Estimating Demand When Turning a Public Bad into an Impure Public Good

Molly J Doruska[1], Christopher B Barrett[1], Samba Mbaye[2], Jason R Rohr[3]

[1] Charles H. Dyson School of Applied Economics and Management, Cornell University, Ithaca, NY, USA
[2] Department of Economics and Management, Université Gaston-Berger de Saint Louis, Saint-Louis, Senegal
[3] Department of Biological Sciences, Environmental Change Initiative, Eck Institute of Global Health, University of Notre Dame, Notre Dame, IN, USA

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Aquatic vegetation is a public bad that grows in common property freshwater resources and provides the habitat for snails that host schistosomes that infect, and reinfect, rural villagers in our northern Senegal study sites. This pre-analysis plan lays out the theory, testable hypotheses, data collection and analysis methods to be used to estimate demand for compost and animal feed made from aquatic vegetation in northern Senegal, with and without information about the production method's public good benefit in controlling the infectious disease schistosomiasis. Our objective is to quantify individuals' willingness to pay (WTP) for as-yet-nonmarketed impure public goods that bundle a public good - reduced infectious disease exposure - with a private good - in this case, the agricultural inputs compost and livestock feed - and to unpack these distinct sources of valuation of each good.

1 Introduction

Aquatic vegetation grows in freshwater access points and contributes to schistosomiasis infection by providing habitat to aquatic snails, the intermediate vector of the parasite. Schistosomiasis is a parasitic, neglected tropical disease that infects more than 200 million people (Gryseels et al., 2006; Steinmann et al., 2006; Hotez et al., 2014; Verjee, 2019). Infection is caused by a snail-hosted flatworm that inhabits aquatic vegetation in freshwater sources. Snails release larval schistosomes into the water that infect individuals when they enter the water to perform daily activities (Stelma et al., 1994; Haggerty et al., 2020). Schistosomiasis disproportionately affects children and causes loss of tissue function, stunted growth, and learning deficits among other ailments, killing up to 200,000 people worldwide each year (King et al., 2005; Kjetland et al., 2006; Mohammed et al., 2007; Verjee, 2019). Traditionally, communities rely on mass deworming campaigns to control schistosomiasis infection. These deworming drugs do not clear infection from water sources, however, so individuals quickly become reinfected (Halstead et al., 2018; Liang et al., 2018). Additionally, aquatic vegetation growth chokes off water access points making it harder for villagers to complete daily tasks, such as bathing or washing clothes. Together, these risks suggest that aquatic vegetation is a public bad or nuisance good.

Aquatic vegetation removal (AVR) targets the infection cycle of schistosomiasis and offers a strategy for long-term infection control (Grimes et al., 2015; Hoover et al., 2018; Liang et al., 2018; Rohr et al., 2022). Initial trials in our study area in northern Senegal confirm that AVR significantly reduces schistosomiasis reinfection rates (Rohr et al., 2022).

However, AVR requires regular activity for an indefinite period to maintain clear waterways, raising a key question around how to induce and sustain aquatic vegetation use. Toward that end, Rohr et al. (2022) experimentally study potential uses for removed aquatic vegetation. Crop trials reveal that compost produced from removed aquatic vegetation significantly increases pepper and onion yields profitability, even under conservative assumptions about the cost of labor used to clear vegetation and make and apply compost. Additional experimental trials found that using removed and dried aquatic vegetation is significantly cheaper than existing purchased feed to supplement sheep diets during periods of low food availability.[1] These potential remunerative uses of biomass harvested through AVR raises the prospect that aquatic vegetation can be turned from a public bad - a common property resources that causes harmful infectious disease - into an impure public good that combines a private good (fertilizer or livestock feed) with the public good of infectious disease control.

Using the same partner organization (Station d'Innovation Aquacole, SIA) and procedures as Rohr et al. (2022), we will produce compost and animal feed from AVR that should have very similar characteristics to the compost and animal feed studied. We will then use a generalized second price auctions to elicit villagers' WTP for compost and animal feed produced from removed aquatic vegetation (Vickrey, 1961).[2] Rohr et al. (2022) estimated the average value of compost and animal feed by using the estimated marginal revenue product of compost used in onion or pepper production or the value of sheep weight gain from the animal feed and estimated the value of the disease control using back-of-the-envelope methods based on national scale epidemiological and valuation of statistical life estimates that do not allow identification of

[1]Most livestock in this system roam freely to forage for food. During the dry season, however, forage often grows scarce. While Rohr et al. (2022) demonstrate that animal feed produced from removed aquatic vegetation is not unconditionally profitable, it is far less expensive than other forms of feed. So, when there is insufficient forage available for livestock, aquatic vegetation offers a low-cost way to supplement their diet.

[2]While it is common to use a Becker-DeGroot-Marshack (BDM) mechanisms to elicit WTP in these settings, we are limited in production and transportation capacity of compost. Therefore, we will use second price auctions that are incentive compatible ways to elicit WTP while also reducing the compost and animal feed requirements.

prospective interhousehold variation in valuation. However, households almost surely vary in their valuation of both the private goods - factors of production, the value of which should vary with land and livestock holdings, cultivation practices, and wealth - and the public good function of AVR - based on household exposure to the disease. Eliciting household-level WTP permits us to estimate demand curves for compost and livestock feed produced from AVR. High transport costs will also likely render markets for compost or livestock feed produced from AVR highly local. The marginal cost of production is largely determined by the value of labor spent harvesting aquatic vegetation and turning it into compost or feed, following near-constant returns. So, we can use our existing estimates of the marginal cost of production, combined with the demand curves elicited from the generalized second price auction to establish likely village-specific equilibrium market prices. We can then estimate consumer surplus and how it varies by household attributes, enabling us to estimate both the surplus created by opening up a novel market for AVR-based compost and feed as well as the distribution of those gains among households within villages. The generalized second price auctions will thereby allow us to better understand variation in household-level valuation of these impure public goods in rural Senegalese villages, the viability of markets for locally produced compost and livestock feed, and who gains the most from such markets. While Rohr et al. (2022) find that it is very profitable on average to produce compost using AVR, villagers' actual demand (i.e. WTP) for the compost and animal feed will determine if a sufficient market might emerge to sustain AVR-based schistosomiasis control from market-based incentives.

