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Childhood vaccines in Uganda and Zambia: Determinants and barriers to vaccine coverage

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ABSTRACT

Background: Improving childhood vaccine coverage is a priority for global health, but challenging in low and middle-income countries. Although previous research has sought to measure determinants of vaccination, most has limitations. We measure determinants using a clearly-defined hypothetical model, multi-faceted data, and modeling strategy that makes full use of the hypothesis and data.
Methods: We use linked, cross-sectional survey data from households, health facilities, patients and health offices in Uganda and Zambia, and Bayesian Structural Equation Modeling to quantify the proportion of variance in childhood vaccination that is explained by key determinants, controlling for known confounding.
Results: We find evidence that the leading determinant of vaccination is different for different outcomes. For three doses of pentavalent vaccine, intent to vaccinate (on the part of the mother) is the leading driver, but for one dose of the vaccine, community access is a larger factor. For pneumococcal conjugate vaccine, health facility readiness is the leading driver. Considering specifically-modifiable determinants, improvements in cost, facility catchment populations and staffing would be expected to lead to the largest increase in coverage according to the model.
Conclusions: This analysis measures vaccination determinants using improved methods over most existing research. It provides evidence that determinants should be approached in the context of relevant outcomes, and evidence of specific determinants that could have the greatest impact in these two countries, if targeted. Future studies should seek to improve our analytic framework, apply it in different settings, and utilize stronger study designs. Programs that focus on a particular determinant should use these results to select an outcome that is appropriate to measure their effectiveness. Vaccination programs in these countries should use our findings to better target interventions and continue progress against vaccine preventable diseases.

1. Introduction

Improving childhood vaccine coverage is a major priority for global health [1], but coverage remains a challenge in low and middle-income countries (LMICs). An estimated 74% of children in Africa receive vaccination [2], raising equity concerns [3] besides merely concerns of missed opportunities. Policy makers and public health practitioners address these issues by identifying determinants and removing barriers [4–6]. Gavi, the Vaccine Alliance, for example, supports health system strengthening (HSS) with aims of improving system bottlenecks [7]. For HSS support, country stakeholders must first identify which barriers are most critical to vaccine coverage in their context.

Barriers to vaccine coverage are complex and difficult to measure though. A recent systematic review shows the large number of determinants and complex structure relating them [8]. Many determinants are associated with coverage, but their effects are mediated and confounded by others. Determinants also vary between different outcomes; the set of barriers to initial engagement with the health system may be different than barriers to completing the dosage schedule, and new vaccines present further challenges [4–6,9].

Although hundreds of research studies have sought to measure determinants and barriers to vaccination in LMICs [8,10–13], most face key limitations. First, the theoretical model for analysis is often informally defined. Issues such as the universe of

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determinants and the structure of their relationships are rarely explicitly stated. Second, studies typically use only household survey data. Household data suitably reflect maternal perceptions and household characteristics, but not community and health system factors. Third, most studies use generalized linear models to estimate odds ratios. These models have limited ability to realistically depict an underlying theoretical model, including mediation and indirectly measurable latent constructs [14]. These limitations can be summarized as theory, confounding, directionality and construct validity.

The objective of this study is to measure vaccination determinants using a more integrated approach. This includes a clearly-defined hypothetical model, multi-faceted data, and a modeling strategy that both realistically represents the hypothetical model and makes full use of the data. We use a conceptual framework from a recent systematic review and qualitative analysis to define the hypothetical model [8]. The data are four linked surveys from an evaluation in Uganda and Zambia [15]. We employ Bayesian Structural Equation Modeling (BSEM) with latent variables to represent the hypothetical model using the data [14,26]. Special emphasis is placed on displaying the results in a manner which is useful to policy-makers, so that the original challenge of identifying key barriers to vaccine coverage can be met.

2. Methods

We carried out separate analyses for four different outcomes, chosen to reflect differences between new vaccines and vaccines already in routine use, and between initiation (receipt of one dose of a vaccine) and drop-out (receipt of at least one dose but not all three). We demonstrate the results by examining regression coefficients, comparing explained variance, and using counterfactual analysis.

