Causal Relationships Between Environmental Biotechnology Service Access and Referral Completion in Uganda

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ABSTRACT

Referral completion in Ugandan district health systems remains a persistent bottleneck, yet the mechanisms through which service continuity in environmental biotechnology applications influence patient navigation are poorly theorised. Rather than treating environmental technologies as a monolithic input, the framework disaggregates service continuity into technical availability, logistical coordination and community engagement, each hypothesised to operate through different mediators at household, facility and district levels. The analysis integrates Andersen's behavioural model of health service utilisation with institutional theories of trust and systems thinking from implementation science, arguing that previous evaluations have conflated access with adherence and have neglected the ecological embeddedness of referral networks. A three-level structural equation modelling design is proposed, with referral completion as the outcome, service continuity dimensions as exposures, and patient activation, facility readiness and inter-facility communication as mediators.

Keywords: *referral completion, service continuity, environmental biotechnology, multilevel mediation, Uganda, health systems, implementation science*

The Referral Paradox in Uganda's District Health System

Uganda'S District Health System Depends On A Functioning Referral Chain

Uganda's district health system depends on a functioning referral chain that moves patients from lower-level facilities toward specialised care, yet the completion of these referrals is neither automatic nor well understood. The Ministry of Health has invested in environmental biotechnology applications, including solar-powered vaccine cold chains, biosand water filtration at health centres and ecological sanitation systems, with the expectation that improved infrastructure will strengthen service delivery and, ultimately, patient outcomes. What remains unresolved is whether these investments actually influence whether a referred patient arrives at the next level of care, and through which causal mechanisms such influence might operate.

The prevailing evaluation paradigm in global health has tended to treat infrastructure provision as a binary exposure, asking whether a technology was

present or absent and then estimating its average effect on utilisation. This approach obscures the reality that technologies function within complex service ecosystems where continuity of operation, maintenance capacity and community acceptance determine whether an installed system delivers value over time. A solar refrigerator that functions for six months and then fails during the dry season does not provide the same service as one that operates continuously, yet most evaluations would classify both as technology exposure.

The Prevailing Evaluation Paradigm In Global Health Has Tended To

This measurement problem is particularly consequential in Uganda, where supply chains are volatile and where district-level variation in technical capacity is substantial. The argument developed here is that service continuity, rather than mere technology presence, constitutes the theoretically meaningful exposure for understanding referral completion. Service continuity refers to the uninterrupted availability of a functioning environmental biotechnology application across time, including its supporting logistics, maintenance and community engagement systems.

The framework distinguishes three dimensions of continuity, technical availability, logistical coordination and community engagement, and proposes that each operates through distinct mediators at different levels of the health system. This conceptual move reframes the evaluation question from whether biotechnology works to under what conditions of continuity it produces downstream health system effects.

Conceptual Foundations: Linking Infrastructure to Patient Behaviour

Understanding How Environmental Biotechnology Service Continuity Might Influence Referral

Understanding how environmental biotechnology service continuity might influence referral completion requires theoretical resources that span individual behaviour, organisational capacity and inter-organisational coordination. Andersen's behavioural model of health service utilisation provides a starting point by distinguishing predisposing characteristics, enabling resources and need factors that shape whether individuals seek and continue care (Andersen, 1995). Within this model, environmental technologies function as enabling resources at the community and facility levels, but the model has been criticised for treating the service environment as a static backdrop rather than as a dynamic system with its own internal logic.

Institutional theories of trust offer a complementary lens by emphasising that patients' willingness to follow through on referrals depends on their confidence in the referring institution and in the broader health system (Gidman, Ward, & McGregor, 2012). Trust is not merely an interpersonal phenomenon but is also institutional, shaped by repeated experiences of reliability or failure. When a health centre consistently has clean water, functioning cold chain equipment and staff who are not diverted to water-fetching duties, patients receive a signal that the institution is competent and worthy of their compliance.

