Please Mind the Sociotechnical Gap: Building, Contextualizing and Scaling Mobile Technologies Towards Improved Human Outcomes at the Margins

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Abstract

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Structural inequities and systems of exploitation at global and national levels profoundly shape the health and economic trajectories of billions in the Global South, creating an urgent need to support marginalized communities as they navigate and resist these intersecting forces. This dissertation explores the design, contextualization, and scaling of mobile and artificial intelligence-based technologies to improve health and economic outcomes of marginalized people.

In the domain of artificial intelligence-enabled diagnostics, it first develops a community health worker-centered artificial intelligence model for atrial fibrillation screening using mobile electrocardiograms, optimized for low-cost deployment within real-world workflows. Next, it contextualizes large language model-based medical chatbots in urban India, finding that patients often reject bots offering clinically validated advice when the advice conflicts with local treatment norms, but the introduction of context-aware nudges significantly improves adoption. Finally, it investigates the challenges of scaling artificial intelligence-driven tools in low-resource health systems, identifying misalignments between institutional expectations of artificial intelligence-

enabled care and the constraints of existing healthcare infrastructure through interviews with Nepali health officials.

In agricultural information systems, it conducts a large-scale survey of rural farmers and focus groups with periurban entrepreneurs to examine mobile technology access, comfort, and use in northwest Tanzania. Using this understanding, it designs and builds a dual-platform agricultural directory, connecting 1,000 farmers to 10,000 local agricultural businesses. It examines usage in context, showing that even smartphone owners often prefer the feature phone-based directory despite its limited user experience at scale. To bridge this gap, it reconceptualizes mobile money agents as general-purpose intermediaries that help farmers navigate the menu-based application and access the information they need.

Across both domains, this dissertation shows that scaling impact at the margins requires much more than innovation, access, or thoughtful design. By bearing witness to human infrastructures, institutional realities, and sociotechnical constraints, it provides a nuanced perspective on creating and sustaining digital interventions that can bring us closer to a just world for all.

Contents

Acknowledgments

To workers in health and agriculture: Thank you for your tireless service to make the world a habitable place. I've learned so much from bearing witness to your lives and hearing your stories.

To my advisor - Richard: Thank you for always nurturing my hope and my skepticism. Your support in my times of need was invaluable.

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To Diablo Lake: Thank you for offering stillness and perspective when I needed it most.

Chapter 1

Introduction

Global and national systems of exploitation and oppression profoundly limit the health and economic trajectories of billions of people in the Global South. There is a pressing need to support health workers, farmers and other marginalized groups as they contend with compounding forces that deepen their vulnerability. For the past two decades, the field of Information and Communication Technologies for Development (ICTD) has explored the potential for increasingly cheaper and more powerful technologies to support access to information and services in regions where institutions have failed or market structures have left significant gaps.

However, many information and communication technologies (ICTs) do not succeed at subverting structural limitations to improve the human condition. For example, the First Look study invested millions of United States Dollars integrating highly accurate, usable ultrasound technology in rural clinics across five LMICs, only to find no improvements in morbidity or mortality outcomes at the end of years long deployment [GNS+18]. Such shortfalls can be largely attributed to *sociotechnical gaps*: the disconnect between what we know *must* be supported and what *can* be supported through seemingly useful technologies. Ackerman warns that if Human-Computer Interaction (HCI) merely contributes “cool toys” to the world, it fails its intellectual mission. He emphasizes that systems must "have at their core a fundamental understanding of how people really work and live in groups, organizations, communities"; otherwise, these systems risk being unusable, misaligned with needs, and ultimately ineffective [Ack00]. While an ultrasound device may diagnose a condition accurately and easily, it cannot resolve systemic inequities and guarantee that a pregnant person can access the necessary treatment to avert adverse outcomes. In other words, ICTs can only amplify the intent and capacity of human and institutional stakeholders, but cannot not substitute for their deficiencies [Toy11]. The success of ICTs, therefore, does not hinge on innovation alone but the artful integration of such innovation into local infrastructures, labor systems, regulatory frameworks, and institutional capacities. Without dedicated efforts to strengthen surrounding structures and human capacity, ICTs not only fail but also exacerbate pressures on already fragile systems.

