cornes and Sandler (1996, p. 30) use the term *easy rider* to denote the more likely and widely applicable scenario wherein—in the limit—people provide a positive amount of the collective good.

[7] While this logic is often repeated, few have explicitly studied the magnitude of the problem. For exceptions, see Miguel and Kremer (2004) and Hamory et al. (2021)

areas without some kind of coordination are less likely to provide the socially optimal amount of disease prevention, and (2) a functional government can implement a tax-and-subsidy schedule to correct the perceived problem (Tullock 1969; Roberts 2006; Gersovitz and Hammer 2003, 2004).

Ambiguity arises, however, when we ignore how both types of incentives—incentives to engage in preventative behavior and incentives to free ride—influence a person's behavior. The total amount of prevention produced within a group might rise or fall depending on whether the incentives to free ride outweigh the prevalence-elastic responses. If the incentives to free ride do outweigh those responses, people will decrease the amount of preventative behavior. Moreover, the effects these incentives have on behavior depend on one another and on their timing. Incentives to free ride might decrease preventative behavior and increase prevalence rates only when free riders have negligible prevalence-elastic responses. If free riders are responsive to changing prevalence rates, such behaviors could negate the effect free riding has on prevalence rates. Similarly, the standard logic of prevalence elasticity implies people are less responsive when they cannot resolve collective-action problems. If people can discover and adopt solutions to collective-action problems—and they face incentives to make such discoveries and adoptions as prevalence rates rise—prevalence-elastic responses will have a larger effect on prevalence rates.

B. A Transaction-Costs Approach to Economic Epidemiology

While the prevalence-elasticity and collective-action approaches clarify relevant incentives people face, they ignore transaction costs. The prevalence-elastic approach assumes that some transaction costs are negligible; for example, people know which behaviors are relevant means of prevention, and they can easily alter a relevant means of prevention. However, it seems that both approaches assume that the transaction costs of resolving collective-action problems are onerous; for example, excluding free riders and rewarding preventative behavior is too costly. These implicit assumptions influence how we think about individuals and their responses to prevention. For example, we might think people are highly elastic in their personal responses to diseases

on the externalities associated with hookworm elimination or Dave, McNichols, and Sabia (2021) on the externalities of COVID-19. Leeson and Rouanet (2021), Carson (2021), and Albrecht and Rajagopalan (forthcoming) argue that externalities associated with COVID-19 are generally overestimated or are inframarginal.

but unlikely to resolve collective-action problems. Such assumptions limit our ability to consider whether people resolve collective-action problems as a kind of prevalence-elastic response.

The scope for responsiveness and resolving collective-action problems expands when people lower transaction costs. Indeed, a long tradition in economics shows that people face incentives to overcome problems related to externalities, free riding, and collective action. For example, Adam Smith, David Hume, Ronald Coase, Harold Demsetz, James Buchanan, Vernon Smith, and Elinor Ostrom discuss how individuals can overcome problems related to free riding and collective action (Cornes and Sandler 1996; Coase 1960, 1974; Buchanan 1965; Demsetz 1970; Ostrom 1990; Smith 1980). Furthermore, the literature on the private provision of public goods continues to develop the conditions under which people resolve externality and collective-action problems (for example, Foldvary 1994; Montgomery and Bean 1999; Candela and Geloso 2018; Mixon and Shaw Bridges 2018; Saito 2019). As Albrecht and Rajagopalan (forthcoming) note, there are many cases in which externalities are inframarginal or are policy irrelevant; for example, homeowners value clean yards despite their external effects (Buchanan and Stubblebine, 1962). The economics of tie-in goods also suggests ways to increase the complementarity between private and collective goods (Demsetz 1970; Klein 1987; Cornes and Sandler 1996; Bakos and Brynjolfsson 2000; Liebowitz and Margolis 2009).

