Social Signaling and Childhood Immunization: A Field Experiment in Sierra Leone

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Abstract

Individuals care about how they are perceived by others, and take visible actions to signal their type. This paper investigates social signaling in the context of childhood immunization in Sierra Leone. Despite high initial vaccine take-up, many parents do not complete the five immunizations that are required in a child's first year of life. I introduce a durable signal - in the form of differently colored bracelets - which children receive upon vaccination, and implement a 22-month-long experiment in 120 public clinics. Informed by theory, the experimental design separately identifies social signaling from leading alternative mechanisms. In a first main finding, I show that individuals use signals to learn about others' actions. Second, I find that the impact of signals varies significantly with the social desirability of the action. In particular, the signal has a weak effect when linked to a vaccine with low perceived benefits and a large, positive effect when linked to a vaccine with high perceived benefits. Of substantive policy importance, signals increase timely and complete vaccination at a cost of 1 USD per child, with effects persisting 12 months after the roll out. Finally, I structurally estimate a dynamic discrete-choice model to quantify the value of social signaling.

1 Introduction

Childhood immunization is one of the most cost-effective ways of reducing child mortality (UNICEF 2018).[1] Over the past decade, remarkable progress has been made in increasing the availability and reliability of immunization services (UNICEF and WHO 2016). In 2008, almost 20 percent of children in Sierra Leone had not received their first vaccine by the age of one (DHS 2008). This number had dropped to five percent by 2013 (DHS 2013). Despite this improvement in initial vaccination rates, only 58 percent of children complete the first-year series of vaccinations, a pattern that is common across many low-income countries.[2] In this paper, I ask two questions: Can we increase timely and complete vaccination, by allowing parents to signal to others that they vaccinated their child? Beyond visibility, what are the mechanisms through which social signals affect decision-making in a dynamic, real-life setting?

To answer these questions, I design a field experiment based on Bénabou and Tirole's (2006; 2011) theory of social signaling, which states that individuals' utility depends on the expectations that others form about their type, based on the actions they take. In the context of my study, there are strong social norms surrounding the importance of vaccination – 83 percent of communities believe that parents who fail to vaccinate their child are negligent. As vaccines are currently imperfectly observable, I create an opportunity for parents to publicly show that they correctly vaccinated their child by introducing a durable signal - in the form of differently colored bracelets - that children receive upon vaccination. I experimentally vary the information that the bracelets provide about the take-up of different vaccines, by randomizing 120 clinics into three treatment arms and one control group.[3] For each clinic, I randomly select two adjacent communities (0 to 2 miles away) and three far communities (2 to 5 miles away), to create a final sample of 578 communities. I exploit two important features of childhood immunization in my experimental design: (1) individuals have to take multiple actions, as children require five vaccinations before the age of one; (2) individuals make decisions over a long time horizon, from the first vaccination at birth to the last vaccination at 9 months of age (WHO 2018).

Using (1), I randomly vary access to three different bracelets with varying signaling content. In each of the first two treatment groups (hereafter Signal 4 treatment and Signal 5 treatment), children receive a yellow bracelet upon their first vaccine. In the Signal 4 treatment, the yellow bracelet is exchanged for a green bracelet once a child completes the fourth vaccine. In the Signal 5 treatment, the yellow bracelet is exchanged for a green bracelet once a child completes the fifth

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[1] The benefits of vaccines go beyond the direct health impacts: vaccines contribute to higher educational outcomes, reduced poverty, and lower household spending (Verguet et al. 2013; van der Putten et al. 2015). It is estimated that every 1 USD invested in immunization programs, results in at least 16 USD in net health and economic benefits (Ozawa et al. 2016).

[2] Global immunization coverage continues to stagnate. For example, in India (DHS 2017), Peru (DHS 2014), and Kenya (DHS 2015), while 91 percent, 91 percent, and 96 percent of children, respectively, begin vaccinations, only 54 percent, 62 percent, and 71 percent complete the full first-year series. Demand-side factors play an increasingly important role in accelerating progress (of Experts on Immunization 2017).

[3] There is a total of 1,221 public clinics in Sierra Leone. The experiment was implemented at a large scale, covering ten percent of clinics.

vaccine. The last treatment, the Uninformative Bracelet, conveys no information about a child's later vaccinations. Parents choose a yellow or green bracelet at the first vaccine and the child keeps the same color bracelet for all subsequent vaccinations. This design allows me to both test the extent to which signaling preferences vary with the perceived benefits of vaccines, and isolate the effect of these preferences from alternative mechanisms such as increased salience, consumption utility, or social learning about vaccines. Finally, the time variation between the various vaccinations allows me to examine the extent to which future signaling payoffs affect parents' decisions to vaccinate their child today.

I combine survey and administrative data for over 6,000 children to estimate the partial effect of social signaling preferences on vaccination decisions. In addition, I collected detailed survey data on individuals' preferences and first- and second-order beliefs about children's vaccine status to test the underlying mechanisms of the theory for a random subsample of 1,314 parents. The beliefs data reveal large information asymmetries: parents in the control group have accurate information about other children's vaccinations for only 47 percent of children in their community. Similarly, parents believe that only 46 percent of other parents in their community have knowledge about their own child's vaccinations. Both the Signal 4 and Signal 5 treatments led to a decrease in information asymmetries (15 and 18 percent, respectively). Parents use signals to learn about the number of vaccines that other children received, consistent with Bayesian learning, updating their beliefs conditional on the bracelet color observed. I find no evidence of learning effects for the Uninformative Bracelet treatment, in spite of similar rates of bracelet retention and visibility. This indicates that parents were able to correctly understand the different bracelet treatments.

The signaling treatments led to a significant increase in the share of children that received the fourth and fifth vaccine, increasing timely shares from 73 to 80 percent, and from 54 to 62 percent, respectively, compared to the control group. The effect is masked by substantial heterogeneity: Signal 4 led to small and insignificant increases of 2.8 percentage points for vaccine four, and 3.8 percentage points for vaccine five, in the share of children vaccinated. Signal 5 led to significant and large increases of 10.6 percentage points for vaccine four, and 13.7 percentage points for vaccine five. Effects remain large and significant (8.1 and 8.2 percentage points) when comparing Signal 5 to the Uninformative Bracelet, providing further evidence for social signaling preferences. Moreover, treatment effects persist for children born 12 months after the launch of the experiment. This finding raises the question of why Signal 5 worked, while Signal 4 did not, if both signals were equally potent in terms of increasing the visibility of vaccinations. Survey data shows that individuals assigned a higher importance to vaccine five than vaccine four, considering the fourth vaccine as the least important among the five. This result suggests that for signals to be effective, they need to be both informative about others' actions and linked to actions that are sufficiently valued. Reassuringly, I find no significant differences in individuals' preferences for different vaccines across treatment and control groups, ruling out that the observed treatment effects are purely due to normative influence of signals or social learning.

In addition to the treatment effects at vaccines five and four, Signal 5 also led to significant

increases in the share of children that were vaccinated for vaccines three (7.1 percentage points) and two (4.3 percentage points). Combining the reduced-form estimates for all five vaccinations, Signal 5 significantly increased the average total number of vaccines completed from 4.0 to 4.4 compared to the pure control group. Importantly, parents were more likely to vaccinate their children for earlier vaccines, responding to a signaling benefit half a year in advance, without necessarily making it to vaccine five and making it all the way to vaccine five. This pattern of treatment effects is consistent with theoretical predictions from a signaling model where individuals make decisions dynamically under uncertainty. More generally, these findings imply that individuals aim to complete later vaccines, but may drop out early due to unforeseen cost or preference shocks.

I structurally estimate a dynamic discrete-choice model that takes into account these features and uses distance to the clinic as a numeraire to quantify the value of social signaling. On average, parents' valuation of social signaling is equivalent to 7 to 10 miles walking distance to clinics. Taken together, these findings are of substantive policy importance: a signal that allows parents to broadcast an action they value for their child's health increased timely and complete vaccination to levels necessary for herd immunity, at a cost of 1 USD per child, far less than estimates from existing interventions.[4]

This study makes four contributions. First, to my knowledge, this is the first field experiment designed to test for social signaling in a dynamic setting. Existing studies have shown that individuals are willing to incur considerable costs when faced with a decision to take an immediate action that allows them to signal their type to others (Bursztyn and Jensen 2017). My findings show that signals can motivate individuals to take an action more than six months in advance, even when there is substantial uncertainty about whether signaling benefits can be realized. Importantly, observed behavior changes are very likely due to social signaling preferences, because I experimentally only vary the margin at which individuals can signal, which allows me to control for leading alternative mechanisms. This is also one of the first experimental studies to examine the effect of a durable signal that allows individuals to continuously signal their type to others (with the exception of Bursztyn et al. (2018)).

Second, this study contributes to a nascent literature of field experiments examining the mechanisms underlying social image concerns (Bursztyn et al. 2018, 2017; Bursztyn and Jensen 2017; Chandrasekhar et al. 2018). In contrast to many existing studies (Ashraf et al. 2014; DellaVigna et al. 2016; Perez-Truglia and Cruces 2017), my experimental design moves beyond manipulating the visibility of actions, by introducing multiple signals that are linked to different actions. By drawing an important distinction between the role of signals in providing information about others' actions and the opportunity they provide to signal one's type, this paper shows that the impact of signals varies significantly with the social desirability of actions. This result illustrates the lim-

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[4]Vaccine four includes, among other diseases, diphtheria, for which reaching herd immunity requires 83-85 percent of children to be vaccinated, and pertussis, for which reaching herd immunity requires 92-94 percent of children to be vaccinated (Anderson, 2013). Signal 5 reaches the former when assessing the share of children vaccinated timely at six months for vaccine four (85 percent), and the latter when assessing the share of children having completed vaccine four by one year of age (93 percent).

itations of social signaling as a mechanism to increase public goods, when individuals assign low private valuation to an action that has large externality benefits.

Third, this paper provides the first evidence on social signaling in health, and therefore contributes to a large literature on incentives to increase the use of health services and public goods in low-income settings (Thornton 2008; Banerjee et al. 2010; Ashraf et al. 2014; Sato and Takasaki 2017; Karing and Naguib 2018). Recent studies have found large effects of cash and consumption incentives. For example, Banerjee et. al (2010) find that offering 1 kg of raw lentils for each vaccination visit and a metal plate upon completion of the full series increases vaccination rates in India from 18 to 39 percent. In contrast, my paper looks at immunization in a context where initial take-up is close to universal and completion rates are much higher than in India, identifying social signals as a potential low-cost way to address the "last-mile problem" of reaching immunization thresholds.

Fourth, the results of this paper have the potential to inform policy strategies for increasing the demand for timely vaccination. Current immunization programs rely heavily on health campaigns and outreach activities to achieve target immunization levels. This paper shows that social signals can increase parents' willingness to travel further to receive vaccinations. This provides relevant information to governments who face trade offs between keeping health workers at central clinics and mobilizing them to more remote areas. Further, this paper provides one of the first estimates of the value of social signaling in a low-income country. While most social signaling studies have been implemented in high-income countries, this study demonstrates the feasibility of implementing a more subtle behavioral intervention through government institutions in a low-resource setting.

The remainder of this paper is organized as follows. Section 2 provides an overview of the empirical setting, including the application of social signaling to childhood immunization in general and the context of Sierra Leone in particular. Section 3 discusses the theoretical framework and predictions for the main outcome and mechanisms. Section 4 describes the experimental design, discusses the implementation and randomization checks. Section 5 presents the experimental results, providing a separate discussing of mechanisms and main outcomes. In Section 6, I provide a structural estimate of the value of social signaling. Section 7 concludes.

2 Childhood Immunization and Sierra Leone

This section provides a brief description of the routine immunization schedule, the health benefits of immunization, and the setting of childhood immunization in Sierra Leone. The information is important for the experimental design and an understanding of individuals' binding constraints to timely and complete vaccination.

2.1 Childhood Immunization

A child under the age of one needs to receive five routine vaccinations: the first vaccine, BCG, at birth or shortly thereafter, the second, third, and fourth vaccines, diphtheria, tetanus, and pertussis (DTP) 1, DTP 2, and DTP 3, at 1.5, 2.5, and 3.5 months of age, respectively, and the fifth vaccine,

Measles, at 9 months of age (WHO 2018).[5] At the same time that DTP 1, 2, and 3 are administered, a child also receives one dose of the Polio, Rotavirus, and PCV vaccine.[6] While the first and last vaccine can be administered together with other vaccines, DTP 1, 2, and 3 need to be given one month apart.[7] According to WHO guidelines, the DTP series should be completed by six months of age (WHO 2018). Complete and timely vaccination provides private benefits by protecting infants from potentially life-threatening diseases, as the immunity from their mother wanes off, and social benefits by increasing overall immunization rates to herd immunity levels.[8] Private and social benefits may not perfectly align: DTP doses 1 and 2 are, for most children, sufficient to obtain protection against the disease; the third dose is necessary in order for 94 to 100 percent of children to have protective antibody levels and hence to reach herd immunity.[9] The latter is particularly important as pertussis predominantly affects children younger than six months, who therefore may be too young to be protected by immunizations.

2.2 Low-Income Country Context of Sierra Leone

Sierra Leone has one of the highest infant and under-five mortality rates, with 92 and 156 deaths per 1,000 live births, respectively. One in every 11 Sierra Leonean child dies before reaching age one and one in every 7 does not survive to her fifth birthday (DHS 2013). Rotavirus is the most common cause of severe and fatal diarrhea in young children worldwide; in Sierra Leone, it is estimated that one third of all under-five diarrheal disease hospitalizations are caused by rotavirus (PATH 2017).

The country is one of the poorest in the world, ranking 181 out of 188 in the Human Development Index (UNDP 2016). Women are the primary caregivers of children, taking them for vaccinations over 99.99 percent of the time. 47 percent of mothers in my endline sample have no education, 30 percent have any primary education, and only 22 percent have any secondary education. 74 percent of mothers are engaged in farm work, and fewer than 12 percent possess a mobile phone. Birth rates are high, with mothers having, on average, three children by the age of 26 years.

In Sierra Leone, vaccines are free of charge and readily available.[10] A possible concern is that, even if vaccines are free of charge, clinics may run out of them. Table 2 provides relevant information: at baseline, fewer than 14 percent of clinics in my study sample reported having a stock-out of one or more vaccines, and during the study period, only 8 percent of clinics experienced any stock-outs of on immunization days.[11] Immunization services are offered on a fixed schedule, either on a

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[5]BCG protects against tuberculosis. DTP is a 3-dose series offering protection against diphtheria, tetanus and whooping cough.

[6]Pneumococcal conjugate vaccine protects against diseases caused by the bacterium Streptococcus pneumoniae.

[7]For example, a child can receive BCG and DTP1, or DTP3 and Measles together in one vaccination visit.

[8]Infants and young children are at the highest risk to fall ill and die from these diseases: one out of five children who get diphtheria at age younger than 5 years old dies (WHO 2017).

[9]The antibody level increases after the second dose of diphtheria toxoid and it is much higher after the third dose; while most children have a base level of protection from the first two doses of DTP, the third doses is necessary for 94-100 percent of children to have protective antibody levels > 0.01 IU/mL and reach herd immunity thresholds (WHO 2017).

[10]Healthcare for children under the age of five, pregnant women, and lactating mothers is free in Sierra Leone since the introduction of the Free Healthcare Initiative in 2010.

[11]The stock-outs were mainly for BCG and Measles vaccines. Less than 3 percent of clinics reported stock-outs for

weekly (65 percent of sample) or monthly (35 percent of sample) basis, and clinics have, on average, two staff trained in child health. At the same time that vaccinations are given, children's weight and height are recorded, and their overall health checked. Vaccinations, both in Sierra Leone and many other low-income countries, are therefore the main point of contact for monitoring newborns' health and detecting problems such as malnutrition. The functionality of the supply side is reflected in communities' perceptions, see Table 1: 83 percent of communities name, as the most common reason, negligence of parents, for delayed or missed vaccination. Distance to clinics and user fees are ranked as secondary factors, mentioned by 34 percent and 15 percent of communities respectively. Importantly, child vaccination is a well-known technology: 94 percent of communities at baseline know that children need five vaccinations, and are aware of the health benefits of vaccinations.[12]

3 Theoretical framework

The experimental design is grounded in Bénabou and Tirole's (2006, 2011) theory of social signaling. In this section, I will map their framework into the specific empirical decision problem of child vaccination. I will discuss the main predictions of the model and augment it to include uncertainty about future cost shocks.

3.1 Social signaling without uncertainty

Preferences are described by:[13]

$$U(a_i; v_i, x, r, \lambda, \omega) = B(a_i; v_i) - C(a_i) \quad + \quad x\lambda\omega \begin{cases} E_{-i}(v|a_i \geq r) & \text{if } a_i \geq r \\ E_{-i}(v|a_i < r) & \text{if } a_i < r \end{cases} \tag{1}$$

Individuals, indexed by i, make a decision to take their child for zero, one, two, three, four or five vaccinations $a_i \in \{0, 1, 2, 3, 4, 5\}$. Individuals differ in their intrinsic motivation v_i to look after their child's health. v_i is drawn from the continuous type distribution of v, $F(v)$, which is common knowledge to all individuals. v_i is known to individual i but not observable to others. $B(a_i; v_i)$ denotes the private benefit of vaccination, which is a function of i's choice a_i and i's type.[14] $C(a_i)$ denotes the cost of vaccination, defined in terms of travel distance to the clinic.

Ignoring the third term of the model, we have a simple maximization problem where individual i chooses the optimal number of vaccines a_i^*, by maximizing $U(a_i; v_i) = B(a_i; v_i) - C(a_i)$. Assuming that $B(a_i; v_i)$ is increasing and concave, and $C(a_i)$ is weakly convex, there is a unique function that maps for each individual i her type v_i to her optimal action: $a_i^* = a(v_i)$. Without loss of generality, assume

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the DTP vaccine.

[12]Individual surveys corroborate this finding: 96 percent of mothers attending vaccinations, who were randomly sampled for short surveys during their clinic visit, were aware that children under the age of one require five vaccinations.

[13]I follow (Bénabou and Tirole 2006), (Bénabou and Tirole 2011) and (Bursztyn and Jensen 2017) here.

[14]I abstract from the externality benefits of vaccines since individuals in the context of my study predominantly think of vaccination as a private good and lack an understanding of externalities.

that $\frac{\partial B(a_i; v_i)}{\partial v_i} > 0$, such that higher types receive greater utility from vaccinating and therefore will choose to vaccinate more[15].

The key part of the model is the third term, the reputational benefits and costs associated with the expectations that others, indexed by $-i$, will form about i's type as actions become visible. Let $r \in \{1, 2, 3, 4, 5\}$ denote the threshold number of vaccines, that partitions the six possible actions a_i into two groups of observable vaccine decisions: others can either observe that i chose to vaccinate her child for at least r vaccines, that is $a_i \geq r$, or that i chose to vaccinate her child for fewer than r vaccines, that is $a_i < r$. Let $x \in [0, 1]$ denote the probability that others observe i's choice. The parameter λ measures how much individual i cares about the expectations that others form about her, and ω corresponds to the social desirability of being seen as a type who chooses $a_i \geq r$. Following the literature, I assume that $\lambda \geq 0$ and $\omega \geq 0$ given that the action $a_i \geq r$ is desirable. In equilibrium, different types choose different actions, leading others to form expectations about i's type conditional on the action observed, that is, $E_{-i}(v | a_i \geq r)$ or $E_{-i}(v | a_i < r)$. Importantly, the expectations of others enter directly into i's utility as expressed in equation 1. Following the logic of Bénabou and Tirole (2006, 2011) there exists a unique set of actions under visibility such that each individual chooses an action a_i^{s*}, given the equilibrium actions of all other individuals. This equilibrium is characterized by the cut-off type $\hat{v}_r$ (who is indifferent between choosing the optimal a_i^* without visibility and deviating to r) and the reputational returns which solve the fixed-point equation:

$$U(r) - U(a_i^*) = \underbrace{B(r; \hat{v}_r) - C(r) - B(a_i^*; \hat{v}_r) + C(a_i^*)}_{\text{Difference in direct benefits}} + \underbrace{\lambda \omega \triangle(\hat{v}_r)}_{\text{Reputational returns}} = 0 \qquad (2)$$

where[16] $\triangle(\hat{v}_r) = \underbrace{E(v | a_i^{s*} \geq r) - E(v | a_i^* < r)}_{\text{Difference in the average type based on \textbf{observed} actions}}$

Given our previous assumption $\frac{\partial B(a_i; v_i)}{\partial v_i} > 0$, in equilibrium individuals with higher types will choose to vaccinate more than those with lower types.[17]

An empirical object of consistent interest in this paper will be the discrete probability density function $g(a) = Pr(a_i(v) = a)$,[18] with the associated discrete cumulative distribution function $G(a) = Pr(a_i(v) \leq a)$. I will use the cumulative distribution function to specify the share of children that completed at least a vaccines, that is, $Pr(a_i(v) \geq a)$.

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[15]Formally $a > a'$ if $v > v'$, $\forall v, v'$.

[16]To make the link between types and actions more transparent, note that $E(v | r \geq r) - E(v | a_i^* < r) = E(v | v \geq \hat{v}_r) - E(v | v < \hat{v}_r)$.

[17]It is relatively straight-forward: Suppose, for the sake of contradiction, that there exists an equilibrium in which the action taken by v, v' with $v > v'$ is $a < a'$. By definition the third term concerning other people's inferences, given actions, is the same for all types v. Consequently, if a lower type v prefers to take the action a' instead of a, then it must be that a higher type must also prefer the action. That contradicts the initial supposition that they higher type prefers a to a'.

[18]I am dropping excess parameters here, since in the empirical part of the analysis these are unobservable.

3.1.1 Equilibrium simulations with signaling:

Figure 1 presents results from two calibrated simulations, first assuming x=0 (no visibility of actions) and second x=1 (full visibility of actions), to illustrate the equilibrium effects of visibility on the cut-off type, $\hat{v}_r$, and type expectations. Using the empirical rates of vaccination for vaccine one, two, three, four and five from the Control Group data, I calibrate the moments of a normal type distribution $v \sim N(\mu_v, \omega_v)$ and the parameters of the utility function:

$$U(a_i; v_i) = (v_i - \kappa D)a_i - \sum_{a=1}^{a_i} \alpha a + x\lambda\omega\mathbb{1}[E(v|a_i = 5) - E(v|a_i < 5)] \tag{3}$$

where I assume that the marginal cost of vaccination κ is constant, and the marginal benefit $v_i - \alpha \cdot a_i$ is declining. $D = 2$ is set to the mean walking distance. The calibrated parameters are $\mu_v = 1.48$, $\sigma_v = 0.41$, $\kappa = -0.1$, $\alpha = -0.3$. I assume that individuals can signal that they took their child for five vaccinations, with $r = 5$ and that $\lambda\omega = 0.2$. I solve for $\hat{v}_r$ and $\triangle(\hat{v}_5)$ using the fixed-point equation 2. Visibility, as indicated by "Signal at 5" in Figure 1, leads to a shift in the cut-off, v_5, to the left, meaning that individuals with lower types are now choosing $a_i^{s*} = 5$. However, given the magnitude of reputational returns $\triangle(\hat{v}_5)\lambda\omega$, only some individuals who previously chose $a_i^* = 4$ now vaccinate further, while everyone who chose $a_i^* < 4$ in the absence of visibility, will continue to choose the same number of vaccines. As v_5 shifted to the left, and lower types starting to vaccinate further, $E_s(v|a = 5) < E(v|a = 5)$ and $E_s(v|a < 5) < E(v|a < 5)$, meaning that visibility lowers the average type expectations for those who vaccinate at 5 (since some low type individuals moved in) and for those who vaccinate at less than 5 (since some high type individuals moved out).

3.1.2 Theoretical predictions

In Section 4 of this paper, I will experimentally manipulate the visibility of vaccines x and threshold number r to test their effects on the share of children vaccinated. I here lay out the theoretical predictions of the effect of x on the distribution $G(a)$ and the empirical predictions that follow from the underlying mechanisms and assumptions of the model.

Main outcome

1. $\frac{\partial Pr(a_i(v) \geq r))}{\partial x} > 0$ the probability of individuals choosing to vaccinate at at least r increases with visibility, if the action is perceived as socially desirable ($\omega > 0$) and individuals value others' perceptions of their type ($\lambda > 0$).

2. $\frac{\partial Pr(a_i(v) \geq r - \tau))}{\partial x} \geq 0$ the probability of individuals vaccinating at at least $r - \tau$ remains constant, unless all individuals who previously vaccinated at $r - \tau$ moved to r, such that $Pr(a_i(v) \geq r)) = Pr(a_i(v) \geq r - \tau)) \forall \tau \in \{1, 2...r - 1\}$.