2.1. Data

The data come from four surveys conducted as part of the Gavi Full-Country Evaluation study [15] in Uganda and Zambia:

1. Household survey (HHS)
2. Health facility survey (HFS)
3. District health office (DHO) survey
4. Patient exit survey (PES)

These surveys were "linked" by design, meaning that households were only sampled from the catchment areas of facilities in the HFS, district offices were only surveyed if they service facilities in the HFS, and patients were only sampled at facilities in the HFS. Sampling design was a stratified, two-stage, clustered random sample described in detail elsewhere [15]. Data collection concluded with a sample size of 4256 households, 177 facilities and 2202 patient interviews in 19 districts in Uganda, and 1070 households, 171 facilities and 3319 patient interviews in 21 districts in Zambia. Further details can be found in Appendix 1. Household survey instruments included maternal, child and household characteristics, vaccination and pregnancy history, knowledge, attitudes and perceptions of vaccines and local vaccine services and others. Health facility and DHO instruments included facility characteristics, resources, supply chain records and others. Patient variables included maternal characteristics, services received, costs and others. A careful data processing procedure was followed, described in Appendix 1.

Four outcome variables were examined. Receipt of at least 1 dose of the pentavalent vaccine (Pentavalent-1), 3 doses of the pentavalent vaccine (Pentavalent-3), 1 dose of pneumococcal conjugate vaccine (PCV1) and 3 doses of pneumococcal conjugate vaccine (PCV3) were analyzed separately for both countries. Coverage was determined based on the child's vaccine card whenever available, and maternal recall if necessary.

Eligible children for the analyses were any child older than 3 months, excluding children who were older than 18 months and born before introduction of PCV (for PCV analyses only), and excluding children whose caretaker was not their biological mother. The recommended vaccination schedule in both countries for both vaccines is at 6, 10 and 14 weeks for dose 1, 2 and 3 respectively.

2.2. Analysis

We used Bayesian Structural Equation Modeling (BSEM) with latent variables [14,16–18] to represent an *a priori* hypothesized model [8] using the survey data. Details on the modeling approach are in Appendix 2. Briefly, SEM is a method for estimating simultaneous regression equations, relying on a "structural model" (theory) and measurement models (data) [14,18]. Latent variable analysis uses systems of equations to represent variables that can only be indirectly measured (sometimes referred to as constructs) [14,18]. Bayesian approaches to SEM have more recently been developed to incorporate prior information about parameters and estimate posterior distributions [16].

2.3. Structural model

The structural model is depicted in Fig. 1. This model ties together constructs from existing theories [19,20] and was developed using systematic review and qualitative methods [8]. The framework hypothesizes three principal determinants of vaccine utilization:

- Intent to Vaccinate - Demand for vaccines on the part of the mother that would result in vaccination in the absence of other barriers.
- Facility Readiness - Supply (by the health system) of vaccine services to adequately meet demand. Incorporates resources (vials, syringes, human resources) and the consistency of their availability.
- Community Access - The ability (or inability) to successfully carry out the transaction of vaccine utilization, i.e. barriers and facilitators between Intent and Readiness.

The rationale, evidence base and methodology behind this hypothesized model are described in detail in Phillips et al. 2017 [8]. These three determinants are represented in the BSEM as latent variables which are indirectly measured by the data. As shown in Fig. 1, Intent to Vaccinate and Facility Readiness are themselves informed by other latent variables.

2.4. Measurement model

The measurement model, i.e. specification of data to define latent variables, was also based on systematic review [8]. Survey instruments were screened for variables which matched or approximated indicators from systematic review. Candidate variables were graphically examined *a priori* to ensure adequate variance in responses and to avoid a methodological issue known as complete separation. Final variable selection was as inclusive as possible. All viable data which, according to literature, informed at least one latent variable were included. For more detail on explanatory variables, see Appendix 3.