Public Mosquito Abatement: A Cluster Randomized Experiment

Josselin Thuilliez and Yves Dumont

Mosquito abatement is a public good. A simultaneous model of mosquito abundance and abatement response is developed. We then use data from a cluster randomized controlled experiment conducted over the period 2012–2014 in urban areas of Réunion in France to study the impact of WHO-recommended mechanical elimination techniques, which involve removing sources of stagnant water around the house, on a number of outcomes, including objective entomological indices and self-declared protective behaviors. Empirical results document that households reduce their protective behavior in response to public control. This study holds implications for arboviral disease control, including Zika control. JEL: O12, I15, I25.

Keywords: Mosquito abatement, Public control, Private behaviors.

Josselin Thuilliez (corresponding author) is a researcher at CNRS—Centre d'économie de la Sorbonne. 106-112, Boulevard de l'Hôpital, 75013 Paris. His email address is josselin.thuilliez@univ-paris1.fr. Yves Dumont is a researcher at CIRAD UMR AMAP, 34398 Montpellier cedex 5. His email address is yves.dumont@cirad.fr. We are very grateful to the editor, three anonymous referees, Achyuta Adhvaryu, Emmanuelle Augeraud-Véron, Jean-Claude Berthélemy, Didier Fontenille, Pierre-Yves Geoffard, Mark Gersovitz, Maria Kuecken, Alessandro Tarozzi, and numerous seminar participants for their valuable comments and suggestions. Special thanks also go to ARS-OI and their team of coordinators, technicians, and agents. In particular, we would like to extend our gratitude to Jean-Sébastien Dehecq, Hélène Thebault, and Olivier Reilhes, the coordinators Thomas Margueron and Manuel Rodicq, as well as the many technicians who helped in the implementation and organization of the fieldwork. Research assistance from Claire Bellia, Marie Hamsany, and Sera Onalan was greatly appreciated. Finally, the study could not have been achieved without the dedication and patience shown by all the agents who conducted the interviews. This program was funded by the French Ministry of Health and Les Fonds Européens and Le Conseil Régional de la Réunion (FEDER). It was undertaken jointly by ARS (Agence Régionale de Santé), IRD (Institut de Recherche Développement), CNRS (Centre National de la Recherche Scientifique) in collaboration with CRVOI (Centre de Recherche et de Veille sur les maladies émergentes dans l'Océan Indien). The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript. The content is solely the responsibility of the authors. "A supplemental appendix to this article is available at http://wber.oxfordjournals.org/."

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I. Introduction

As emphasized by Carlson and Debord (1976), " *the absence of nuisance insects which are highly mobile is a public good. Mosquitoes are similar to other airborne irritants in that they ignore property lines and decrease human health and comfort. Most mosquito control originated for human disease control but has gradually changed to nuisance prevention.*" In this article, we study environmental management methods to control mosquitoes and reduce human-vector contact. Particularly, we assess a zone-based public vector control program.[1] We focus on mechanical elimination techniques that, in this study, refer primarily to the elimination of sources of stagnant water to reduce the mosquito population around the house. Mechanical elimination is among the cheapest interventions recommended by the World Health Organization (WHO) for vector management[2] and can therefore result in high monetary returns. Such methods have been recommended by the World Health Organization for the control of arboviral diseases and malaria (for exophagic/exophilic *aedes* or *anopheles* that are best controlled through the destruction of breeding sites) and can be implemented either by an external agency or directly by households in their private dwellings (WHO 2009).

In this article, we argue that eliminating sources of stagnant water is a choice made by the household and, consequently, that adoption rates reflect the household's trade-off between costs and efficacy. In addition, we show that a mechanical elimination intervention piloted by an external agent might act as a substitute for private protection rather than as a complement. Moreover, if individuals do not account for the aggregate consequences of their individual compensation, the externality may lead to an over-compensatory response. As a result, those who received the intervention may be worse off than if they had not received it. Similarly, Bennett (2012) highlighted the potentially perverse effects of public health interventions in the Philippines and showed that piped water introduction increased poor sanitary behaviors and thus actually led to a slight increase in the

1. Vector control is any method to limit or eradicate the mammals, birds, insects or other arthropods that transmit disease pathogens.

2. According to WHO (2009), environmental vector management methods are of three types: "*(i) Environmental modification - long-lasting physical transformations to reduce vector larval habitats, such as installation of a reliable piped water supply to communities, including household connections. (ii) Environmental manipulation or mechanical elimination - temporary changes to vector habitats involving the management of "essential" containers, such as frequent emptying and cleaning by scrubbing of water-storage vessels, flower vases and desert room coolers; cleaning of gutters; sheltering stored tyres from rainfall; recycling or proper disposal of discarded containers and tyres; management or removal from the vicinity of homes of plants such as ornamental or wild bromeliads that collect water in the leaf axils. (iii) Changes to human habitation or behaviour - actions to reduce human-vector contact, such as installing mosquito screening on windows, doors and other entry points, and using mosquito nets while sleeping during daytime.*" In addition to environmental management, chemical control using larvicides, adulticides, or insecticides is intended to reduce mosquito densities, longevity, and other transmission parameters. Biological control is based on the introduction of organisms that prey upon, parasitize, compete with, or otherwise reduce populations of the target species.

incidence of diarrhea in children. Our study contributes to the understanding of public policy aspects of environmental management. Achieving widespread adoption of appropriate behaviors requires costly sustained subsidies or taxation (Arrow 1963; Gersovitz and Hammer 2005). Moreover, two systematic reviews of published evaluations have been conducted that assess zone-based dengue or chikungunya control programs (Heintze, Garrido, and Kroeger 2007; Ballenger-Browning and Elder 2009). They show that existing studies have generated little concrete evidence that demonstrates the efficacy of mosquito abatement programs in reducing the risk of arboviruses.

Our study takes place in Réunion, a French island and an overseas French department located in the Indian Ocean, where *Aedes albopictus*[3] is well established and the socioeconomic development of the population is high. Education levels are also high as is knowledge of disease transmission and recommended practices specific to the elimination of larval sites. Though our study is applicable to risk from dengue and chikungunya[4] and *Aedes* mosquitoes, it also offers implications for Zika control. Réunion has experienced a number of epidemics due to the favorable environment it provides for the mosquito species to thrive. Past outbreaks of chikungunya and dengue prompted authorities on the island to implement strategies to control mosquito density. Following the resurgence of dengue in 2004, the local vector control services, referred to as the "Services de Lutte Antivectorielle", or LAV, began developing a control strategy targeted at urban vectors, primarily *Aedes albopictus*. The major chikungunya outbreak that swept through Réunion in 2005-2006 further increased the authorities' motivation to establish entomologic surveillance of *Aedes albopictus* in all urban areas. This surveillance effort remains in place through the monitoring of traditional stegomyia indices at immature stages (i.e., the Container Index, House Index, Breteau Index)[5] as used in other control programs (Pierre et al. 2006). *Aedes albopictus* remains the main target of the work of the LAV, a service organized by the Regional Health Agency (Agence Régionale de la Santé, or ARS) in Réunion. The vector control strategy integrates four core activities: vector surveillance, mechanical control, chemical control (larvicides and adulticides being applied rarely), and public health education campaigns. Vector control services also undertake the early detection and treatment of cases of arboviral infection

3. *Aedes albopictus*, commonly known as the Asian tiger mosquito, is an anthropophilic, daytime-biting species that rapidly establishes itself in new urban areas, owing to its propensity to breed in both artificial and natural containers of stagnant water (Benedict et al. 2007). The tiger mosquito is particularly threatening due to its potential for transmitting a wide range of arboviruses, including dengue, chikungunya, yellow fever, and several other types of encephalitides (Gratz 2004; Angelini et al. 2008; Delatte et al. 2010; Paupy et al. 2010).