The more we recognize that transaction costs influence both sets of incentives and that people can lower transaction costs, the more the two approaches appear to be different sides of the same coin. That is, people exhibit prevalence-elastic responses that resolve collective-action problems. Solutions to collective-action problems are a kind of prevalence-elastic behavior and are found when people lower transaction costs. This logic follows that of Coase (1960), Buchanan (1965), Demsetz (1970), and others and suggests that the producers and beneficiaries of prevention are more likely to negotiate and coordinate on preventative behaviors when transaction costs are lower. Coase (1960) specifies the conditions under which parties create and internalize externalities: they are more likely to internalize externalities through clarifying or rearranging property rights. Such clarification and rearrangement are more likely when transaction costs fall—for example, when people can more easily communicate, negotiate, monitor, and enforce contracts. Buchanan (1965) develops this logic by noting that organizations can alter transaction costs; for

example, clubs can monitor and enforce entry and exit rules. Thus, clubs can provide the optimal amount of a public good, resolve free-riding problems, and internalize externalities when they lower exclusion costs. The easier it is to exclude members, the more a club can provide its optimal amount of a public good. Like Buchanan, Demsetz (1970) notes that exclusion costs fall further when people can easily exclude nonpayers and when people tie the production of private and collective goods. These approaches to externalities form the core theoretical argument of my proposed synthesis. That is, producers and recipients of prevention face additional incentives and more opportunities to cooperate and lower prevalence rates when they can lower transaction costs.

When people can lower transaction costs, we should expect a larger amount of prevention within a group. We should also expect additional kinds of prevalence-elastic responses and additional ways to resolve collective-action problems. Consistent with analysis in which people make choices across multiple margins, we should expect people to be responsive in standard ways and to search for behaviors, rules, innovations, and other mechanisms to resolve collective-action problems. With the advent of the germ theory of disease, for example, the transaction costs of discovering relevant ways to avoid infection and improve hygiene fell. Such changes allowed people to better understand how personal decisions influence private and public health. Moreover, people found ways to capture the gains associated with health improvements via higher productivity, income, and perhaps IQ (see, for example, Mokyr and Stein 1996; Mokyr 2000; Bleakley 2010; Carson 2016; Hamory et al. 2021).

Such solutions might not eliminate externalities and collective-action problems, but they represent areas in which people make conscious decisions in response to diseases.[8] They also indicate a larger scope for individuals to adjust, innovate, and improve. Just as a government can establish taxes and subsidies to discourage and reward infectious and preventative behaviors, people might be willing to devise various ways to mitigate externality problems—especially as transaction costs fall or as people find ways to lower transaction costs.

[8] Such a process might require a Barzelesque kind of analysis—that is, one emphasizing that a larger division of labor increases transaction costs and monitoring problems, which necessitates explicit contracting and the formation of a larger organization to facilitate cooperation (Barzel 1997).

III. Choices, Transaction Costs, and Malaria

A. The Standard Economic Approach to Malaria

The tension and synthesis described above can be refined by focusing on mosquito control and malaria. Malaria is a parasitic disease—spread by *Anopheles* mosquitos—and a major source of morbidity for adults and mortality for children. While there are no known licensed vaccines—although there are promising candidates with relatively successful human trials—there are viable alternative means of malaria prevention. Since Ronald Ross's discovery that mosquitos spread malaria in the late 1890s, people have attempted to control and eliminate mosquito populations as a means of malaria prevention. Mosquito control remains a common means of malaria prevention. Methods of mosquito control include spraying oil and kerosene in stagnant bodies of water; screening doors, windows, and porches; and draining swamps and marshes (see, for example, Howard 1902; Barber 1929; Russell 1955). As Raina (1991) explains, "Effective anti-malaria measures include measures to prevent infective species of mosquitoes from breeding, offensive campaign against mosquitoes in all stages of development, careful defensive action to protect human beings from the bite of mosquito, and administration of drugs to kill the parasite injected into the system by mosquitoes that survive offensive action and penetrate defenses" (p. 44). With advances in knowledge about mosquitos and malaria, moreover, people discover more opportunities to tailor how and where to control mosquitos.[9]