Institutional Theories Of Trust Offer A Complementary Lens By Emphasising

Conversely, when technologies fail and services are interrupted, institutional trust erodes and patients may reasonably conclude that the referral destination will be no better than the referring facility. Systems thinking from implementation science provides the third theoretical pillar by directing attention to the interconnections among components of the referral pathway (de Savigny & Adam, 2009). A referral is not a single event but a sequence of decisions and actions that includes the initial consultation, the referral decision, patient preparation, transport arrangements, reception at the destination and follow-up.

Each link in this chain can fail independently, and the resilience of the chain depends on the coordination among facilities, district health offices and community structures. Environmental biotechnology applications are embedded within this chain at multiple points, and their continuity or interruption can have cascading effects on patient confidence and logistical feasibility.

Three Dimensions of Service Continuity

Technical Availability Is The Most Obvious Dimension Of Service Continuity

Technical availability is the most obvious dimension of service continuity and refers to whether a technology is physically operational and delivering its intended function. For solar-powered cold chain equipment, technical availability means that vaccines are maintained at appropriate temperatures throughout the referral network. For biosand water filters, it means that the filter media is functioning and producing safe water.

Technical availability depends on initial installation quality, routine maintenance, availability of spare parts and the technical competence of local operators (WHO, 2015). In Uganda, technical failures are often traced not to the technology itself but to breakdowns in the maintenance supply chain, including delayed

procurement of spare parts and inadequate training of biomedical engineers at district level. Logistical coordination constitutes the second dimension and refers to the alignment of supporting systems that enable a technology to function within the referral pathway.

Logistical Coordination Constitutes The Second Dimension And Refers To The

A functioning cold chain requires not only working refrigerators but also reliable electricity supply, transport for vaccine distribution and communication systems that alert facilities to supply schedules. Similarly, water treatment technologies require consumables, quality monitoring and waste management systems. Logistical coordination is inherently inter-organisational, involving health facilities, district health offices, national medical stores and sometimes private sector suppliers (Chandler et al., 2008).

When coordination fails, even technically functional equipment may not deliver services because supporting inputs arrive late or not at all. Community engagement represents the third dimension and captures whether local populations understand, accept and participate in the maintenance and governance of environmental technologies. Technologies that are imposed without community consultation often fall into disuse, while those that are co-managed with community health committees tend to achieve higher levels of sustained functionality (Rifkin, 2014).

Community engagement also shapes referral behaviour indirectly through its effects on health-seeking norms and on the perceived legitimacy of health facilities. In Ugandan districts where community health workers are actively involved in technology oversight, they also tend to play stronger roles in patient education and referral follow-up, creating a synergy between technical and social dimensions of service delivery.

Mediators Between Continuity and Referral Completion

The Framework Proposes That The Three Dimensions Of Service Continuity

The framework proposes that the three dimensions of service continuity influence referral completion through three classes of mediators operating at different levels of analysis. At the household level, patient activation, defined as the knowledge, skills and confidence that individuals bring to managing their health and navigating the health system, mediates the relationship between community engagement and referral completion (Hibbard, Stockard, Mahoney, & Tusler,

2004). When communities are engaged in technology governance, patients receive consistent messages about the value of completing referrals and develop greater confidence in the health system's ability to provide quality care at the next level.

At the facility level, institutional readiness mediates the relationship between technical availability and referral completion. Institutional readiness encompasses staffing levels, clinical competence, availability of diagnostic equipment and the facility's capacity to prepare patients adequately for referral (Durlak & DuPre, 2008). A facility with reliable water and electricity can devote more staff time to clinical care rather than to compensating for infrastructure failures, and can provide patients with clearer referral instructions and better preparation for what to expect at the destination.

At The Facility Level Institutional Readiness Mediates The Relationship Between

Technical availability thus operates not directly on patient behaviour but through its effects on the quality and reliability of facility-level care processes. At the district level, inter-facility communication mediates the relationship between logistical coordination and referral completion. Referral systems function poorly when referring and receiving facilities do not share information about patient status, expected arrival times and required follow-up (Murray & Pearson, 2006).

Logistical coordination of environmental technologies often requires communication infrastructure, including reliable phone networks and data systems, that also serves clinical referral communication. When district health teams coordinate supply chains effectively, they typically also coordinate referral networks, creating a spillover effect that improves the probability that referred patients are expected, received and followed up appropriately.