4. There are no specific antiviral medicines or vaccines against chikungunya and dengue.

5. The house index is defined as the percentage of houses infested by larvae and/or pupae. The container index is defined as the percentage of water-holding containers with active immature stages of mosquitoes. The Breteau index is defined as the number of positive containers per 100 houses, a positive container being one that contains larval and/or pupal stages of mosquito.

to prevent the spread of new epidemics. Generally, the day-to-day activities of LAV officers involve yard sanitation, education, and the promotion of vector control at the household level. These officers have been routinely visiting households in Réunion since 2006 and provide education to families on the importance of eliminating sources of stagnant water around the house, such as emptying water from pots and the plates placed under potted plants.

Given the investment of both financial and human resources toward the control of *Aedes albopictus* and the observed rise of *Aedes albopictus* density in Réunion from 2006 to 2011 despite public action (Boyer, Foray, and Dehecq 2014), we begin by modeling the household decision to eliminate larval sites before providing an experimental test of the theory as recommended by Frondel and Schmidt (2005). The aim of a randomized controlled trial (RCT) is to identify whether the current strategy — of eliminating the presence of larval breeding sites and changing the behavior of persons by means of home visits — is effective. This article thus presents one of the few RCTs that evaluates the impact of public sector mechanical elimination techniques (eliminating sources of stagnant water in and around private dwellings). In our study, we use data collected during a pre-intervention household survey conducted in July 2012 (baseline) and a post-intervention survey completed two years later in March–April 2014 (endline survey). The intervention took place in January and February 2014. Each survey was conducted by interviewing approximately 1000 households, using similar sample sizes from various urban areas in Réunion. Since the study design assigned a randomly determined subset of zones (or clusters) to have access to mechanical elimination of larval habitats by the LAV, the data can be used to gauge the impact of increased access to external (public) mechanical elimination of larval habitats on private protective behaviors in study areas. We show that the elimination of larval habitats by an external public agent increases entomological indexes three months after the intervention in the treated group relative to the control group.

The remainder of this paper is organized as follows. Section 2 provides a simultaneous model of mosquito abundance and abatement response. The experiment is then described in section 3. We include the details of the estimation strategy in section 4, where we also describe the results. Finally, section 5 concludes and outlines the main policy implications.

II. The Simple Model Underlying The Experiment

Following Bennett (2012), we begin with a simple economic model in which a zone consists of two households, which are indexed by i. We focus on nuisance reduction instead of health, because the intervention takes place during an interepidemic stage when human infection is absent, and we assume that nuisance is proxied by the number of mosquitoes, M_i. Thus, we regard Household utility as an additively separable function of Mosquitoes and other consumption, c_i.

For simplicity, we assume that there is only a single technology to protect people from (the nuisance of) mosquitoes: mechanical elimination of larval sites. Mechanical elimination can be provided publicly when public agents remove the larval sites or privately when individuals remove the larval sites. In our experiment, public intervention is allocated randomly (exogenously) at the zone level.

The number of mosquitoes, M_i, is a decreasing and convex function of the public intervention, *Pub*, and private elimination of breeding sites by both households, $Priv_i$ and $Priv_{-i}$. By including $Priv_{-i}$, we explicitly incorporate an externality. This externality arises because the elimination of larval sites by one person directly decreases the nuisance for the others and thus increases their comfort.

Households, which are endowed with income, Y, face positive prices of public intervention (p_{Pub}) through taxes, individual behavior (p_{Priv}), and other consumption (p_c). Thus, each household i wants to minimize the mosquito nuisance and the consumption, which is equivalent to solve the following utility minimization problem:

$$\min_{\mathrm{Priv}_i, c_i} \Big(M_i(\mathrm{Priv}_i, \mathrm{Priv}_{-i}, \mathrm{Pub}))) + c_i \Big), \tag{1}$$

or, equivalently, to solve the following maximization problem:

$$\max_{\mathrm{Priv}_i, c_i} -\Big(M_i(\mathrm{Priv}_i, \mathrm{Priv}_{-i}, \mathrm{Pub}))) + c_i \Big), \tag{2}$$

subject to

$$p_{Priv} Priv_i + p_{Pub} Pub + p_c c_i \leq Y_i. \tag{3}$$

We recover a standard maximization problem with constraint: max $_x f(x)$ subject to $g(x) \leq C$, with C a positive real. The Lagrangian is $\mathscr{L}(x, \lambda) = f(x) + \lambda(C - g(x))$. According to the Kuhn-Tucker theorem, if $x^* \geq 0$ and $\lambda^* \geq 0$ verify the Kuhn-Tucker conditions, i.e., $\partial_j f(x^*) - \lambda^* \partial_j g(x^*) = 0$ and $\lambda^*(C - g(x^*)) = 0$, then, f being concave, and g being linear (convex), x^* is a solution of the constrained problem. We set $x^* = (Pub^*(Priv_i, c_i; P, Y_i)$, $Priv_i^*(Pub, c_i; P, Y_i)$ and $c_i^*(Priv_i, Pub; P, Y_i))$, where P is the set of cost parameters, i.e., $P = (p_{Pub}, p_{Priv}, p_c)$.

We proceed to derive some comparative statics that motivate the randomized controlled experiment. We treat Household 2 as the rest of the zone. Several situations may be derived from this simple model.[6] For the reader's convenience, we describe below all cases and discuss after what case(s) is (are) plausible according to the experiments conducted in Réunion:

6. As in Bennett (2012), we assume that the rest of the zone is much larger than the index household, and hence, $\partial Priv_2 / \partial Priv_1 \approx 0$.

- *Case 1*: if public and individual private mechanical elimination are substitutes ($\partial Priv_i/\partial Pub \prec 0$) and

  (a) if the elimination levels of neighbors are complements ($\partial Priv_i/\partial Priv_{-i} \succ 0$), then

$$\frac{dPriv_1^*}{dPub} \approx \frac{\partial Priv_1}{\partial Pub} + \frac{\partial Priv_1}{\partial Priv_2}\frac{\partial Priv_2}{\partial Pub} \tag{4}$$

  According to (4) we have $\frac{dPriv_1^*}{dPub} \prec 0$ (and, similarly, $\frac{dPriv_2^*}{dPub} \prec 0$), showing that public elimination reduces private elimination by both households. The complementarity of private elimination among neighbors increases the overall effect by incorporating the feedback from Household 2 to Household 1.

  (b) if the elimination levels among neighbors are substitutes ($\partial Priv_i/\partial Priv_{-i} \prec 0$), then according to (4), the sign is undetermined. Thus, we can have two situations:

$$\frac{dPriv_1^*}{dPub} \prec 0 \text{ if (and only if) } \left|\frac{\partial Priv_1}{\partial Pub}\right| \succ \left|\frac{\partial Priv_1}{\partial Priv_2}\frac{\partial Priv_2}{\partial Pub}\right|$$

or

$$\frac{dPriv_1^*}{dPub} \succ 0 \text{ if (and only if) } \left|\frac{\partial Priv_1}{\partial Pub}\right| \prec \left|\frac{\partial Priv_1}{\partial Priv_2}\frac{\partial Priv_2}{\partial Pub}\right|$$

Thus, public elimination either increases or decreases private elimination.