This dissertation foregrounds socio-technical gaps to build, contextualize and scale mobile technologies towards improving the health and economic outcomes of marginalized people. My passion for this work began when my grandfather suffered a fatal heart attack in Nepal. Despite his high chance of survival, quality medical care was out of reach in the rural region that he had traveled to. Recognizing the outsized impact that access to care has on health outcomes, I started my doctoral work by developing AI-enabled diagnostic software and hardware for community health systems in Global South. As I was growing fluent as a builder, I yearned to situate and integrate ICTs into marginalized contexts and examine their benefit (or detriment) to human outcomes. Transitioning to HCI-rooted research, I moved to Tanzania to design, develop an agricultural directory and deploy to farmers in 100 villages. Through months of fieldwork, I gained a deep understanding of how to build technology and surrounding structural support that can integrate into rural communities. Bringing these learnings back to my work in health, I experimentally interrogated AI-enabled diagnostics in context and examine the implications of integrating them into health system at scale.

My thesis work crosses paths with several core challenges that deployed ICTs face, such as limited access, infrastructural challenges, low digital and language literacy, cultural barriers, high costs and inadequate training and support to help users navigate systems [AGB16]. Being cognizant of these challenges during the building, integrating, and scaling of ICTs, I make the following contributions:

- In Chapter 2, I build the first AI model that can use mobile electrocardiograms obtained within 60 days of an atrial fibrillation event to enable community health worker led atrial fibrillation in rural Nepal.

- In Chapter 3, I survey 1014 farmers in rural Tanzania and conduct focus groups with 46 smartphone supported business owners in periurban Tanzania gain a nuanced, demographics-stratified understanding of mobile technology access and use in this region.

- In Chapter 4, I design, build and deploy a dual-platform agricultural directory of 10,000 businesses to 1,014 farmers in Tanzania.

- In Chapter 5, I propose leveraging mobile money agents to build a scalable intermediation infrastructure for our agricultural directory, conducting focus groups with agents and a pilot where they support low comfort users' navigation of our tool.

- In Chapter 6, I run a two-phase experiment to quantify preferences in LLM-enabled diagnostic chatbots in regions where common medical practice deviates from clinical guidelines, and measure the impact of context-aware nudges in realigning patient preferences with safe treatment practices.

- In Chapter 7, I document the imaginaries and realities associated with integrating AI-enabled diagnostics into the Nepali Health system through interviews with Nepali health workers and leaders. I then propose the juxtaposition of imaginaries and realities as a method to assess a priori whether a conceived AI has the capacity to scalably impact human outcomes within a given sociotechnical context.

Most contributions in this thesis have first appeared as journal or conference publications. These publications are: [RNS+23] (Chapter 2), [RKM+23](Chapter 3), [RME+24] (Chapter 4), [RJMA23](Chapter 5). Chapters 6 and 7 are works in submission. My other publications (such as [CRMG22, GRJS24]) are out of the context of this thesis.

Chapter 2

Building Artificial Intelligence Based Cardiovascular Disease Diagnostics

2.1 Introduction

In LMICs, health care delivery faces significant challenges exacerbated by the increasing prevalence of noncommunicable diseases (NCDs). In contrast with communicable diseases that often have clear prevention and treatment options such as vaccines or antibiotics, NCDs often go undetected without regular screening and are harder to manage because they are chronic, requiring long-term specialized care. Recognizing the urgency of addressing non-communicable diseases (NCDs), Sustainable Development Goal (SDG) 3 includes reducing premature NCD mortality by one-third by 2030.

Cardiovascular diseases (CVDs) are NCDs that account for 32% of global mortality. They have a disproportionate burden in LMICs like Nepal, where CVD prevalence has steadily risen over the past two decades [hrsdc]. Atrial fibrillation (AF) is the most common cardiac rhythm disorder and is considered a 21st-century CVD epidemic, affecting over 33 million people worldwide [LGB+24]. If