3. $\frac{\partial Pr(a_i(v) \geq r + \tau))}{\partial x} \geq 0$ the probability of individuals choosing to vaccinate at at least $r + \tau$ depends on the cost-benefit structure of vaccination. The probability remains constant if the marginal

net benefits are constant or declining ($\frac{B(a_i;v_i)-C(a_i)}{a_i} \leq 0$), and it increases if marginal net benefits are increasing $\frac{B(a_i;v_i)-C(a_i)}{a_i} > 0 \ \forall \tau \in \{1, 2...S-1\}$.

4. $\frac{\partial^2 Pr(a_i(v) \geq r))}{\partial x \partial \lambda} > 0$ the effect of an increase in x is increasing in the value individuals assign to their social image.

5. $\frac{\partial^2 Pr(a_i(v) \geq r))}{\partial x \partial \omega} > 0$ the effect of an increase in x is increasing in the social desirability of being seen as type who chooses $a \geq r$. If there are no concerns of social approval or disapproval ($\omega = 0$), changing x should have no effect on vaccine outcomes.

Mechanisms

i. Individuals observe others' actions more often than not: $\text{Pr}_{-i}(a_i \geq r | a_i \geq r)) - \text{Pr}_{-i}(a_i \geq r | a_i < r) > 0$.

ii. Individuals form expectations about others' types conditional on the actions observed: $\triangle(v) = \text{E}_{-i}(v | a_i \geq r) - \text{E}_{-i}(v | a_i < r) > 0$.

Assumption

Individuals have imperfect information about others' actions, so that visibility in actions provides new information about others' actions (and subsequently types).

3.2 Social signaling with uncertainty

The above model assumes that individuals have perfect information about the future. However, uncertainty is a common feature of many decision-making processes in low-income countries. Individuals are exposed to cost or preference shocks, in the form of sickness of household members or unforeseen work obligations, that make it difficult to travel to the clinic. Instead of assuming that individual i has perfect information and ex-ante decides on the optimal number of vaccinations, I now consider the case where she decides in each period t whether to take her child for the next vaccine, or stop. The flow utility of a vaccine at time $t \in \{1, 2, 3, 4, 5\}$ is:[19]

$$u_{it} = b(a; v_i) - c(a) \quad + \quad \lambda \omega \triangle(\hat{v}_r) \mathbb{1}\{t = r\} + \epsilon_{it}$$

and the utility of stopping vaccination is:

$$u_{it} = \epsilon_{it}.$$

This gives the value function at time t is:

$$V_{it} = \max\{0, u_{it} + \underbrace{E[V_{it+1}|v_i]}_{\text{Continuation value}}\} \quad \text{for t} < 5$$

$$V_{i5} = \max\{0, u_{i5}\} \quad \text{for t} = 5$$

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[19]For simplicity I am dropping parameters here and denoting $u_t(a; v_i, x, r, \lambda, \omega)$ as u_{it}.

where $b(a; v_i)$ and $c(a)$ denote the marginal benefit and cost of vaccine $a \in \{1, 2, 3, 4, 5\}$, $\lambda \omega \triangle(\hat{v}_r)$ the reputational return from vaccinating up to $t = r$,[20] and ϵ_{it} a new, second source of unobserved individual heterogeneity in the form of iid type I extreme value shocks. Individuals are assumed to know the distribution of shocks, but only learn in period t about the realization of their shock. Individuals therefore maximize the *expected* future value of vaccines. This decision-problem is solved by backward recursion, with individuals optimizing according to the decision-rule: vaccinate if $V_{it} > 0$, stop otherwise.[21]

Comparing individual decision-making under uncertainty to that without, theoretical predictions 2 and 3 change. As individuals plan dynamically, individuals' decision to deviate from the optimal action chosen in the absence of visibility, is now partly decoupled from their decision to vaccinate up to r. Individuals choose to vaccinate further if the option value of signaling is sufficiently large (for them to expect to vaccinate up to r), and will stop vaccinating before reaching r if receiving a too negative cost draw. As a result, individuals are more likely to complete earlier vaccines ($r - \tau \ \forall \tau \in \{1, 2...r - 1\}$), even if not making it to r, where the signaling benefit occurs (formally $\frac{\partial Pr(a_i(v) \geq r - \tau)}{\partial x} \geq 0$, without the condition $Pr(a_i(v) \geq r) = Pr(a_i(v) \geq r - \tau)$). Further, individuals are more likely to vaccinate for $r + \tau$ vaccines even if the marginal net benefit of vaccination is declining. Some of the individuals who vaccinate up to r, receive a positive cost shock in $t = r + \tau$ making it optimal for them to vaccinate further.

Figure 2 shows how augmenting the social signaling model to include uncertainty changes the qualitative predictions of the model, by comparing the simulated effects of visibility at vaccine four and five on $G(a)$, for the cases with and without uncertainty. Extending the signaling model to include uncertainty produces less stark bunching predictions at thresholds $r \in \{4, 5\}$ and more continuous shifts in the distribution $G(a)$.

4   Experimental design

The first part of this section introduces the signaling mechanism used in this study and the different experimental treatment used to test the theoretical predictions. Next, I describe the selection and randomization of clinics and communities, followed by a discussion of the identification of signaling preferences. I then provide information about the timeline and the data sources collected at different points of the experiment. Finally, I discuss balance checks and compliance with the implementation protocol.

4.1   Experimental Treatments: Bracelets as Signals

To create visibility in actions, I experimentally introduce a signal - in the form of colored bracelets that children receive upon vaccination at public clinics. The bracelets create an opportunity for parents to publicly signal that they correctly vaccinated their child. Specifically, I introduce exper-

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[20]I am assuming we are in equilibrium, with individuals taking reputational returns as given.

[21]Further details on the solution to the dynamic problem are discussed in Section 6 of this paper.

imental variation in two ways to test the theoretical predictions of the model: (1) I increase the visibility of vaccination decisions; (2) I exploit the fact that children need to receive multiple vaccinations and place signals at different vaccination. Figure 3 displays the four experimental groups and the specific bracelet treatments that health workers implement at each of the five vaccinations:

Control Group: No bracelets are given to children at vaccinations.

Signal at 4: Children receive a yellow "1st visit" bracelet when coming for the first vaccine. Children keep the same bracelet for vaccines two and three. When a child comes in a timely way (before reaching six months age) for vaccine four, health workers exchange the yellow bracelet for a green "4th visit" bracelet. If a child comes late for vaccine four, the bracelet is exchanged for an identical yellow "1st visit" bracelet. At vaccine five, the bracelet is exchanged for a new but identical green "4th visit" bracelet (or yellow "1st visit" bracelet if the child was late for vaccine four).

Signal at 5: Children receive a yellow "1st visit" bracelet when coming for the first vaccine. Children keep the same bracelet for vaccines two and three, and the bracelet is exchanged for an identical yellow "1st visit" at vaccine four. If a child comes in a timely way (by 11 months age) for vaccines five, health workers exchange the yellow bracelet for a green "5th visit" bracelet. If a child is late for vaccine five, the bracelet is exchanged for an identical yellow "1st visit" bracelet.

Uninformative Bracelet: Parents can choose a green or yellow "1st visit" bracelet at vaccine one. Children keep the same bracelet for vaccines two and three. At vaccines four and five the bracelet is exchanged for a new identical "1st visit" bracelet of the originally chosen color.

In all three signaling treatments actions are grouped into two signals. In Signal at 4, others can only tell whether a child was vaccinated for four or more vaccines, or whether a child received fewer than four vaccines. In Signal at 5, the yellow and green bracelets allows others to observe if a child received five vaccines, or fewer. The Uninformative Bracelet allows parents to signal that their child started vaccination but provides no information about the completion of later vaccinations.

Figure 4 shows the actual bracelets that were given out at clinics. All bracelets were made out of silicone and were size-adjustable so that they could comfortably fit the wrist of a child between the ages of zero and twelve months. The latter was key for the experimental design i) as it made the bracelet a *durable signal* that could be observed by others and allow for comparisons beyond the time of the vaccination, and ii) so that the size of the bracelet would not be informative about the number of vaccinations a child has completed.[22] Over the course of the experiment, a total of 36,000 bracelets were handed out by health workers.

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[22]As a child's wrist grows, even in the absence of a change in bracelet color, a too small bracelet that no longer fits, could be informative about whether a child is up-to-date with its vaccinations.

4.2 Identifying Effects

The combined effect of increased salience (e.g. reminder, nudge effects), consumption utility, and social signaling preferences is captured by the comparison of the share of children vaccinated at vaccines four and five[23] in the Control Group to Signals at 4 and 5.

The comparison of Signal at 4 and Signal at 5 to the Uninformative Bracelet at vaccines four and five allows me to isolate the effect of social signaling preferences on vaccination decisions. I implement bracelet hand outs and exchanges in all three signaling treatments at the same vaccines in order to hold constant any additional consumption utility of bracelets. By distributing bracelets and using the colors green and yellow in all three signaling treatments, I further hold constant salience and reminder effects that are due to (1) the general visibility of vaccinations through bracelets, and (2) the introduction of new colors over time. In other words, the only difference remaining is what actions can be signaled, that is, the completion of a specific vaccine.

A larger increase in the share of children who are timely vaccinated for vaccine four in Signal at 5 compared to Signal at 4 implies a higher social signaling value in treatment Signal at 5 compared to treatment Signal at 4: $\lambda \omega_4 \triangle(\hat{v}_4) < \lambda \omega_5 \triangle(\hat{v}_5)$. This could be due to two reasons: (i) differences in the social desirability parameter for the timely completion of vaccine four and five, that is, $\omega_4 < \omega_5$, how much does society value the completion of these vaccines, or (ii) differences in the type expectations that others form upon observing the timely completion of vaccine four versus vaccine five, such that Signal at 4 is less informative about different types, that is, $E_{-i}(v|a_i \geq 4) - E_{-i}(v|a_i < 4) < E_{-i}(v|a_i = 5) - E_{-i}(v|a_i < 5)$.

An increase in the share of children who complete earlier vaccines (vaccines 1, 2, or 3 for Signal at 4; vaccines 1, 2, 3, or 4 for Signal at 5), without transition probabilities from vaccines three to four and four to five respectively equaling one, demonstrates the individuals make decisions dynamically and under uncertainty. Parents who vaccinate their children for earlier vaccines due to an increase in the future value of vaccination but do not make it to vaccine four (for Signal at 4) or five (for Signal at 5), must have *targeted* to complete four or five vaccines but stopped earlier due to unforeseen cost or preference shocks in later periods.

Finally, a comparison of the share of children vaccinated at vaccine five in Signal at 4 to the Uninformative Bracelet quantifies the extent to which observed treatment effects are due to some form of social learning or normative influence. If individuals have incorrect priors over the share of parents in their community vaccinating their children and are uncertain about the benefits of vaccination, observing signals about timely take-up of vaccine four or five, could lead to updates in beliefs about take-up levels and the usefulness of vaccinations. Similarly, health workers providing a "reward" to parents for vaccination, could act as a signal about the importance of vaccination for children's health. By design, parents in the Signal at 4 treatment have no signaling incentive to complete vaccine five, as green bracelets do not allow for a distinction between parents who took their children for four vaccines, versus those who went for five. An increase in the share of

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[23]I omit the comparison of the Uninformative Bracelet and the Control at vaccine one, since take-up is almost universal for the first vaccine.

children vaccinated at vaccine five could therefore be due to two reasons: (i) if uncertainty plays an important role, some parents who now complete vaccine four in Signal at 4 treatment receive a positive cost or preference and also take vaccine five; (ii) parents learn from signals about the benefits of vaccinations, leading them to also increase their valuation of vaccine five. To distinguish (i), which still falls within the predictions of the signaling model, from (ii) which is an alternative behavioral mechanisms, I can compute the transition probability between vaccine four and five. If I observe an increase in this probability in Signal at 4 relative to the Uninformative Bracelet, it strongly suggests that learning is a relevant alternative mechanism.

Lastly, to address concerns regarding learning about the importance of vaccine five in Signal at 5 compared to the Uninformative Bracelet or Control Group, I elicit individuals' preferences for the different vaccinations and test for differences across arms.

4.3 Clinic Randomization and Community Selection

Treatment was randomized at the clinic level so that every child living in the catchment area[24] of a clinic was eligible for the same bracelet treatment.[25] In total, I selected 120 clinics across four of Sierra Leone's 14 districts to be part of the study. To randomly draw 230 clinics from the pool of 335 public clinics across the four districts, I used an acceptance-rejection method whereby I randomly picked clinics, checked their acceptability based on their overlap with already selected clinics, and if accepted, added them to the selected sample. This process was repeated until it had selected the requisite number of clinics. If no acceptable clinic remained before completion, the whole process was restarted. Each clinic had a 5 mile radius as catchment circle. A clinic was considered acceptable if its catchment circle did not leave any of the already selected clinics' non-overlapping catchment circle smaller than 35 percent of its area. Clinics were then randomly assigned, stratified over the four districts and two implementation waves[26], to the three different treatments and the Control Group. Figure 5 shows the geographic span of the experiment across the four districts in Sierra Leone and the final selection of clinics. During the launch of the study in each clinic, surveyors selected - using in-field randomization - two communities at close distance (0 to 2 miles) and three communities at far distance (2 to 5 miles) from the clinic, from the pre-specified non-overlapping catchment are of each clinic. Figure A2, the upper map, shows the non-overlapping catchment areas and the lower map provides an example map for one of these clinic areas, that surveyors were given for the in-field selection. In total, the experiment included 578 communities. Table A8 provides a break down of the number of communities by district, as well as the mean travel distances between

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[24]A catchment area of a clinic is defined by the communities surrounding it that the clinic serves.

[25]Children that were born before the launch of the experiment and had already started vaccinations, would receive their first bracelet when coming for their next vaccination (e.g. "4th visit" green if came for vaccine five timely in Signal at 5 treatment).

[26]The experiment was phased in in two waves: wave one from mid-June to mid-July where 44 clinics were launched (11 in each of the intervention arms), and wave two from end of September to end of November where the remaining 76 clinics were launched.

clinics and communities. On average individuals walk 2 miles to clinics.[27]

4.4   Information Treatment

While such a high level of randomization significantly increased the logistical demands of the experiment, it was key to reducing the risk of incorrect implementation by health workers, and creating a common understanding of the bracelets among individuals.

At the launch of the experiment, surveyors visited each of the selected 578 communities to hold an information meeting with the community (see Table 1 Panel B for balance tests). The objective was to highlight the health and economic benefits of timely and complete vaccinations, to discuss existing barriers, and in signaling treatments, to inform a wide range of community members about the bracelets and create common knowledge about their meaning. The average meeting attendance was 43 people, with almost all meetings attended by a health representative (95 percent, e.g. a community health worker or traditional birth assistant) and a community leader (98 percent e.g. chief). A second information meeting was held with each community two to four months later, to again go over the importance of timely and complete vaccinations and discuss the meaning of the bracelets, now that clinics were handing them out.

4.5   Experiment Timeline and Data

Below, I illustrate the timeline for experiment implementation and the main data collection periods.

Jun '16 - Nov '16	**Experiment launch:** baseline clinic and community survey; training of 348 government health workers across 120 clinics in messaging to parents and implementation of bracelets; information meetings in 578 communities including close to 25,000 adults about the benefits of vaccination and meaning of bracelets.
Jul '16 - Apr '18	**Monitoring of implementation:** health workers hand out bracelets as part of regular monthly or weekly routine vaccination services at clinics; surveyors regularly visit clinics (every 1-2 months) to verify the correct hand out and exchanges of bracelets, messages given to parents, and recording of vaccine visits; training of new clinic staff in implementation; digitization of administrative records for ~ 37,892 children; follow-up information visits in communities.
Sep '17 - Jan '18	**Listing survey:** comprehensive listing of 14,061 children in selected communities.
Feb '18 - Apr '18	**Endline data collection:** survey of 1,314 parents and 120 nurses in charge of vaccination services; choice experiment with 123 parents in control group.

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[27]86 percent of parents surveyed during clinic visits report to travel to clinics by foot. 13 percent travel by motorbike and 1 percent by car. The average one-way travel time to a clinic is 49 minutes, the median time 35 minutes.

I will use several data sources that I collected at different points of the experiment for the analysis:[28]

(1) *Baseline data:*

(i) Clinic survey: survey of nurses in charge of clinic that records staff numbers, regularity of vaccination services (monthly versus weekly), supply side conditions (stock outs, cold chain), and list of catchment communities and characteristics (distance to clinic, size, proximity to other clinics) to determine eligibility for selection.

(ii) Community survey: survey conducted with participants of information meetings, knowledge about vaccinations, and perceived barriers to complete and timely vaccination; further captured data on attendance and implementation of meetings.

(2) *Administrative data:* Throughout the experiment, surveyors digitized vaccination records of children that visited our study clinics including names of children and parents, date of birth, vaccine received, date of vaccination and whether the child received a bracelet, the color of the bracelet, and whether the child had lost the bracelet.

(3) *Listing survey data:* surveyors conducted a census of all children (age 0 to 18 months) residing in the 578 selected communities, recording status of children (residing in community, traveling, permanently moved, deceased), names of children and parents, date of birth, list of vaccines received (from vaccine card and memory), date of vaccination, bracelet ownership and observability.

(4) *Endline data:* survey of 1,314 mothers[29] across 381 communities that were randomly sampled, stratified by distance (2 far and 1 close community for each clinic) from the list of 578 communities, eliciting first and second order beliefs about other children's vaccinations, bracelet and color, preferences and knowledge about vaccinations.[30]

4.6 Balance Checks and Compliance with Implementation Protocoll

Tables 1 and 2 report the experimental balance checks. I report results separately for clinic, community and individual level characteristics, as well as implementation of the experiment launch and main listing survey. 8 of 138 coefficients are statistically significant at the 10 percent level across all comparisons. Attrition is low and not affected by treatment: 11 percent of children had moved or were permanently traveling, and 2.6 percent of children were deceased at the time of the listing survey. There are no statistically significant differences in the timing of the clinic launches across treatments or the survey implementation. I further find no statistically significant difference in pre-trends.

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[28]The analysis includes 119 clinics, excluding one clinic in the urban Western Area where the implementation and data collection were seriously impeded by turn-over of clinic staff, relocation of selected communities and compliance in monitoring and data collection by the surveyor.

[29]I only surveyed mothers as they are the ones who take children for vaccines. I did not have sufficient funding to also survey other household members e.g. fathers. If mothers did not understand the signals, and there was no impact on beliefs, I would not expect to find effects for other household members.

[30]Choice experiment analysis to be added in future: including 123 parents from a random sample of 12 control clinics and 42 communities, eliciting preferences for bracelet color and love of variety through a two-stage choice experiment where mothers were first given a bracelet (random color assignment) as a gift for the participation in the endline survey and two weeks later the opportunity to exchange the bracelet for a new bracelet of the same or a different color for a cost, mimicking the cost of travel to the clinic.

To verify whether health workers correctly handed out and exchanged bracelets, surveyors asked each parent to report the bracelet color that was given to the child during vaccination, and the number of vaccines the child had received by that time. Figure 6 shows the fraction of children in each group that received a yellow, green, or no bracelet, conditional on the number of vaccines received. Almost every child had a bracelet (94%), with no significant differences across arms. In the Uninformative Bracelet treatment, there is no overall significant relationship between the number of vaccines a child has received and the reported bracelet color.[31] We can see that the majority of individuals prefer the color yellow (63%) over the color green (37%).
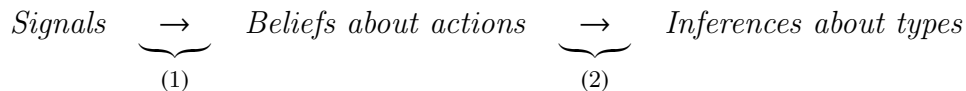
For Signal 4 and Signal 5, there is a clear relationship between child's bracelet color and the number of vaccination received: there is a large increase (up to 62% for Signal 4 and 70% for Signal 5) in the share of children with a green bracelet at vaccine four and five, respectively. Children who received vaccine four and/or five but had a yellow bracelet either came late for the vaccine or received the incorrect bracelet from health workers (see Figure A3 in Appendix). Therefore, a yellow bracelet on an older child[32] provides a noisy signal about the number of vaccines received. Conversely, almost no child (2.23%) is reported to have received a green bracelet before the signaling threshold. A green bracelet is therefore a highly informative signal about a child receiving vaccine 4 or 5 in the signaling treatments.

5   Do Signals Affect Vaccination Decisions?

I now present the main results of this paper, separately discussing the mechanisms underlying the theory. I will first test the extent to which individuals use signals to learn about others' actions and make subsequent type inferences, and second test the extent to which individuals' value the opportunity to signal that they correctly vaccinated their child for vaccine four and five.

5.1   Informativeness of Signals

In this experiment, the bracelet signals are aimed to create an opportunity for parents to show that they correctly vaccinated their child. For this to work, individuals must (1) learn about others' actions from signals, and (2) form expectations about others' types conditional on the signals observed. In this subsection, I will empirically verify these mechanisms and the assumptions associated with them.

$$\textit{Signals} \quad \underbrace{\rightarrow}_{(1)} \quad \textit{Beliefs about actions} \quad \underbrace{\rightarrow}_{(2)} \quad \textit{Inferences about types}$$

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[31]There is only a small significant increase in the share of children with a green bracelet for vaccine five.

[32]Child that is 6+ months in the Signal at 4 treatment or 11+ months in the Signal at 5 treatment.

5.1.1 Method

I first elicit individuals' first- and second-order beliefs about vaccine decisions and the perceptions of others.[33] To measure **beliefs**, I give each mother at endline a random sample of five other children in her community and asked separately for each child the following questions:[34]

1. "What is your relation to the child's mother?"

First-order beliefs

2. "How many vaccinations do you think this child has received?"[35]

3. "Does the child have a bracelet?; If so, what color bracelet does the child have?"

Second-order beliefs

4. "Do you think the mother knows that you have taken your child for [x] vaccines?"

5. "Do you think that the woman knows you have a [color] bracelet?"

To measure **perceptions**, each mother was asked about her perceptions of others' concerns about her own child's vaccinations:

1. "Is there anyone in your community or your house who is concerned about your child's vaccination?; If so, who?"

2. "How would community members view you?" and "What actions would they take if you?"

   a. "...took your child for all vaccinations?"

   b. "...missed taking your child for vaccinations?"

The sample used for the beliefs analysis is mothers of all children who were eligible to have received a specific vaccine. The sample size therefore differs across different outcomes.[36] For the analysis of perceptions, the answers of all mothers are included, as these questions are not specific to a particular vaccine, and therefore age category. All regressions include strata fixed effects, and standard errors are cluster bootstrapped at the clinic level. Beliefs regressions include controls for own or other child age and the relationship between endline respondents and other mothers. To assess the accuracy of first-order beliefs about other children's vaccinations, I linked respondents'

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[33]These questions were extensively piloted over the course of the experiment, to be easily understandable for respondents - regardless of their level of education - and to mitigate social desirability biases.

[34]If a mother did not recognize the name of another child/mother, she was given the name of a different child/mother until she identified a total of 5 children. On average, respondents were asked about 6.5 other children in their community and recognized 4.6 children. 74.39 percent of respondents were able to recognize 5 children. For those who recognized fewer, there were either fewer than 5 children in the community, or respondents were unable to recognize 5 other children. There are no significant differences in the average number of children recognized or number of children asked about across treatment arms.

[35]This question was incentivized: mothers received a small reward in form of a maggi seasoning cube (value of US 3 Cents) for each child they correctly guessed the number of vaccines.

[36]For example, the sample of children used in the analysis of beliefs about completion of vaccine four will be larger than that used for beliefs about vaccine five, since a greater number of children will have reached 3.5 months age (the time when vaccine four can be administered) by the time the endline survey was conducted, and fewer that were born since the start of the experiment would be 9 months age (the time when vaccine five is due) or older at endline.

answers with administrative clinic records of children.[37,38]

5.1.2 Do individuals learn from signals about actions?

Assumptions

For individuals to draw new information from signals, two assumptions have to be met: (i) individuals have imperfect information about other parents' vaccination decisions, (ii) signals are publicly visible. Table 4 quantifies the information asymmetries, revealing they are large. The Control Group means shown in Columns 1 and 2 indicate that mothers in the Control Group have accurate knowledge about the number of vaccinations a child received for only 45.1 to 46.5 percent of children in their community age 3.5 months and older.[39] Similarly, Columns 3 and 4 show that mothers believe that only 47.2 to 45.6 percent of other mothers in their community have knowledge about their own child's vaccination, if their own child is 3.5 months and older. There is no statistically significant difference in these information asymmetries across mother-pairs with distant and close relationships.[40] These findings suggest there is scope for signals to provide information about others' vaccination decisions.