- *Case 2*: If zone-level public and individual private mechanical elimination are complements ($\partial Priv_i/\partial Pub \succ 0$) and

  (a) if the elimination levels among neighbors are substitutes ($\partial Priv_i/\partial Priv_{-i} \prec 0$), then according to (4), the sign is undetermined, and we derive the following two possible situations (the opposite of case 1(b):

$$\frac{dPriv_1^*}{dPub} \succ 0 \text{ if (and only if) } \left|\frac{\partial Priv_1}{\partial Pub}\right| \succ \left|\frac{\partial Priv_1}{\partial Priv_2}\frac{\partial Priv_2}{\partial Pub}\right|$$

or

$$\frac{dPriv_1^*}{dPub} \prec 0 \text{ if (and only if) } \left|\frac{\partial Priv_1}{\partial Pub}\right| \prec \left|\frac{\partial Priv_1}{\partial Priv_2}\frac{\partial Priv_2}{\partial Pub}\right|$$

In other words, the direct impact of zone-level public elimination on individual private mechanical elimination should be greater (lower) than the externality effect.

(b) if the elimination levels of neighbors are complements ($\partial Priv_i/\partial Priv_{-i} \succ 0$), then, according to (4), we deduce that $\frac{dPriv_1^*}{dPub} \succ 0$ ($\frac{dPriv_2^*}{dPub} \succ 0$). In other words, public elimination should increase private elimination, which is clearly not what we observe in the experiment.

Overall, it is difficult to distinguish between Cases 1(a), 1(b), and 2(a).
Following the same reasoning, if we consider the impact of public elimination on M_1, we derive

$$\frac{dM_1}{dPub} \approx \frac{\partial M_1}{\partial Pub} + \frac{\partial H}{\partial Priv_1}\frac{\partial Priv_1}{\partial Pub}.$$

Clearly, only when public elimination and private elimination are complements does public elimination affect the mosquito population, $\frac{dM_1}{dPub} \prec 0$, and thus the nuisance level. The same results hold for the impact of private elimination on M_1:

$$\frac{dM_1}{dPriv_1} \approx \frac{\partial M_1}{\partial Priv_1} + \frac{\partial H}{\partial Pub}\frac{\partial Pub}{\partial Priv_1}.$$

According to the experiments conducted in Réunion, we recover only on case 1(a). Cases 1(a), 1(b) (first expression), and 2(a) (second expression) are consistent with public abatement actually making mosquitoes more abundant. However, case 1(a) makes more sense than case 1(b) (first expression) or 2(a) (second expression). In case 1a, public and private abatement efforts are substitutes while the private abatement efforts by neighbors are strategic complements, which could arise, for instance, through social norms. In the presence of an externality and strategic complementarities, aggregate relationships will overstate individual elasticities and exaggerate the private response to public abatement. This mechanism is prominent in Bennett (2012) and recent work by Guiteras, Levinsohn, and Mobarak (2015).

In case 1(b), public and private abatement efforts are substitutes while the private abatement efforts by neighbors are also substitutes. In case 2(a), public and private abatement efforts are complements, but the private abatement efforts of neighbors are substitutes. Either expression of case 1(b) or 2(a) could be true on its own, but there is no reason for these conditions to go together in our experiment. They will need very specific assumptions on the differential effects of the public intervention among the two households, which do not fit with our experiment. It is important to note that, as the level of information and knowledge in Réunion is very high (Setbon and Raude 2009; Duret, Cubizolles, and Thiannbo 2013; Thuilliez et al. 2014), we do not discuss the role of information in this model, although we test this explanation in the following sections.

An alternative explanation is that perceived nuisance is imperfectly correlated with the objective risk of being bitten. Indeed, the level of tolerance for mosquitoes might be higher in the treatment group after the intervention, or, in other words, perceived nuisance might be lower, leading to decreased protective behavior. Households may also feel absolved of the responsibility to remove the larval habitats themselves if they believe that the intervention is efficacious.

Some predictions of the model can be tested easily with a randomized experiment in which an exogenous mechanical intervention is introduced at the zone level. The following sections provide the design and results of an intervention conducted in Réunion. Section 3 presents the study design, and section 4 reports the results of the experiment.

III. Study Design And Baseline Summary Statistics

The Intervention

The intervention evaluated here is called ALIZES ("Actions de Lutte Intégrée sur Zone et Education Sanitaire")[7] and managed by the ARS.[8] The intervention is privileged during interepidemic stages. Its aim is to prevent and eliminate the presence of larval sites and to change the behavior of persons through door-to-door visits. Homeowners generally allow LAV officers of the ARS to enter their private dwellings to carry out routine vector control activities. ARS officers identify the causes of strong larval development in the private and public domains, eliminate them mechanically, monitor quantitatively vector populations,[9] conduct health education related to the presence of *Aedes Albopictus,* and demonstrate best practices to eliminate larval sites.[10] The systematic identification of larval breeding areas is intended to convince the population to eliminate all deposits immediately following the demonstration and to adopt these habits in the future to maintain efficacy. Note that demonstrations (e.g., yard sanitation) and mechanical elimination are conducted simultaneously to health education among a population that has relatively high levels of knowledge on disease transmission and education (compared with other developing regions). The educational messages are based on two publicly available documents: the first focuses on

7. ALIZES, as undertaken by the ARS when our study took place, is described at http://ars.sante.fr/fileadmin/OceanIndien/Internet/Votre_sante/Lutte_anti_vectoriel/Bulletin_GIP-LAV_n__6_2011.pdf

8. This intervention follows WHO recommendations (WHO 2009) and is a routine zone-level intervention that is undertaken, on average, every 18 months per zone. WHO defines changes to human habitation or behavior as actions to reduce human-vector contact. According to WHO, the chosen approach should be effective, practicable, and appropriate to local circumstances.

9. They calculate stegomyia indices (specifically, the Breteau index, House index, and Container index) and follow-up on the typology of the larval habitats.

10. Mosquito control is framed legally by texts at the national level that are adapted to the local level in Réunion through prefectural orders. The fundamental order is no. 2966 related to the determination of a departmental area of mosquito control, signed September 14, 2007. This order established, in a general sense, the approach to mosquito control across the island's 24 municipalities. Each year, a prefectural order clarifies the application of the fundamental order. In addition, it allows vector control agents to annually renew their authorization in the 24 communes of the department to continue to combat mosquitoes and the diseases they transmit.

environmental management ("*Adoptons les bons gestes!*") and the second focuses on disease knowledge and risk ("*Moustiques & Maladies à La Réunion*"). With respect to mechanical elimination, the main messages are the following: (i) clean water reservoirs once a week; (ii) check water disposal; (iii) clean green waste in the garden; and (iv) clean waste dumped in the garden or near the house. ARS officers also distribute informational leaflets to the population in addition to conducting oral explanations and knowledge tests. Chemical spraying is not used in interepidemic stages, except if a case of dengue or chikungunya is detected and confirmed.

Note that the objective was to assess public action, as performed routinely by public agents. It was not possible to modify this protocol for administrative and legal reasons. Although the intervention is a package, making it impossible to separately identify the effects of knowledge transfer and mechanical control, Réunion exhibits a very high educational level. Therefore, we assume that the effect of knowledge transfer will be marginal in keeping with the model provided in section 2 and confirmed by the results reported in section 4.