This study broadly contributes to the literature on impure public goods and the private provision of public goods. Theoretical models of impure public goods were perhaps first introduced by Kotchen (2006) and Kotchen (2009). Chan and Kotchen (2014) and Wichman (2016) develop further extensions of the model. In these settings, consumers have preferences over characteristics of goods. We take ideas developed around preferences for impure public goods and integrate them into an agricultural household model (Singh, Squire, & Strauss, 1986). We also build on literature on the private provision of public goods (Ajayi, Jack, & Leimona, 2012; Polasky, Lewis, Plantinga, & Nelson, 2014; Li, Anderson, & Swallow, 2016; Liu & Swallow, 2019) where auction mechanisms incentivize the provision of public goods.

In a developing country context, deworming presents a similar problem to malaria control through insecticide treated nets (ITNs) and water quality improvements. Mass deworming in schools in Kenya for schistosomiasis and other helminth infections has significant impacts on relatively short-term schooling outcomes (Miguel & Kremer, 2004), long-term impacts on labor market outcomes years after deworming (Baird et al., 2016; Hamory et al., 2021) and spillovers to younger siblings of children who were dewormed (Ozier, 2018). In the same setting, however, take up of deworming dropped dramatically to insufficient levels to maintain infection control, suggesting that there were not strong enough private incentives to maintain the private provision of public goods (Kremer & Miguel, 2007). Similarly, Cohen and Dupas (2010)'s work on ITNs shows that any non-zero price dramatically reduces take-up to levels not high enough for infection control while Hoffmann, Barrett, and Just (2009)'s work finds low market demand for ITNs using auctions. Additionally, Cohen, Dupas, and Schaner (2015) find that current subsidies for malaria treatments fail to fully reach the target population leaving many vulnerable. Finally, Kremer et al. (2011) studies the health impacts of spring protection to improve water quality in Kenya once again finding significant health impacts from improved water quality. However, travel-cost based revealed preferences suggest that household valuation of improved water quality is below the social planner's optimal valuation. In all these cases, either deworming, using ITNs, treating malaria, or improving water quality the act is an impure public good as the individual taking the medication or using the ITN receives a benefit of better health while the community receives the public good of reduced infection risk. However, in all settings the private incentive of better health is not sufficient to fully reduce community infection risk, so there are insufficient private incentives to provide the public good.

Here, we study a new innovation with perhaps stronger private incentives as households receive private agricultural economic benefits in addition to the private and public health benefits. We evaluate the viability of a market for the impure public good. Most closely related to our setting is Huth, McEvoy, and Morgan (2018) who evaluate the potential private market for lionfish fillets. Lionfish are an invasive species in the Caribbean and developing local markets could provide food for consumers (the private benefits) while also reducing the lionfish population (the public benefits). Similar to our setting, this would turn a public bad into a public good. However, the context and product differ greatly. In the case of lionfish, private individuals could potentially breed lionfish in closed settings to meet consumer demand. However, growing aquatic vegetation for compost or animal feed requires individuals use shared open water access points, increasing risks for everyone who uses these water access points. Thus, strong market incentives also carry risks of private cultivation that may not actually result in optimal public good provision that are not found within the lionfish setting. Additionally, our impure public good is an input to production instead of a final consumption good.

2 Theoretical Model

We develop a variant of the nonseparable agricultural household model to conceptualize household decision making and valuation of the public good of AVR within this context. In this nonseparable agricultural household model, consumption and production decisions become inextricably linked by multiple market failures (Singh et al., 1986). The economic model begins with the household, which maximizes utility, defined over consumption of food, consumption of an aggregate household good[3], leisure, and the health status of members of the household. We assume that utility is well-defined, increasing in all its arguments and concave. We model health status using a health production function that depends on the amount of vegetation in the water source, the household's nutrient intake via food consumption, the number of children in the household,[4] and the household's knowledge about schistosomiasis. In this context, knowledge about schistosomiasis includes information like a household's past experience with schistosomiasis, whether or not a household is informed about AVR and its benefits, and any past experience with AVR. We assume that health status increases with food consumption, representing the value of more nutrition. Health status decreases as vegetation increases since more vegetation leads to more infection (Rohr et al., 2022). Consistent with Rohr et al. (2022), we allow for a small amount of labor to clear the water source so only small fraction of households' overall labor availability is required to clear the water source. Households with more children have lower health status since children are more susceptible to schistosomiasis. Knowledge about the link between vegetation and health increases health status. There is no market for health in the model.

The household engages in agricultural production of both crops and livestock and the main decision facing the household is how to allocate time and money. They can choose to allocate time between cultivating crops, harvesting aquatic vegetation, selling labor on the labor market or leisure. Households can also buy labor on the labor market to be used in crop production or aquatic vegetation harvest. Because aquatic vegetation is a common pool resource, there is no market for aquatic vegetation, either in the water or as harvested vegetation. Thus, the market failures in health status and aquatic vegetation create nonseparability between the household's production and consumption decisions. We also assume that there is no land market because there are relatively little land rentals in this region. Harvested vegetation becomes compost or animal feed, which increases agricultural productivity (Rohr et al., 2022). Households produce crops using land, labor, fertilizer, and compost from harvested aquatic vegetation. Producing harvested vegetation only requires labor.[5] Livestock production only depends on the amount of food provided to the animal, which can either be produced from vegetation or bought in the market.

Let i denote the different goods a household consumes, produces, or uses as an input. Let q_i denote the quantity of goods produced or used as inputs in the production process by the household. The household produces ($q_i \geq 0$) of crops ($i = f$) using land ($i = d$), labor ($i = lf$), fertilizer ($i = u$), and compost (δq_v). The household makes compost from harvested vegetation ($i = v$), and harvesting vegetation requires labor

[3] The aggregate household good represents all non-food goods and services a household can consume that are available on the market.