Second, Table A4 shows that bracelets were highly visible in all three signaling treatments. Column 1 presents respondents' knowledge about whether other children in their community have a bracelet, while Column 2 presents respondents' beliefs about other mothers' knowledge of their own child's bracelet color. For 90 percent of children, mothers report knowing whether they have a bracelet.[41] For 95 percent of these children, respondents also report knowing the child's bracelet color.[42] Importantly, for the majority of children (87 percent), respondents state that they know the baby has a particular color of bracelet because they saw the child with that bracelet color. Only for 10 percent of children do respondents state that they know from the number of vaccines the child has (reverse inference) or because every child receives a bracelet.

Similarly, respondent mothers believe that 76.8 percent of other mothers know about their own child's bracelet color, with no significant differences across signaling treatments. The perceived knowledge of others about the color is key for any potential differential impact of Signal at 4 and

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[37]The challenge with vaccinations is: as children are all of different ages, they all have different due dates for the specific vaccines. In order to accurately measure the correctness of beliefs, vaccination data has to be collected at the (almost) same time as beliefs are elicited. Using earlier collected vaccine data, such as the listing data, would mismeasure information asymmetries. Digitizing administrative clinic records, also allowed me to verify beliefs for a larger sample of other children - instead of just for respondent-other mother pairs where both were surveyed at endline and their children's vaccine data directly collected from mothers.

[38]Only 2 percent of respondent-other mother belief answers could not be verified, since surveyors were unable to find administrative records for 49 children (out of the total 2353 other children). There is no significant difference in the share of children not found across intervention arms.

[39]The age range at which they are eligible for Vaccine four and five.

[40]39 percent of other mothers were identified as regular community members, while 35 percent as relatives (see Table **??**).

[41]Only four percent of children are believed to have no bracelet (with equal probability across arms).

[42]There is a significant difference in respondents' reported knowledge about other children's bracelet color between treatment groups. 98 percent of Signal at 4 and Signal at 5 treatment groups report knowing other children's colors. This number drops to 90 percent in the Uninformative Bracelet group - a significant difference of eight percentage points.

5, compared to the Uninformative Bracelet. The visibility of bracelets for all signaling treatments is further verified by the fact that retention of bracelets was similar across groups (see Appendix, Table A5).

Beliefs Updating

Figure 7 shows mothers' beliefs about the number of vaccinations other children in their community received, conditional on bracelet color, testing the underlying mechanism that signals convey information about others' actions[43]:

$$Pr_{-i}(a_i \geq r|\text{Green}_i) - Pr_{-i}(a_i \geq r|\text{Yellow}_i) > 0.$$

Using respondents' joint beliefs about the color of bracelet a child has and the number of vaccines the child has completed, I compute the conditional probabilities of a child having completed at least three, four, or five vaccines, conditional on having a yellow or green bracelet. The almost perfectly overlapping green and yellow bars for the Uninformative Treatment group [44] in Figure 7 demonstrate that there is no significant difference in the probabilities that mothers assign to children having completed vaccines three, four, and five when comparing children with yellow bracelets to those with green bracelets. In contrast, for Signal at 4 and Signal at 5, I observe large and significant differences in the probabilities assigned: mothers in both treatments believe that 57 and 68 percent of children (respectively) with a yellow bracelet completed vaccine four, compared to 90 and 98 percent of children with a green bracelet - an increase by 34 and 30 percentage points respectively. The same applies to vaccine five: mothers in both treatments believe that 36 and 37 percent of children (respectively) with a yellow bracelet completed vaccine five, compared to 62 and 78 percent of children with a green bracelet - an increase by 28 and 41 percentage points respectively. While different in magnitude, there is no statistically significant difference between individuals' inferences in the Signal at 4 and Signal at 5 treatments. Both signals were equally potent in indicating parent's vaccination decisions.

Figure A4 reveals that individuals' beliefs are consistent with Bayesian learning. Mothers in Signal at 4 and Signal at 5 correctly recognize that some children with a yellow bracelet came for vaccines four and five (either because of untimeliness or implementation errors). The comparison further reveals that mothers do not fully update their beliefs in response to bracelet signals: the probabilities assigned to a child having attended vaccine four in Signal at 4, and vaccine four and five in Signal at 5 should have been one.

To what extent did signals reduce information asymmetries about actions? Columns 1 and 2 in Table 4 show that mothers have more accurate knowledge about other parents' vaccination decisions in their community: mothers are between 17 and 23 percent more likely to correctly infer the number

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[43]The probability that others assign to a mother's own child having completed vaccine a conditional on her child's bracelet color, is equivalent to the probability that the mother assigns to other children having completed vaccine a conditional on their bracelet color.

[44]The difference between the conditional probabilities for vaccine five for children with green versus yellow bracelets, in the Uninformative Bracelet treatment, is not statistically significant.

of vaccines a children have received in Signal at 4 and 5 treatments compared to the Control Group - for both younger (eligible for vaccine four) and older children (eligible for vaccine five). This result is corroborated by the treatment effects on second-order beliefs displayed in Columns 3 and 4: mothers are significantly more likely to believe that other mothers have greater knowledge about their own child's vaccinations, with significant increases between 10 to 17 percentage points over the control means of 47.2 and 45.6 percent, for children eligible for vaccine four and five respectively. Treatment responses are larger, up to twice in magnitude, for Signal at 4 and 5 compared to the Uninformative Bracelet though I cannot reject that the coefficients for the three treatment groups are equal. I find no significant difference in changes in information asymmetries across mothers with both distant and close social connections.

5.1.3 Do individuals learn from signals about types?

Figure A5 shows that mothers believe that community members[45] form different opinions about them - in terms of their intrinsic motivation - depending on the vaccinations that their child completed. 92 percent of mothers state that others would view them as "caring" if they took their child for all vaccinations, and "careless" if they missed any, verifying the underlying mechanism that higher actions are linked to higher types, that is:

$$E_{-i}(v|a_i \geq r) - E_{-i}(v|a_i < r) > 0.$$

On the contrary, few believed that others link their vaccine decision to their knowledge about benefits $B(a_i)$ (e.g. "know of importance", or "are ignorant") or cost-factors $C(a_i)$ (e.g. "are too busy with work", or "too poor to travel to the clinic"). These answers also shed light on the question of what individuals are trying to signal to others when making actions visible (Bursztyn and Jensen 2015). There are two immediate explanations in my context: (i) mothers want to signal that their child is healthy and does not pose a threat to other children in terms of spreading diseases ($\sim$ inference about child's health status); (ii) mothers want to show that they look after their child's health ($\sim$ inference about responsible parent). The first explanation does not seem to be a motive for signaling: the majority of mothers view vaccines as beneficial only to their own child's health and lack an understanding of the externalities of vaccination. Specifically, fewer than 20 percent believe that other, unvaccinated children can be harmful to their own child's health, or that their child could be harmful to others if not vaccinated.[46]

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[45]Community members are one of four main reference groups mothers believe are concerned about their child's vaccinations. 61 and 62 percent of mothers respectively named their husband/father of the child and family members as individuals who are concerned, and named second, with 30 and 36 percent respectively, regular community members and community health workers/nurses.

[46]At endline 91 percent of mothers believe that vaccinations are helpful for their own child's health, stating that "[they] help my child to grow well and healthy" and "prevent my baby from paralysis [and] blindness". Only 15 and 19 percent of mothers respectively agree that other children can pose a risk to their child when not being vaccinated, or that their child could be harmful to others if she is not vaccinated, stating reasons such as: "Because if she is not immunized, she can transfer diseases like measles if she happens to contact it". When mothers are asked why they think their vaccination decisions cannot help others, common answers were: "'Because they do not have the same body, or same blood" or "because the vaccines in my child won't jump and help other children".

Taken together, the mechanism results show that mothers in the Signal at 4 and 5 treatments, as intended, used the color of bracelets to learn about other children's vaccinations, and make different inferences about parents' motivation to look after their child's health conditional on their vaccine decisions.[47]

5.2 Effect of Signals on Vaccine Decisions

The main outcome of the experiment is the share of children vaccinated in a timely manner for a given vaccine. The experimental design allows for a direct test of the effect of social signaling preferences on the outcome. Having established that bracelets as signals were informative about parents' actions and their types, this subsection tests to what extent parents value signaling that they look after their child's health. Specifically, the reduced form tests if the parameters λ and ω jointly are greater than zero.

5.2.1 Empirical Strategy

My preferred specification for the main outcome is:

$$Vaccine_i = \alpha + \beta T_{j(i)} + \delta X_i + \rho_{s(i)} + \varepsilon_i \tag{4}$$

in which Vaccine$_i$ denotes the binary outcome variable for a child i being vaccinated for a given vaccine $a \in \{1, 2, 3, 4, 5\}$ by the age of 3 months for vaccine one, 4 months for vaccine two, 5 months for vaccine three, 6 months for vaccine four, and 11.5 months for vaccine five; $T_{j(i)}$ are treatment indicators for Signal at 4, Signal at 5, and the Uninformative Bracelet assigned at the clinic level (j); X_i denotes the control variables of child age and an indicator for the administrative data; and $\rho_{s(i)}$ denotes the strata fixed effects. Standard errors are cluster bootstrapped at the clinic level.

The timeliness cut-offs were determined following WHO guidelines that state that the DTP series should be completed by six months of age (WHO 2018). I allow for an equal 2.5 months buffer window for each vaccine such that for vaccine one, which is due at birth or shortly thereafter, the timeliness cut-off is set at 3 months, for vaccine two which is due at 1.5 months, the timeliness cut-off is set at 4 months, etc. In the main specification, I code children that received a given vaccine before the timeliness cut-off as one and zero otherwise. In the later part of the analysis, I will also consider the effect of signals on complete vaccination by the age of one year, independent of the time a child received the vaccine.

I combine data collected during the listing survey with data from administrative clinic records to measure outcomes. The listing survey data provides the sample of all children that reside in the selected communities and were born since the launch of the experiment. I use the administrative

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[47]Beyond the *opinions* that mothers believe others will form about them as parent, they also name specific *actions* that they believe others will take. 74 percent of mothers (see Figure in the Appendix) believe that others would scold them if they missed vaccinations, while 22 percent said they would be praised in the community and people would speak well about them.

data to extend the vaccine history for children that had not yet reached one year of age at the time of the listing survey.[48] Given the sequential timing of vaccines and the corresponding timeliness cut-offs of 3, 4, 5, 6 and 11.5 months, I observe more children for vaccine one and two than for vaccines four or five. I include all available data and the sample size therefore differs across the five different vaccine outcomes. In total, I observe 7,482 children for vaccine one, 7,052 for vaccine two, 6,095 for vaccine three, 5,909 for vaccine four and 2,350 children for vaccine five across 119 clinics and 578 communities.[49] For children age one year and above, I observe a total of 1,972.

5.2.2 Effect of Signals on Timely Completion of Vaccines 4 and 5

The discussion of the empirical results follows the theoretical predictions outlined in Section 3.1.1 and the experimental identification outlined in Section 4.2.

I first examine the effect of signals on timely completion of vaccines:

$$\frac{\partial Pr(a_i(v) \geq r))}{\partial x} > 0$$

Figure 8 shows the combined effect of Signals at 4 and 5 on the share of children timely vaccinated for all five vaccines over the Control Group. Vaccination levels in the Control Group reveal a sharp drop-off between vaccines three and four (11.7 percentage points), and vaccines four and five (19.3 percentage points), illustrating the scope for parents to signal the timely completion of these vaccines. The signaling treatments led to a significant increase in the share of children that received vaccine four and five, increasing timely shares from 73 to 80 percent and from 54 to 62 percent, respectively. The effects indicate that the signaling treatment reduced drop-off by 56 and 44 percent, respectively.[50]

The effect is masked by substantial heterogeneity.[51] Figures 9 and 10 show treatment responses for each signal separately: Signal at 4 led to a small and insignificant increase of 2.8 percentage points for vaccine four, and 3.8 percentage points for vaccine five. Signal at 5, on the other hand, led to a significant and large increase of 10.6 percentage points for vaccine four, and 13.7 percentage points for vaccine five. A comparison between the Uninformative Bracelet and the Control Group, in Figure 11, reveals that the effect of bracelets as a consumption incentive and reminder nudge was limited: I find small to moderate treatment effects of the Uninformative Bracelet of 2.5 and 5.5 percentage points for vaccine four and five respectively.[52] [53] As a result, the effects of Signal at 5 for vaccines four and five remain large and significant (8.1 and 8.2 percentage points) when compared to the

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[48]As indicated in the timeline in subsection 4.5, the listing survey was implemented between September 2017 and January 2018, while the administrative data was collected between February and April 2018 and therefore provides further information about children's vaccinations.

[49]One clinic of the 120 selected, located in Western Area (WA) Rural district is excluded from the analysis due to serious complications in the implementation and data collection.

[50]Regression results for all comparisons can be found in Table 5.

[51]Regression results for all comparisons can be found in Table 6.

[52]The effects on vaccine five are mainly driven by a large positive effect early in the experiment.

[53]See treatment effects for first two birth cohorts after the launch in Figures 15 and 16.

Uninformative Bracelet, providing compelling evidence for social signaling preferences. Bracelets as signals for completion of vaccine five increased timely completion of the DTP series to levels necessary to reach herd immunity for diphteria.[54]

5.2.3 Social Desirability of Different Signals

I now examine the social desirability of different signals:

$$\frac{\partial^2 Pr(a_i(v) \geq r))}{\partial x \partial \omega} > 0$$

Health workers in both Signal at 4 and Signal at 5 implemented the same bracelet hand outs and exchanges,[55] with the only difference being the vaccine at which children receive a green bracelet.[56] Moreover, as shown in the previous subsection, bracelets were equally visible and informative about actions across both signaling treatments. Observed differences in treatment responses therefore must be linked to differences in the signaling *value* of each bracelet, either caused by (i) differences in the social desirability of actions, i.e. ω or (ii) differences in type expectations, i.e. $i(\hat{v})$. The similarly large drop-off between vaccines three and four and vaccines four and five, and mothers' awareness of both (see Figure 7[57]), suggests that there should be a similar wedge in type expectations for Signal at 4 and Signal at 5, rendering (ii) an unlikely reason to explain such a large difference in treatment effects.

To capture differences in social desirability, mothers were asked at endline what they considered to be the most (and second most) important vaccine.[58] Figure 14 shows that mothers assign a higher importance to vaccine five than vaccine four, considering the fourth vaccine overall to be the least important among the five and ranking vaccine five as the second most important vaccine after vaccine one. These preferences (taken at face value) imply a low valuation of a signal for vaccine four, and a higher valuation of a signal at vaccine five.

This raises the question: how informative is Signal at 4 about a child having received vaccine five? Put differently, if Signal at 4 is as informative about the completion of vaccine five, as is Signal at 5 then we would expect to see similar treatment effects for both, despite the differences in preferences. Figure 14 (Vaccine 5) shows that both Signal at 4 and 5 were significantly more informative about the completion of vaccine five than was the Uninformative Bracelet. In terms

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[54]Herd immunity for diphtheria requires 83-85 percent (Anderson and May 2013) of the population to be vaccinated with all three doses.

[55]Table A4 Column 3 shows that there are no significant differences in bracelet exchanges at vaccines four and five across Signal at 4, Signal at 5, and the Uninformative Bracelet.

[56]While there are fewer children that have a green bracelet in Signal at 5 compared to Signal at 4 treatment, I find no evidence for that scarcity or abundance of green (compared to yellow) bracelets could drive the observed differences in treatment effects.

[57]Comparing mothers' beliefs about take-up, the probabilities assigned to a child (unconditional on bracelet color) completing vaccines four and five are approx. 90 and 70 percent respectively.

[58]Ideally, I would also have elicited second-order beliefs about preferences, asking mothers what they thought others thought were the most important vaccines. Piloting showed that these question are difficult to implement.

of magnitude, Signal at 4 was approximately two-thirds as informative about the completion of vaccine five as Signal at 5.[59] Scaling the observed treatment effect on vaccine four for Signal at 5 accordingly,[60] we would expect to see a treatment effect of around 7.2 percentage points on vaccine four for Signal at 4. The actual point estimate is 2.8 and therefore 2.5 times smaller. Given the noisiness of the coefficient one should consider the confidence interval of the estimate, which does include the value.[61] I interpret these results as evidence for the importance of linking signals to actions that are commonly perceived as valuable, and that the information they provide about other closely-related actions might be down-weighted by individuals.

Reassuringly, Table A1, shows that there are no significant differences in individuals' preferences for different vaccines across treatment and control groups, ruling out that the observed treatment effects for Signal at 5 are due to normative influence of signals or social learning.

5.2.4 Effect of Signal at 5 on Timely Completion of Earlier Vaccines

I next examine the effect of Signal at 5 on vaccinations before the signaling threshold at vaccine five:

$$\frac{\partial Pr(a_i(v) \geq r - \tau))}{\partial x} \geq 0$$

Figures 10 and 12 depict that in addition the treatment effects at vaccines five and four, Signal at 5 also led to significant increases in the share of children that were vaccinated for vaccines three (7.1 and 4.2 percentage points) and two (4.3 and 1.8[62] percentage points compared to the Control Group and Uninformative Bracelet). The pattern of treatment responses reveals that parents were more likely to vaccinate their children for earlier vaccines, without necessarily making it to vaccine five. That is, parents responded to a signaling benefit at vaccine five ($\sim$ option value of signaling) six to nine months in advance, without being able to necessarily realize the benefit. These effects are consistent with the theoretical predictions from the signaling model discussed in Section 3.2 where individuals make decisions dynamically under uncertainty. More generally, this responses to treatment imply that individuals aim to complete later vaccines, but drop out early due to unforeseen preference or cost shocks.

Table 7 Column 1 combines the reduced form treatment estimates for all five vaccinations. Signal at 5 significantly increased the average total number of vaccines completed from 4 to 4.4, over the Control Group and from 4.2 to 4.4 over the Uninformative Bracelet. I find no significant difference between the Uninformative Bracelet and Signal at 4.

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[59]Simple calculation: $\frac{Pr^{S5}_{-i}(a_i \geq 4 | Green) - Pr^{S5}_{-i}(a_i \geq 4 | Yellow)}{Pr^{S4}_{-i}(a_i \geq 4 | Green) - Pr^{S4}_{-i}(a_i \geq 4 | Yellow)} = \frac{0.28}{0.41} = 68.29$.

[60]10.6 percentage points $\cdot$ 0.68 = 7.2 percentage points.

[61]Note that the confidence interval is: [-5.43,11.03].

[62]The effect for vaccine two of Signal at 5 compared to the Uninformative Bracelet is only marginally significant with a p-value of 0.11.

5.2.5 Treatment Effects over Time

Figures 15 and 16 plot the time trends of average treatment effects of Signal at 4, Signal at 5, and the Uninformative Bracelet, compared to the Control Group for vaccines four and five, by birth cohorts. Children are binned into birth cohorts of two months. The vertical grey line represents the time of the launch of the experiment. Looking at effects over time for Signal at 4, there is some indication of a positive trend in treatment effects for children born six to 12 months after the roll out. Such patterns are consistent with a signal with an initially low value, due to it being linked to an action that is not considered relevant for social image concerns, but that becomes more valuable as the visibility and salience of the action increases the relevance that people assign to it. For the Uninformative Bracelet, I observe the opposite trend: the bracelet led to large and significant increases in timely take-up of vaccine four for children born zero to four months after the roll out, but had zero effect for cohorts born six to 12 months after the launch. Importantly, for Signal at 5, the patterns across time shows consistently high treatment effects of 10 percentage points for vaccine four, which persist for children born 12 months after the launch of the experiment (see Figure 15). For vaccine five, where I observe fewer cohorts (see Figure 16), treatment effects seem to increase over time, from 7 percentage points for children born immediately after the roll out to 16 percentage points for children born six months into the implementation.

5.2.6 Intensive vs. Extensive Margin Effect of Bracelets

Signals were tied to the timely completion of vaccinations. An alternative measure used in public health is the share of children that received a given vaccination by the age of one year. Table 8 Columns 1 to 3 show that almost all children had received vaccine one, two and three by twelve months age, with levels of completion at 98.9, 97.8 and 95.3 percent. However, there is still a substantial drop off for vaccines four and five, with 88.1 and 67.6 percent of children completing those. Columns 4 and 5 shows the effects of all three bracelet treatments on the share of children vaccinated for vaccines four and five, compared to the Control Group.[63] Signal at 5 treatment not only led to intertemporal shifts, encouraging parents to vaccinate their children more timely, but also led to shifts on the extensive margin, with more children getting vaccinated by the age of one: shares increased by 5.2 (to 93.3 percent) and 13.5 percentage points (to 81.1 percent) for vaccines four and five respectively. Treatment effects are similarly large for Signal at 4 and the Uninformative Bracelets for vaccines four (5.4 and 5.8 percentage points) and five (10.1 and 8 percentage points respectively). Bracelets, as small rewards, incentivizing parents through their consumption value, or by increasing the salience of vaccines, acting as a reminder, had a significant and large effect on the completion of routine vaccinations by the age of one year. Particularly relevant for protection levels against these diseases, bracelets raised completion rates for the DTP series to over 93 percent,

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[63]Note: by changing the definition to children vaccinated by the age of one, I restrict the sample to children who were at least one year old by the end of the experiment, which results in a sample that is composed of birth cohorts who were early on exposed to the intervention. Given the dynamics observed in Figures 15 and 16 for the Uninformative Bracelet, it is plausible that extensive margin effects would look different for this treatment for children that were born later.

reaching immunization rates necessary for herd immunity against whooping cough, and increasing Measles vaccination rates up to 81 percent.

5.3 Discussion

The preceding analysis yields three main takeaways. First, the results provide the first field experimental evidence of the impact of social signaling in a low-income setting, showing that individuals are willing to take meaningful actions to signal their type as good parents. Parents vaccinated their children more timely, and completed on average an additional 0.5 vaccinations at a cost of 1 USD per child. This finding provides compelling evidence for the potential of social signaling, as an informal enforcement mechanism[64], to increase public goods. Second, the findings show that for signals to be effective, they need to both be informative about individuals' actions and to be *clearly* linked to actions that are sufficiently valued and therefore considered as socially desirable. By placing a signal on an action that is commonly valued, individuals can be motivated to take actions they value less, such as taking their child more timely for vaccine four. Alternatively, signals may need to be combined with a normative messaging intervention, that highlights the externality effects of an action and increases social image concerns through that. Third, these results show that parents make dynamic decisions when deciding about the optimal number of vaccinations. Parents respond to the option value of signaling, by taking their children timely for earlier vaccines, without necessarily making it to vaccine five and realizing the benefit. This is relevant information when considering the optimal structure of signaling or other types of incentives. For example, there is a multitude of (preventative or curative) health behaviors where individuals are required to follow through with multiple visits but after initial take-up of treatment people drop out (Bai et al. 2017). My results highlight that a non-linear incentive scheme, with a social signaling benefit in the far future, can be effective at mitigating drop out. However, given the continued "gap" between individuals' target number of vaccinations and the actual number of vaccinations they complete, a linear incentive scheme, with a benefit at each vaccine could potentially lead to further increases in completion rates.

6 The Value of Social Signaling under Dynamic Decision-Making

In order to quantify the value of social signaling taking into account i) the dynamic nature of decision-making, where parents respond to the option value of social signaling and ii) the uncertainty over future cost or preference shocks, I estimate a structurally estimate a dynamic discrete-choice model. I use distance to the clinic as a numeraire to price out the signaling value. To do so, in this section, I first demonstrate the reduced form relationship between distance and its impact as a cost on vaccination outcomes. Secondly, I set up the dynamic model estimating the relevant parameters.

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[64]Compared to formal laws that require parents to vaccinate their child for them to be allowed to attend daycare, like in the U.S..

6.1 Distance as Cost in Reduced Form

Figure A8 plots a bin scatter of the average number of timely vaccines completed against the travel distance from communities to clinics, separately for the Control Group and Signal at 5. Distance has a linear effect on the number of vaccinations completed: in the Control Group, the total number of vaccines completed declines from 4.25 at zero miles to 3.5 vaccines at five miles. Figure 17 shows the effect of distance on the share of timely vaccinated children by vaccine. Each vaccine graph plots a bin scatter of the share of children vaccinated (for vaccine 2, 3, 4 and 5) against the distance from communities to clinics, separately for the Control Group and Signal at 5. It is evident again that distance has a linear effect on the share of children vaccinated for each vaccine. Importantly, both figures make clear that Signal at 5 mitigated the negative effect of distance, increasing the share of children vaccinated at four miles to that of children vaccinated at zero miles. Differently put, the reduced form results show that Signal at 5 increased parents' willingness to walk for a given vaccine by four miles distance to the clinics.

It is important to note that distance was not exogenously varied in this experiment. We should therefore be worried about the effect of distance on vaccination behavior being confounded by other observable or unobservable characteristics. While I cannot account for the latter, Tables A2 and A3 show that the inclusion of relevant observable characteristics, such as mothers' education, economic status, or the birth order of children, has no significant effect on the impact of distance on vaccinations in the endline sample.