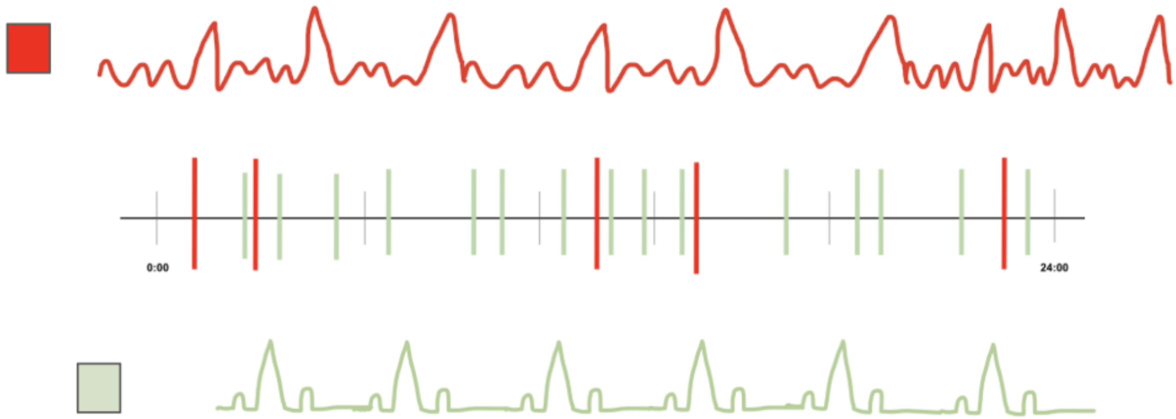


Figure 2.1: Red ECGs are captured during an AF episode, and green ECGs are are captured while the heart is "resting". Therefore, if an ECG is captured even minutes after an AF episode, the heart looks to be healthy to trained cardiologists.

AF is diagnosed early, it can be effectively managed with low-cost, easily administered treatments. However, diagnosing AF is challenging given that it begins as sudden and unpredictable episodes of irregular heartbeat that occur once in a week, few months or even few years. These short-lived episodes, lasting only minutes to hours, often go undetected by traditional diagnostic methods, which rely on capturing an electrocardiogram (ECG) *while AF is actively occurring* (see Figure 2.1 for a visual example). As a result, diagnosis often requires prolonged hospital-based monitoring, serial ECG tests, or outpatient monitoring with implantable cardiac devices, posing significant challenges in resource-limited settings such as Nepal, where only 80 cardiologists serve a population of 30 million [Vai11].

To make matters even more challenging for rural Nepali people, 90% of Nepali cardiologists live in Kathmandu, leaving rural people to rely exclusively on local health clinics where community health workers (CHWs) act as all round primary carers. Expanding early detection of AF through CHW-led screening could provide a viable way of reducing the risk of blood clots, stroke, and other fatal complications associated with CVD morbidity and mortality [AJC09, DK17]. However, CHWs currently lack the necessary skills and tools to conduct AF screening, leaving a broad unmet need for AF screening in rural Nepal. This chapter covers my research with collaborators at UW Medical Center and AliveCor, Inc. on the design and analysis of AI models that are supportive of CHW-led AF screening [RNS+23]. My work enables large scale screening in the following ways:

1. Understanding that a useful screening tool in a national AF screening program must be able to identify adults at risk for AF even if they are not in the midst of an AF episode, therefore predicting AF status using resting (also termed "sinus rhythm") ECGs
2. Expanding this understanding of a sinus rhythm ECG to those collected within a ±30 day window of an AF event, centering the workflow of Nepali CHWs that visit rural homes once in a two-month period, and
3. Collecting ECGs from adults to be screened on a low-cost mobile ECG (mECG) device where novice users can self administer ECGs with no attachments.

Our model, trained on 267,614 mECGs, achieved 71% accuracy, comparable to state-of-the-art approaches that rely on hospital-acquired ECGs.

2.2 Related Work

Artificial intelligence models have been successfully trained to detect AF on hospital-acquired AF ECGs, i.e. *those collected when an AF episode is occurring* [HSM+23, RRP+20]. Even still, early detection of AF occurs only in 5–20% of AF patients [SFR11], suggesting that a significant number of individuals do not undergo timely hospital-based screening. Mobile ECG (mECG) devices are portable, compact tools that allow users to record heart activity outside of traditional clinical settings. Although they have fewer and smaller sensors [1], their signals have demonstrated

[1] sampling rate and spatial resolution 40% and 50% lower than traditional ECGs

excellent correlation with hospital-acquired ECGs [FFF+21, KDB+21]. There are several advantages to leveraging mECG devices to screen for AF in LMICs settings. mECG devices typically cost under $100 and require no disposables, while hospital-grade ECG devices range from $1650-$5000+ and rely on disposables for every use. Additionally, mECGs are designed to be self-administered by novice users without accessing a healthcare facility. The ease of acquisition allows for more frequent sampling. Using AI models to interpret the acquired mECGs represents a scalable means of detecting AF in those without access to traditional cardiovascular care.