[4] Children are most affected by schistosomiasis.

[5] While it requires a pit to convert vegetation into compost, we assume that there exists sufficient unused and free land within the village such that land is not a constraint to the production of compost and thus land does not enter into the production of vegetation or compost. Animal feed simply requires drying the vegetation, which can be done on available marginal land.

$(i = lv)$. Households can also hire labor to produce food L_f^h or to harvest vegetation L_v^h. Let $L_f = q_{l,f} + L_f^h$ be the total amount of labor used in the production of food and $L_v = q_{l,v} + L_v^h$ be the total amount of labor used to harvest vegetation. The household's production technology for food is then given by $F(L_f, q_d, q_u, q_v)$ and the production technology for vegetation is $G(L_v)$. The household produces $(q_i \geq 0)$ of livestock $i = a$ using feed q_{af} and endowment of livestock e_a with the production technology $J(q_{af}, e_a)$. Vegetation becomes livestock feed with technology $K(L_v)$.

Let $\boldsymbol{c}$ denote the vector of all goods consumption, comprised of food $(i = f)$, non-food household goods $(i = g)$, and leisure $(i = l)$. Let $H(V, c_f, n, I)$ denote the household's health status, where $V(L_v)$ is the amount of vegetation in the water source, n is the number of children in the household, I is the information set of the household, and c_f is food consumption. Household utility is denoted $U(\boldsymbol{c}, H)$.

Each household has endowments of labor e_l, land e_d, and livestock e_a. Each household member has one unit of labor; however, infection reduces the labor availability of an individual to τ where $0 \leq \tau \leq 1$. Infection reduces nutrient absorption from food and overall results in less labor productivity, effectively reducing the labor availability of infected individuals. The labor available to the household a_l is the sum of the labor availability of its individual members. A household generates income by growing food and selling its labor in the local labor market, L^m. The household buys and sells labor at wage w. There are perfectly competitive markets for food, the aggregate household good, labor, fertilizer, livestock, and animal feed (the tradables set $T = \{f, h, l, u, a, af\}$), but there are not markets for vegetation, land, and health (the non-tradables set $NT = \{v, d, H\}$). Each household must fully self-provide non-tradable goods. Finally, let p_i denote the market price for good i.

Thus, in each period, the household solves the problem:

$$\max_{(\boldsymbol{c},\boldsymbol{q})} U(\boldsymbol{c}, H) \tag{1}$$

subject to the budget constraint for tradable goods,

$$p_f c_f + p_g c_g \leq p_f(F(L_f, q_d, q_u, q_v)) - w(L_f^h + L_v^h) - p_u q_u + p_a J(q_{af}(L_v)) - p_{af} q_{af,b} + wL^m \tag{2}$$

the constraint for vegetation use,

$$q_v - c_v \geq 0 \tag{3}$$

the constraint on the household's labor endowment,

$$a_l \geq q_{lf} + q_{lv} + L^m + c_l \tag{4}$$

and the health production function.

$$H = H(V, c_f, n, I) \tag{5}$$

The household will optimally use all its land in food production and all of its harvested aquatic vegetation turns into compost, an agricultural input, or animal feed according to

$$q_v = G(q_{lv}, L_v^h) \tag{6}$$

and

$$q_{af,v} = K(q_{lv}, L_v^h) \tag{7}$$

where the total animal feed is the sum of the amount produced from vegetation and the amount bought on the market, $q_{af} = q_{af,v} + q_{af,b}$,

The labor constraint can be substituted into the budget constraint to create a full income constraint:

$$p_f c_f + p_g c_g + w(c_l + q_{lf} + q_{lv}) \leq p_f(F(q_{lf}, L_f^h, q_d, q_u, q_v(q_{lv}, L_v^h)) - w(L_f^h + L_v^h) + p_a J(q_{af,v}(q_{lv}, L_v^h), q_{af,b}) - p_{af} q_{af,b} - p_u q_u + wL^m \tag{8}$$

Assuming an interior solution, and a Lagrange multiplier λ on the household's full income constraint, the first order conditions for the maximization problem are

$$\frac{\partial U}{\partial c_f} + \frac{\partial U}{\partial H}\frac{\partial H}{\partial c_f} = \lambda p_f \tag{9}$$

$$\frac{\partial U}{\partial c_g} = \lambda p_g \tag{10}$$

$$\frac{\partial U}{\partial c_l} = \lambda w \tag{11}$$

$$\lambda p_f \frac{\partial F}{\partial q_{l,f}} = \lambda w \tag{12}$$

$$\frac{\partial U}{\partial H}\frac{\partial H}{\partial V}\frac{\partial V}{\partial q_{lv}} + \lambda(p_f \frac{\partial F}{\partial q_v}\frac{\partial q_v}{\partial q_{lv}} + p_a \frac{\partial J}{\partial q_{af,v}}\frac{\partial q_{af,v}}{\partial q_{lv}}) = \lambda w \tag{13}$$

$$p_f \frac{\partial F}{\partial L_f^h} = w \tag{14}$$

$$\frac{\partial U}{\partial H}\frac{\partial H}{\partial V}\frac{\partial V}{\partial L_v^h} + \lambda(p_f \frac{\partial F}{\partial q_v}\frac{\partial q_v}{\partial L_v^h} + p_a \frac{\partial J}{\partial q_{af,v}}\frac{\partial q_{af,v}}{\partial L_v^h}) = \lambda w \tag{15}$$

$$p_f \frac{\partial F}{\partial q_u} = p_u \tag{16}$$

$$p_a \frac{\partial J}{\partial q_{af,b}} = p_{af,b} \tag{17}$$

Equations (9), (10), and (11) can be rearranged to show that the ratio of the marginal benefit of consuming food (which includes direct increases in utility and indirect utility increases through improved in health) to the marginal benefit of consuming the aggregate household good or leisure equals the price ratio. Equation (12) demonstrates that labor is used in crop production until the value of the marginal product equals the shadow wage and equation (14) states the same condition for the use of hired labor in food production, so the marginal product of labor equals the wage. Equations (13) and (15) indicate that the value of labor in vegetation removal has multiple benefits. First, there is the benefit that comes from more food and livestock production via the creation of compost and animal feed, which generally means that labor is used until the value of the marginal product of labor in AVR equals the shadow wage for household labor or the market wage for hired labor. In this model, however, labor used in AVR impacts utility indirectly via the health production function. Therefore, the optimal use of labor in AVR depends on the household health status in addition to the wage and/or shadow wage. Finally, equations (16) and (17) say fertilizer is used and animal feed is bought until the value of the marginal product equals the marginal cost.