6.2 Quantifying Social Signaling Utility

Following the discussion of the model of signaling under uncertainty in Section 3.2, I empirically specify the flow utility at time $t \in \{1, 2, 3, 4, 5\}$ as follows:

$$U_{it} = v_i - \kappa D_i + S_4 T_{4i} \mathbb{1}\{t = 4\} + S_5 T_{5i} \mathbb{1}\{t = 5\} + \epsilon_{it}. \tag{5}$$

The model includes two dimensions of unobservable heterogeneity: (i) ϵ_{it} cost or taste shocks which are independent and identically distributed (iid) extreme value type I, and (ii) individuals differ in their type v, which is assumed to be randomly drawn from a normal distribution in period zero and is persistent across time t. The mean μ_v and variance σ_v of the type distribution will be identified in the structural estimation as I observe individuals making decisions across multiple periods. Further, the model includes two dimension of observable heterogeneity: (i) individuals' travel distance D_i which discretely varies from zero to five miles and (ii) the signaling treatments T_{4i} and T_{5i} which are exogenously assigned. The parameter κ captures the marginal disutility of one additional mile distance to the clinic. The parameters S_4 and S_5 capture the social signaling utility $\lambda \omega_r \Delta(\hat{v}_r)$.

The reduced form effects of the Signal at 5 treatment at earlier vaccines operate solely through option value. The implied valuation must be filtered through individuals' expectations about the probability that they make it to the end and receive the signaling payoff. At $t = 5$ there is no option value component left and the problem becomes a static one, but the valuation is that of a

non-random subset of individuals (in terms of their type v), and not the type population as a whole. Computing the valuation from the reduced form requires linking of all the choice probabilities and treatment effects at each t together. The structural model allows me to do that. I estimate the model using maximum likelihood.

Table 9 presents the results from the structural estimation, with Column 1 showing the parameters from an estimation where I compare the shares of children vaccinated timely in Signal at 5 and Signal at 4 to those in the Control Group, and Column 2 showing the parameter estimates comparing both signaling treatments to the Uninformative Bracelet. Taking the ratio of the parameters S_5 and κ gives an estimate of the social signaling utility in miles. On average, parents' valuation of social signaling is equivalent to 7 to 10 miles walking distance to the clinic.

7   Conclusion

This study analyzes the effect of social signaling in the dynamic setting of childhood immunization, examining how individuals respond to the opportunity of signaling to others that they are responsible parents. Different to most studies, the experiment implements a durable signal that allows parents to continuously signal their type over the first year of a child's life. My results suggest that the effects of social signals are large, when the action signaled is sufficiently valued. This provides impetus for future research on how the effects of social signals could be enhanced if they are combined with normative messages that emphasize the otherwise undervalued social benefits of actions (like the completion of vaccination series). Moreover, this study shows that individuals' response to signals is consistent with decision-making under uncertainty, shedding light on the constraints that parents face to timely vaccinating their children in contexts like Sierra Leone. It is a question for further research whether a non-linear incentive scheme, where a signaling benefit is only provided at completion of all vaccines is optimal, or if a more linear scheme with signals at multiple points could lead to further reductions in drop-off. On the one hand, signaling benefits might be smaller if there is less scope for parents to separate themselves from others in their intrinsic motivation; on the other hand, if the variance of cost shocks is large, even a smaller signaling benefit at each vaccine could compensate parents for unanticipated cost shocks.

Overall, the findings of this study are of substantive policy importance: signals increased immunization rates to levels necessary for herd immunity at a cost of 1 USD per child. Moreover, they address a problem pertinent to many low-income countries: scarcity of trained health workers and relatively low rural population density. As social signals increase parents' willingness to travel further to receive vaccinations, health workers can remain at clinics and make themselves available to as many patients as possible. Importantly the effects of this intervention persist for children 12 months after the launch of the experiment, demonstrating that a subtle behavioral intervention like this can feasibly be implemented at a large-scale through existing government institutions.

Figure 1: Simulation of the Effect of Signaling at Vaccine 4 and 5 on the Cumulative Distribution of Vaccinations, With and Without Uncertainty
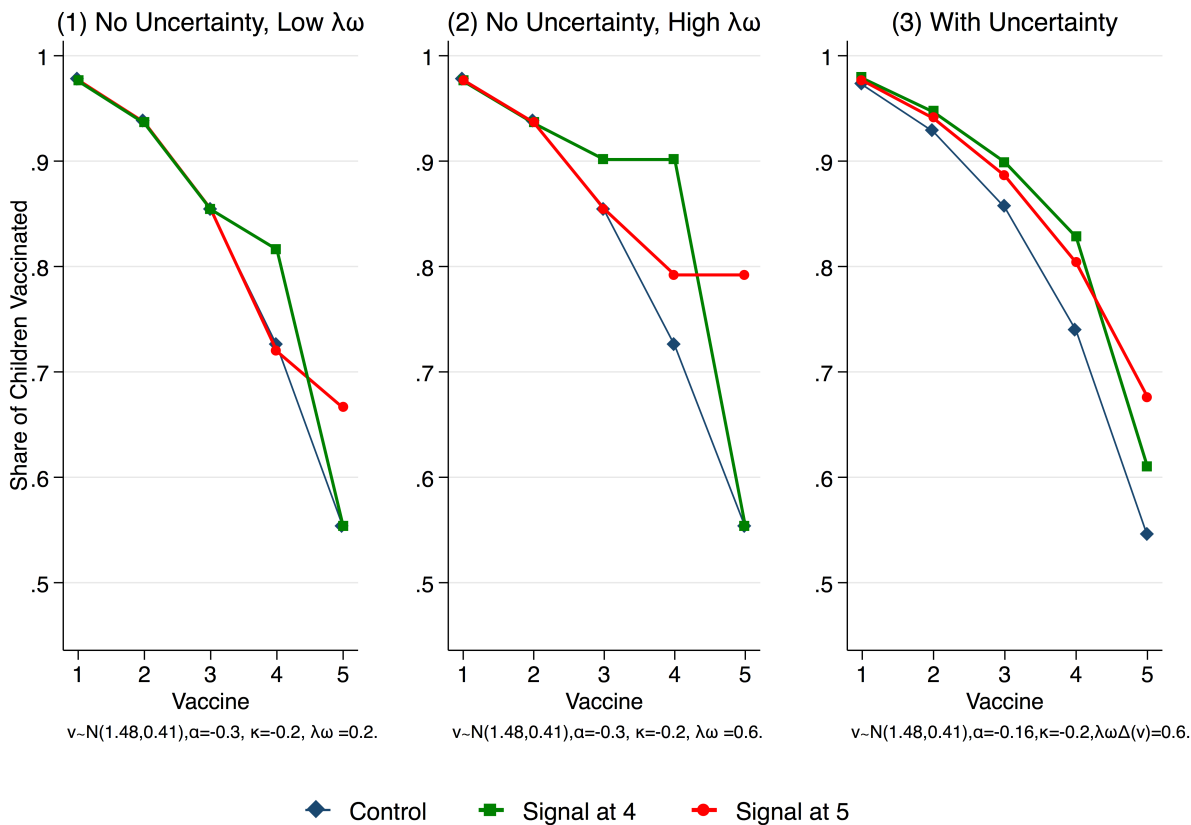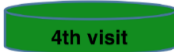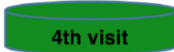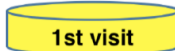

Notes: This figure shows the simulated cumulative distributions of vaccine take-up for the case without signaling (x=0) - calibrated based of the observed levels of vaccine take-up from the Control Group - and with signaling at Vaccine 4 and 5, with and without uncertainty over future cost or preference shocks. Individual i's utility is given by: $U(a_i; v_i) = (v_i - \kappa D)a_i - \sum_{a=1}^{a=a_i} \alpha a + x\lambda\omega \mathbb{1}(a_i = r)[E(v|a_i \geq r) - E(v|a_i < r)]$ with two signaling thresholds $r \in \{4, 5\}$ and $D = 2$ set to the mean walking distance. The parameter values used are indicated under each graph, with $\lambda\omega$ being set to 0.2 in graph (1) and to 0.6 in (2). For the no uncertainty case, displayed in graphs (1) and (2) I solve the fixed-point equation 2, to obtain v_4^s and v_5^s and the corresponding equilibrium type expectations $\triangle(\hat{(v)}) = E_s(v|a_i \geq r)$ - $E_s(v|a_i < r)$. For the case of uncertainty, I assume that signaling utility $\lambda\omega\triangle(\hat{(v)})$ is the same as under certainty with $\lambda\omega = 0.6$ and simulate vaccine take-up, assuming that shocks ϵ_{it}, which are iid type I extreme value distributed, enter i's utility function.

Figure 2: Simulation of the Effect of Signaling at Vaccine 5 on Cut-off Type and Expectations
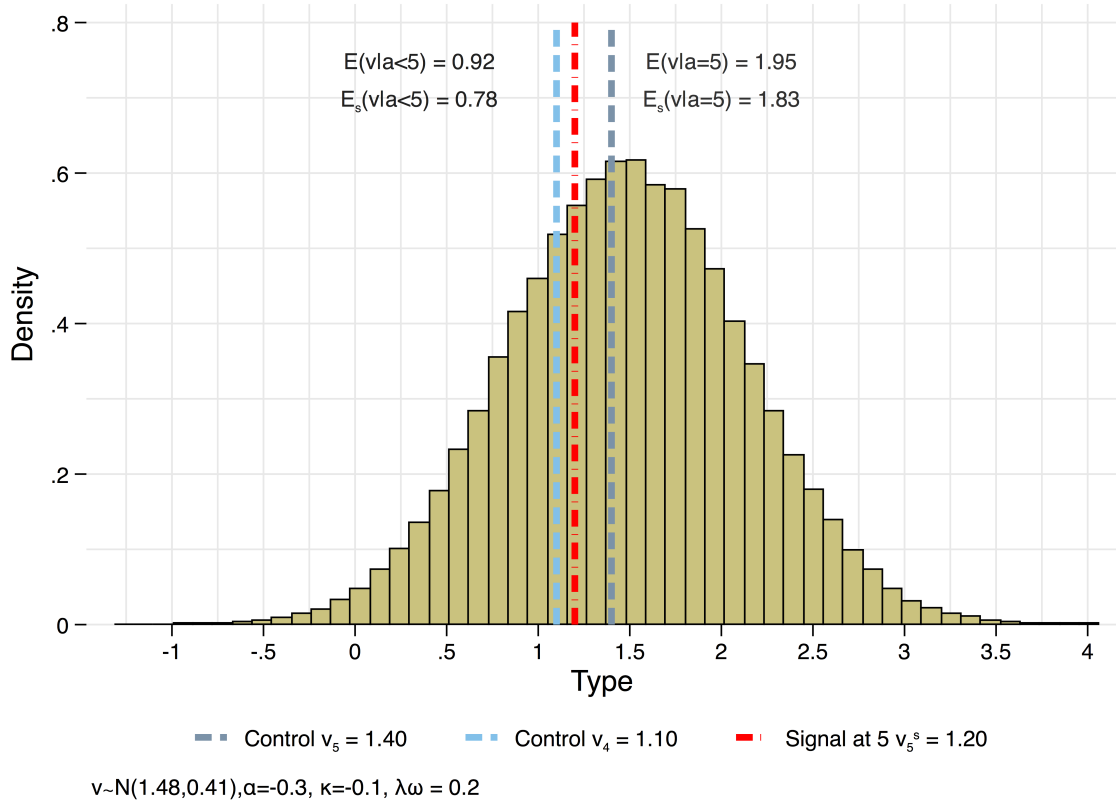
Notes: This figure shows a simulated type distribution, calibrated based on the observed levels of vaccine take-up in the Control Group. I assume that the type distribution is normal, the marginal cost of vaccination is constant (captured by the parameter κ interacted with D miles walking distance to the clinic) and the marginal benefit is declining (captured by the parameter α), with individual i's utility being given by: $U(a_i; v_i) = (v_i - \kappa D)a_i - \sum_{a=1}^{a=a_i} \alpha a + x\lambda\omega \mathbb{1}(a_i = r)[E(v|a_i \geq r) - E(v|a_i < r)]$ with two signaling thresholds $r \in \{4, 5\}$ and $D = 2$ set to the mean walking distance. The calibrated parameters are $\mu_v = 1.48$, $\sigma_v = 0.41$, $\kappa = -0.1$, $\alpha = -0.3$. I assume $\lambda\omega = 0.2$, i.e. the weight assigned to social image is equivalent to 2 miles walking. Control v_5 and v_4 are cut-off types for vaccine 5 and 4, in the absence of signaling (x=0). I solve for v_5^s under signaling (x=1), solving the fixed-point equation 2. E and E_s define the expectations formed about types conditional on actions. The cut-off type v_5^s pins down the new equilibrium type expectations $E_s(v|a_i < 5) = E_s(v|v < v_5^s)$ and $E_s(v|a_i = 5) = E_s(v|v \geq v_5^s)$. $v_4 < v_5^s < v_5$ implies that some individuals who previously chose $a^* = 4$ now choose $a_s^* = 5$, while anyone who chose $a^* = 3$ will still choose $a_s^* = 3$, given parameters.

Figure 3: Experimental Treatment Groups

	Vaccine 1 Hand Out	**... 2**	**... 3**	**Vaccine 4** Exchange	**Vaccine 5** Exchange
Control					
Signal at 4	Yellow — 1st visit	••••	••••	Green — 4th visit	4th visit
Signal at 5	1st visit	••••	••••	1st visit	5th visit
Uninformative Bracelet	1st visit / 1st visit	••••	••••	1st visit / 1st visit	1st visit / 1st visit

Notes: This figure displays the four different treatment groups and the bracelet hand out and exchanges that take place at each of the five vaccinations. At vaccine one children receive a bracelet that has written on it "1st visit" and has the color yellow in Signal at 4 and Signal at 5 treatments. In the Uninformative Bracelet, parents can choose for their child a yellow or green bracelet. A child keeps the same bracelet for vaccines two and three. At vaccine four, in the Signal at 4 treatment, the yellow bracelet is exchanged for a green bracelet that says "4th visit" if the child comes timely (i.e. before 6 months age), otherwise the bracelet is exchanged for another identical yellow bracelet. In the Signal at 5 the bracelet is exchanged for another identical yellow bracelet. In the Uninformative Bracelet treatment, the bracelet is exchanged for an identical bracelet, of the same color as the parent chose at the first visit. At vaccine five, in the Signal at 4 treatment, the green (or yellow, depending on whether the child was timely at vaccine four) is exchanged for an identical bracelet. In the Signal at 5 treatment, the bracelet is exchanged for green bracelet that says "5th visit" if the child comes timely (i.e. by 11 months age). In the Uninformative Bracelet, the bracelet is again exchanged for an identical "1st visit" bracelet of the color that the parent originally chose.

Figure 4: Different Bracelets handed out across Three Signaling Treatments

Notes: The image displays the actual bracelets that health workers give out at clinics: the top yellow "1st visit" bracelet is used in Signal at 4, Signal at 5 and the Uninformative Bracelet treatment; the second green "1st visit" bracelet is only given to children in the Uninformative Bracelet treatment; the green "4th visit" bracelet is given to children in the Signal at 4 treatment and the bottom green "5th visit" bracelet to children in the Signal at 5 treatment. All bracelets are made out of silicone and are *size-adjustable* so that they can comfortably fit the wrist of a child between the ages of zero and twelve months. The latter was important for the experimental design i) as it made the bracelet a durable signal that could be observed by others and allow for comparisons beyond the time of the vaccination, and ii) so that the size of the bracelet would not be informative about the number of vaccinations a child has completed. As a child's wrist grows, even in the absence of a change in bracelet color, a too small bracelet that no longer fits, could be informative about whether a child is up-to-date with its vaccinations. Over the course of the experiment, a total of 36,000 bracelets were handed out by health workers.

Figure 5: Clinic Randomization
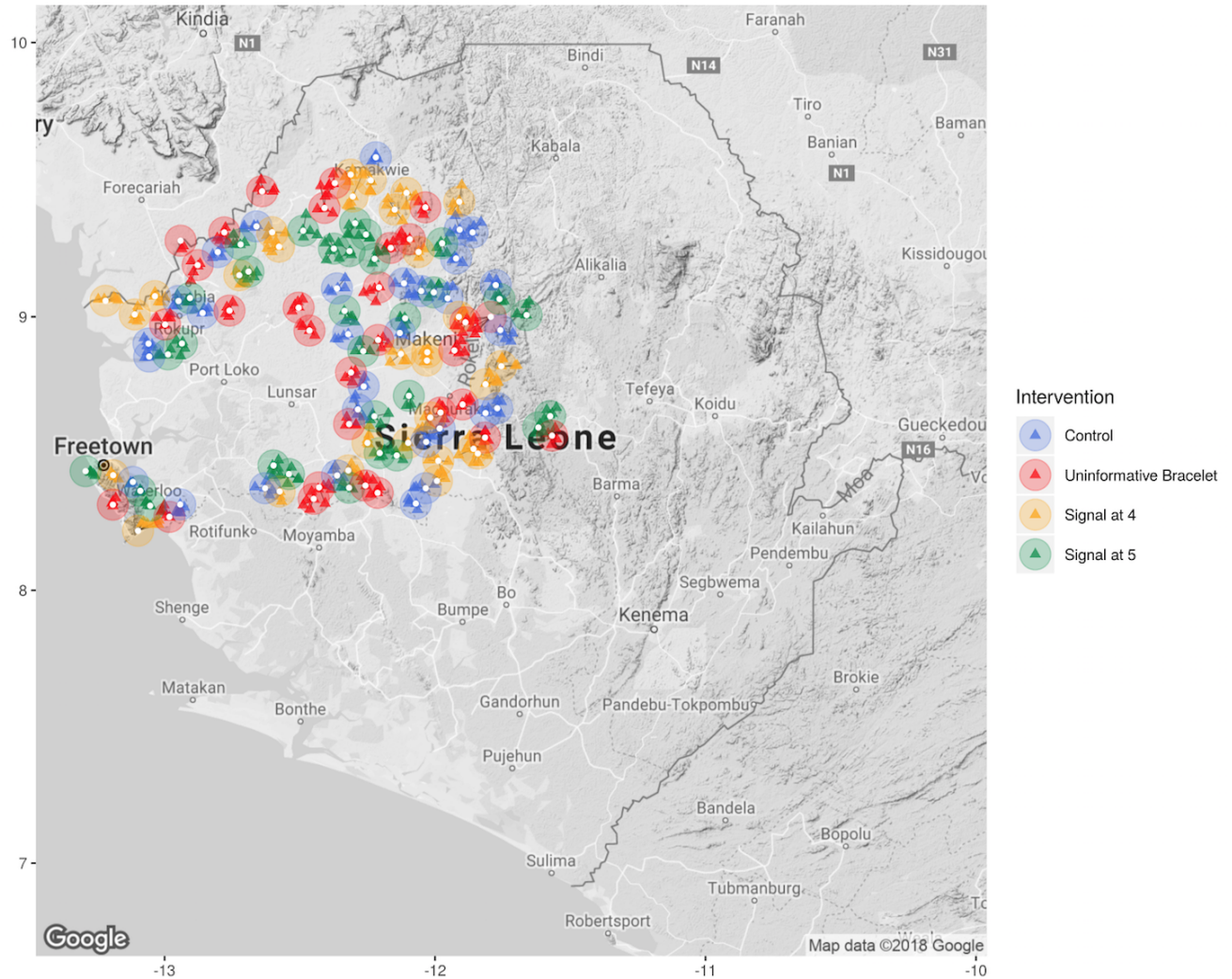
Notes: Map of Sierra Leone that shows the geographic span of the experiment, with 120 clinics, that is ten percent of Sierra Leone's public clinics, being randomized into the four different treatment groups. The clinic randomization was stratified by district. Four out of Sierra Leone's 14 districts were selected for the experiment in collaboration with the Government and partners, based on the criteria: i) baseline vaccination rates, ii) Ebola affectedness, iii) reliability of supply side, and iv) other ongoing interventions. To avoid spillovers, the set of 120 clinics was chosen from a sample of 243 clinics, using an algorithm that ensured that each selected clinic had a catchment radius of 5 miles, of which at least 35 percent of the area was non-overlapping with any adjacent clinic's catchment area.

Figure 6: Correct Hand Out of Bracelets by Treatment Groups
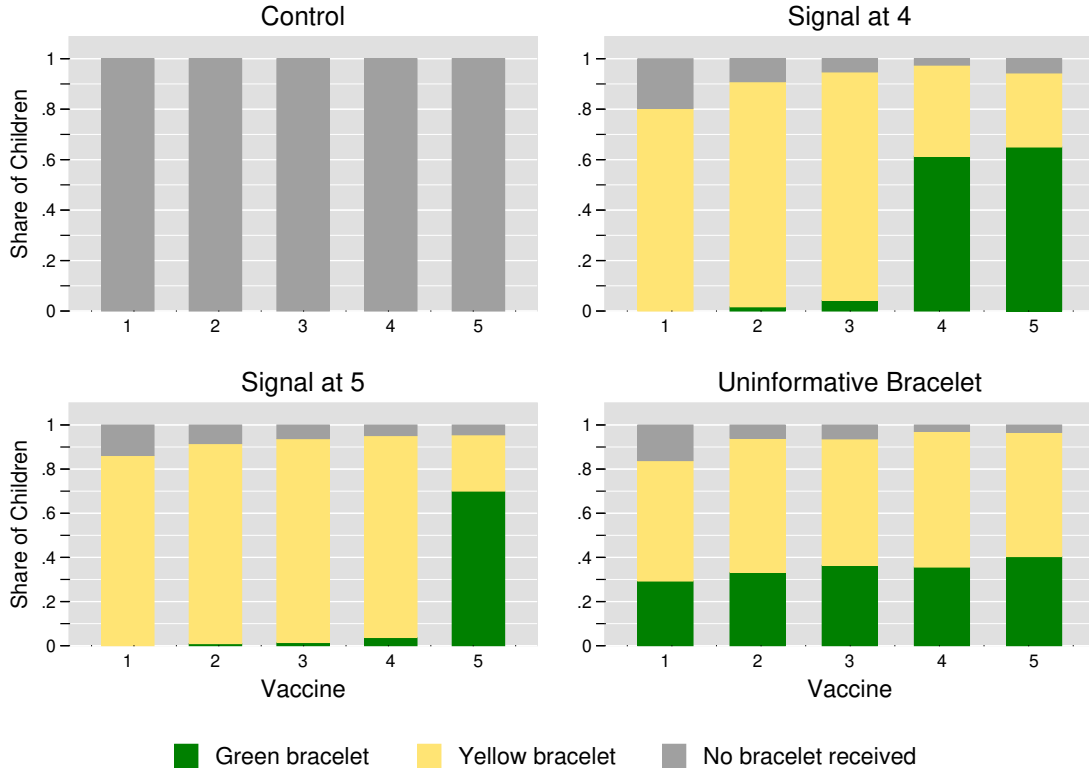
Notes: This figure displays the share of children with a green, yellow, or no bracelet conditional on the number of vaccines a child has received, separately for each treatment arm. The sample includes 6,922 children that were born after the experiment was launched and that were surveyed during the listing survey, which took place 12 - 15 months after the intervention was launched in a particular clinic. Surveyors asked each parent "What color bracelet was your child given when you went for vaccination?" and recorded all vaccines the child had received up to that point. The share of children with "No bracelet received" shows that almost every child received a bracelet (94%) across all three bracelet treatments. In the Uninformative Bracelet treatment, there is overall no significant relationship between the number of vaccines a child received and the color of bracelet (there is only small significant increase in the share of children with a green bracelet for vaccine five). For Signal at 4 and Signal at 5, there is a clear relationship between color of bracelet and the number of vaccines a child received: there is a large spike - from close to zero to 62 percent for Signal at 4 and 70 percent for Signal at 5 - in the share of children with a green bracelet at vaccine four and five respectively. Children who had taken vaccine four and/or five but had a yellow bracelet had either come late for the vaccine (~ one-third) or health workers had missed to give the correct bracelet (~ two-thirds).