A Multilevel Mediation Architecture

The Proposed Analytical Design Recognises That Referral Completion Is A

The proposed analytical design recognises that referral completion is a multilevel phenomenon in which patients are nested within facilities, facilities within districts and districts within regions. Standard regression approaches that ignore this nesting produce biased standard errors and cannot distinguish compositional from contextual effects (Raudenbush & Bryk, 2002). The framework therefore specifies a three-level structural equation model in which patient-level referral completion is modelled as a function of patient characteristics, facility-level mediators and district-level exposures, with random intercepts at facility and district levels to account for unobserved heterogeneity.

Formally, the model can be expressed as a set of equations that link the exposure variables to mediators and outcomes across levels. At the patient level, the probability of referral completion is modelled as a function of patient activation and individual covariates. At the facility level, institutional readiness is modelled as a function of technical availability and facility characteristics.

At the district level, inter-facility communication is modelled as a function of logistical coordination and district characteristics. The mediation pathways are then estimated by combining the coefficients from these equations, with bootstrap confidence intervals for the indirect effects.

$$logit(P(Y_{ijk} = 1)) = \beta_0 + \beta_1 A_{ijk} + \beta_2 X_{ijk} + u_{jk} + v_k \quad (1)$$

Formally The Model Can Be Expressed As A Set Of

Where Yijk represents referral completion for patient i in facility j in district k, Aijk represents patient activation, Xijk represents individual covariates, ujk is a facility-level random effect and vk is a district-level random effect. The facility-level equation models institutional readiness as a function of technical availability, and the district-level equation models inter-facility communication as a function of logistical coordination. Cross-level interactions can be specified to test whether the effect of patient activation on referral completion is moderated by facility readiness or district communication quality.

The identification of mediation effects in multilevel settings requires careful attention to confounding at each level. At the patient level, socioeconomic status, distance to the referral facility and perceived severity of illness are potential confounders of the relationship between activation and completion. At the facility level, facility size, staffing levels and historical performance may confound the relationship between technical availability and readiness.

At the district level, overall health system investment and governance quality may confound the relationship between logistical coordination and communication. The design should therefore include measured confounders at each level and should acknowledge that unmeasured confounding remains a threat to causal interpretation (Imai, Keele, & Tingley, 2010).

Measurement and Operationalisation Challenges

Operationalising Service Continuity Requires Moving Beyond Binary Measures Of Technology

Operationalising service continuity requires moving beyond binary measures of technology presence toward continuous or ordinal measures that capture the duration and reliability of functioning. A facility that has experienced three weeks

of cold chain failure in the past year differs meaningfully from one with uninterrupted function, yet both would be classified as having cold chain technology under conventional approaches. The framework proposes that service continuity be measured through routine facility assessments that document technology functionality at multiple time points, combined with maintenance logs and supply chain records (WHO, 2015).

Patient activation can be measured using validated instruments such as the Patient Activation Measure, which assesses the knowledge, skills and confidence that individuals bring to health management (Hibbard et al., 2004). However, these instruments have been developed primarily in high-income settings and require cultural adaptation for Ugandan populations. The framework recommends a mixed-methods approach to measurement development, combining cognitive interviewing with quantitative validation to ensure that items are meaningful in the Ugandan context and that response scales function appropriately.

Patient Activation Can Be Measured Using Validated Instruments Such As

Institutional readiness is a multidimensional construct that includes both structural elements, such as staffing and equipment, and process elements, such as clinical protocols and referral documentation practices. The WHO Service Availability and Readiness Assessment provides a standardised approach to measuring facility readiness that has been applied in multiple African countries (WHO, 2013). Inter-facility communication is more difficult to measure routinely, and the framework proposes that district health information systems be augmented with specific indicators of referral communication, including whether receiving facilities acknowledge receipt of referred patients and whether referring facilities receive feedback on patient outcomes.