The key first order conditions governing the amount of vegetation harvest and thus the amount of compost and animal feed from AVR produced are equations (13) and (15). From these first order conditions we can define the reduced form relationship between household and community characteristics and their price of compost p_v and animal feed $p_{af,v}$:

$$\left.\begin{array}{r} p_v \\ p_{af,v} \end{array}\right\} = f(V, n, I, w, p_f, p_a, p_{af,b}, e_a, e_d, \lambda) \tag{18}$$

So, the households WTP for compost or animal feed depends on their household-specific information I, the number of children they have n, and their land and livestock endowments e_d and e_q. Household WTP also depends on community-level characteristics: vegetation in the water source V and market prices w, p_f, p_a, and $p_{af,b}$. With village fixed effects to control for these community-level characteristics, household WTP for compost and animal feed depends on the household-specific information, number of children, and livestock and land endowments that can be estimated using the following equation:

$$\begin{split} WTP_{iv} = \beta_0 + \beta_1 Public\ Benefits_{iv} + \beta_2 Land_{iv} + \\ \beta_3 Crops_{iv} + \beta_4 Livestock_{iv} + \beta_5 Past\ Schistosomiasis_{iv} + \beta_6 Children_{iv} + \delta_v + \varepsilon_{iv} \end{split} \tag{19}$$

The household-specific information set is determined by whether or not the household receives information on the public benefits of aquatic vegetation removal and the household's past experience with schistosomiasis. The number of children, household land holdings and livestock holdings follow directly from the model. We include whether or not the household cultivates crops to model since compost only applies to crop and thus WTP for compost should depend on the household's cultivation decisions.

3 Experimental Design

We will use a generalized second price auction to estimate demand curves for two impure public goods, compost and animal feed produced using AVR. We will vary the information provided to participants at the time of the auction. In treatment arm, households will be told of the private productivity gains of using compost and the potential cost savings from animal feed. In another treatment arm they will also be told of the additional benefit of reduced schistosomiasis exposure from AVR. We use this experimental design to the hypothesis that households' valuation of these agricultural inputs, the impure public goods, partly incorporate their valuation of reduced disease exposure.

3.1 Sample Selection and Implementation

We propose to enroll 800 participants in 20 villages to participate in these auctions and a demographic survey. Villages included must:

- Have between 500 and 5000 residents
- Be within 10 km of a freshwater source with schistosomiasis transmission
- Have at least one water access point with emergent vegetation

to be considered for inclusion in the study. Once we receive permission from the village chief to work within the village, we will enroll 40 households to participate. We will enroll household heads or other knowledgeable household members who are more than 18 years old, in good health, and speak Wolof fluently to comply with IRB guidelines and ensure that participants understand the survey and auctions they are participating in.

Participation in the study will consist of two days of in-person visits for participants. Each village will be visited three times to announce the study, enroll participants, and complete the auctions.

3.2 Information Treatment Arms

To disentangle the two sources of value for compost and animal feed produced from removed aquatic vegetation, we will assign each participant to one of two information treatment arms:

1. **Private productivity gains information**

   All participants receive information about the private benefits of using compost and animal feed from AVR. Material will be based on estimates from Rohr et al. (2022) and will be developed with the team directly involved in the production of compost and animal feed for Rohr et al. (2022). The same team, SIA, will produce compost and animal feed using the procedure developed in Rohr et al. (2022) to match the characteristics of the compost and animal feed as best as possible. All information treatments will be reviewed by local partners and presented in a culturally appropriate way.

2. **Public health impacts information**

   Participants assigned to the public information treatment will receive all of the information in the private information treatment arm. In addition, participants will receive information about the public benefits of AVR to reduce schistosomiasis exposure, explaining that the compost and feed are co-products along with infectious disease control. Material will be based on estimates from Rohr et al. (2022) and will be developed with the teams directly involved in Rohr et al. (2022). Information will focus on reduced schistosomiasis transmission as estimated by Rohr et al. (2022). All information treatments will be reviewed by local partners and presented in a culturally appropriate way.

3.3 Sample Sizes

We plan to enroll 800 participants in the study. We will enroll 40 household heads in 20 villages and run four generalized second price auctions in each village. Each auction will have a minimum of 7 participants. We will include two additional individuals in each treatment arm at initial enrollment to account for attrition so the initial enrollment will be 10 individuals per auction. Two auctions will be assigned to each treatment arm, so we will have overall samples of at least 280 participants in the private productivity gains information treatment arm and 280 participants in the public health impacts information treatment arm. Thus, the sample will have a minimum of 560 participants, and we will target enrollment of 800 individuals.

We base the sample size calculations on a power analysis guided by data from the Harmonized Survey on Household Living Standards in Senegal from the 2018-2019 agricultural season (WAEMU Commission, 2018-2019). Assuming a standard deviation of 100 FCFA, 0.05 significance, and 80% power, we estimate a detectable effect of just under 50 FCFA (less than $0.10 USD) between the two auction treatment arms with seven participants in each auction.

Randomization will be done at the individual level, so within each village individuals will be randomly assigned to an auction in one of the two treatment arms. We will stratify participants based on the procedure in the next section.