Figure 7: The Effect of Signals on Beliefs about Other Children's Vaccinations

Vaccine 3 N = 3301, Vaccine 4 N = 3196, Vaccine 5 N = 1155
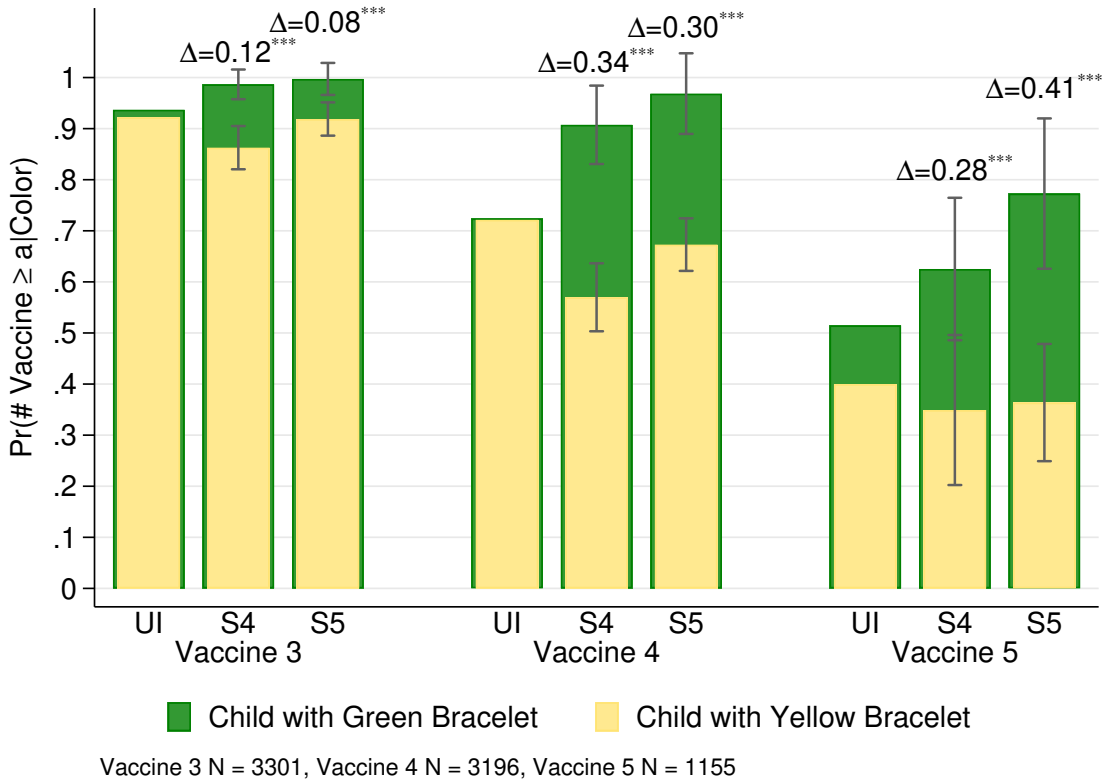
Notes: This figure shows endline respondents' beliefs about the number of vaccinations a child received conditional on the color of bracelet. Beliefs are shown by vaccine, and by treatment, where UI = Uninformative Bracelet, S4 = Signal at 4, S5 = Signal at 5. The yellow and green bars show the conditional probability Pr(# Vaccine ≥ a | Color) of a child having received (at least) vaccine 3, 4, or 5 (i.e. a = {3,4,5}) conditional on the respondent observing the child having a yellow or green bracelet. Vaccines one and two are excluded from the figure since individuals believe that (close to) 100 percent of children complete these vaccines. The confidence intervals (at 95 percent) for Signal at 4 and Signal at 5, on the green and yellow bars respectively, compare the beliefs in the signaling treatments to those in the Uninformative Bracelet. △ denotes the difference between the two conditional probabilities: Pr(# Vaccine ≥ a | Green) - Pr(# Vaccine ≥ a | Yellow). The samples used for each vaccine include all children below the age of one who were eligible for the specific vaccine: age 2.5, 3.5 and 9 months and older for vaccines three, four and five respectively. Using the estimated joint probabilities from regressions of a binary variable for a child having a green (yellow) bracelet and at least *a* vaccines (fewer than *a* vaccines), on treatment indicators for Signal at 4 and Signal at 5, with the Uninformative Bracelet as excluded category (e.g. Pr(Green and Vaccine # ≥ 4) and Pr(Green and Vaccine # < 4) I compute the marginal probabilities for bracelet color (e.g. Pr(Child has Green Bracelet)) and finally the conditional probabilities e.g. $\Pr(\# \text{ Vaccine} \geq 4 \mid \text{Green}) = \frac{\Pr(\text{Green and Vaccine} \# \geq 4)}{\Pr(\text{Child has Green Bracelet})}$. Estimating the probabilities in a regression framework, I control for the mean take-up level of vaccine *a* at the clinic and child age. Both controls are demeaned. All regressions include strata fixed effects. Standard errors are clustered at the clinic level.

Figure 8: The Combined Effect of Signals at 4 and 5 on Timely Vaccinations

Notes: This figure shows the results from a linear probability model of the binary outcome variable for a child being vaccinated for 1, 2, 3, 4, or 5 vaccinations by the age of 3, 4, 5, 6 and 11.5 months, respectively, on a treatment indicator for Signal at 4 and 5, with the omitted category being the Control Group. The sample includes all children born since the launch of the experiment. All regressions include strata-fixed effects, the demeaned control for child age, and an indicator that is coded one if the vaccine entry comes from the administrative data. The 95 percent confidence intervals were computed using standard errors that are cluster bootstrapped (1000 repetitions) at the clinic level.

Figure 9: The Effect of Signal at 4 on Timely Vaccinations
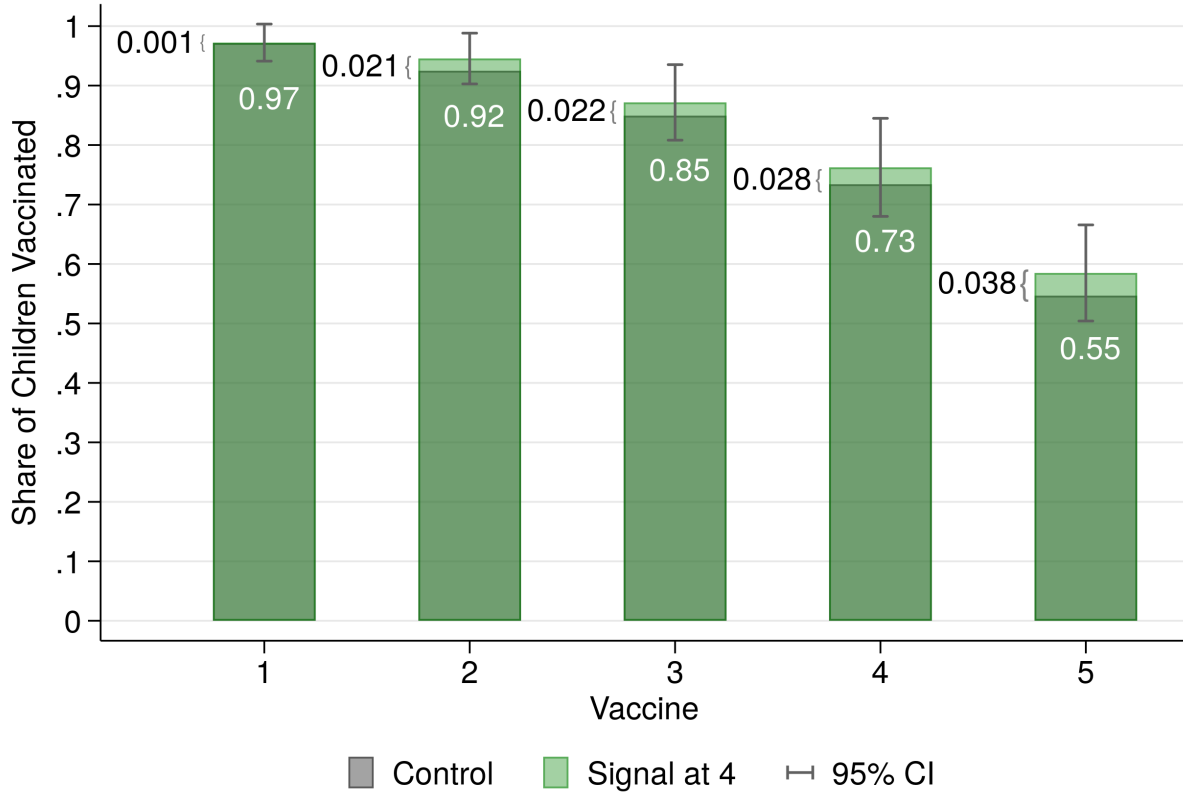
Number of Children for Vaccine 1, 2, 3, 4, 5: 3884, 3665, 3369, 3068, 1240.

Notes: This figure shows the results from a linear probability model of the binary outcome variable for a child being vaccinated for 1, 2, 3, 4, or 5 vaccinations by the age of 3, 4, 5, 6 and 11.5 months, respectively, on a treatment indicator for Signal at 4, with the omitted category being the Control Group. The sample includes all children born since the launch of the experiment. All regressions include strata-fixed effects, the demeaned control for child age, and an indicator that is coded one if the vaccine entry comes from the administrative data. The 95 percent confidence intervals were computed using standard errors that are cluster bootstrapped (1000 repetitions) at the clinic level.

Figure 10: The Effect of Signal at 5 on Timely Vaccinations
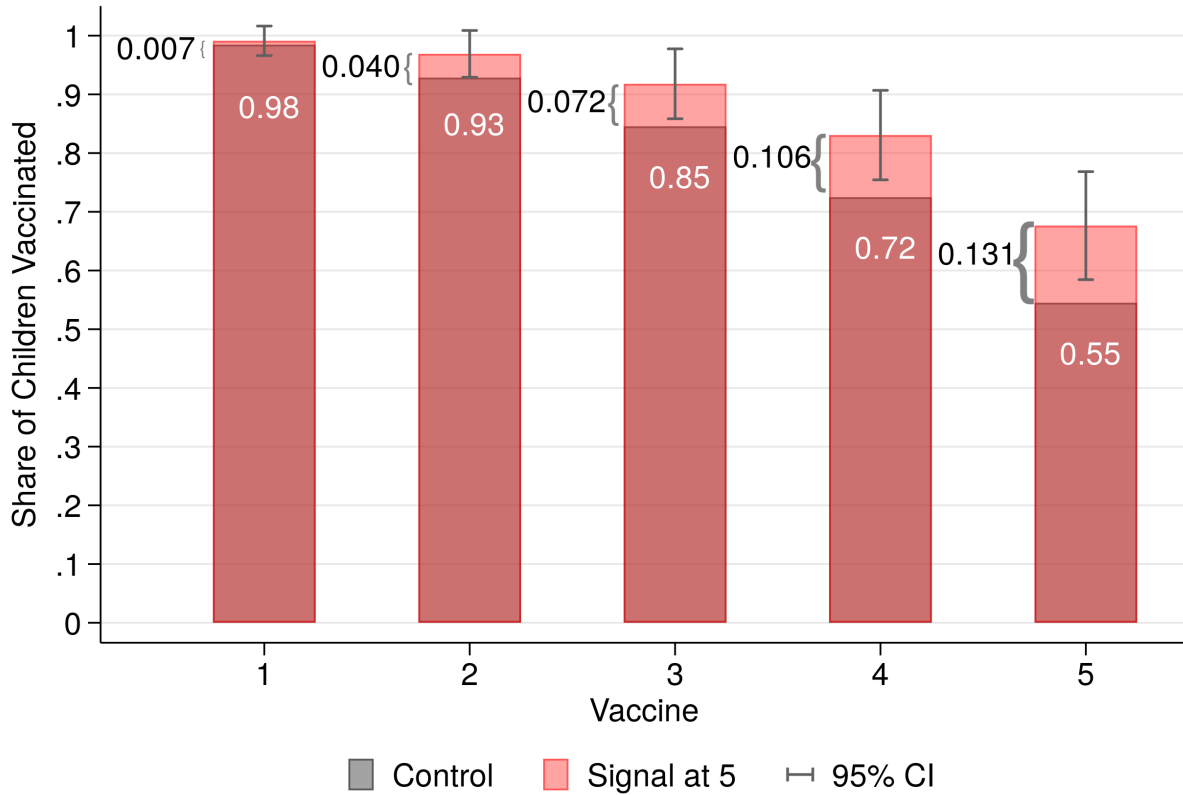
Number of Children for Vaccine 1, 2, 3, 4, 5: 3649, 3433, 3165, 2864, 1159.

Notes: This figure shows the results from a linear probability model of the binary outcome variable for a child being vaccinated for 1, 2, 3, 4, or 5 vaccinations by the age of 3, 4, 5, 6 and 11.5 months, respectively, on a treatment indicator for Signal at 5, with the omitted category being the Control Group. The sample includes all children born since the launch of the experiment. All regressions include strata-fixed effects, the demeaned control for child age, and an indicator that is coded one if the vaccine entry comes from the administrative data. The 95 percent confidence intervals were computed using standard errors that are cluster bootstrapped (1000 repetitions) at the clinic level.

Figure 11: The Effect of the Uninformative Bracelet on Timely Vaccinations
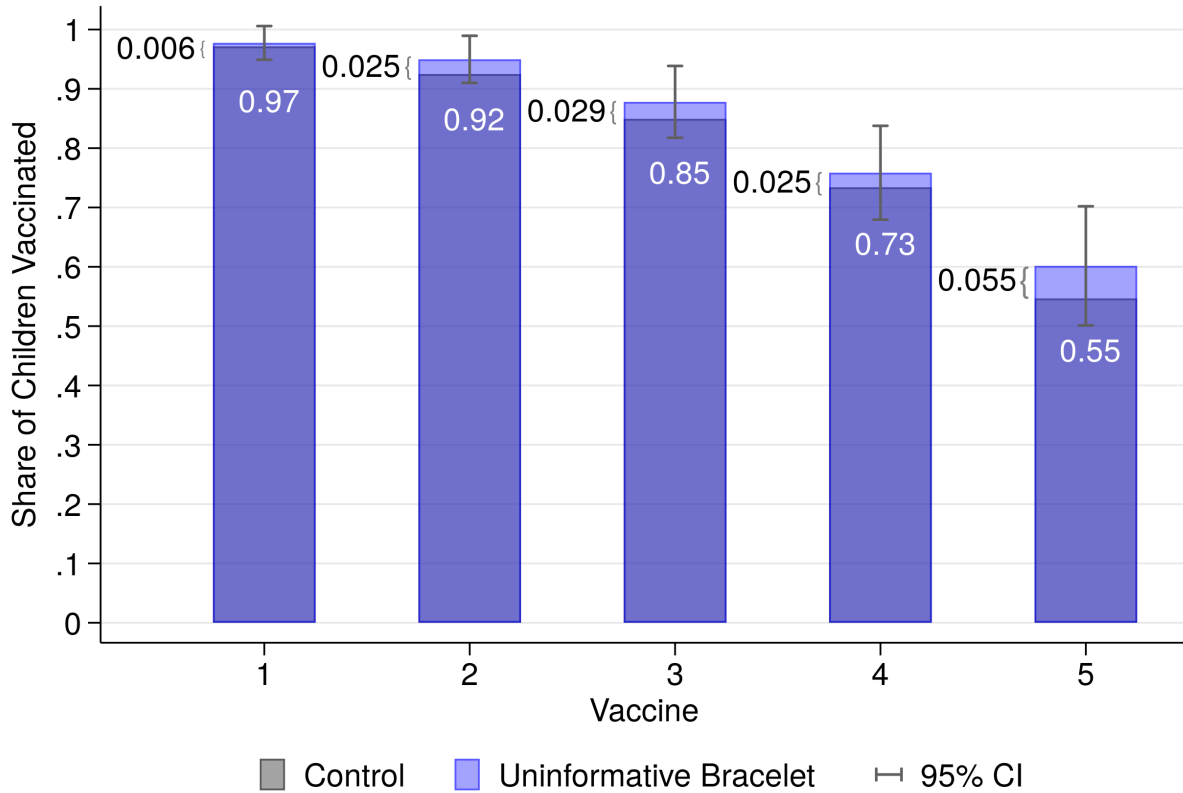
Number of Children for Vaccine 1, 2, 3, 4, 5: 3509, 3031, 3031, 2769, 1075.

Notes: This figure shows the results from a linear probability model of the binary outcome variable for a child being vaccinated for 1, 2, 3, 4, or 5 vaccinations by the age of 3, 4, 5, 6 and 11.5 months, respectively, on a treatment indicator for the Uninformative Bracelet, with the omitted category being the Control Group. The comparison captures the effect of bracelets through increases in consumption utility and salience (e.g. reminder effects). The sample includes all children born since the launch of the experiment. All regressions include strata-fixed effects, the demeaned control for child age, and an indicator that is coded one if the vaccine entry comes from the administrative data. The 95 percent confidence intervals were computed using standard errors that are cluster bootstrapped (1000 repetitions) at the clinic level.

Figure 12: The Effect of Signal at 5 versus the Uninformative Bracelet on Timely Vaccinations
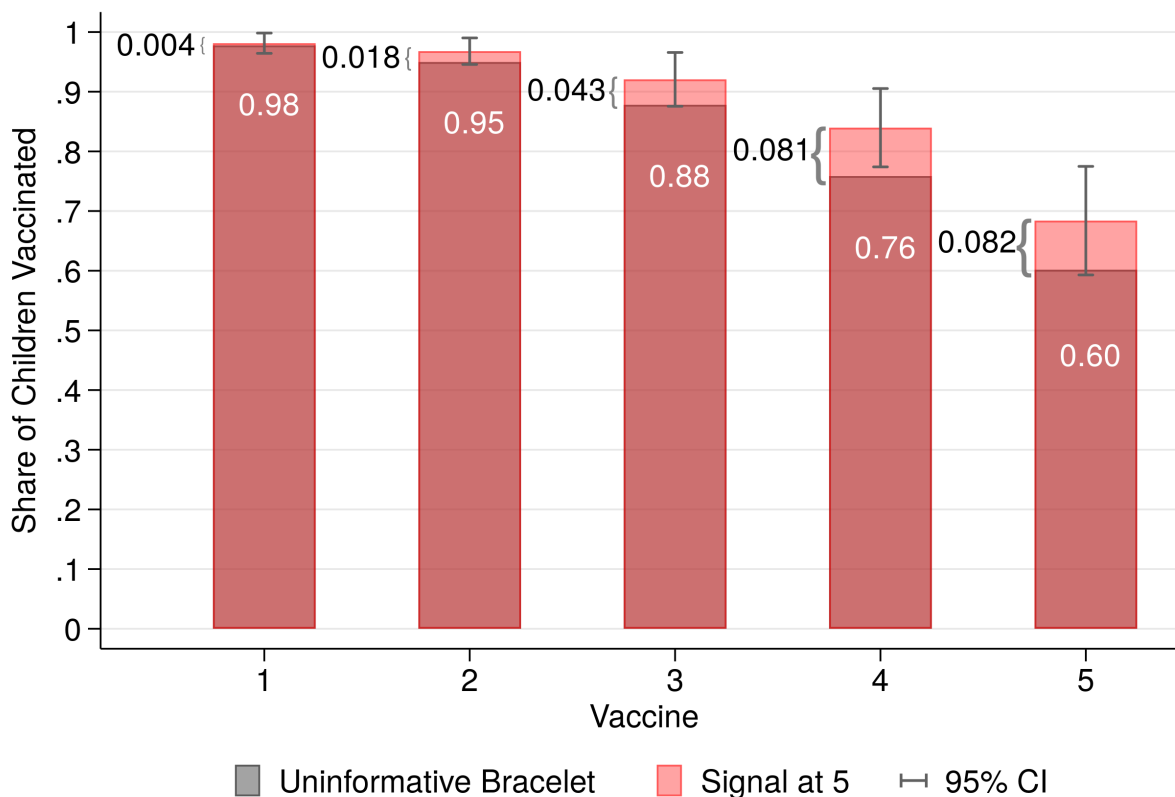
Number of Children for Vaccine 1, 2, 3, 4, 5: 3598, 3760, 3140, 2841, 1146.

Notes: This figure shows the results from a linear probability model of the binary outcome variable for a child being vaccinated for 1, 2, 3, 4, or 5 vaccinations by the age of 3, 4, 5, 6 and 11.5 months, respectively, on a treatment indicator for Signal at 5, with the omitted category being the Uninformative Bracelet. The comparison holds constant the effect of bracelets through increased consumption utility and salience (e.g. reminder effects). The sample includes all children born since the launch of the experiment. All regressions include strata-fixed effects, the demeaned control for child age, and an indicator that is coded one if the vaccine entry comes from the administrative data. The 95 percent confidence intervals were computed using standard errors that are cluster bootstrapped (1000 repetitions) at the clinic level.

Figure 13: The Effect of Signal at 4 versus the Uninformative Bracelet on Timely Vaccinations
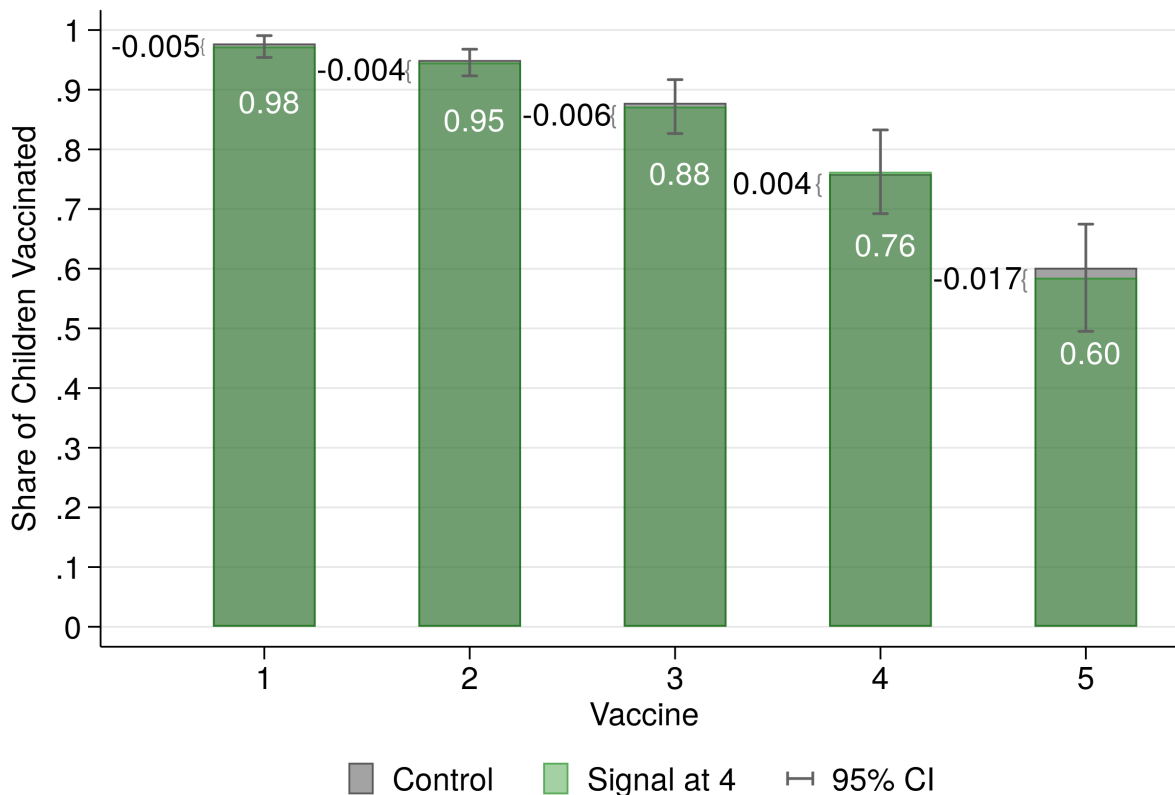
Number of Children for Vaccine 1, 2, 3, 4, 5: 3833, 3619, 3344, 3045, 1191.

Notes: This figure shows the results from a linear probability model of the binary outcome variable for a child being vaccinated for 1, 2, 3, 4, or 5 vaccinations by the age of 3, 4, 5, 6 and 11.5 months, respectively, on a treatment indicator for Signal at 4, with the omitted category being the Uninformative Bracelet. The comparison holds constant the effect of bracelets through increased consumption utility and salience (e.g. reminder effects). The sample includes all children born since the launch of the experiment. All regressions include strata-fixed effects, the demeaned control for child age, and an indicator that is coded one if the vaccine entry comes from the administrative data. The 95 percent confidence intervals were computed using standard errors that are cluster bootstrapped (1000 repetitions) at the clinic level.

Figure 14: Preferences for Different Vaccinations

Which vaccine do you consider the (second) most important?