The economic literature on malaria is limited, but it follows the standard approaches discussed above. Berthélemy et al. (2013) analyze the choices people make to avoid exposure to mosquitos and then analyze how such choices influence prevalence rates. Their study contrasts with the economic scholarship on malaria that views malaria as a relatively immutable burden to individuals (see, for example, Gallup and Sachs 2001; Sachs and Malaney 2002).[10] Whereas such studies downplay the role individuals' choices have on their malarial

[9] Living away from swamps used to be a common means of malaria prevention because people did not know of other relevant responses; people can adopt more relevant means of prevention, however, with more knowledge about the etiology and epidemiology of a disease. This indicates an implicit condition under which this analysis applies, namely infectious diseases regarding which individuals have choices—and knowledge of such choices—about how to produce prevention.

[10] Datta and Reimer (2013), however, recognize that endogeneity is a concern. Also see Shretta, Avanceña, and Hatefi (2016) for a discussion on the feasibility of mosquito control and elimination.

exposure, Berthélemy et al. (2013) suggest that people choose to sleep under a bed net when the probability of infection and the health gains of prevention rise and when the opportunity cost of prevention and the marginal utility of income fall. While this approach explicitly relies on marginal considerations to explain changes in exposure, it does not account for potential externalities. Thus, these papers do not address whether people face transaction costs or find ways to resolve collective-action problems as Coase (1960), Buchanan (1965), Demsetz (1970), and others might suggest.

Scholars continue to view individuals as uncoordinated and unable to reliably internalize the benefits of mosquito control and malaria prevention, and they believe that governmental coordination is justified (see, for example, Gersovitz and Hammer 2003, 2004). One of the first references to collective-action problems and mosquito control comes from the entomologist Leland Howard, who states, "But with mosquito work, just as with so many other public measures, what is everybody's business is nobody's business, and the result is that in many localities everyone submits to the mosquito evil" (Howard 1902, p. 167). Tullock (1969) explicitly develops a logic of collective action undertaken for mosquito abatement and notes how club-like organizations could pool resources and provide mosquito control; but he presumes such arrangements would be unable to effectively limit free riding. Similarly, some recognize the private-public nature of mosquito control and malaria prevention, especially for specific inputs of control (for example, indoor residual spraying), which influences the extent to which there are external effects (Hanson 2004). While Hanson (2004) recognizes a potentially wider scope for individuals, her analysis does not consider whether people engage in prevalence-elastic responses and whether, in doing so, they can discover ways to lower transaction costs.

Even in cases in which we might expect people to have strong incentives to internalize such benefits—and contract around externalities following Coase (1960)—people might not be responsive. For example, Sedlmayr (2018) analyzes a randomized allocation of bed nets among cotton farmers who contracted with Dunavant Zambia, the largest cotton producer in Zambia, in 2010–11. The study finds that farmers reported fewer malaria episodes, but those health gains did not translate into increased productivity or net revenue for Dunavant Zambia. Following Coase (1960, pp. 38–39) and his discussion on contracting costs, it seems likely that the cotton producer faces substantial costs associated with monitoring how

subordinates make use of their improved health after they increase their bed-net usage. While Sedlmayr (2018) admits that contractual design is a potential solution—but not that it could be the problem—whether the firm was adequately compensated remains unclear.[11] Thus, one could argue that positive externalities remain, and philanthropy and government subsidies are required to encourage further prevention.

One underexplored implication of these approaches is that despite the potential private gains from mosquito control and malaria prevention, individuals are unable to realize those gains because of transaction costs. That is, individuals might behave rationally and provide some amount of control and prevention, but they tend to succumb to externality, free-riding, and collective-action problems. When we ignore the role transaction costs play, we might be more likely to assume privately optimal behavior encourages an amount of control and prevention below the amount that is socially desired. Yet this would be a partial examination of how people might respond to mosquitos and malaria, especially when people can lower transaction costs.