Study Site, Inclusion Criteria, and Experimental Design

The experiment was performed in urban areas of Réunion. The island is divided into four geographic sectors (North/South/East/West), 24 municipalities, and 273 neighborhoods. These neighborhoods are divided into 1253 zones used by the ARS for *Aedes albopictus* surveillance and control. These homogenous zones are defined according to urban planning and environmental criteria. They extend over 275 km2, or 11%, of the island and mostly cover urban areas.[11]

A number of inclusion criteria were specified for the selection of zones included in this study. We used zones located at less than 500 meters in altitude, where the presence of mosquitoes from one year to the next is most likely to persist, to ensure relative homogeneity in environmental factors. Next, we focused on zones that showed relative stability in mosquito density and were subject to control actions by the ARS on a minimum of three occasions between 2007 and 2011. We classified these as either *negative* or *positive* zones using criteria based on the Breteau Index (i.e., the number of positive containers per 100 houses). Using historical data gathered over this five-year period, we defined a *negative* zone as one that had a value for the Breteau Index during routine LAV visits that was lower than 50% of the average Breteau Index value during the same month and year in all zones. A *positive* zone was defined as having a value for the Breteau Index during routine LAV visits that was higher than 50% of the average Breteau Index value during the same month and year in all zones. A zone was retained for inclusion in the study if it was classified as *positive* or *negative* a

11. According to the National Institute of Statistics and Economic Studies (or INSEE) in France, an urban area is defined as an agglomeration of more than 2000 residents where no dwelling is separated from the next closest dwelling by more than 200 meters.

majority of times during all routine LAV visits (e.g., classified as *positive* twice during three routine visits conducted between 2007 and 2011). This was done to ensure a degree of stability in the classification of zones over time. A total of 184 zones, 68 positive zones and 116 negative zones, were identified using this selection criterion.

Since conducting face-to-face interviews in 184 zones was not feasible, a two-stage cluster (zone) random sample was drawn from this first selection in 2012. In the first stage, a random sample of 26 zones (13 *positive* and 13 *negative*) was drawn, taking into account the geographic distribution of the island's population across the four sectors (North/South/East/West), using a stratified sample without replacement. Next, within every zone, 40 households were randomly selected based on maps of the zones and habitats provided by the IGN (National Geographic Institutes).[12] For each selected household, the LAV officers conducted both a face-to-face interview that was addressed to the head of the household and an observational survey of the exterior of the dwelling itself. The data collected were validated by comparing key characteristics of our sample to information provided in the latest census (e.g., number of household members by age of the head of household, level of education of the head of household, socioeconomic status). No significant differences were found for these key characteristics.

After the first survey was finalized, the intervention described above was randomly assigned at the zone level to 13 zones, thus ensuring that research staff and participants were blind to the randomization process. If any, an observer effect—or Hawthorne effect—should therefore operate similarly in the control and treated groups for self-reported outcomes. The 26 zones were next surveyed following the same process as above (random household selection based on directions).[13] Figure 1 provides the map of control and treated zones.[14]

Baseline Summary Statistics

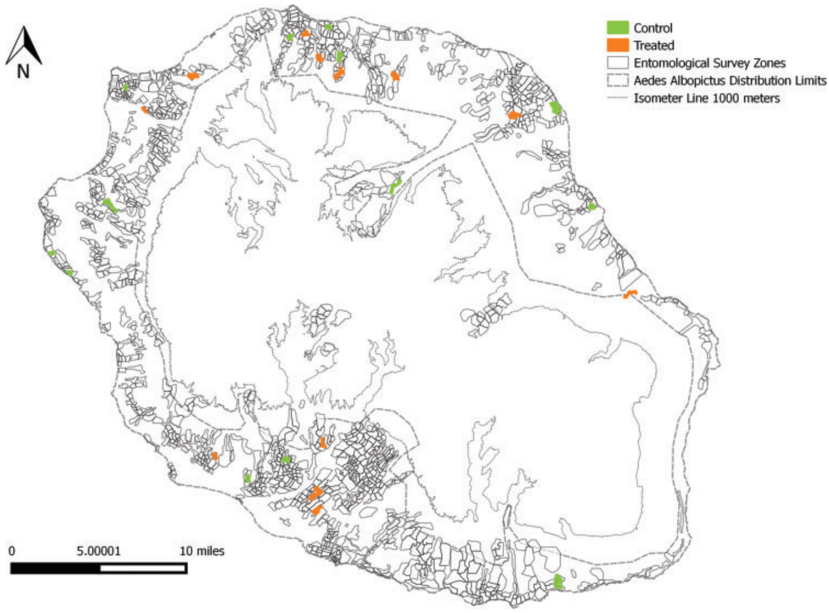
The randomization was successful overall at producing balance in a broad range of statistics between the treated and control groups. Table 1 shows that treatment and comparison areas did not differ in their baseline levels of house and

12. The average size of a zone is 212 households (median = 193). The average percentage of absentees was 36% (range of 5% to 50%), and the average percentage of refusals was 12% (range of 4% to 24%). The most frequently cited reason for refusing to participate in the survey was a lack of time to respond to the questionnaire.

13. Sample size was determined to ensure an 80% probability of rejecting the null of no effect at the 5% significance level, assuming an intraclass correlation of 0.05 and an effect size of a 20 percentage-point difference between the two experimental arms.

14. The ethics evaluation committee of Inserm (IORG0003254, FWA00005831), the Institutional Review Board (IRB 00003888) of the French Institute of Medical Research and Health, reviewed and approved the research project (Decision 14–137).

FIGURE 1. Map showing the locations of treatment and control zones



garden environment, socioeconomic and demographic factors, stegomya indices (an objective measure of mosquito presence), perceived risk of a new epidemic, nuisance and past infections, knowledge of mosquitoes, self-reported household protective behaviors during the past month, and access to health information.

The summary statistics document the high socioeconomic status of sample households. As presented in Table 1, the average head of household is 52 years old, living with 3.11 family members in the household. Most people have a high level of education, with 71% having a secondary or post-secondary level of education. The percentage of homes infested by larvae and/or pupae was approximately 20% in July 2012. Of the respondents, 77% report having mosquitoes at home. Knowledge of diseases transmitted by mosquitoes was good, with an average score of 3.73 on a scale from zero to five (five being the maximum score). The perceived risk of a new epidemic of dengue or chikungunya was high (2.7 and 2.7 on a scale from zero to three). Access to health information was globally high through TV, radio, or general practitioners (74%, 55%, 94%).