Most important vaccine   Second most important vaccine

N =1314
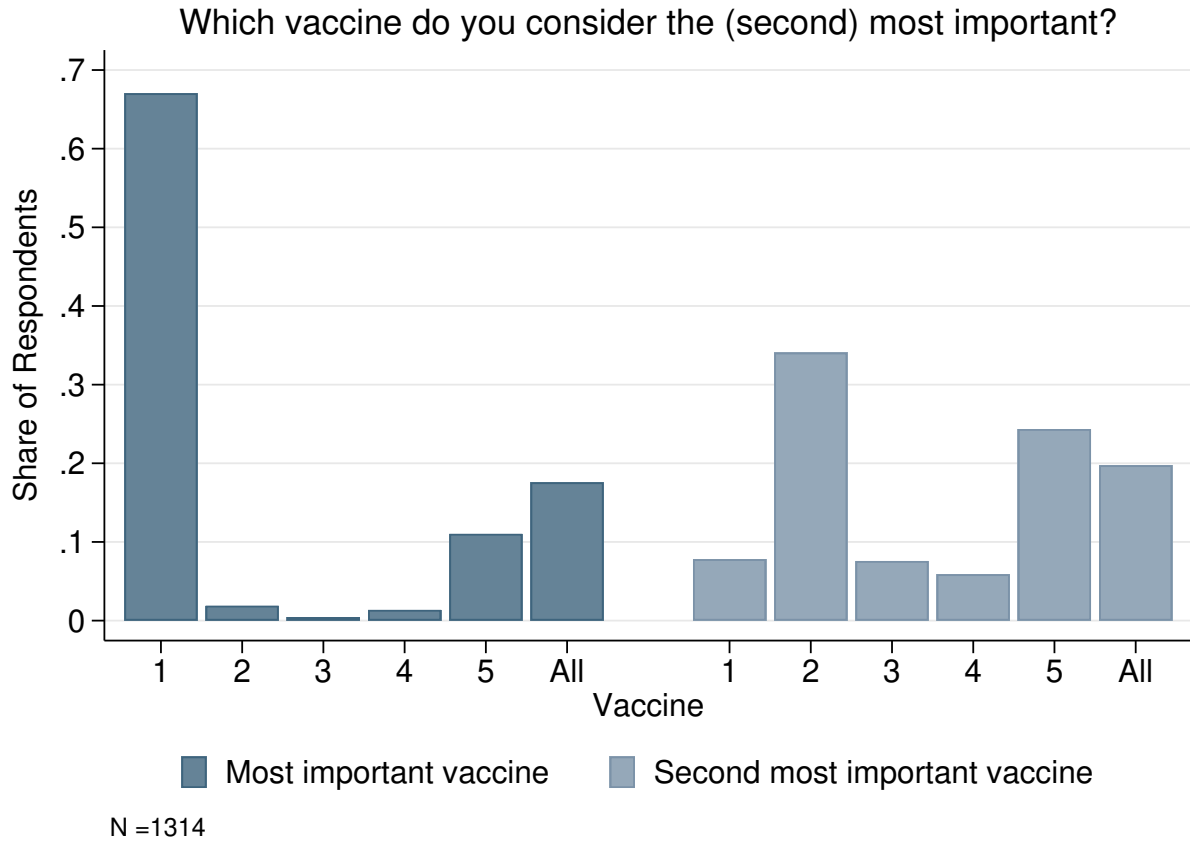
Notes: This figure shows mothers' perceptions about the relative importance of the five vaccinations. Mothers were first asked about which vaccination they thought was the most important, and then which one they thought was the second most important (conditional on not having answered "All" to the first question). The figure plots the share of respondents that answered vaccine one, two, three, four, five or all vaccines are the most important (on the left), and the second most important (on the right). The sample includes all mothers that were surveyed at endline. Answers are pooled across treatments. As Table A1 shows there is no significant difference in preferences across intervention arms.

Figure 15: Treatment Effects over Time for Vaccine 4
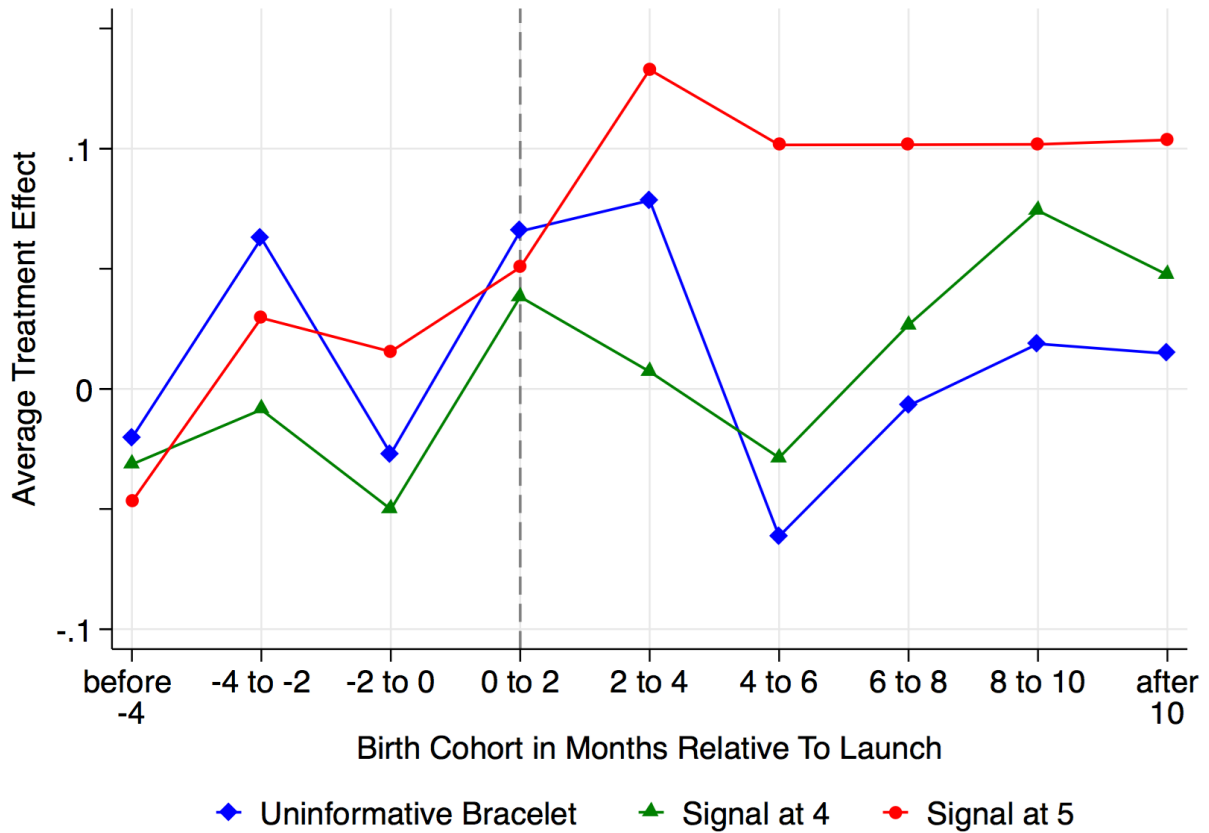
Notes: This figure plots the average treatment effect of Signal at 4, Signal at 5 and the Uninformative Bracelet treatment compared to the Control Group for vaccine four, by birth cohorts. Children are grouped into birth cohorts of two months. The dotted line indicates the launch of the experiment. The sample size (number of children) in each bin, starting from the left, is 1455, 501, 899, 918, 939, 948, 1126, 967 and 1024.

Figure 16: Treatment Effects over Time for Vaccine 5
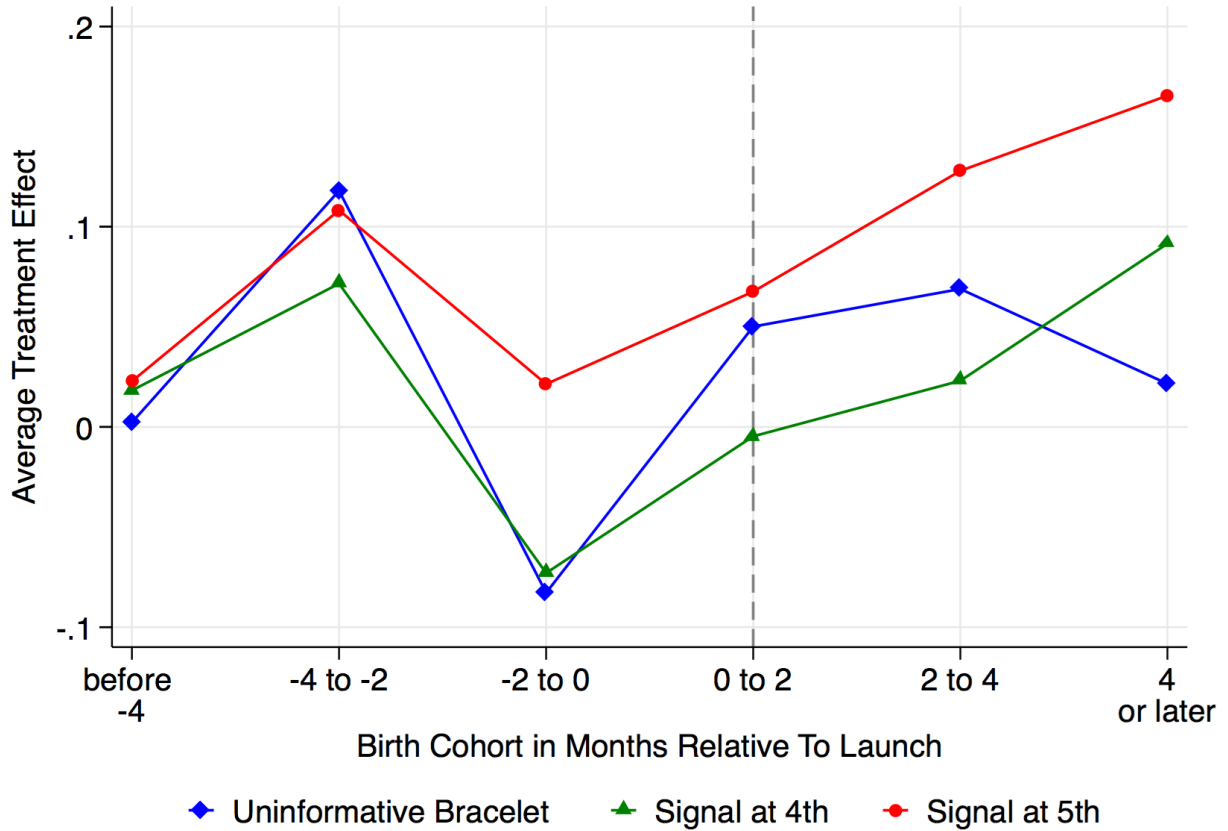
Notes: This figure plots the average treatment effect of Signal at 4, Signal at 5 and the Uninformative Bracelet treatment compared to the Control Group for vaccine five, by birth cohorts. Children are grouped into birth cohorts of two months. The dotted line indicates the launch of the experiment. The sample size (number of children) in each bin, starting from the left, is 1455, 501, 899, 903, 720 and 738.

Figure 17: The Effect of Distance on Take-up for in the Control and Signal at 5 group
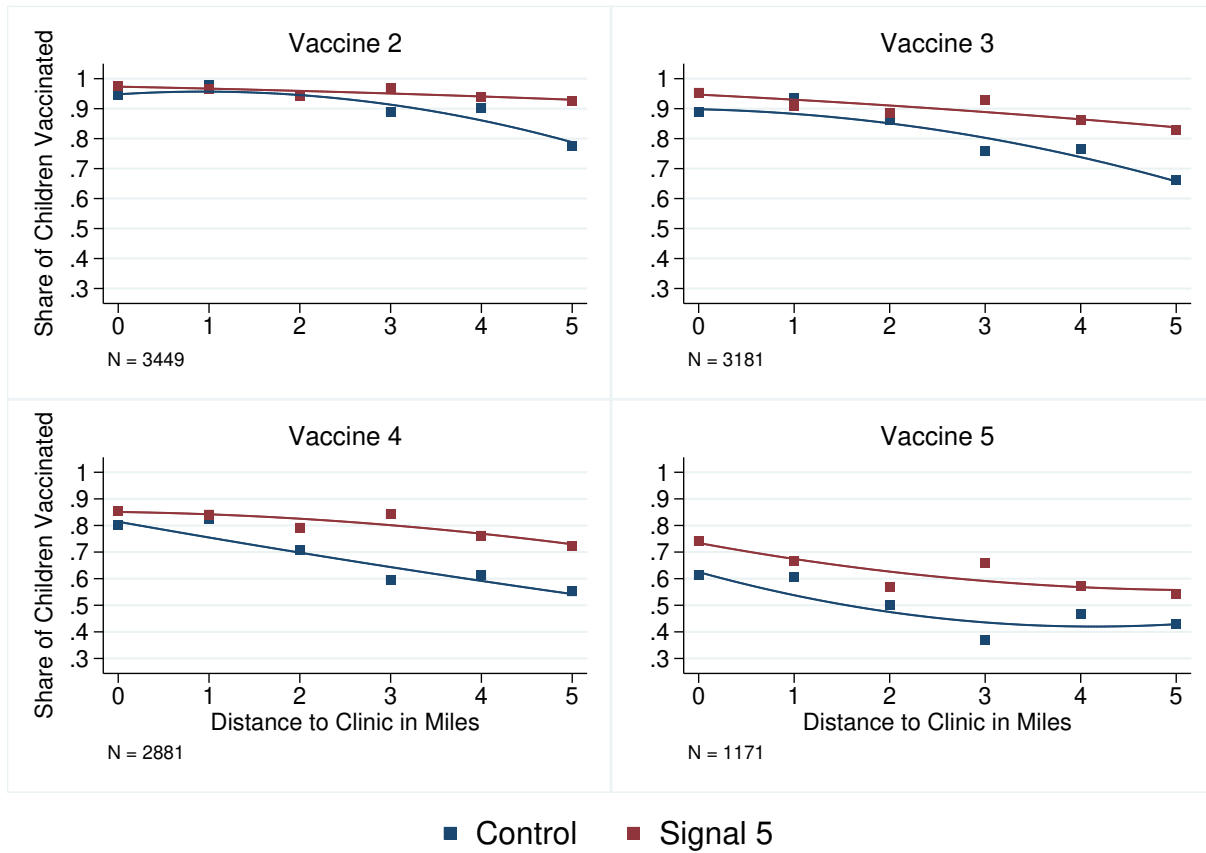
Notes: The graph shows the effect of distance on the share of timely vaccinated children by vaccine. Each vaccine graph plots a bin scatter of the share of children vaccinated (for vaccine 2, 3, 4 and 5) against the distance from communities to clinics, separately for the Control Group and Signal at 5. The sample includes all children born since the launch that were at least 4, 5, 6 and 11.5 months old by the end of the experiment, to be considered for vaccine 2, 3, 4 or 5 respectively. Similar to Figure A8 Signal at 5 mitigated the negative effect of distance across all vaccines, increasing vaccination rates at four miles to those at zero miles in the Control Group.

Table 1: Description of Study Sample from Endline Survey

Variable	(1) Control Mean/SE	(2) Signal at 4 Mean/SE	(3) Signal at 5 Mean/SE	(4) Uninformative Mean/SE	T-test P-value (1)-(2)	(1)-(3)	(1)-(4)	(2)-(3)	(2)-(4)	(3)-(4)	F-test for joint orthogonality
Mother age	26.240 (0.454)	26.275 (0.293)	26.176 (0.366)	26.565 (0.366)	0.918	0.984	0.550	0.808	0.555	0.501	0.911
Birth order of child	3.311 (0.104)	3.404 (0.078)	3.376 (0.087)	3.500 (0.093)	0.426	0.462	0.151	0.851	0.449	0.374	0.546
Is married	0.603 (0.044)	0.468 (0.051)	0.545 (0.049)	0.539 (0.053)	0.037**	0.398	0.260	0.200	0.257	0.814	0.209
Lived in community for over 1 year	0.966 (0.009)	0.976 (0.008)	0.969 (0.010)	0.958 (0.012)	0.412	0.678	0.576	0.618	0.171	0.489	0.625
Education											
Has no education	0.437 (0.031)	0.480 (0.035)	0.467 (0.033)	0.500 (0.039)	0.328	0.313	0.139	0.883	0.627	0.500	0.501
Has some primary education	0.323 (0.028)	0.330 (0.029)	0.307 (0.029)	0.265 (0.030)	0.909	0.682	0.065*	0.531	0.058*	0.157	0.200
Has some secondary education	0.240 (0.030)	0.190 (0.033)	0.226 (0.026)	0.235 (0.032)	0.265	0.459	0.908	0.441	0.293	0.656	0.657
Occupation											
Works on farm	0.760 (0.032)	0.734 (0.046)	0.693 (0.038)	0.768 (0.035)	0.619	0.300	0.661	0.654	0.405	0.127	0.449
Assets											
Has a mobile phone (1=Yes, 0=No)	0.117 (0.023)	0.107 (0.020)	0.154 (0.028)	0.092 (0.017)	0.719	0.506	0.219	0.203	0.343	0.027**	0.147
Floor (1=Cement/Tile, 0=Mud)	0.320 (0.031)	0.373 (0.037)	0.376 (0.044)	0.330 (0.041)	0.292	0.478	0.911	0.787	0.417	0.496	0.661
Roof (1=Corrugated iron, 0=Thatch)	0.898 (0.025)	0.902 (0.021)	0.912 (0.018)	0.859 (0.021)	0.899	0.780	0.144	0.839	0.121	0.052*	0.291
Observations	338	339	319	318							
Clinics	30	30	29	30							

Notes: This table summarizes socio-economic characteristics for a random sample of 1,314 endline survey respondents. All respondents were mothers, who had a child that was born since the start of the experiment, and who resided in one of the selected clinic catchment communities. The table reports mean values of each variable for every treatment group. The final column reports the joint significance level of treatment indicators in a regression with strata-level fixed effects. The value displayed for t-tests and F-tests are p-values. Standard errors are clustered at the clinic level. ***, **, and * indicate significance at the 1, 5, and 10 percent critical level.

Table 2: Description of Clinic and Baseline Community Characteristics

Variable	(1) Control Mean/SE	(2) Signal at 4 Mean/SE	(3) Signal at 5 Mean/SE	(4) Uninformative Mean/SE	T-test P-value (1)-(2)	(1)-(3)	(1)-(4)	(2)-(3)	(2)-(4)	(3)-(4)	F-test for joint orthogonality
Immunization services											
Number of staff	2.034 (0.189)	1.966 (0.093)	2.241 (0.313)	2.000 (0.099)	0.740	0.575	0.891	0.402	0.799	0.468	0.858
Immunization day frequency (1=weekly, 0=monthly)	0.690 (0.087)	0.621 (0.092)	0.690 (0.087)	0.586 (0.093)	0.592	0.991	0.429	0.595	0.815	0.434	0.804
Stockout of vaccines in the past 2 months (1=Yes, 0=No)	0.172 (0.071)	0.138 (0.065)	0.138 (0.065)	0.103 (0.058)	0.725	0.710	0.463	0.999	0.687	0.708	0.904
Experiment implementation											
Number of days at which launched relative to first clinic	83.207 (10.266)	99.310 (10.263)	92.241 (10.160)	82.241 (10.848)	0.263	0.528	0.979	0.602	0.262	0.527	0.615
Number of days listing survey implemented after first clinic	67.647 (7.274)	76.871 (7.324)	73.418 (7.875)	64.057 (7.669)	0.364	0.590	0.758	0.731	0.234	0.414	0.629
Number of monitoring visits	10.655 (0.395)	11.138 (0.417)	11.690 (0.463)	11.931 (0.496)	0.373	0.061*	0.037**	0.366	0.231	0.757	0.108
Observations	30	30	29	30							
Clinics	30	30	29	30							
Panel B: Community characteristics											
Community knowledge											
Know number of vaccines required (1=Yes, 0=No)	0.949 (0.022)	0.937 (0.025)	0.906 (0.026)	0.951 (0.019)	0.662	0.131	0.972	0.309	0.648	0.128	0.417
Perceptions of reasons for parents to miss vaccines											
Negligence from parents	0.848 (0.045)	0.789 (0.053)	0.790 (0.058)	0.874 (0.047)	0.318	0.440	0.653	0.875	0.172	0.257	0.433
Lack of knowledge of benefits	0.703 (0.069)	0.690 (0.065)	0.717 (0.060)	0.727 (0.061)	0.902	0.809	0.712	0.799	0.544	0.992	0.952
Distance to clinic	0.319 (0.055)	0.373 (0.053)	0.312 (0.053)	0.343 (0.058)	0.287	0.973	0.676	0.361	0.669	0.584	0.708
User fees	0.181 (0.055)	0.127 (0.043)	0.145 (0.050)	0.147 (0.048)	0.424	0.647	0.687	0.769	0.688	0.943	0.891
Staff attitude	0.101 (0.041)	0.176 (0.046)	0.101 (0.038)	0.091 (0.031)	0.169	0.986	0.765	0.218	0.097*	0.766	0.359
Observations	142	147	138	148							
Clinics	30	30	29	30							

Notes: This table summarizes relevant clinic and community characteristics collected at the start of the experiment. The table reports mean values of each variable for every treatment group. The final column reports the joint significance level of treatment indicators in a regression with strata-level fixed effects. The value displayed for t-tests and F-tests are p-values. Standard errors are clustered at the clinic level for regressions assessing community characteristics. ***, **, and * indicate significance at the 1, 5, and 10 percent critical level.

Table 3: Visibility of Bracelets by Treatment Group

Dependent variable:	(1) Know if other child has bracelet	(2) Others know own child's bracelet color
Signal at 4	0.028	0.046
	(0.032)	(0.037)
Signal at 5	0.005	0.042
	(0.018)	(0.038)
Uninformative Bracelet mean	0.896	0.768
Observations	3340	3130
Age of child	Yes	Yes
Relationship to mother	Yes	Yes

Notes: This table shows endline respondents' first- and second-order beliefs about the visibility of bracelets. The unit of observation is a respondent-other mother pair. Column (1) reports first-order beliefs, asking respondents if they know if another (randomly selected, but to the respondent known) child in their community has a bracelet. Know if other child has bracelet is a dummy variable that equals one if the respondent answered "Yes" and zero if the respondent answered "No" or "Don't know". The sample includes answers from all endline respondents across the three bracelet treatments. Column (2) reports second-order beliefs, asking respondents if they thought that another (randomly selected, but to the respondent known) mother in their community knew what color bracelet their own child had. Others know own child's bracelet color is a dummy variable that equals one if the respondent answered "Yes" and zero if the respondent answered "No" or "Don't know". All regressions include strata-fixed effects and controls for child age and relationship to other mother. Controls are demeaned. Standard errors are cluster bootstrapped (1000 repetitions) at the clinic level. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 4: The Effect of Signals on First- and Second-Order Beliefs about Vaccine Decisions

Dependent variable:	Know # of vaccines other children		Others know # vaccines own child	
	(1)	(2)	(3)	(4)
	>3.5 months age	>9 months age	>3.5 months age	>9 months age
Signal at 4	0.079**	0.103*	0.130***	0.134**
	(0.038)	(0.058)	(0.041)	(0.061)
Signal at 5	0.097***	0.100*	0.103**	0.170***
	(0.034)	(0.056)	(0.047)	(0.065)
Uninformative Bracelet	0.056	0.062	0.084**	0.085
	(0.037)	(0.052)	(0.043)	(0.075)
Control Group mean	0.465	0.451	0.472	0.456
Observations	4028	1437	4485	1626
Age of child	Yes	Yes	Yes	Yes
Relationship to mother	Yes	Yes	Yes	Yes
p(UI = S4)	0.557	0.439	0.201	0.468
p(UI = S5)	0.270	0.442	0.642	0.229
p(S5 = S4)	0.632	0.955	0.489	0.485
Joint F-test	0.014	0.253	0.018	0.063

Notes: This table shows results from endline respondents' first- and second-order beliefs about other children's and own child's vaccinations. I linked respondents' answers with administrative records to assess the correctness of first-order beliefs; that is, if respondents had more accurate beliefs about other parents' vaccine decisions. The unit of observation is a respondent-other mother pair. Columns (1)-(2) show regression results of a binary variable for correct knowledge of the number of vaccinations another child has received (~ first-order beliefs) on treatment indicators for Signal at 4, Signal at 5 and Uninformative Bracelet, with the Control Group as excluded category. The outcome variable is coded one if respondents correctly guessed the number, and zero if the answer was incorrect or the respondent answered "Don't know". Column (1) displays the result for the sample of other children ages 3.5 months and above (i.e. who are eligible for Vaccine 4 and therefore receive a green bracelet in Signal at 4); Column (2) the results for other children ages 9 months and above (i.e. who are eligible for Vaccine 5 and therefore receive a green bracelet in Signal at 5). Columns (3)-(4) show regression results of a binary variable for respondent's belief about another mother's knowledge of her own child's number of vaccinations (~ second-order beliefs). The outcome variable is coded one if a respondent answered "Yes", i.e. the other mother knows, and zero if a respondent answered "Don't know" or "No", i.e. the other mother does not know. Column (3) displays the result for the sample of own children age 3.5 months and above (i.e. who are eligible for Vaccine 4 and a green bracelet in Signal at 4 therefore); Column (4) displays the results for own children age 9 months and above (i.e. who are eligible for Vaccine 5 and a green bracelet in Signal 5 therefore). The bottom rows give the p-values from a test that the effect of the Uninformative Bracelet (UI) is equivalent to the effect of Signal at 4 (S4) or to Signal at 5 (S5), and that the effect of Signal at 4 is equivalent to that of the Signal at 5. Last is a joint hypothesis test of all three bracelet treatments. All regressions include strata-fixed effects and controls for child age and relationship to other mother. Controls are demeaned. Standard errors are cluster bootstrapped (1000 repetitions) at the clinic level.* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 5: The Combined Effect of Signals at 4 and 5 on Timely and Complete Vaccination