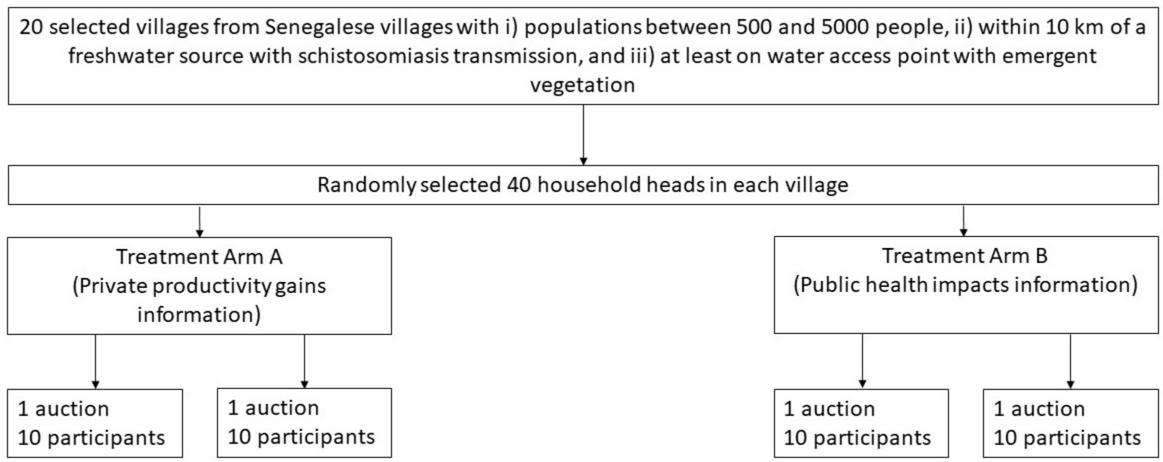

Figure 1: Flow Chart of Sample Sizes by Treatment Arm

4 Eliciting willingness to pay (WTP) using a Generalized Second Price Auction

A generalized second price auction will elicit each participant's WTP for compost and animal feed. Participants will bid on 5 kg of available compost in a single bag and a bag of compost around 5kg in size.

We will visit each village three times to introduce the study, enroll participants, and complete the auctions.

4.1 Visit 1

The initial village visit will be to introduce the study to the village. We will meet with the village chief to describe the broader project, how the project fits with any current or past studies taking place within the village (if necessary, based on previous researcher contact with the village), and to describe the specific activities to take place within the village. If the village chief grants permission to conduct the study within the village, we will schedule the subsequent follow-up visits to complete the household enrollment and auction. At this time, we will also explain the sampling strategy to the village chief.

Between Visit 1 and Visit 2 we will contact the village chief to confirm when we will arrive for the study and remind them about their village's participation.

4.2 Visit 2

During this visit we will enroll 40 household heads or other knowledgeable members of the household in the study in the morning and then complete the auctions in the afternoon. We will gain consent for participation from each participant, including explaining to them that they may have the option to purchase compost or animal feed at a specified later date and time. Upon enrollment, we will complete the short socio-economic survey with the participant.

Between the enrollment survey and the auctions we will stratify participants in each village based on the number of children in the household and their land holdings. If we are unable to stratify on these two dimensions, we will only stratify on the land holdings. We will then randomly assign each individual to an auction. Thus, within each village we have individual-level randomization. We will also confirm with each participant that they know the auction is in the afternoon and explain that they may have the option to purchase compost or animal feed and they should be prepared to make the purchase.

While doing the auction in the afternoon does not give participants much time to search for funds, we are only selling 5 kg of compost and animal feed, which is quite small in this setting. The cost is not very much and in the pilot, participants were able to spend more money than expected in these auctions with less warning. Therefore, we believe that between the participant payment of 1500 FCFA and the morning announcement of the auctions, there is sufficient time for participants to acquire sufficient funds to participate.

During the afternoon, we will complete the auctions. Upon arrival, participants will receive a FCFA cash gift for participating in the study. This gift will also relax prospective liquidity constraints for the auction. We will start by breaking up the participants into their assigned auction.

We will then provide information about the compost and animal feed that will be used in the study including the productivity enhancing benefits of the compost and the cost reducing benefits of feed, as reported in Rohr et al. (2022). We will not report on the estimated impact of vegetation harvest on the risk of schistosomiasis infection. In this way, we ensure everyone gets the private benefits, but only one treatment arm gets the public health benefits information prior to the auction, and only at the time of the auction minimizing the risk of information spillover within the village to the treatment arm receiving only information on the private productivity/cost benefits of the AVR-based agricultural inputs. The private benefits treatment arm will receive information on the public health benefits of AVR at the end of the auction, after all bids have been received, so as to ensure that all survey participants receive potentially beneficial information. We will emphasize that this information is to discuss the potential benefits on AVR and we will follow up with information on how to safely practice AVR at a later time.[6]

The generalized second price auction will be implemented using the following process:

1. At the agreed upon time, participants will be split into the assigned auction groups and taken into four areas in the village so that activities in the other auctions are not observable by other participants.

2. Once each group is off in their own area, the enumerator will explain the rules of the auction

   (a) The auction is won by the household who offers the highest price per unit. The winning household pays the second highest price per unit offer for the good and buys the quantity listed in their offer.

   (b) If the winning household cannot pay or their is additional product available after the first household buys all of the product they bid on, continue with the household who offered the second highest price per unit. This household pays the third highest price per unit for the good and purchases the quantity listed in their offer. If this household cannot pay or there is product remaining, continue down the list in this manner. This process continues until the supply is exhausted or demand is exhausted, whichever comes first. It is important to explain to households that their offers are important and if they win, you will visit to sell the product. We will develop procedure to minimize the instances of nonpayment by winning households.

3. The enumerator will explain the bid procedure (steps 6-8).

4. The enumerator will then complete the practice auction so participants can learn the auction procedure.

5. The enumerator will invite each household to write their "proposition" - the maximum price per unit at which you would buy the agricultural equipment (ex. sickle) and the number they want at that price - on the proposition paper that contains your name and your proposed price.