B. Synthesizing Individual and Collective Responses to Malaria

Few have recognized the extent to which people face incentives to resolve externality problems related to mosquito control and malaria prevention. Carson (2020) shows that when individuals lower the transaction costs associated with producing goods like mosquito control, they are more likely to internalize the benefits. During the early twentieth century, property owners in Connecticut and in New York internalized the benefits of mosquito control because they tied that good with the value of their land, homes, and businesses. Following the logic of tying (Demsetz 1970), these individuals—producers of mosquito abatement—lowered the costs of exclusion because they were selling relatively private property such that the price of the property reflected the value of mosquito abatement to recipients. Similarly, anti-mosquito associations in New Jersey and firms in the private sector (primarily in the southern United States) produced mosquito control and malaria prevention because they lowered the

[11] Sedlmayr (2018, p. 423) recognizes the role contracts might play when he concludes, "There may be substantial promise in microeconomic innovations that improve contractual design, and in behavioral innovations that improve relationships between farmers and buyers."

costs related to producing mosquito control and monitoring subordinates (Carson 2016). The hierarchical relationship between owners, managers, and subordinates encourages firms to produce mosquito control, which lowers transaction costs.

The following choices related to mosquito control and malaria prevention are opportunities for individuals to consider—explicitly or implicitly, and across multiple margins—how they value mosquito control and differences in malaria prevalence rates. These choices relate to where to live, when to improve the quality of their house, and how to live with neighbors. As some of these choices are easily tied with private inputs into mosquito control or they are relatively cheap means to lower transaction costs, following the logic of Coase (1960), Buchanan (1965), and Demsetz (1970), people are more likely to be responsive and resolve collective-action problems. Accordingly, they suggest a more expansive scope for individuals to provide mosquito control and respond to malaria.

i. Housing Location

When people decide to live in a particular area (or decide to move), they are interested in the local mosquito population—and whether mosquitos carry malaria—on the margin. Such private decisions give individuals options to internalize the benefits and costs of mosquito control and malaria prevention. The relatively tight connection between decision-makers and the costs and benefits of a decision indicates lower transaction costs and more opportunities to internalize externalities, following Coase (1960). For example, individuals kept the Roman Campagna and the Pontine Marshes sparsely settled for millennia because the lowlands and marshlands facilitated the propagation of mosquitos and spread of malaria. Given the relatively high probability of being infected with malaria in these parts of Italy, most people stayed away from there.[12] The temporary reclamation and settlement of these lands—driven primarily by the political interests of the Italian government after 1922 (Caprotti 2006; Snowden 2006)—also speaks to the low marginal value people placed on its use.[13] That is, people would not have reclaimed these lands otherwise.

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[12] Even if people did not know what caused malaria—and it was not known scientifically until the late 1890s—they were aware of pestilential areas to avoid (swamps, lowland, and marshlands).

[13] "Formerly it was a place of great desolation and solitude—a few herds of wild-looking cattle or horses, a few miserable straw huts, and vast, silent stretches of water" (Frost 1934, p. 584).

Migration from the southern United States to the northern United States in the early twentieth century also lowered the probability of contracting malaria. After the mid-eighteenth century in South Carolina, the shift away from swampy areas (Merrens and Terry 1984) and the construction of houses on pine ridges (Dubisch 1985) indicate conscious decisions to avoid potentially malarial areas. Summer vacationing also represents a way to avoid areas with large mosquito populations; this was particularly relevant for people living in South Carolina and in Virginia (Brewster 1947; Merrens and Terry 1984; Dubisch 1985; Tuten 2010).[14]

Seasonal and permanent moving habits, however, are neither necessary nor sufficient for providing mosquito control. Many individuals might choose to remain in areas where mosquitos thrive and where malaria spreads because they have personal attachments to an area, they are too sick or too poor to move, or they do not have access to developed credit markets. These people will still face the burden of mosquitos and malaria. Even if a person can move, malaria might remain because of a variety of initial conditions related to the area's preexisting ecological and geographical features that raise the costs of mosquito control and malaria prevention.