Dependent variable:	Vaccine 1	Vaccine 2	Vaccine 3	Vaccine 4	Vaccine 5
	(1)	(2)	(3)	(4)	(5)
Panel A:			Compared to Control Group		
Signal at 4 and 5	0.005	0.031	0.046	0.065*	0.084**
	(0.014)	(0.022)	(0.030)	(0.035)	(0.040)
	[0.611]	[0.065]	[0.080]	[0.053]	[0.024]
Control Group mean	0.971	0.924	0.848	0.731	0.538
Observations	5753	5429	5006	4536	1819
Panel B:			Compared to Uninformative Bracelet		
Signal at 4 and 5	-0.002	0.005	0.016	0.040	0.031
	(0.007)	(0.009)	(0.019)	(0.031)	(0.045)
	[0.983]	[0.660]	[0.448]	[0.178]	[0.390]
Uninformative Bracelet mean	0.978	0.949	0.878	0.758	0.602
Observations	5702	5383	4981	4513	1806

Notes: This table shows results from a linear probability model of the binary outcome variable for a child being vaccinated for 1, 2, 3, 4, or 5 vaccinations by the age of 3, 4, 5, 6 and 11.5 months, respectively, on a treatment indicator for Signal at 4 and 5, with the omitted category being the Control Group in Panel A and the Uninformative Bracelet in Panel B. The sample includes all children born since the launch of the experiment. All regressions include strata-fixed effects, the demeaned control for child age, and an indicator that is coded one if the vaccine entry comes from the administrative data. Standard errors are cluster bootstrapped (1000 repetitions) at the clinic level. Values in brackets [] show the p-values from randomization inference, that were computed using the *ritest* command in Stata with treatment being randomly reassigned 5000 times.* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 6: The Effect of Signals on Timely and Complete Vaccination, Separate by Treatment

Dependent variable:	Vaccine 1	Vaccine 2	Vaccine 3	Vaccine 4	Vaccine 5
	(1)	(2)	(3)	(4)	(5)
Signal at 4	0.001	0.021	0.022	0.028	0.038
	(0.016)	(0.022)	(0.032)	(0.042)	(0.041)
Signal at 5	0.010	0.043**	0.071**	0.106***	0.137***
	(0.015)	(0.022)	(0.033)	(0.038)	(0.043)
Uninformative Bracelet	0.006	0.025	0.029	0.025	0.055
	(0.014)	(0.020)	(0.031)	(0.040)	(0.051)
Control Group mean	0.971	0.925	0.849	0.734	0.547
Observations	7482	7052	6509	5909	2350
$S_4 > 0$: p(UI = S4)	0.581	0.709	0.784	0.914	0.715
$S_5 > 0$: p(UI = S5)	0.660	0.109	0.064	0.016	0.076
p(S4 = S5)	0.368	0.070	0.044	0.023	0.003
Joint F-test	0.796	0.119	0.082	0.013	0.005

Notes: This table shows results from a linear probability model of the binary outcome variable for a child being vaccinated for 1, 2, 3, 4, or 5 vaccinations by the age of 3, 4, 5, 6 and 11.5 months respectively on treatment indicators for Signal at 4, Signal at 5 and Uninformative Bracelet, with the Control Group as the excluded category. The sample includes all children born since the launch of the experiment. The bottom rows give the p-values from a test that the effect of the Uninformative Bracelet (UI) is equivalent to the effect of Signal at 4 (S4) or to Signal at 5 (S5), identifying social signaling preferences ($S_4 > 0$, $S_5 > 0$), and that the effect of Signal at 4 is equivalent to the Signal at 5. Last is a joint hypothesis test of all three bracelet treatments. All regressions include strata-fixed effects, the demeaned control for child age, and an indicator that is coded one if the vaccine entry comes from the administrative data. Standard errors are cluster bootstrapped (1000 repetitions) at the clinic level.* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 7: The Effect of Signals on the Total Number of Vaccines Completed

Dependent variable:	Total # of vaccines timely	Total # of vaccines by one year age
	(1)	(2)
Signal at 4	0.083	0.203**
	(0.123)	(0.084)
Signal at 5	0.391***	0.232***
	(0.119)	(0.084)
Uninformative Bracelet	0.187	0.166**
	(0.137)	(0.084)
Control Group mean	3.973	4.482
Observations	2350	1972
$S_4 > 0$: p(UI = S4)	0.380	0.569
$S_5 > 0$: p(UI = S5)	0.090	0.267
p(S4 = S5)	0.002	0.650
Joint F-test	0.002	0.042

Notes: This table shows results from regression of the discrete variable "total number of vaccines", coded 1, 2, 3, 4 or 5, on the treatment indicators Signal at 4, Signal at 5 and Uninformative Bracelet, with the Control Group as the omitted category. The sample includes all children born since the launch that were at least 11.5 months old (Column (1)) and 12 months old (Column (2)) by the end of the experiment. Column (1) shows treatment effects on the total number of timely vaccines received, that is by age 3, 4, 5, 6 and 11.5 months for vaccines 1, 2, 3, 4 and 5; Column (2) shows treatment effects on the total number of vaccines received by the age of 12 months, irrespective of the time of vaccination. The bottom rows give the p-values from a test that the effect of the Uninformative Bracelet (UI) is equivalent to the effect of Signal at 4 (S4) or to Signal at 5 (S5), identifying social signaling preferences ($S_4 > 0$, $S_5 > 0$), and that the effect of Signal at 4 is equivalent to the Signal at 5. Last is a joint hypothesis test of all three bracelet treatments. All regressions include strata-fixed effects and the demeaned control for child age and an indicator that is coded one if the vaccine entry comes from the administrative data. Standard errors are cluster bootstrapped (1000 repetitions) at the clinic level.* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 8: The Extensive Margin Effect of Bracelets: Complete Vaccination by Age one Year

Dependent variable:	Vaccine 1	Vaccine 2	Vaccine 3	Vaccine 4	Vaccine 5
	(1)	(2)	(3)	(4)	(5)
Signal at 4	0.005	0.011	0.020	0.054*	0.101**
	(0.008)	(0.009)	(0.016)	(0.030)	(0.047)
Signal at 5	0.000	0.007	0.018	0.052*	0.135***
	(0.009)	(0.011)	(0.017)	(0.030)	(0.045)
Uninformative Bracelet	0.003	0.008	0.018	0.058**	0.080*
	(0.008)	(0.010)	(0.015)	(0.029)	(0.046)
Control Group mean	0.989	0.978	0.953	0.881	0.676
Observations	1972	1972	1972	1972	1972
p(UI = S4)	0.737	0.781	0.843	0.859	0.578
p(UI = S5)	0.716	0.904	0.975	0.764	0.104
p(S4 = S5)	0.540	0.743	0.890	0.911	0.309
Joint F-test	0.903	0.729	0.645	0.242	0.026

Notes: This table shows results from a linear probability model of the binary outcome variable for a child being vaccinated for 1, 2, 3, 4, or 5 vaccinations by the age of 12 months - ignoring whether a child received a given vaccine on time - on treatment indicators for Signal at 4, Signal at 5 and Uninformative Bracelet, with the Control Group as the excluded category. The sample includes all children born since the launch of the experiment that were 12 months or older when last observed. The bottom rows give the p-values from a test that the effect of the Uninformative Bracelet (UI) is equivalent to the effect of Signal at 4 (S4) or to Signal at 5 (S5), and that the effect of Signal at 4 is equivalent to the Signal at 5. Last is a joint hypothesis test of all three bracelet treatments. All regressions include strata-fixed effects and the demeaned control for child age and an indicator that is coded one if the vaccine entry comes from the administrative data. Standard errors are cluster bootstrapped (1000 repetitions) at the clinic level.* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 9: Structural Estimation Results Dynamic Discrete-Choice Model

Parameter	Estimate	SE	Estimate	SE
	Compared to Control Group		Compared to Uninformative Bracelet	
S_5	0.686	0.109	0.431	0.084
S_4	-0.131	0.098	-0.305	0.096
κ	-0.066	0.008	-0.056	0.009
μ_v	0.824	0.047	1.095	0.062
σ_v	0.284	0.055	0.592	0.058
Signaling utility $\frac{S_5}{\kappa}$	**10.39 miles**		**7.7 miles**	

Notes: This table shows the parameters estimated from the dynamic-discrete choice model. S_5 and S_4 denote the parameters capturing the signaling utility of treatments Signal at 5 and Signal at 4, κ denotes the parameter measuring the marginal disutility of walking one miles, μ_v and σ_v capture the mean and standard deviation of the normal type distribution. The sample used for the estimation is the same as used in the reduced form estimations, that is, all children that were born since the start of the experiment. Regular standard errors are reported (not clustered). Columns 1 and 2 report the results from the estimation, with the effect of signals being compared to the Control Group. Columns 3 and 4 report the results from the estimation, with the effect of signals being compared to the Uninformative Bracelet.

A Supplementary Appendix

Figure A1: Babies wearing Bracelets

Notes: Mothers are sitting outside a clinic, waiting for their child to be vaccinated. The children in this photo are wearing yellow "1st visit" bracelets on their wrist.

Figure A2: Process of Clinic and Community Selection
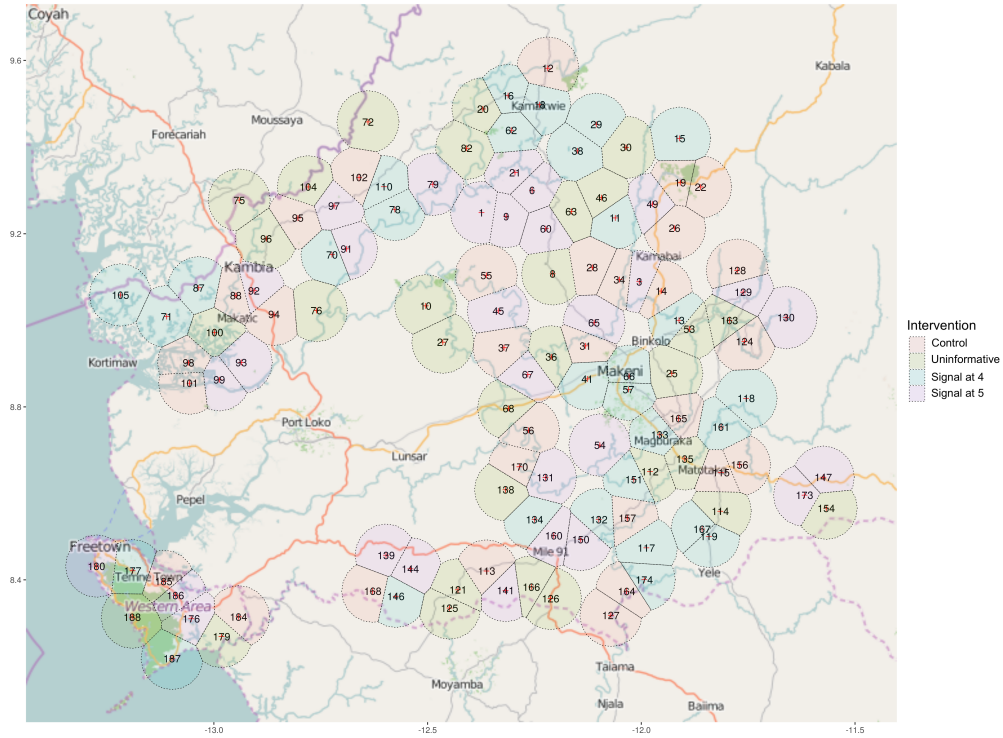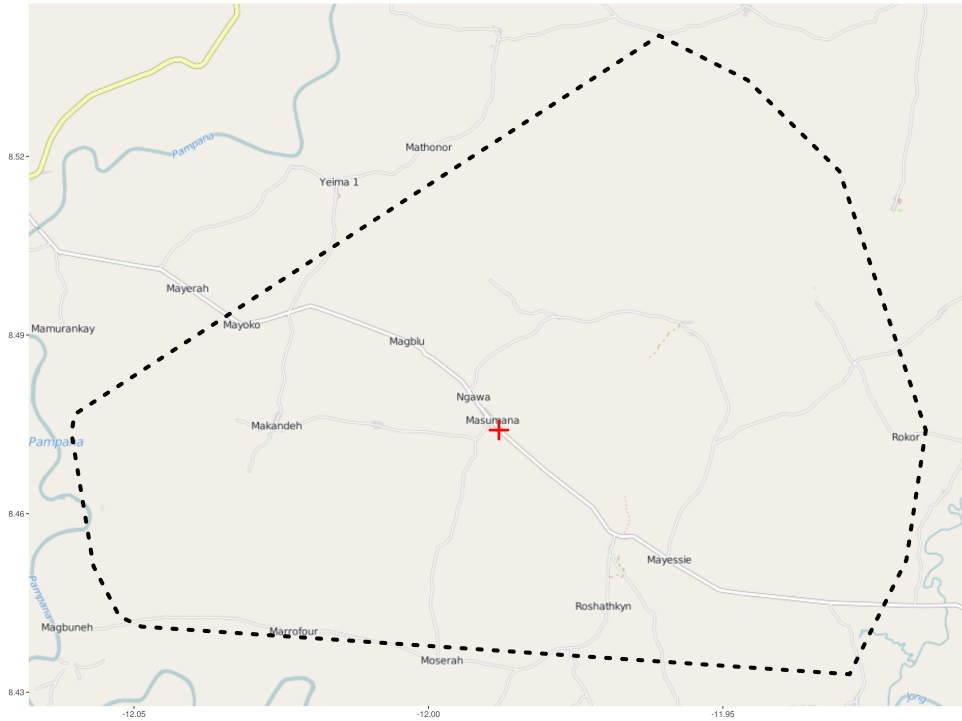
Notes: The upper map displays the 120 selected clinics and their non-overlapping catchment areas, with radius of five miles around each clinic. The bottom map displays one out of the 120 maps that surveyors were subsequently given, that showed the area that is non-overlapping and from which they would select five communities (two at close, 0-2 miles distance from the clinic and three communities at far, 2-5 miles distance).

Figure A3: Hand Out of Green Bracelets in Signals at 4 and 5 according to Timely Vaccination
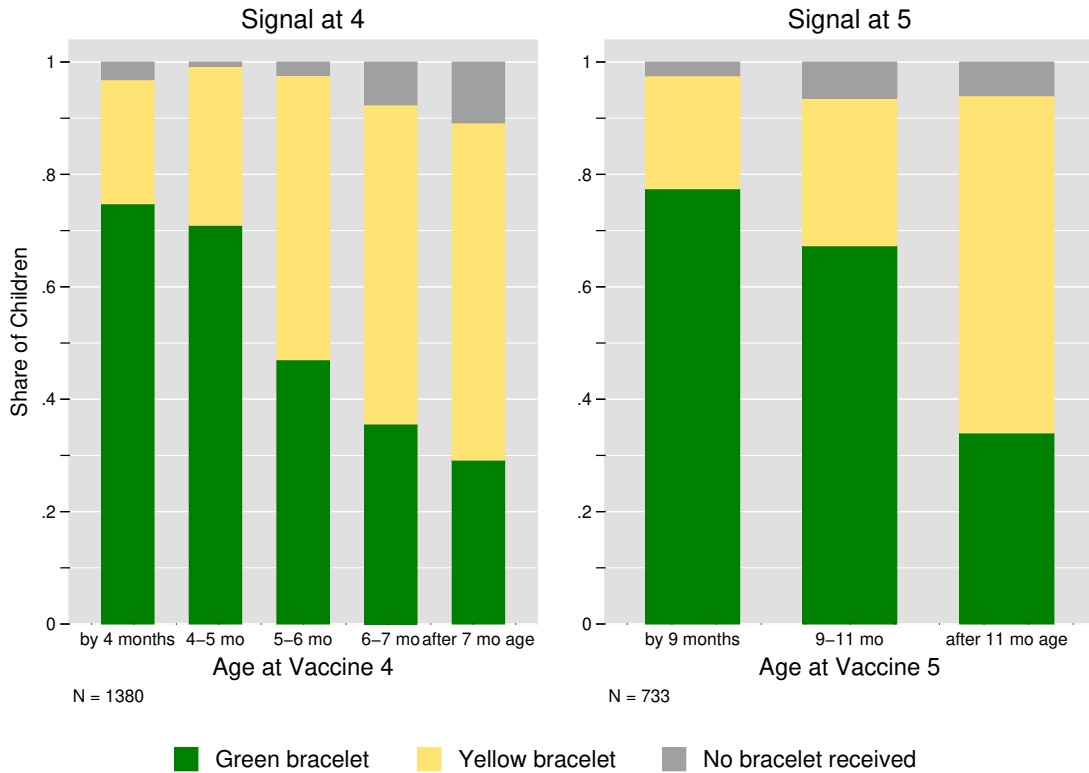
Notes: This figure shows the share of children with a green or yellow bracelet according to the time they took vaccine four and five in Signal at 4 and Signal at 5 treatments. Health workers were instructed to give the child a green bracelet if it came for vaccine four before six months of age (Signal at 4) and vaccine 5 by 11 months of age (Signal at 5). If a child came after this time, health workers were instructed to exchange the green bracelet for a new yellow "1st visit" bracelet instead. The sample includes children that were born since the start of the experiment. The column on the left (Signal at 4) shows that the probability of receiving a green bracelet is monotonically decreasing in the age at which the child took vaccine four, from 74.45 percent if the vaccine was taken by four months age, to 70.07, 46.34, 34.78 and 28.81 percent if the child received the vaccine by 5, 6 or 7 months, or after 7 months age. The column on the right (Signal at 5) shows a similar pattern: the probability of receiving a green bracelet is monotonically decreasing in the age at which the child comes for vaccine five, from 77.45 percent if the vaccine was taken by 9 months age, to 67.30 and 34 percent by 11 months and after 11 months age.

Figure A4: Stated Beliefs Compared to Beliefs under Bayesian Learning
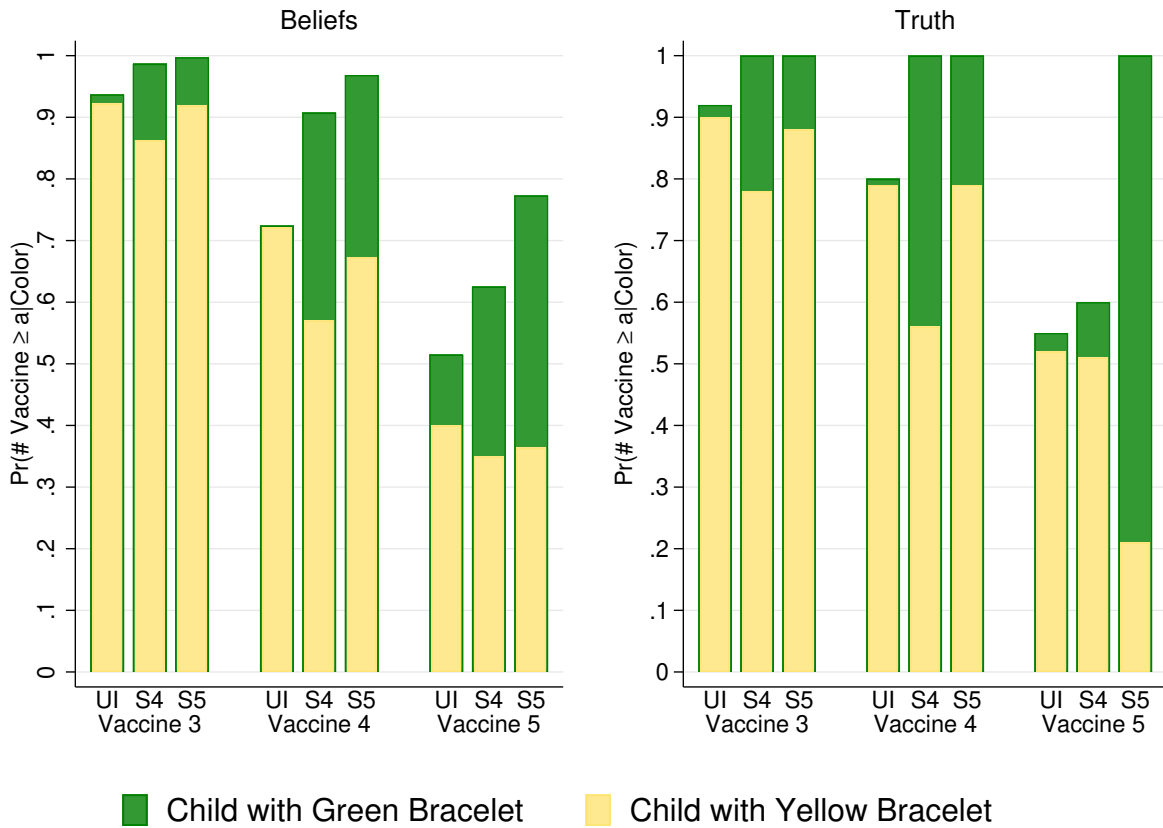
Notes: This figure compares individuals' beliefs about the number of vaccines children received conditional on having a yellow or green bracelet ("Beliefs"), to beliefs under Bayesian learning ("Truth"). The latter are simulated using the observed true vaccination outcomes from the survey and administrative data and the probabilities of a child receiving a green or yellow bracelet for a given vaccination and vaccine age from the observed implementation (see Figure 6). Same as in Figure 7, beliefs are shown by vaccine, and by treatment, where UI = Uninformative Bracelet, S4 = Signal at 4, S5 = Signal at 5.

Figure A5: Inferences about Types Conditional on Vaccine Decisions

How would community members view you if you...

took your child for all vaccinations?

missed to take your child for vaccinations?
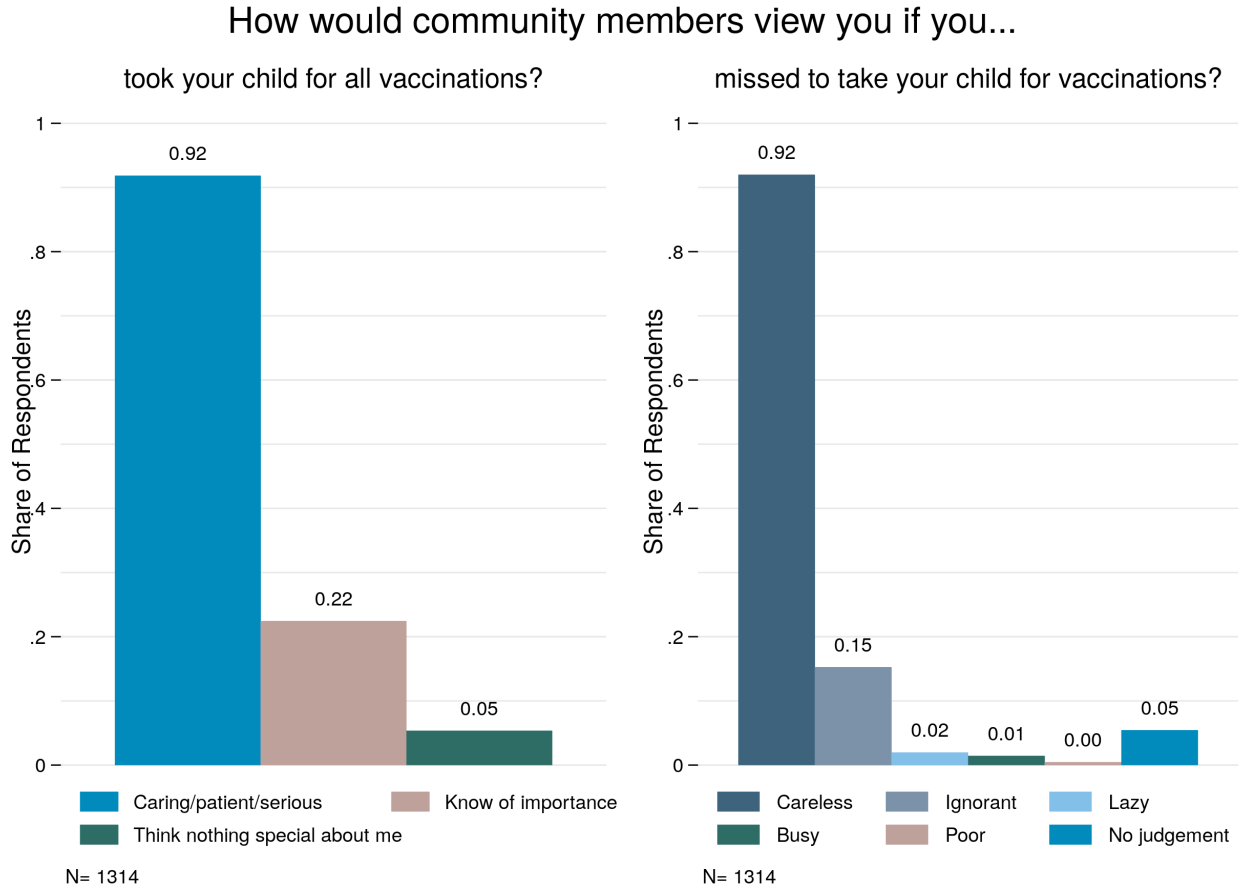
Notes: This figure shows mothers' beliefs about the inferences that community members would make, conditional on observing that they took their child for all vaccinations or missed any. The sample includes all endline survey respondents. There are no significant differences for these responses across treatment arms.