Deviations from the Experimental Protocol

The results in Table 1 show a good degree of balance in observed characteristics between treatment and control areas. However, the implementation agency did not always comply with the experimental protocol because new cases of arboviruses appeared during the period, which was an obvious public health priority

Table 1. Baseline Descriptive Statistics

	Treatment group	Control group	Diff (T-C)	p-Value
House, Garden environment				
Natural Garden	0.333	0.298	0.035	0.519
Gutter	0.503	0.370	0.133	0.926
Septic tank	0.364	0.354	0.010	0.943
Waste dumped in the garden	0.143	0.141	0.002	0.943
Socioeconomic and demographic factors				
Number of rooms in the house	6.088	5.912	0.176	0.180
Air conditioning	0.239	0.266	−0.027	0.636
Swimming pool	0.092	0.073	0.019	0.366
Washing machine	0.944	0.938	0.006	0.676
Dishwasher	0.233	0.185	0.048	0.326
Flat screen TV	0.620	0.627	−0.007	0.850
Internet	0.511	0.513	−0.002	0.968
Number of cars	1.072	1.065	0.007	0.950
Wealth index	0.050	−0.052	0.102	0.641
Head: Age	52.994	51.703	1.291	0.443
Head: Female	0.649	0.623	0.026	0.512
Head: level of education - No schooling	0.059	0.065	−0.006	0.812
Head: level of education - Primary	0.241	0.213	0.028	0.452
Head: level of education - Secondary	0.538	0.589	−0.051	0.251
Head: level of education - Post-secondary	0.160	0.131	0.029	0.468
Number of household members	3.118	3.119	−0.001	0.996
Number of children (<18)	0.773	0.824	−0.051	0.693
Number of elderly (>60)	0.659	0.615	0.044	0.510
Stegomya Indices (objective indices)				
Historical stability index	0.540	0.478	0.062	0.763
Infested Household	0.203	0.193	0.010	0.787
Proportion of infested containers	12.741	11.451	1.290	0.618
Number of infested containers per Household	0.390	0.456	−0.066	0.468
Perceived risk of new epidemic, nuisance and past infections				
A member of the household was diagnosed with chikungunya	0.771	0.761	0.010	0.820
Perceived risk of a new epidemic of chikungunya (0–4 scale)	2.663	2.680	−0.017	0.833
Perceived risk of a new epidemic of dengue (0–4 scale)	2.755	2.745	0.010	0.886
Presence of mosquitoes at home	0.751	0.796	−0.045	0.218
Are you bothered by mosquitoes?	0.904	0.896	0.008	0.721
Are you bothered by mosquitoes bites?	0.856	0.822	0.034	0.273
Knowledge on mosquitoes				
Female is biting gender	0.410	0.358	0.052	0.259
Average distance traveled by the tiger mosquito is less than 500 meters	0.486	0.426	0.060	0.216
Diseases transmitted by mosquitoes (score between 0 and 5)	3.712	3.762	−0.050	0.646

(Continued)

Table 1. *Continued*

	Treatment group	Control group	Diff (T-C)	p-Value
Household protective behaviors during past month (self reported)				
Use Mosquito coils	0.666	0.715	−0.049	0.343
Use Insect/mosquito repellent sprays for the house	0.525	0.528	−0.003	0.959
Use Anti-mosquito body sprays/creams	0.352	0.384	−0.032	0.616
Use Treated or untreated mosquito nets	0.136	0.149	−0.013	0.708
Use Fans	0.162	0.233	−0.071	0.225
Use Air-conditioning	0.074	0.087	−0.013	0.674
Clean water reservoir daily or weekly	0.582	0.635	−0.053	0.294
Access to health information				
Health information through ARS	0.114	0.149	−0.035	0.360
Health information through Internet	0.348	0.340	0.008	0.857
Health information through TV	0.756	0.733	0.023	0.648
Health information through Radio	0.572	0.529	0.043	0.505
Health advice through doctor	0.959	0.934	0.025	0.151
Health advice through pharmacist	0.394	0.326	0.068	0.453

Notes: Data from baseline (2012) survey. Sample size is 1024, of which 522 are assigned to Treatment and 502 are assigned to Control. Columns 1 and 2 report statistics for households in each group. Column 3 shows the difference between the mean for households in zones assigned to ALIZES and the means in column 2. Column 4 shows p-values for the test of equality of means, robust to intrazone correlation. The number of zones is 26. The joint null of equal means is rejected at standard levels.

and required public action. In reality, 15 zones were treated instead of 13, and, therefore, actual control coincided with the randomly assigned control zones in 11 instead of 13 control zones.

In table S1, we report the results of a linear probability model in which we regress a dummy variable equal to one if the household resided in a zone where ALIZES was actually introduced on another dummy variable equal to one when the zone was assigned to ALIZES and a list of observed household characteristics. Assigned treatment is the strongest predictor of treatment, and other coefficients are small and not significant at standard levels. A joint test of the significance of all slopes except assigned treatment is rejected. The results of this regression thus suggest no selective program placement as toward areas that were wealthier or more educated.

Endline Survey, Attrition Concerns, and Subsample Cohort Analysis

The endline survey was completed in March and April 2014, approximately two years after the pre-intervention survey. As explained above, the endline sample was drawn independently from the baseline sample and selected randomly according to administrative directions. This does not allow us to evaluate attrition in a straightforward way, which has potentially important implications for the interpretation of the results (see Tarozzi, Desai, and Johnson (2015)).

Our focus on intent to treat estimates nevertheless allows us to interpret the main results as causal impacts of assigning zones to receive ALIZES. However, the interpretation of intent to treat estimates would change if the intervention had an impact on the composition of the surveyed sample (differential migration or differential response rates as emphasized by Tarozzi, Desai, and Johnson (2015)). In table S2, we evaluate whether either actual or assigned treatment was systematically associated with certain household characteristics such as mobility (travels outside Réunion), household composition, and head of household characteristics that were least likely to have changed directly as a consequence of the intervention. Significant changes in these characteristics could signal differential migration or survey response, but we find no evidence of this issue. The results in table S2 suggest that migration and differential survey response are unlikely to bias the results. However, we cannot definitively rule out these concerns with this test.

It is acknowledged that the cohort design is theoretically more powerful from a statistical perspective since it allows an analysis that controls for individual baseline values, thus allowing the effect of intervention to be estimated with greater precision. However, as shown by Feldman and McKinlay (1994), this advantage must be weighed against the risk of loss to the follow-up that arises in any longitudinal study. The "worst-case scenario" arises when the loss to follow-up differs across intervention groups, as the final estimate of the intervention effect may then be subject to substantial bias. Even when subject attrition is unrelated to treatment assignment, a large loss to follow-up rate may result in reduced efficiency relative to a cross-sectional design. Other disadvantages of the cohort design, as reviewed by Atienza and King (2002), include: (i) a loss of representativeness of the target population related to the aging of the cohort; and (ii) "learning effects" that may result from repeated assessments of the same individual. These considerations suggest that a cohort design is most effective when participating clusters are relatively small in size, the study population is relatively stable and compliant, and follow-up times are not lengthy (which is not the case here). It follows that for studies enrolling large communities, where complete follow-up is rarely feasible, cross-sectional designs have often been preferred. To avoid the analytic limitations of cross-sectional designs, an approach adopted by some investigators has been to augment this design by subsampling a cohort consisting of a relatively small number of subjects in each zone.[15] We followed this approach and randomly selected 180 households to be followed in cohort design, 174 of which were included in the final cohort. Table S3 provides the comparison between the cohort subsample ($N = 174$) and the remainders ($N = 850$) at baseline and shows no statistically significant differences across groups except for

15. Methods of analysis that are particularly suited to cross-sectional designs have been discussed by Ukoumunne and Thompson (2001) and Nixon and Thompson (2003) for the case of binary outcomes and by Koepsell et al. (1991) and Murray (2001) for the case of continuous outcomes.

the number of elderly individuals living in the household. Table S4 provides baseline descriptive statistics for the cohort subsample and shows a good degree of balance in observed characteristics between areas assigned to treatment and control (as in Table 1). The endline regression results provided in table S5 do not affect our main conclusions, although the *p*-values are higher than for the main sample, which can be easily explained by the size of the sample. Table S6 provides Difference-in-Differences estimates. The conclusions remain unchanged.