ii. Housing Improvement

When people remain in areas with large mosquito populations and high rates of malaria, their housing-related choices also influence their exposure to mosquitos and malaria. Such choices are means of responding and of internalizing the external effects of prevention. That is, people lower transaction costs by tying the provision of mosquito control and lower malaria prevalence rates with the value of their improved homes, following the logic of tying (Demsetz 1967). Following their marginal values, people can limit exposure by altering the design or improving the quality of preexisting houses, grounds, and other immobile property. The marginal benefit of improving a roof—for example, by patching holes and eliminating gaps between walls—includes lower exposure to mosquitos, whereas the marginal cost is the opportunity cost associated with purchasing the materials and labor required to improve the roof. For example, in Stafford, Connecticut, a land-improvement company constructed a dike to drain marshland

[14] Gallup and Sachs (2001, pp. 90–91) come close to recognizing this logic when they describe the effects of eliminating malaria: "Few tourists thought of basking on shores of the Aegean when Greece was the most malarial country in Europe."

(where mosquitos bred), upon which they built popular summer homes (Howard 1902).

Making a home airtight—to prevent mosquitos from entering—is another way of internalizing external effects. This is particularly useful in the evening, when people are less active or asleep. Screening has historically been a dominant method of improving the quality of one's house and avoiding mosquitos (Howard 1902; Russell 1955). On the benefits of screening, Raina (1991, p. 73) states:

> Screening of buildings in malarious localities is of great value. The following figures by Hanif as early as 1928, showing the result of screening in British troop barracks in Lahore, speak for themselves:

Year	Admissions per 1000 screened barracks	Unscreened
1926	182.1	572
1927	45.6	265.9

People still screen their doors and windows today. Building techniques, home-construction projects, and electrostatic nets also limit people's exposure to mosquitos (Chaves et al. 2021; Tusting et al. 2015, 2017; Tusting, Willey, and Lines 2016; Okumu 2017).

The following examples show how people implicitly and explicitly lower transaction costs associated with mosquito control. In ancient Egypt, Herodotus suggests, the construction of higher buildings and towers was a way to avoid contact with insects: "In the parts of Egypt above the marshes the inhabitants pass the night upon lofty towers, which are of great services, as the gnats are unable to fly to any height on account of the winds" (Russell 1955, p. 148). More recently, Howard (1902) tells the story of a family in New York for whom a few drops of oil in their water well dramatically lowered their mosquito population:

> Some years ago I was visiting a family in the mountains. It was during a dry season, and water was scarce. There were no swamps, no lakes or pools, and the drinking-water was taken from springs; yet mosquitoes were so plentiful that it was necessary to screen the porches, that sitting out of an evening might be made possible. I asked where the water came from in which they washed their clothes, and they replied, as expected, 'From a rain-water tank,' which, as it happened, was situated under the porch. I investigated the tank and found it literally alive with mosquito larvae. A pint of kerosene stopped the breeding, and as the water was drawn from

> a faucet near the bottom of the tank the kerosene did not injure it. (p. v)

The installation of private rainwater tanks, similarly, can prevent the breeding cycle of mosquitos, especially as nearby inhabitants might wish to avoid the mosquito bites and their diseases.

Individuals might also improve their homes by hiring experts in mosquito control—for example, entomologists, pest-control agencies, land surveyors, engineers, and experts in drainage (see Carson 2020 for examples). Contracts between these parties are important mechanisms whereby individuals lower the transaction costs associated with organizing mosquito control. Howard (1902) was one such expert; he mentions numerous colleges and universities from Mississippi to California that employed groundskeepers to systematically drop oil throughout their respective campuses. Deaton (2015, p. 98) suggests that Princeton University attracted students to its campus throughout the nineteenth century partly because of its relatively high elevation, which made it a healthier learning environment than the surrounding malarial, swampy areas.