A growing body of CSCW and HCI literature centers the intersection of CHW-led health systems and ICTs to improve provision of healthcare at the margins [FE13]. Across LMICs, CHWs provide culturally appropriate healthcare in areas where there is no acknowledged market for the extension of the public or private health services. Their grassroots presence and interpersonal skills enable them to build trust with populations that may be wary of interventions, therefore, national CHW programs are "no longer viewed as temporary solutions; rather, as enduring investments in health systems that prioritize responsiveness and community engagement" [SGV19]. There is broad acknowledgment that CHWs' tasking will continue to grow and change amidst the increase in non communicable diseases such as CVD, making them "key *infomediaries*" between ICTs and patients [IKK18].

The SMART-India trial piloted CHW-led AF screening using an AI-enabled mECG device in 60 villages in India [SKF+19]. The AI models on this device had been trained to disambiguate AF mECGs from resting mECGs (similar models have been trained to detect AF when it is happening on an Apple watch [PMH+19]). During the trial, CHWs were instructed to visit the homes of their 2600 patients three times over the course of a five day window (a total of 7,800 visits). Researchers hoped that at least one visit to a patient's home would yield an mECG coinciding with an AF event that the AI models could flag. It is clear from a human infrastructure perspective that it would be impossible for CHWs to shoulder the additional labor that underlies such an AI-enabled screening program in addition to their regular tasks. For population level screening to be feasible, CHWs need to be able to visit each patient once and assess their risk of the underlying condition without an AF episode occurring simultaneously. Therefore, AI models must be trained to identify AF from resting mECGs. This is feasible as it has been hypothesized that subtle, non-sinus electrical activity alters resting ECG morphology in patients with AF. Attia et al. and Raghunath et al. achieve an AUC of 0.90 and 0.85 respectively in predicting AF from resting 12-lead, hospital acquired ECGs [ANLJ+19, RPUC+21]. However, AF prediction using resting mECGs remains unexplored, and our work bridges this gap.

Creating a model that can predict AF from resting mECGs both prospectively and retrospectively may have a significant clinical impact. Thromboembolic stroke often occurs before a diagnosis of AF is made [LWB+95]. By identifying individuals at high risk for AF, clinicians may be able prescribe anticoagulation before a stroke occurs and use traditional long-term ECG monitoring techniques more cost-effectively. Predicting future AF events can enable novel paradigms of pharmacotherapy. For example, rhythm-controlling medications are associated with significant side effects if taken long term. If a future AF event could be predicted with high accuracy, these medications could be taken prospectively, reducing side effects and decreasing pill burden. Similarly, in the case of anticoagulation medication for stroke prevention, AI algorithms could tailor anticoagulation therapy to periods of high likelihood of an AF event in the future, resulting in more patient-centered and effective clinical care.

2.3 Model Design & Evaluation

Below, I detail our dataset curation, study design, model development and evaluation.

Dataset Curation Our data consisted of mECGs acquired from KardiaMobile mECG device users (AliveCor, Inc., Mountain View, CA) from June 28, 2019, to February 19, 2021. The KardiaMobile device (see Panel A in Figure 2.2) is a Food and Drug Administration cleared, portable, wireless, mECG platform that can obtain up to 5 minutes of mECG data with no wires, patches, or gels. To record an mECG with KardiaMobile, users place their fingers or thumbs on the top electrodes, place the bottom electrode on the bare skin of their left ankle or left knee, and hold for 30 seconds (see Panel B in Figure 2.2). If an uninterpretable mECG is obtained, the reading is erased, and the user is prompted to resubmit another reading. After mECG acquisition, data are transmitted through the AliveCor smartphone application to a cloud-based data repository. Data validity is maintained by trained AliveCor personnel through rigorous auditing. The Institutional Review Board of the University of Washington provided a waiver of informed consent because all study data were de-identified.