6. All households in the auction group will be invited to submit their proposals and put them in a jar.

7. Once all bids are submitted, the enumerator will open the jar and publicly read the propositions.

8. The household that wrote the highest proposition wins the auction and will buy the agricultural equipment at the second highest price per unit proposed in the jar. They will buy the quantity they put on their proposition. If there is remaining agricultural equipment, continue with the second highest price per unit bidder paying the third highest price per unit and follow this process until all fertilizer has been purchased.

[6] All AVR required to make the compost and animal feed will be conducted by villagers hired by SIA and all individuals will wear PPE to minimize infection risk associated with going in the water to remove vegetation.

9. Then, the enumerator will complete the auction using the following procedure.

   (a) First, the enumerator informs all participants of the benefits found in Rohr et al. (2022) relating to private productivity gains (benefits to pepper and onion production, cheaper than traditional forms of animal feed). If the participant has been assigned to the public health impacts treatment arm, we will also inform them of reduced schistosomiasis infection risk from AVR. Then, the enumerator will allow households to inspect the products carefully prior to making their bids.

   (b) The enumerator will then explain the bid procedure (steps 10c-10e).

   (c) The enumerator will ask each household to write their "proposition" - the maximum price per unit at which you will would buy to compost or animal feed and the amount you will buy at that price - on the proposition paper that contains your name and your proposed price.

   (d) All households in the auction group will be invited to submit their proposals and put them in a jar

   (e) Once all bids are submitted, the enumerator will open the jar and publicly read the propositions.

   (f) The household that wrote the highest proposition wins the auction and will buy the compost or animal feed at the second highest price per unit proposed in the jar. They will buy the quantity they put on their proposition. If there is remaining compost or animal, continue with the second highest price per unit bidder paying the third highest price per unit and follow this process until all compost or animal feed has been purchased or their are no bids remaining, whichever comes first.

The second price auction mechanism is incentive compatible, and a utility-maximizing participant should reveal their true maximum WTP (Vickrey, 1961).

For the private productivity gains treatment arm, at the end their auction they will receive the public health benefits information. This ensures that all participants will receive all information shared throughout the course of the study. All auctions will take place simultaneously to minimize spillovers within the village.

To limit the amount of outliers and to help with the elicitation of willingness to pay, we will have participants fill out a demand schedule that lists a price and asks participants how many units of compost or animal feed they would like at this price. The current prices are anchored to prices of similar goods (urea and other sources of animal feed) in the region, but the exact price schedule used will be determined after the pilot.

5 Analysis

We will run two analyses. First, we will trace out the demand curves for compost and animal feed, respectively, based on the elicited WTP for each of the products using the generalized second price auction. Second, we will use regressions to understand the factors that influence individuals' WTP for compost and animal feed. All regressions will include village fixed effects and standard errors will be clustered at the village level. Since we have a small number of clusters, we will also use a wild-cluster bootstrap (Cameron, Gelbach, & Miller, 2008). Additionally, with two auctions per treatment arm per village, we can use village or even village by treatment arm fixed effects to minimize concerns about confounders in the WTP elicitation.

5.1 Testing for factors that influence WTP

We will run the following regression separately for compost and animal feed that will allow us to test hypotheses about factors that influence WTP in a linear-in-parameters first order approximation of the shadow price functions derived previously:

$$\begin{aligned} WTP_{iv} = \beta_0 + \beta_1 Public\ Benefits_{iv} + \beta_2 Land_{iv} + \\ \beta_3 Crops_{iv} + \beta_4 Livestock_{iv} + \beta_5 Past\ Schistosomiasis_{iv} + \beta_6 Children_{iv} + \delta_v + \theta_s + \varepsilon_{iv} \end{aligned} \quad (20)$$

where WTP_{iv} is the individual's WTP for compost or animal feed elicited by a generalized second price auction for participant i in village v, $Public\ Benefits_{iv}$ is a binary indicator of whether the participant was randomly assigned to receive information on the public benefits of compost and animal feed from AVR in addition to the information on the private benefits that everyone received, $Land_{iv}$ is the land holdings of the participant's household in hectares, $Crops_{iv}$ indicates that the participant's household grows crops, $Livestock_{iv}$ indicates that the participant's household owns livestock, $Past\ Schistosomiasis_{iv}$ indicates that the participant's household has been diagnosed with schistosomiasis within the last year[7], $Children_{iv}$ is the number of children in the household, δ_v are village fixed effects, and θ_s control for stratification in the randomization process.

Prediction 1: Information about public and private benefits

Informing participants about the public benefits of compost or animal feed (reducing schistosomiasis infection) in addition to the private benefits will increase WTP.

$$H_0 : \beta_1 = 0 \quad vs. \quad H_A : \beta_1 > 0$$

[7]Based on pilot surveys in the summer of 2022, most households have at least one member who has been diagnosed with schistosomiasis. We can also measure exposure based on the use of deworming medication or experiencing reinfection.

Prediction 2: Higher land holdings

More land - which proxies for more income- will increase WTP.

$$H_0 : \beta_2 = 0 \quad vs. \quad H_A : \beta_2 > 0$$

Prediction 3: Cultivation

Cultivating crops will increase WTP for compost. Specific crops like peppers and onions that were used in the trial will have the largest effect on WTP. We will first run the main estimating equation with the basic crop indicator. Then, we will run a second estimating equation with a vector of indicators for the main crops grown the region (rice, pepper or onions, cassava) to isolate how growing specific crops impacts WTP. In this estimating equation $\mathbf{Crops}_{iv} = \{Rice_{iv} \quad PepperOnions_{iv} \quad Cassava_{iv}\}'$ where $Rice_{iv}$ is a binary indicator for if the household grows rice, $PepperOnions_{iv}$ is a binary indicator for if the household grows peppers or onions, and $Cassava_{iv}$ is a binary indicator for if the household grows cassava.