Recently, the advent of modern pest-control technologies has allowed people to cheaply consume a particular amount and kind of mosquito control. Such technologies indicate there would be a greater potential for malaria prevention if prevalence rates were to increase. The technology of pest control minimizes potential free-riding problems and encourages contracts between providers of mosquito control (for example, a pest-control firm) and primary beneficiaries (for example, homeowners). Thus, we see a proliferation of pest-control companies that provide anti-mosquito services (for example, TruGreen, Mosquito Authority, Mosquito Squad, Mosquito Joe). Similarly, people can purchase various kinds of anti-mosquito repellents from hand sprays to battery-powered devices that rebuff or kill mosquitos in and around one's yard or throughout the premises of a firm. That these devices can be tailored to produce mosquito control in varying amounts and for different land features suggests people can now more easily internalize externalities according to their marginal values.

iii. Housing Communities

Individuals might improve their house in a privately optimal way, but mosquitos and malaria might persist in a neighborhood. For example, there might be geographical and ecological factors that indicate

mosquitos thrive outside of the home; people might be unwilling to pay for such improvements; and people might not have reliable access to financing or credit markets. Furthermore, a person's property rights might only extend so far, less than what might be required to provide meaningful mosquito control.

While such difficulties are relevant, people face additional choices over which they can lower transaction costs and encourage mosquito control. Residential communities and neighborhood associations provide additional opportunities for individuals to be responsive to mosquitos and malaria; individual- and group- level incentives now become relevant (see, for example, Ostrom 1990 on the conditions under which people in groups cooperate to resolve social dilemmas). For example, relatively small groups of neighbors can form local governance organizations, from which they can pool resources and monitor each other's behavior, which can encourage mosquito control. For example, the Twentieth Century Club (discussed in Carson 2020) was an early voluntary association that helped to eliminate mosquitos in the Richmond Hill area of Long Island. While the association could not compel neighbors and residents to contribute to the campaign, sufficient financing and mosquito control was achieved and it was deemed successful. Associations in Japan also seemed effective as hundreds of Japanese mosquito-control associations had formed by 1950, which helped to improve health and productivity (Kurihara 1983).[15]

Free-riding problems can be resolved, given the financial incentives homeowners might face to maintain the value of their property and their ability to form homeowners' associations, both of which encourage mosquito control. Whereas homeowners retain the benefit of higher property values via mosquito control, homeowners' associations maintain those gains through selecting members based on various entry and exclusion conditions, assessing monthly or yearly fees, and stipulating how to maintain yards and property (see, for example, Nelson 2005). The logic of clubs (Buchanan 1965) becomes relevant, as such associations can require the provision of mosquito control throughout one's property or assess fees for mosquito control. Individual homeowners, homeowners' associations, and the rules they impose thus can provide the desired amount of mosquito control

[15] Kurihara (1983, p. 110) states that "a resolve, thus, slowly grew up on the part of the villagers themselves that they should assume responsibility for spraying."

throughout the domain of the association—which can rival the size of moderately sized cities.

For example, the Association of Poinciana Villages—one of the largest associations in the country and the largest in Florida—is home to over 150,000 residents over nine villages spanning over forty-seven thousand acres. While mosquito control is not one of the public works the association claims to provide, the association lists dedicated crews for lawn mowing, drainage, and park maintenance, which monitor over 180 miles of roadways and 134 miles of Versa ditching. This kind of organization and the services it can provide indicate the potential for reliable mosquito-control services provided by individuals and the associations they create. Moreover, this association indicates the potential that homeowners have to prevent malaria if prevalence rates increase.

The Spring Shadows Civic Association of Houston, Texas—currently comprising 1,967 homes—provides an example in which a homeowners' association provides mosquito-control services in addition to other amenities in exchange for a yearly maintenance fee of $336. Its website states that the Health/Mosquito Committee "monitors and supervises the contract operations of mosquito control projects or other measures necessary for the maintenance of the general health and well-being of the residents of Spring Shadows community."

IV. Discussion and Conclusion

The preceding logic connects independent approaches to economic epidemiology to better understand the role individuals play in disease prevention. The synthesis developed suggests that people are more likely to resolve issues related to externality and collective-action problems when they engage in marginal adjustments and can lower transaction costs.