Boundary Conditions and Alternative Pathways

The Proposed Framework Does Not Assume That Service Continuity Effects

The proposed framework does not assume that service continuity effects are universal across all environmental biotechnology applications or all Ugandan districts. Boundary conditions are likely to include the type of technology, the strength of the referral network, the prevalence of alternative water and energy sources and the degree of community dependence on the health facility for essential services. In districts where households have multiple sources of safe water, the marginal effect of biosand filter continuity at health facilities on referral behaviour may be smaller than in districts where the health facility is the only reliable source of safe water.

Alternative pathways may also operate. Service continuity might influence referral completion through its effects on health worker morale and retention, which in turn affect the quality of patient counselling and preparation for referral. Environmental technologies that reduce the burden of water-fetching and other non-clinical tasks may free health worker time for patient education and follow-up.

Alternative Pathways May Also Operate

These pathways are not captured directly in the proposed mediation architecture but could be incorporated as additional mediators or as moderators of the primary pathways. The framework also recognises that referral completion is not always the optimal outcome. Some referrals may be clinically unnecessary, and some patients may appropriately choose not to complete a referral because of financial constraints or competing family obligations.

The framework does not assume that higher referral completion is always better, but rather that when clinically indicated referrals are not completed, the health system has failed to support patients through the continuum of care. Future applications of the framework should therefore distinguish between appropriate and inappropriate non-completion, although this distinction requires clinical review of referral decisions that may not be feasible in routine data systems.

Implications for Evaluation Practice and Policy

The Theoretical Architecture Developed Here Has Direct Implications For How

The theoretical architecture developed here has direct implications for how environmental biotechnology investments are evaluated in Uganda and similar settings. Programme evaluations should measure service continuity rather than technology presence, should collect data at multiple levels to support multilevel analysis and should specify mediation pathways a priori rather than conducting exploratory analyses after data collection. These design choices require additional investment in monitoring systems but are essential for understanding not only whether investments work but how they work and for whom.

For policy makers, the framework suggests that investments in environmental biotechnology should be accompanied by attention to the supporting systems that determine service continuity. Procuring solar refrigerators without ensuring maintenance capacity and spare part supply chains is unlikely to produce sustained improvements in cold chain performance. Similarly, installing water treatment technologies without engaging communities in their governance may

fail to achieve the institutional trust effects that the framework hypothesises are necessary for improved referral behaviour.

For Policy Makers The Framework Suggests That Investments In Environmental

The framework thus argues for a systems-oriented approach to technology investment that addresses technical, logistical and social dimensions simultaneously. The framework also has implications for how Uganda's district health teams monitor referral performance. Rather than tracking referral completion as a single indicator, monitoring systems should capture information about the quality of referral preparation, the functioning of communication systems between facilities and the experiences of patients who do and do not complete referrals.

This information would enable district teams to identify bottlenecks in the referral pathway and to target interventions where they are most needed, whether in patient education, facility readiness or inter-facility coordination.

Conclusion: From Technology Presence to Service Continuity

The Central Contribution Of The Present Analysis Is To Reframe

The central contribution of the present analysis is to reframe the relationship between environmental biotechnology and referral completion in Uganda from a question of technology presence to a question of service continuity. By distinguishing technical availability, logistical coordination and community engagement as three dimensions of continuity, and by proposing patient activation, institutional readiness and inter-facility communication as mediators operating at different levels, the framework provides a theoretically grounded architecture for understanding how infrastructure investments translate, or fail to translate, into improved patient outcomes. The multilevel mediation design offers a rigorous approach to testing these pathways while respecting the nested structure of Uganda's health system.

The framework's emphasis on boundary conditions and alternative pathways reflects a commitment to theoretical precision over universal claims. Environmental biotechnology is not a panacea for weak referral systems, and service continuity is not sufficient to guarantee referral completion in the absence of broader health system strengthening. However, by specifying the mechanisms through which service continuity is hypothesised to operate, the framework enables empirical research to identify where and for whom these mechanisms are most consequential.

The Framework'S Emphasis On Boundary Conditions And Alternative Pathways Reflects

This knowledge is essential for designing interventions that address the specific bottlenecks in Uganda's referral pathway and for ensuring that investments in environmental biotechnology contribute to the goal of universal health coverage.

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