$$H_0 : \beta_3 = 0 \quad vs. \quad H_A : \beta_3 > 0$$

Prediction 4: Livestock

Household ownership of livestock will increase WTP for animal feed. The effect will be largest for sheep. The effect of cattle or goat ownership on WTP for animal feed is a priori unclear. Cattle headers are concerned about Fasciola from aquatic plants which may decrease WTP for animal feed. Goats did not eat vegetation in livestock trails run by researchers, which will be included in the information about the animal feed. Thus, goat ownership may decrease WTP for animal feed. As with crops we will run two regressions. First, we will include a general indicator for if the household owns livestock. Then, we will run a second regression where we replace the basic livestock indicator with a vector of variables that includes whether the household owns cattle, sheep, goats, poultry, or other livestock. poultry, and other livestock. In this estimating equation $\mathbf{Livestock}_{iv} = \{Cattle_{iv} \quad Sheep_{iv} \quad Goats_{iv} \quad Poultry_{iv} \quad Other_{iv}\}'$ where $Cattle_{iv}$ is a binary indicator for if the household owns cattle, $Sheep_{iv}$ is a binary indicator for if the household grows owns sheep, $Goats_{iv}$ is a binary indicator for if the household owns goats. $Poultry_{iv}$ is a binary indicator for if the household owns poultry, and $Other_{iv}$ is a binary indicator for if the household owns any other type of livestock.

$$H_0 : \beta_4 = 0 \quad vs. \quad H_A : \beta_4 > 0$$

Prediction 5: Prior exposure to schistosomiasis

Households with prior exposure to schistosomiasis will have higher WTP for compost and animal feed because they have better information about the morbidity impacts of schistosomiasis and will value the reduced infection risk more. We hypothesize that this effect will be largest when households are informed of the public benefits of the compost and animal feed. We will test for different effects of prior exposure to schistosomiasis across information treatments (only private benefits vs. private and public benefits) by interacting prior exposure to schistosomiasis and the indicator for the public benefits treatment. We will implement this by replacing $Past\ Schistosomiasis_{iv}$ with the vector $\{Past\ Schistosomiasis_{iv}(Past\ Schistosomiasis \times Public\ Benefits)_{iv}\}$.

$$H_0 : \beta_5 = 0 \quad vs. \quad H_A : \beta_5 > 0$$

Prediction 6: Children

Since children bear the burden of schistosomiasis infection, households with children will have higher WTP for compost and animal feed. This effect will be largest when households are informed of the public benefits of the compost and animal feed. We will test for different effects of children in the household across information treatments (only private benefits vs. private and public benefits) by interacting prior exposure to schistosomiasis and the indicator for the public benefits treatment. We will implement this by replacing $Children_{iv}$ with the vector $\{Past\ Schistosomiasis_{iv}(Children \times Public\ Benefits)_{iv}\}$.

$$H_0 : \beta_6 = 0 \quad vs. \quad H_A : \beta_6 > 0$$

We also hypothesize that prior exposure to researcher vegetation removal will increase WTP as participant are overall more familiar with the ideas around vegetation removal, its potential productivity, and its impact on infection control as some of the villages in our sampling frame were part of the randomized control trial of Rohr et al. (2022). However, this variation is at the village level and is mopped up by the village fixed effect in our main specification. We will also run the analysis without village fixed effects but with an indicator for being exposed to previous vegetation removal to probe the effect of inclusion in previous vegetation removal studies on WTP. The estimating equation becomes

$$\begin{aligned} WTP_{iv} &= \beta_0 + \beta_1 Public\ Benefits_{iv} + \beta_2 Land_{iv} + \\ &\beta_3 Crops_{iv} + \beta_4 Livestock_{iv} + \beta_5 Past\ Schistosomiasis_{iv} + \beta_6 Children_{iv} + \beta_7 Prior\ Exposure_v + \varepsilon_{iv} \end{aligned} \tag{21}$$

where $Prior\ Exposure_v$ is a binary indicator for whether village v experienced previous vegetation removal since 2017. We test the hypothesis

$$H_0 : \beta_7 = 0 \quad vs. \quad H_A : \beta_7 > 0$$

References

Ajayi, O. C., Jack, B. K., & Leimona, B. (2012). Auction design for the private provision of public goods in developing countries: lessons from payments for environmental services in malawi and indonesia. *World Development*, *40*(6), 1213–1223.

Baird, S., Hicks, J. H., Kremer, M., & Miguel, E. (2016). Worms at work: Long-run impacts of a child health investment. *The Quarterly Journal of Economics*, *131*(4), 1637–1680.

Cameron, A. C., Gelbach, J. B., & Miller, D. L. (2008). Bootstrap-based improvements for inference with clustered errors. *The Review of Economics and Statistics*, *90*(3), 414–427.

Chan, N. W., & Kotchen, M. J. (2014). A generalized impure public good and linear characteristics model of green consumption. *Resource and Energy Economics*, *37*, 1–16.

Cohen, J., & Dupas, P. (2010). Free distribution or cost-sharing? evidence from a randomized malaria prevention experiment. *The Quarterly Journal of Economics*, 1–45.

Cohen, J., Dupas, P., & Schaner, S. (2015). Price subsidies, diagnostic tests, and targeting of malaria treatment: evidence from a randomized controlled trial. *American Economic Review*, *105*(2), 609–45.

Grimes, J. E., Croll, D., Harrison, W. E., Utzinger, J., Freeman, M. C., & Templeton, M. R. (2015). The roles of water, sanitation and hygiene in reducing schistosomiasis: A review. *Parasites & Vectors*, *8*(1), 1–16.

Gryseels, B., Polman, K., Clerinx, J., & Kestens, L. (2006). Human schistosomiasis. *The Lancet*, *368*(9541), 1106–1118.

Haggerty, C. J., Bakhoum, S., Civitello, D. J., De Leo, G. A., Jouanard, N., Ndione, R. A., ... others (2020). Aquatic macrophytes and macroinvertebrate predators affect densities of snail hosts and local production of schistosome cercariae that cause human schistosomiasis. *PLoS Neglected Tropical Diseases*, *14*(7), e0008417.