This synthesis has the following implications for developing the economic approach to epidemiology. Studies on prevalence elasticity might examine a wider array of choices people face when they perceive the threat of infectious diseases; specifically, studies should encompass efforts people take to internalize externalities and resolve collective-action problems. Individuals can engage in prevalence-elastic responses in standard ways, in addition to resolving collective-action problems, which implies a greater scope for decentralized coordination or private regulation. While externalities might remain, it is not clear

people are as uncoordinated as standard theory suggests, let alone that government provides the only opportunity for Pareto improvements.

Similarly, this synthesis provides another way to discuss the potential links between economic freedom and people's responses to epidemics and public health crises. While Troesken (2015) argues liberal economic and political institutions discourage some forms of public health improvements, recent scholarship suggests economic freedom improves immediate responses to epidemic crises as well as recovery efforts (see, for example, Geloso and Pavlik 2021; Candela and Geloso 2021; Geloso, Hyde, and Murtazashvili 2021). That is, to the extent economic freedom protects property rights and encourages the formation of markets, norms of commerce, and expectations regarding a person's status as a residual claimant, it also lowers transaction costs, which encourages additional and novel kinds of responsiveness.

The scope for private efforts against disease expands when we consider infectious diseases with differing etiological and epidemiological characteristics, as well as the various private inputs into prevention. For example, people who believe that wearing face masks, social distancing, and getting vaccinated limit the spread of COVID-19 can follow those approaches. They can also choose to limit their time spent in places where the disease is likely to spread and limit contacts based on health status. Indeed, the extent to which people can avoid disease and externalities altogether—by imposing various entry conditions based on symptoms and health status—seems like a feasible mechanism to improve private and social welfare especially compared to unilateral lockdown policies (Leeson and Rouanet 2021; Albrecht and Rajagopalan forthcoming). Such responses might entail transaction costs, but we should recognize when and where people are likely to be responsive and when and where they can resolve collective-action problems.

The persistence of mosquitos and malaria often depends on factors beyond our control—for example, geography, climate, and ecology. However, health outcomes also depend on factors people can influence—namely, the size and scope of markets and the transaction costs they face. Markets for housing, for experts on mosquito control and malaria, and for goods and services related to mosquito control become particularly relevant. When people improve their housing stock, when they acquire additional mobility and migrate to more salubrious areas, when they can more easily develop associations, and

when they develop related markets, they can discover ways to move closer to their preferred degree of exposure to mosquitos and malaria.

Transaction costs and the ability to lower such costs also influence health outcomes. These costs might be relatively small in such places as the northern United States during the early twentieth century, where property rights were relatively well defined, tradeable, and protected. This logic explains why people tied the production of mosquito control with the value of land, houses, hotels, and universities; why people formed associations and hired experts in mosquito control; and why firms in the private sector were willing and able to provide similar services (Carson 2016, 2020). Moreover, many firms in the private sector face incentives to provide mosquito control (Watson 1953; Utzinger, Tozan, and Singer 2001; Utzinger et al. 2002; Ebama and Urbach 2011).[16]

Not everyone can lower transaction costs to the same degree, as they have different constraints and endowments. This suggests a limit to individual responsiveness and private efforts to control mosquito populations, but it does not necessarily suggest a market failure. If anything, the preceding analysis suggests mosquitos thrive in areas where markets are not operable (because of high transaction costs) or where they are prevented from developing (because of regulations). Such a logic follows Cornes and Sandler (1996, p. 40) in their discussion on how externality problems arise from the *absence* of markets.

For instance, people might find various barriers to entry into an area's housing market (for example, rent control); there might be immigration barriers that discourage mobility; taxes and regulations might raise the costs of goods and services related to mosquito control. In the southern United States during the early twentieth century, for example, most tenant workers did not have clear property rights or incentives to engage in mosquito control (Carson 2020). Similarly, while mosquito-control companies—and the larger market for mosquito repellents—are widespread in some countries, other countries might provide poor incentives for entrepreneurs and producers of such services. People might not be willing to pay for these services, given the opportunity cost. And there might also be

[16] Disney World is another outstanding example. Walt Disney implicitly recognized this logic when he acquired acres of land to build his theme park and invested in mosquito control.

crowding-out effects, where the governmental provision of anti-mosquito services discourages their private provision.

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