IV. Estimation Methods And Results

To estimate the impact of the ALIZES intervention in an area, we focus on intent to treat (ITT) estimates, which are simple comparisons of the averages in treatment and comparison areas. We present ITT estimates of the effect of ALIZES on self-reported household protective behaviors and objective measures of arbovirus risk. Each column reports the results of a regression of the form

$$\mathrm{y}_{iz} = \alpha + \beta \times \mathrm{Treat}_{iz} + X_i + \Phi_z + \varepsilon_i, \tag{5}$$

where y_{iz} is an outcome for household i in zone z, Treat_{iz} is an indicator for living in a treated zone, and β is the ITT effect. X_i is a vector of household control variables at endline, including observed presence of a natural garden, a gutter, a septic tank, waste dumped in the garden, and fans and declared presence of mosquitoes. Φ_z is a vector of control variables, calculated as zone level baseline values, including the average wealth index, educational level of the head of household, and the Breteau Index. Standard errors are adjusted for clustering at the zone level.

With respect to objective entomological household outcomes, we use three main variables: (i) a binary variable for infested/not infested house; (ii) the proportion of infested containers per house (number of infested containers / total number of containers, infested or not); and (iii) total number of infested containers per house.

With respect to self-reported behaviors, we also create a summary measure of multiple self-reported protective behaviors collected in the survey, following Kling, Liebman, and Katz (2007) and Dammert, Galdo, and Galdo (2014), defined as the unweighted average of the various indicators as follows:

$$\mathrm{y}^*_{iz} = \frac{1}{k}\sum_{k=1}^{k}\frac{y_{iz}-\mu_k}{\sigma_k} \tag{6}$$

where each indicator k is standardized by the mean and variance of the control group. Thus, the magnitude of the estimated index shows where the mean of the treatment group is in the distribution of the control group in terms of standard deviation units. This allows us to test whether the treatment had an overall positive or negative ITT effect.

As an alternative, we estimate a model analogous to (1) using two-stage least squares (2SLS), replacing the dummy for assigned treatment with a dummy for actual treatment using the former exogenous variable to instrument for the latter potentially endogenous variable.[16]

Self-Reported Protective Behaviors

We start with the analysis of the impact of ALIZES on households' self-reported behavior (Table 2). The evidence suggests that ALIZES decreases slightly the overall standardized index by 0.107 standard deviations, the ITT estimate being significant at the 10% level and the 2SLS estimate being nearly significant at the 5% level (p-value = 0.056). Behaviors such as cleaning waste dumped in the garden and covering or cleaning water reservoirs were also reported less frequently in the "treated" group than in the "control" group (7% less and 5% less, respectively). None of the other three impacts on private behaviors was significantly different from zero at standard levels, although all estimates are negative and some of them are large in magnitude. The results are thus suggestive of a negative impact.

Objective Entomological Measures

Next, we turn to the analysis of the impact of ALIZES on entomological measures. Treatment effects on household entomological outcomes and disaggregated indexes—using the site typology provided by Boyer, Foray, and Dehecq (2014)—are reported in table 3. ITT and 2SLS estimates differ only slightly, and we demonstrate that the intervention led to substantive and statistically significant increases in entomological indexes.

Recalling that a positive container is one in which larval and/or pupal stages of mosquitoes are present, the figures in columns 1, 2, and 3 show that assignment to ALIZES increased the probability of being infested by eight percentage points. The proportion of infested households in the control group at endline is 18.65%. The null of the impact is rejected at the 5% level for the ITT and 2SLS estimates. The proportion of infested containers per house increased by 6.1 percentage points (significant at the 5% levels for the ITT and 2SLS estimates; the

16. As emphasized by Tarozzi, Desai, and Johnson (2015), because "*randomly assigned treatment status is an exogenous and strong instrument for treatment, 2SLS will estimate the ITT impact of providing access to ALIZES if program impact is homogeneous across areas*." 2SLS will estimate a local average treatment effect (Imbens and Angrist 1994). The LATE can thus be interpreted as the impact only for "complier" zones.

Table 2. Treatment effect on Household protective behaviors during past month (self reported)

	(1) Overall Standardized index	(2) Tend the garden	(3) Clean green waste in the garden (fruit, branches, etc)	(4) Clean waste dumped in the garden	(5) Cover or clean water reservoirs	(6) Clean water reservoirs daily or weekly
ITT	−0.107*	−0.051	−0.022	−0.072**	−0.049**	−0.037
	(0.055)	(0.031)	(0.030)	(0.030)	(0.021)	(0.036)
R2	0.03	0.026	0.034	0.033	0.024	0.026
2SLS	−0.128*	−0.061	−0.026	−0.086**	−0.059**	−0.044
	(0.067)	(0.038)	(0.036)	(0.039)	(0.025)	(0.042)
Observations	1043	1043	1043	1043	1043	1043

Notes: Data from endline (2014) survey. Sample size is 1043, of which 523 are assigned to Treatment and 520 are assigned to Control. Standard errors (in brackets) and tests are robust to intrazone correlation (there are 26 zones or clusters). All regressions include household control variables at endline, including observed presence of a natural garden, a gutter, a septic tank, waste dumped in the garden, and fans and declared presence of mosquitoes. All regressions also include zone-level baseline values, including average wealth index, educational level of the head of household, and average Breteau Index. The dependent variables are defined as follows: the Overall Standardized Index is a summary of multiple self-reported protective behaviors collected in the survey, following Kling, Liebman, and Katz (2007) and Dammert, Galdo, and Galdo (2014), defined as the unweighted average of the different indicators and detailed in equation (30). All other dependent variables are dummies for self-reported behavior. The ITT line represents the intent-to-treat coefficients. The 2SLS line represents the 2SLS estimation of the model with treatment defined in terms of zone-level actual treatment status with the corresponding zone-level randomly assigned status used as an instrument. *, ** and *** denote statistical significance at the ten, five and 1% level, respectively.

proportion of infested containers per house is 12.906% in the control group), and the number of infested containers per house increased by 0.5 containers on average (significant at the 5% and 1% levels for the ITT and 2SLS estimates respectively; the average number of infested containers per house in the control group is 0.369).

With respect to the typology of sites, an interesting result concerns the fact that the presence of small positive containers (flower pots, saucers, small water containers) were significantly more present in the treated group than in the control group. This is not the case for large water containers or gutters, which are likely more difficult to empty on a weekly basis.

As the productivity of breeding sites (which was not observed here) can differ according to site typology but will be similar across pots, saucers, small water containers) were significantly more present in the treated group than in ad to a higher density of adult mosquitoes in the treated group. Lastly, we note that the main results are not affected when we remove cluster-level controls from the regression, that may reflect endogenous mosquito abatement choices (table S7).