Halstead, N. T., Hoover, C. M., Arakala, A., Civitello, D. J., De Leo, G. A., Gambhir, M., ... others (2018). Agrochemicals increase risk of human schistosomiasis by supporting higher densities of intermediate hosts. *Nature Communications*, *9*(1), 1–10.

Hamory, J., Miguel, E., Walker, M., Kremer, M., & Baird, S. (2021). Twenty-year economic impacts of deworming. *Proceedings of the National Academy of Sciences*, *118*(14), e2023185118.

Hoffmann, V., Barrett, C. B., & Just, D. R. (2009). Do free goods stick to poor households? experimental evidence on insecticide treated bednets. *World Development*, *37*(3), 607–617.

Hoover, C. M., Sokolow, S. H., Kemp, J., Sanchirico, J. N., Lund, A. J., Jones, I., ... others (2018). Prawn aquaculture as a method for schistosomiasis control and poverty alleviation: A win-win approach to address a critical infectious disease of poverty. *bioRxiv*, 465195.

Hotez, P. J., Alvarado, M., Basáñez, M.-G., Bolliger, I., Bourne, R., Boussinesq, M., ... others (2014). The global burden of disease study 2010: Interpretation and implications for the neglected tropical diseases. *PLoS Neglected Tropical Diseases*, *8*(7), e2865.

Huth, W. L., McEvoy, D., & Morgan, O. A. (2018). Controlling an invasive species through consumption: The case of lionfish as an impure public good. *Ecological Economics*, *149*(C), 74–79.

King, C. H., Dickman, K., & Tisch, D. J. (2005). Reassessment of the cost of chronic helmintic infection: A meta-analysis of disability-related outcomes in endemic schistosomiasis. *The Lancet*, *365*(9470), 1561–1569.

Kjetland, E. F., Ndhlovu, P. D., Gomo, E., Mduluza, T., Midzi, N., Gwanzura, L., ... Gundersen, S. G. (2006). Association between genital schistosomiasis and hiv in rural zimbabwean women. *AIDS*, *20*(4), 593–600.

Kotchen, M. J. (2006). Green markets and private provision of public goods. *Journal of Political Economy*, *114*(4), 816–834.

Kotchen, M. J. (2009). Voluntary provision of public goods for bads: A theory of environmental offsets. *The Economic Journal*, *119*(537), 883–899.

Kremer, M., Leino, J., Miguel, E., & Zwane, A. P. (2011). Spring cleaning: Rural water impacts, valuation, and property rights institutions. *The Quarterly Journal of Economics*, *126*(1), 145–205.

Kremer, M., & Miguel, E. (2007). The illusion of sustainability. *The Quarterly Journal of Economics*, *122*(3), 1007–1065.

Li, Z., Anderson, C. M., & Swallow, S. K. (2016). Uniform price mechanisms for threshold public goods provision with complete information: An experimental investigation. *Journal of Public Economics*, *144*, 14–26.

Liang, S., Abe, E. M., & Zhou, X.-N. (2018). Integrating ecological approaches to interrupt schistosomiasis transmission: Opportunities and challenges. *Infectious Diseases of Poverty*, *7*(1), 1–6.

Liu, P., & Swallow, S. K. (2019). Providing multiple units of a public good using individualized price auctions: experimental evidence. *Journal of the Association of Environmental and Resource Economists*, *6*(1), 1–42.

Miguel, E., & Kremer, M. (2004). Worms: identifying impacts on education and health in the presence of treatment externalities. *Econometrica*, *72*(1), 159–217.

Mohammed, A. Z., Edino, S. T., & Samaila, A. A. (2007). Surgical pathology of schistosomiasis. *Journal of the National Medical Association*, *99*(5), 570.

Ozier, O. (2018). Exploiting externalities to estimate the long-term effects of early childhood deworming. *American Economic Journal: Applied Economics*, *10*(3), 235–62.

Polasky, S., Lewis, D. J., Plantinga, A. J., & Nelson, E. (2014). Implementing the optimal provision of ecosystem services. *Proceedings of the National Academy of Sciences*, *111*(17), 6248–6253.

Rohr, J. R., Bakhoum, S., Barrett, C. B., Chamberlin, A. J., Civitello, D. J., Doruska, M. J., ... Wolfe, C. (2022). A planetary health solution for disease, sustainability, food, water, and poverty challenges. *medRxiv*. Retrieved from `https://www.medrxiv.org/content/early/2022/08/03/2022.08.02.22278196` doi: 10.1101/2022.08.02.22278196

Singh, I., Squire, L., & Strauss, J. (1986). *Agricultural household models: Extensions, applications, and policy.* The World Bank.

Steinmann, P., Keiser, J., Bos, R., Tanner, M., & Utzinger, J. (2006). Schistosomiasis and water resources development: Systematic review, meta-analysis, and estimates of people at risk. *The Lancet Infectious Diseases*, *6*(7), 411–425.

Stelma, F., Talla, I., Verle, P., Niang, M., & Gryseels, B. (1994). Morbidity due to heavy schistosoma mansoni infections in a recently established focus in northern senegal. *The American Journal of Tropical Medicine and Hygiene*, *50*(5), 575–579.

Verjee, M. A. (2019). Schistosomiasis: still a cause of significant morbidity and mortality. *Research and Reports in Tropical Medicine*, *10*, 153.

Vickrey, W. (1961). Counterspeculation, auctions, and competitive sealed tenders. *The Journal of Finance*, *16*(1), 8–37.

WAEMU Commission. (2018-2019). *Harmonized Survey on Households Living Standards, Senegal 2018-2019. Ref. SEN_2018_EHCVM_v02_M.* Dataset downloaded from www.microdata.worldbank.org on September 23, 2022.

Wichman, C. J. (2016). Incentives, green preferences, and private provision of impure public goods. *Journal of Environmental Economics and Management*, *79*, 208–220.