What action would they take if you...

took your child for all vaccinations?   missed to take your child for vaccination?
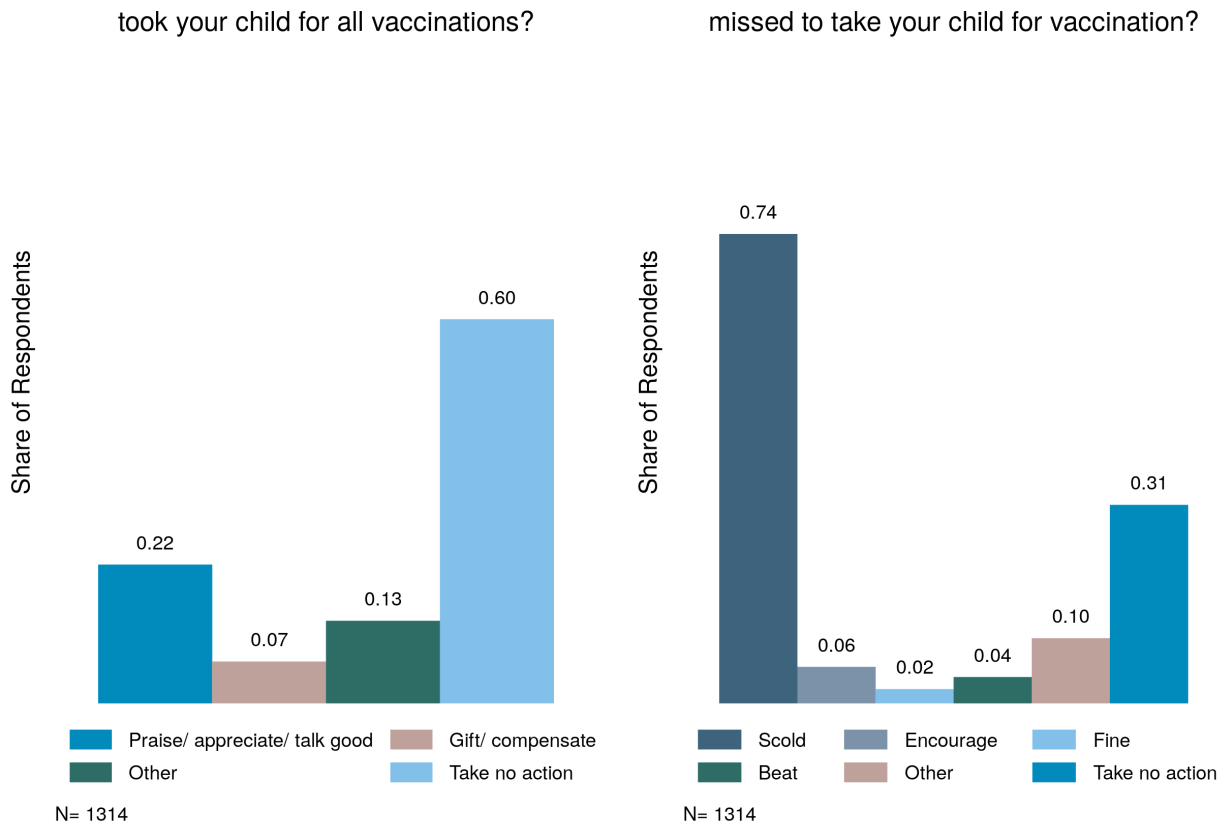
Notes: This figure shows mothers' beliefs about the actions that community members would take, conditional on observing that they took their child for all vaccinations or missed any. The sample includes all endline survey respondents.

Figure A7: Reference Groups for Social Signaling

Who is concerned about your child's vaccination?

N = 1314
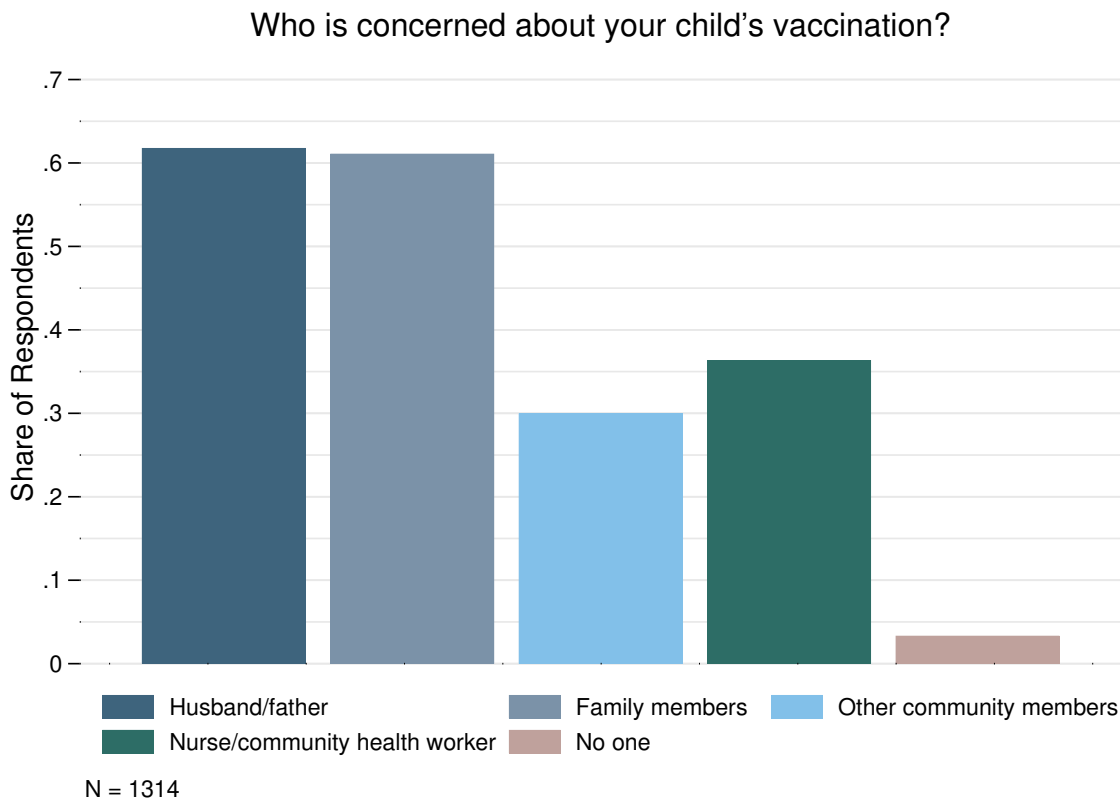
Notes: This figure displays the different reference groups mothers believe are in general concerned about their own child's vaccinations and might form opinions about their actions. The sample includes all endline survey respondents.

Table A1: The Effect of Signals on Preferences for Different Vaccinations

Dependent variable:	Vaccine 1	Vaccine 2	Vaccine 3	Vaccine 4	Vaccine 5	All vaccines
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A:			Most Important Vaccine			
Signal at 4	-0.022	-0.012	0.006	-0.015	0.014	0.038
	(0.047)	(0.010)	(0.004)	(0.011)	(0.026)	(0.048)
Signal at 5	-0.021	-0.008	0.003	-0.019*	0.009	0.041
	(0.053)	(0.013)	(0.003)	(0.011)	(0.031)	(0.040)
Uninformative Bracelet	-0.017	0.000	0.010*	-0.008	-0.013	0.037
	(0.045)	(0.012)	(0.005)	(0.012)	(0.026)	(0.045)
Control Group mean	0.685	0.024	-0.000	0.024	0.108	0.147
Observations	1314	1314	1314	1314	1314	1314
p(UI = S4)	0.912	0.212	0.590	0.467	0.209	0.990
p(UI = S5)	0.947	0.509	0.323	0.253	0.427	0.942
p(S4 = S5)	0.974	0.730	0.588	0.606	0.853	0.956
Panel B:			Second Most Important Vaccine			
Signal at 4	-0.025	0.032	-0.002	0.034	-0.027	-0.006
	(0.026)	(0.058)	(0.033)	(0.030)	(0.049)	(0.019)
Signal at 5	0.020	0.090*	-0.030	0.003	-0.064	-0.006
	(0.036)	(0.053)	(0.031)	(0.027)	(0.047)	(0.018)
Uninformative Bracelet	-0.011	0.022	-0.028	0.027	0.014	-0.015
	(0.025)	(0.055)	(0.029)	(0.029)	(0.048)	(0.017)
Control Group mean	0.099	0.379	0.107	0.056	0.314	0.032
Observations	1075	1075	1075	1075	1075	1075
p(UI = S4)	0.463	0.856	0.370	0.809	0.406	0.533
p(UI = S5)	0.321	0.181	0.921	0.327	0.093	0.469
p(S4 = S5)	0.152	0.285	0.364	0.239	0.413	0.986

Notes: This table shows results from a linear probability model of the binary outcome variables for vaccine 1, 2, 3, 4 or 5, or all vaccines being considered as most (second most) important vaccine on treatment indicators for Signal at 4, Signal at 5 and Uninformative Bracelet, with the Control Group as excluded category. The outcome variable is coded one if an endline survey respondent named a vaccine as being the most (second most) important, and zero otherwise. Panel A shows the results for the question "Which vaccine do you consider the most important?" and Panel B results for the question "Which vaccine do you consider the second most important?". The latter question was only asked conditional on a respondent not having answered "All vaccines" to the first question. The respondent sample in Panel B is therefore smaller. The bottom rows give the p-values from binary comparisons between the Uninformative (UI) and Signal at 4 (S4) and Signal at 5 (S5), testing for any significant differences in preferences between bracelet treatments. All regressions include strata-fixed effects. Standard errors are cluster bootstrapped (1000 repetitions) at the clinic level.* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table A2: Correlation of Distance with Socio-Economic Characteristics

Dependent variable:	Vaccine 3	Vaccine 4	Vaccine 5	Vaccine 3	Vaccine 4	Vaccine 5
	(1)	(2)	(3)	(4)	(5)	(6)
Distance 1 mile	0.061**	0.058	-0.129	0.067**	0.057	-0.143
	(0.031)	(0.050)	(0.118)	(0.031)	(0.051)	(0.124)
Distance 2 miles	-0.061	-0.038	-0.191*	-0.050	-0.036	-0.233**
	(0.056)	(0.066)	(0.106)	(0.056)	(0.067)	(0.113)
Distance 3 miles	-0.089**	-0.114**	-0.177*	-0.081**	-0.109**	-0.180*
	(0.042)	(0.051)	(0.096)	(0.041)	(0.051)	(0.098)
Distance 4 miles	-0.066**	-0.101**	-0.250***	-0.054*	-0.094**	-0.266***
	(0.030)	(0.046)	(0.091)	(0.031)	(0.046)	(0.087)
Distance 5 miles	-0.082**	-0.074	-0.313***	-0.072**	-0.075*	-0.342***
	(0.034)	(0.046)	(0.101)	(0.034)	(0.045)	(0.103)
Child age				-0.000**	-0.001***	-0.000
				(0.000)	(0.000)	(0.001)
Birth order				0.003	-0.022	-0.026
				(0.012)	(0.016)	(0.033)
Mother age				-0.001	0.001	-0.006
				(0.003)	(0.004)	(0.008)
Floor cement				0.022	0.036	0.074
				(0.019)	(0.030)	(0.066)
Roof corrugated iron				0.043	0.035	0.032
				(0.034)	(0.049)	(0.115)
Has any education				0.030***	0.024*	-0.016
				(0.011)	(0.014)	(0.032)
Works on farm				0.033	0.061	0.228
				(0.030)	(0.058)	(0.138)
Trader				0.023	0.010	0.118
				(0.033)	(0.062)	(0.158)
Outcome Mean	1.006	0.965	0.760	0.908	0.890	0.887
Observations	1077	958	247	1077	958	247

Notes: This table shows the effect of distance on timely completion of vaccine 3, 4 and 5, comparing treatment effects from regressions without and with covariates. The sample includes all children (age 4 months and above, to be counted for vaccine 3 etc.) whose parents were surveyed at endline and for whom I therefore observe socio-economic characteristics. Columns (1)-(3) show regression results without covariates, and columns (4)-(6) results for the same specification with covariates. The covariate child age is coded in days, mother age in years; the variable birth order takes values 1 through 6. The variables Floor cement, Roof corrugated iron, Has any education, Works on farm and Trader are all indicator variables that take the value one if the respondent's floor is made of cement etc. and zero otherwise. The distance variable takes the values zero to five miles, specifying how far the respondent's community is from the clinic. Zero is the excluded category in all regressions. All regressions include strata-fixed effects. Standard errors are clustered at the clinic level.* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table A3: Test of the Equality of Distance Coefficients from Regressions with and without Covariates

	Distance 1 mile	2 miles	3 miles	4 miles	5 miles
	(1)	(2)	(3)	(4)	(5)
Vaccine 5	0.021	0.023	0.001	0.011	0.033
	(0.039)	(0.030)	(0.019)	(0.026)	(0.028)
Observations	247	247	247	247	247
Vaccine 4	0.005	-0.003	-0.006	-0.007	0.002
	(0.011)	(0.008)	(0.008)	(0.011)	(0.009)
Observations	958	958	958	958	958
Vaccine 3	-0.003	-0.011	-0.009	-0.013*	-0.012
	(0.009)	(0.007)	(0.006)	(0.008)	(0.007)
Observations	1077	1077	1077	1077	1077

Notes: This table tests for the equality of the coefficients from the regressions of vaccine 5, 4, and 3 on distance dummy variables with and without covariates (see A2), using seemingly-unrelated estimation. The table displays the difference in coefficients and the associated p-values in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table A4: Additional Information on Bracelet Retention and Correct Bracelet Hand Out

Dependent variable:	Child wears bracelet	Child lost bracelet	Bracelet was exchanged
	(1)	(2)	(3)
Signal at 4	-0.058	0.024	0.021
	(0.060)	(0.042)	(0.072)
Signal at 5	-0.019	-0.063*	-0.057
	(0.055)	(0.037)	(0.065)
Uninformative Bracelet mean	0.370	0.224	0.629
Observations	3901	941	742
p(S4 = S5)	0.523	0.008	0.281

Notes: This table shows results from a linear probability model of the binary outcome variables (1) for a child wearing a bracelet when observed during the listing survey, (2) whether a child still had or lost her bracelet at endline, and (3) whether a child's bracelet was exchanged when it came for vaccine 4 or 5, on treatment indicators Signal at 4 and Signal at 5, with the Uninformative Bracelet as the omitted category. The sample used for (1) includes all children that were born since the experiment was launched and were physically present during the listing, and surveyors could see the wrist of the child. The sample for (2) includes all children in bracelet treatments that were part of the endline survey; sample (3) does the same but conditions on a child having received vaccine 4 or 5 (as otherwise the child would not have been eligible for an exchange of the bracelet). All regressions include strata-fixed effects. Standard errors are clustered at the clinic level. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table A5: Supplementary to Table A4, Column (1)

Dependent variable:	Child wears bracelet
Child age	-0.0008***
	(0.0001)
Outcome Mean	0.5145
Observations	3898

Notes: This table shows results from a linear probability model of the binary outcome variable for a child wearing a bracelet when observed during the listing survey on the continuous variable child age, measured in days. Data is pooled across Signal at 4, Signal at 5 and Uninformative Bracelet as no significant differences for "Child wears bracelet" were found in Table A4, Column (1). Around 50 percent of children age 3 months or below wear the bracelet when visited during the listing survey. The probability declines to 40 and 33 percent for children of age 3 to 6, and 6 to 10 months respectively. Among children that are 12 months or older, 22 percent wear the bracelet. When asking parents during endline, why the child is not wearing the bracelet, the most common answer was that they are afraid of the child losing the bracelet by biting on it or playing with it. Parents further report that the child wears the bracelet when going to the clinic or on special occasions, when visiting relatives or at community events. The regression includes strata-fixed effects. Standard errors are clustered at the clinic level. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table A6: Relationship of respondent to other mother.

	Percent
Regular community member	39
Neighbor	14
Relative	35
Friend	7
Other carer	5
Total	100
Observations	5,573

Notes: This table displays the social connection between endline respondents and a sample of randomly selected (other) mothers in their community, conditional on the respondent recognizing the other mother. There are 5,573 respondent-other mother pairs in my endline sample, across all four treatment groups, including 1,304 unique respondents and 2,348 unique other mothers from 119 clinics. Ten endline respondents across all treatments (less than 1% of the sample) did not recognize any of the other mothers.

Table A7: Number of Clinics and Children across Four Districts

District	Clinics					Children				
	Control	Signal 4	Signal 5	Uninform	All	Control	Signal 4	Signal 5	Uninform	All
Bombali	11	11	11	11	44	442	629	551	471	2093
Kambia	6	6	6	7	25	425	371	399	394	1589
Tonkolili	11	11	10	10	42	577	766	622	507	2472
WA Rural	2	2	2	2	8	84	75	65	131	355
Total	30	30	29	30	119	1528	1841	1637	1503	6509

Notes: The sample includes all children that were born since the start of the experiment, are from one of the selected catchment communities, attend one of the study clinics, and had at least reached the timeliness cut-off for vaccine three. The sample is slightly larger when also including children that were younger (and are included in the estimation of treatment effects for vaccine one and two) and smaller when excluding children that had not yet reached the timeliness cut-off for vaccine four and five (which results in a smaller sample used in the estimation of treatment effects for vaccine four and five). The clinic randomization was stratified by district. One clinic of the 120 selected, located in Western Area (WA) Rural district is excluded from the analysis due to serious complications in the implementation and data collection.

Table A8: Number of Communities and Children by Distance to Clinic

| Treatment	All Communities			Close (0-2 miles)			Far (2-5 miles)		
	Coms	Distance	Children	Coms	Distance	Children	Coms	Distance	Children
Control	144	1.88 (1.76)	1522	65	0.63 (0.81)	939	78	3.83(0.84)	583
Signal 4	145	1.83 (2.05)	1841	57	0.41 (0.76)	1116	88	4.01 (0.84)	725
Signal 5	141	2.11 (1.90)	1623	69	0.78 (0.87)	963	70	3.99 (0.85)	660
Uninform	148	2.08 (1.99)	1503	61	0.45 (0.78)	833	87	4.11 (0.84)	670
Total	578	2.03 (2.01)	6489	252	0.56 (0.82)	3851	323	3.99 (0.85)	2638

Notes: For each clinic, surveyors selected five communities, using in-field randomization. Surveyors obtained a list of all catchment communities from clinic staff. A community was considered as eligible for selection if i) it was primarily served by the clinic (instead of another close-by clinic), ii) if it had at least ten dwelling units (a dwelling unit has on average between three to four households), iii) the community was not an outreach point i.e. community where health workers would regularly travel to vaccinate children. Among the five communities, one was by default the clinic community. In addition, one other close (located up to two miles distance from the clinic) community was randomly selected. Three far communities (located further than two miles up to five miles distance from the clinic) were selected. For clinics that had fewer than three far or two close communities, surveyors were asked to replace the community with another close or far community instead. Means reported. Standard deviation in parentheses.

Table A9: Verifying the Correct Implementation of Bracelets, Regression Results for Figure 6

Dependent variable:	Signal at 4		Signal at 5		Uninformative Bracelet	
	Green	Yellow	Green	Yellow	Green	Yellow
	(1)	(2)	(3)	(4)	(5)	(6)
Vaccine 2	0.013	0.095***	0.012***	0.042	0.040	0.069
	(0.009)	(0.033)	(0.004)	(0.040)	(0.060)	(0.054)
Vaccine 3	0.035*	0.107**	0.018**	0.053**	0.070*	0.034
	(0.019)	(0.044)	(0.007)	(0.021)	(0.036)	(0.044)
Vaccine 4	0.613***	-0.437***	0.044***	0.044	0.063	0.064*
	(0.049)	(0.079)	(0.006)	(0.027)	(0.039)	(0.034)
Vaccine 5	0.643***	-0.502***	0.706***	-0.608***	0.106***	0.018
	(0.036)	(0.067)	(0.046)	(0.054)	(0.041)	(0.041)
Vaccine 1 mean	0.003	0.798	-0.005	0.867	0.294	0.546
Observations	2018	2018	1803	1803	1615	1615

Notes: This table shows the regression results of a binary variable for green or yellow bracelet on the total number of vaccines a child has received and strata fixed effects, with standard errors cluster bootstrapped (1000 repetitions) at the clinic level.* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Figure A8: The Effect of Distance on the Total Number of Vaccines Completed
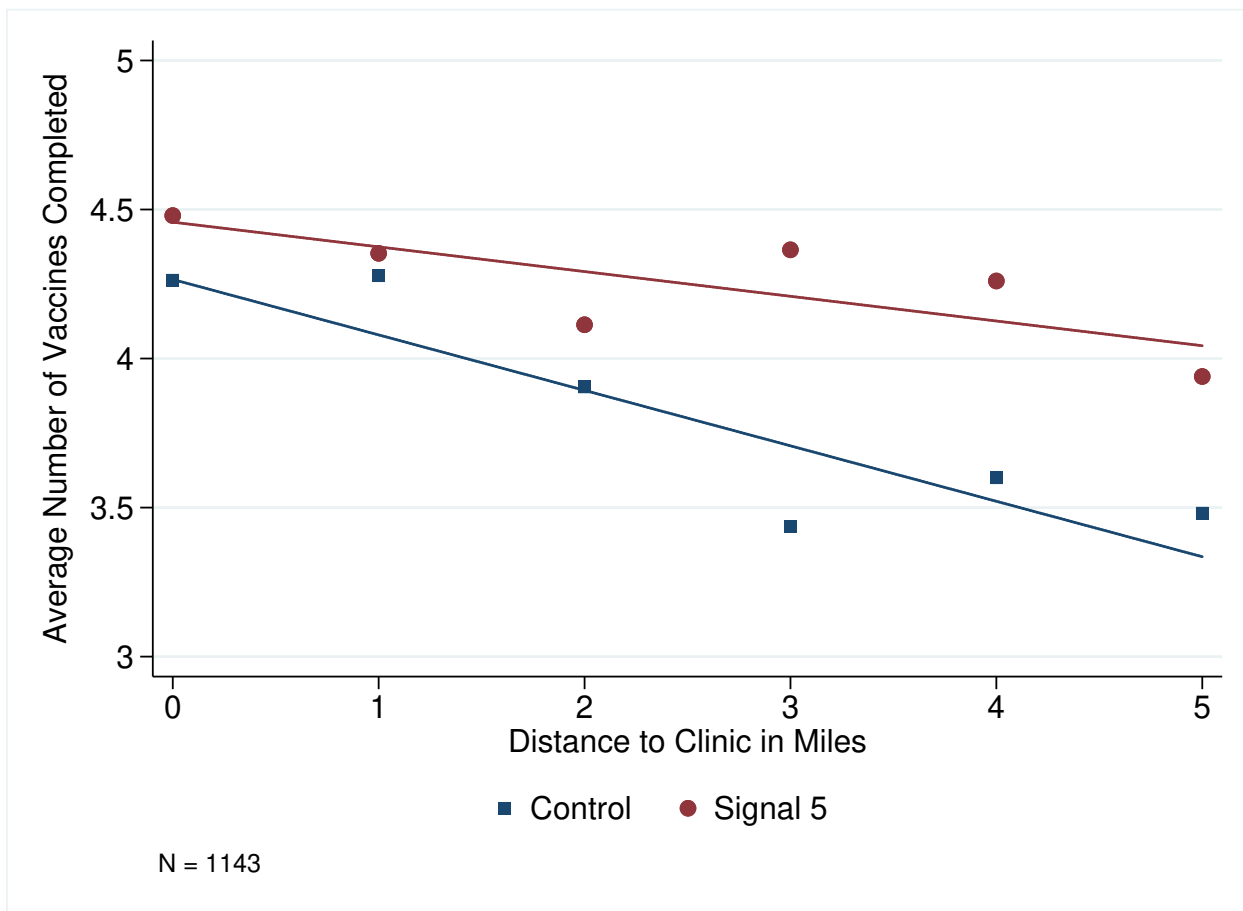
Notes: The graph plots a bin scatter of the average number of timely vaccines completed against the travel distance from communities to clinics, separately for the Control Group and Signal at 5. The sample includes all children born since the launch that were at least 11.5 months old by the end of the experiment, to be considered for all five vaccinations. The plot shows that distance has a linear effect on the number of vaccinations completed in the Control Group. Signal at 5 mitigated the negative effect of distance: the average total number of vaccines completed at zero miles in the Control Group (4.25) is equivalent to the average number completed at 4 miles in Signal at 5.

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