Table 3. Treatment effect on stegomya indices (objective measures of risk)

	Stegomya Indices			Types of water holding containers (with larvae and/or pupae)							
	(1) Infested Household	(2) Proportion of infested containers per Household	(3) Number of infested containers per Household	(4) Flower pots and vases	(5) Saucers under Flower pots	(6) Small water container	(7) Large water container	(8) Natural containers	(9) Tyre	(10) Gutter	(11) Strippedvehicleor abandonedcar part
ITT	0.087**	6.148**	0.259**	0.031*	0.071**	0.089*	0.015	0.002	0.017	0.009	0.025
	(0.039)	(2.578)	(0.103)	(0.015)	(0.031)	(0.049)	(0.022)	(0.014)	(0.015)	(0.006)	(0.017)
R2	0.083	0.071	0.05	0.012	0.016	0.032	0.025	0.010	0.301	0.046	0.023
2SLS	0.105**	7.372**	0.311**	0.037**	0.085**	0.107*	0.018	0.003	0.02	0.011	0.030
	(0.047)	(3.109)	(0.126)	(0.018)	(0.037)	(0.057)	(0.027)	(0.017)	(0.018)	(0.007)	(0.021)
Observations	1043	1043	1043	1043	1043	1043	1043	1043	1043	1043	1043

Notes: Data from endline (2014) survey. Sample size is 1043, of which 523 are assigned to Treatment and 520 are assigned to Control. Standard errors (in brackets) and tests are robust to intrazone correlation (there are 26 zones or clusters). All regressions include household control variables at endline, including observed presence of a natural garden, a gutter, a septic tank, waste dumped in the garden, and fans and declared presence of mosquitoes. All regressions also include zone-level baseline values, including average wealth index, educational level of the head of household, and average Breteau Index. The 3 main dependent variables are infested household (0/1), the proportion of infested containers per household, and the number of infested containers per household. All other dependent variables are numbers of positive containers classified by type of container at the dwelling (household) level. The ITT line represents the intent-to-treat coefficients. The 2SLS line represents the 2SLS estimation of the model with treatment defined in terms of zone-level actual treatment status with the corresponding zone-level randomly assigned status used as an instrument. *, ** and *** denote statistical significance at the ten, five, and 1% level, respectively.

Potential Mechanisms

Knowledge, perceived risk, perceived efficacy and other protective measures.

Knowledge, perceived risk, and perceived efficacy would represent alternative explanations if the average values of these variables were significantly higher in the control group than in the treated group at endline.[17]

As shown in table 4, knowledge and perceived risks of new epidemics were globally unaffected by the intervention. None of the coefficients from column (1) to column (4) were significantly different from zero at standard levels. This result can be explained by the fact that the educational level in Réunion is already high, and people are well aware of the risk of new epidemics and modes of transmission of arboviral diseases. Approximately 88% of households believe that eliminating larval sites is effective at reducing nuisance, but the intervention had no significant impact on this perception.

As shown in table 5, the other self-reported protective measures (sprays, coils, mosquito nets, fans, and air conditioning) follow the same pattern as the elimination of larval sites. The evidence suggests that ALIZES decreases the use of mosquito nets and fans. None of the other impacts on private behaviors was significantly different from zero at standard levels, although half of the estimates are negative.

Therefore, the variables tested and reported on in tables 4 and 5 do not seem to provide convincing explanations for the results provided above (increased stegomya indices and less frequent self-reported behaviors).

Nuisance Perception and Associated Effects

As discussed in section 3, the finding that self-reported protective behaviors occur at a lower frequency in the treated group could be consistent with an imperfect correlation between perceived and objective nuisance or a psychological effect induced by the intervention. For instance, the level of tolerance for mosquitoes could be higher in the treated group after the external intervention despite having higher stegomya indexes. To test this prediction, individuals were asked at endline to indicate the extent to which mosquitoes bothered them. The ITT and 2SLS results (table 4) for this question show that the treated individuals declare themselves to be less affected by mosquitoes and less affected by mosquito

17. The dependent variables are: (i) dummies on knowledge of diseases transmitted by mosquitoes (an ordinal score ranging from zero to five from different possible answers, dengue, flu, malaria, HIV, chikungunya); (ii) knowledge of mosquitoes based on two binary questions (female is biting gender and distance traveled by the tiger mosquito); (iii) perceived risk of epidemics of chikungunya or dengue (on a 0–4 scale from no risk to high risk, the exact question being: *In your opinion, what is the current risk to have a new epidemic of chikungunya?*); (iv) inconvenience related to mosquitoes or mosquito bites; and (v) perceived efficacy of private elimination is also a binary variable.

Table 4. Potential mechanisms

	(1) Diseases transmitted by mosquitoes (score between 0–5)	(2) Female is biting gender	(3) Average distance travelled by Tiger mosquito	(4) Perceived risk of a new epidemic of chikungunya	(5) Perceived risk of a new epidemic of dengue	(6) Are you bothered by mosquitoes?	(7) Are you bothered by mosquitoes bites?	(8) Do you think that elimination of larval sites is efficacious?
ITT	−0.011	−0.010	0.029	0.001	0.046	−0.022	−0.037	−0.018
	(0.061)	(0.037)	(0.039)	(0.080)	(0.082)	(0.022)	(0.031)	(0.022)
R2	0.056	0.053	0.029	0.023	0.020	0.017	0.029	0.014
2SLS	−0.014	−0.012	0.034	0.001	0.056	−0.026	−0.049	−0.021
	(0.071)	(0.044)	(0.046)	(0.094)	(0.093)	(0.026)	(0.038)	(0.027)
Observations	1043	1043	1043	1043	1043	1043	1043	1043

Notes: Data from endline (2014) survey. Sample size is 1043, of which 523 are assigned to Treatment and 520 are assigned to Control. Standard errors (in brackets) and tests are robust to intra-zone correlation (there are 26 zones or clusters). All regressions include household control variables at endline, including observed presence of a natural garden, a gutter, a septic tank, waste dumped in the garden, and fans and declared presence of mosquitoes. All regressions also include zone-level baseline values, including average wealth index, educational level of the head of household, and average Breteau Index. The dependent variables are: (i) dummies on knowledge of diseases transmitted by mosquitoes (an ordinal score ranging from zero to five from different possible answers: dengue, flu, malaria, HIV, chikungunya); (ii) knowledge of mosquitoes based on two binary questions (female is biting gender and distance travelled by the tiger mosquito); (iii) perceived risk of epidemics of chikungunya or dengue (on a 0–4 scale) and inconvenience related to mosquitoes or mosquito bites; and (iv) the last question on the efficacy of private elimination is also a binary variable. The 2SLS line represents the 2SLS estimation of the model with treatment defined in terms of zone-level actual treatment status with the corresponding zone-level randomly assigned status used as an instrument. *, ** and *** denote statistical significance at the ten, five, and 1% level, respectively.

Table 5. Other protective measures (self-reported)

	(1) Anti-mosquito body sprays/creams	(2) Insect or mosquito repellent and sprays for the house	(3) Rechargeable vaporizers or diffusers	(4) Mosquito coils	(5) Treated mosquito nets	(6) Mosquito netsfor children	(7) Fans	(8) Air-conditioning
ITT	0.041	−0.02	0.006	0.025	−0.014*	−0.002	−0.103**	0.006
	(0.032)	(0.046)	(0.029)	(0.029)	(0.007)	(0.013)	(0.037)	(0.019)
R2	0.029	0.027	0.015	0.010	0.013	0.006	0.063	0.198
2SLS	0.049	−0.023	0.007	0.030	−0.017*	−0.002	−0.124***	0.007
	(0.038)	(0.054)	(0.034)	(0.034)	(0.008)	(0.015)	(0.043)	(0.023)
Observations	1043	1043	1043	1043	1043	1043	1043	1043

Notes: Data from endline (2014) survey. Sample size is 1043, of which 523 are assigned to Treatment and 520 are assigned to Control. Standard errors (in brackets) and tests are robust to intra-zone correlation (there are 26 zones or clusters). All regressions include household control variables at endline, including observed presence of a natural garden, a gutter, a septic tank, waste dumped in the garden, and fans and declared presence of mosquitoes. All regressions also include zone-level baseline values, including average wealth index, educational level of the head of household, and average Breteau Index. The dependent variables are dummies for self-reported behavior. The ITT line represents the intent-to-treat coefficients. The 2SLS line represents the 2SLS estimation of the model with treatment defined in terms of zone-level actual treatment status with the corresponding zone-level randomly assigned status used as an instrument. *, ** and *** denote statistical significance at the ten, five, and 1% level, respectively.

Table 6. Heterogeneous Treatment Effect

	Infested Household	Proportion of infested containers per Household	Number of infested containers per Household	Infested Household	Proportion of infested containers per Household	Number of infested containers per Household	Infested Household	Proportion of infested containers per Household	Number of infested containers per Household
	PANEL A: 2012 Breteau Index higher than average			PANEL B: Household believe that private elimination is efficacious			PANEL C: North		
ITT	0.076	7.278*	0.319*	0.087**	6.140**	0.239**	0.064*	2.275	0.319***
	(0.050)	(3.549)	(0.163)	(0.040)	(2.682)	(0.103)	(0.031)	(1.605)	(0.054)
R2	0.111	0.089	0.078	0.090	0.074	0.052	0.111	0.093	0.058
2SLS	0.095	9.066*	0.397*	0.106**	7.490**	0.292**	0.078***	2.783*	0.391***
	(0.059)	(4.631)	(0.211)	(0.049)	(3.333)	(0.129)	(0.027)	(1.508)	(0.112)
Observations	521	521	521	921	921	921	277	277	277
	PANEL D: South			PANEL E: East			PANEL F: West		
ITT	−0.003	−2.498	−0.057	0.085***	3.113	0.224***	0.281***	22.338***	0.546***
	(0.051)	(3.297)	(0.173)	(0.017)	(2.168)	(0.049)	(0.043)	(4.337)	(0.083)
R2	0.089	0.053	0.079	0.154	0.092	0.123	0.094	0.083	0.067
2SLS	−0.003	−2.498	−0.057	0.085***	3.113	0.224***	0.660***	47.976***	1.289***
	(0.047)	(3.031)	(0.159)	(0.015)	(1.946)	(0.044)	(0.072)	(7.111)	(0.144)
Observations	320	320	320	200	200	200	159	159	159

Note: Data from endline (2014) survey. Sample size is 1043, of which 523 are assigned to Treatment and 520 are assigned to Control. Standard errors (in brackets) and tests are robust to intra-zone correlation (there are 26 zones or clusters). All regressions include household control variables at endline, including observed presence of a natural garden, a gutter, a septic tank, waste dumped in the garden, and fans and declared presence of mosquitoes. All regressions also include zone-level baseline values, including average wealth index, educational level of the head of household, and average Breteau Index. The dependent variables are dummies for self-reported behavior. The ITT line represents the intent-to-treat coefficients. The 2SLS line represents the 2SLS estimation of the model with treatment defined in terms of zone-level actual treatment status with the corresponding zone-level randomly assigned status used as an instrument. *, ** and *** denote statistical significance at the ten, five, and 1% level, respectively.

bites than the control group, but these results were not significant. Baseline comparisons for these indicators revealed no differences (table 1).

A psychological effect should be related to the perceived efficacy of mechanical elimination. As this perceived efficacy is not affected by the intervention, we test heterogeneous effects conditional on perceived efficacy (table 6). Indeed, if a psychological effect exists, we should have a higher effect for this subsample. This does not seem to be the case, and, therefore, we conclude that the psychological explanation is fragile. We note, however, that a high proportion (88% = 921/1043) believe that mechanical elimination is an efficient method, which may explain why we obtain very similar results when compared with those in table 3.[19]

Heterogeneous Treatment Effects

Heterogeneous treatment effects are provided in table 6. Panels A and B test heterogeneous treatment effects for zones with a value higher than the average of the Breteau Index in 2012 (pre-intervention) and for households who believe that elimination of larval sites is efficacious. We do not find significant differences with respect to these two variables. Panels C, D, E, and F test heterogeneous effects across geographic areas (North, South, East, West). There is some evidence of heterogeneous effects, as the increase in entomological indexes was concentrated in the North, the East and the West, but not in the South. The most affected area is the western part of the island.

V. Discussion And Conclusions

Externalities associated with risky behaviors usually justify public interventions. Using a cluster randomized field trial in Réunion, we evaluate the effect of a public intervention intended to reduce larval habitats in urban areas on entomological indices and behavioral outcomes. This empirical strategy might be useful for two reasons: (i) to know whether the public intervention serves as a substitute or a complement for private behaviors; and (ii) to observe the rate at which households are willing to substitute personal protective behavior for an improved comfort. We show that a mechanical elimination intervention piloted by an external agent might act as a substitute for private protection rather than as a complement in the short term (i.e., three months after the intervention). Moreover, our empirical results show that households overcompensate for the public intervention. These results suggest that individuals do not account for the aggregate consequences of their individual compensation. Although there may be counterexamples, policymakers should be aware of such perverse effects when

19. We also note that the correlation coefficients between the three entomological household outcomes and the two nuisance perception outcomes were never significantly different from zero in either the treated or control group at endline.

implementing environmental management methods to control mosquitoes and reduce human-vector contact.

Our results are subject to some limitations. For example, the context under study is very specific, where the population's socioeconomic level, education, and knowledge of the disease are very high. However, mosquito nuisance and dengue and chikungunya are prevalent primarily in low- or middle-income countries, where information and income constraints could have a greater effect on the adoption of new technologies, meaning that there is a greater role for external vector control management policies. Moreover, the intervention is a package, making it impossible to separately identify the effects of knowledge transfer and mechanical control. As a first step, we have shown that the educational level is very high in Réunion, and knowledge transfer thus likely plays a minor role in our context. However, much remains to be understood regarding the extent to which knowledge transfer may affect the dynamics described above. It was also not possible to employ a placebo in the current study, and, therefore, we were unable to isolate possible placebo effects. Finally, we note that we assessed the effect of the program within a very short time frame despite that similar interventions have been occurring for seven years. Because we cannot exclude the potential for marginal decreasing returns of the ALIZES intervention, it is possible that the procedure was more efficient at reducing mosquitoes in 2007 (just after the major chikungunya crisis in Réunion). Long-term evaluations of such interventions and a deeper understanding of the mechanisms constitute avenues for future research.

Nonetheless, we believe that our analysis can inform the debate on potentially perverse effects of public interventions for nuisance prevention. Our results lead to three recommendations. First, policymakers implementing zone-based vector control programs should consider such negative externalities. Even if the intervention is fully subsidized, the number of mosquitoes and the risk of disease may converge to form a nuisance trap with a high number of adult mosquitoes and a relatively low proportion of protected individuals. Second, it might not be optimal for the government to promote health education through demonstrations that are conducted simultaneously with government agents' implementation of the preventative actions, because doing so induces reductions in private protective measures. An alternative is the use of mobile technologies as surveyed by Fjeldsoe, Marshall, and Miller (2009) or tested by Dammert, Galdo and Galdo (2014). They show that repeated exposure to SMS-delivered information encourages households' uptake of preventative measures, in keeping with recent evidence showing that households are responsive to information on the risks they face (Dupas, 2011). Our study also has important implications for similar programs used for Zika control. As there is no preventive treatment for or vaccine against Zika, vector management is crucial to prevent the disease.

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