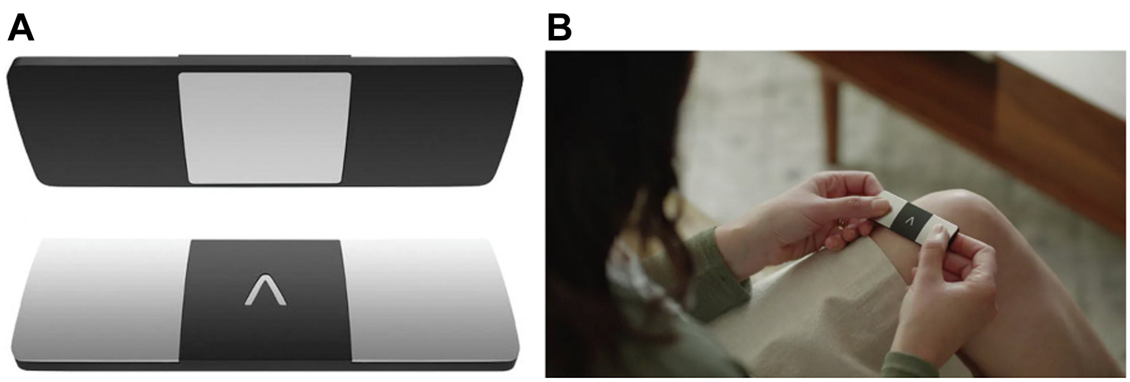


Figure 2.2: **Panel A** shows the KardiaMobile mECG device containing three electrodes: two on the top surface and one on the bottom surface. **Panel B** shows mECG acquisition through contact with one finger from each arm, and from the knee or ankle from a lower limb.

Model Design and Implementation We framed the detection of AF from mECGs as a time series classification problem. The input to our neural network was a nine thousand by two dimensional matrix, which represented two sensors (or *leads*) sampling at 300 Hz for 30 seconds.

Although the KardiaMobile device acquires ECG data in leads I, II, III, aVL, aVR, and aVF, only data in leads I and II were used as input because the four remaining leads are a linear combination of the first two leads. The model architecture consisted of three sequential parts: a convolutional neural network (CNN); a gated recurrent unit (GRU); and standard dense neural network layer [HZRS16]. We used a modified version of the CNN architecture of Attia et al. [ANLJ+19] to build our Resnet-based CNN layers. Each Resnet block contained three convolutional layers with a fixed filter count and kernel length. Skip connections were used between layers to increase depth and prevent the vanishing gradient. Each Resnet block was followed by a dropout layer to prevent overfitting of the model to the training samples. Our convolutions focused on the longer axis to extract temporal features, and results were combined across both leads.

We appended a recurrent neural network (RNN) block to the CNN to provide persistence and memory for temporal patterns found across longer patches of signal. We used a bidirectional GRU architecture for our RNN. The GRU, using update and reset gates, also minimized the vanishing gradient problem and decreased the number of parameters, contributing to easy training and reduced overfitting. The dense layer at the end of the architecture reduced the result of the GRU to a two-dimensional output vector. A softmax activation function was applied to the output vector, yielding predictive probabilities corresponding to the occurrence or absence of AF.

Study Design We identified 76,891 users from the pool of all users of the KardiaMobile platform who recorded at least one 30-second mECG from the study period. Users were categorized as not having AF (control cohort) if they had no AF readings and had at least 10 sinus rhythm mECG recordings in the AliveCor database. Users were categorized as having AF (study cohort) if they used the device for over a year, and submitted at least one mECG with AF, as determined by the proprietary, FDA-cleared Kardia AI algorithm package (FDA clearance K181823) [FA19]. This algorithm uses a mixture of deep learning and conventional machine learning to detect AF from lead I of an ambulatory bandwidth ECG with 95% specificity and 95% sensitivity. Users were excluded if they had persistent or permanent AF (defined, for the study purpose, as AF present in all sample mECGs from an individual) or were less than 18 years old. mECGs were excluded if they were less than 30 seconds in duration.

For the primary analysis, we randomly sampled one AF mECG from each participant in the study cohort, which served as our case mECG. Then, from the same participant, we randomly sampled at most ten sinus rhythm mECGs within ±0−30 days of the sampled AF mECG to include in our study sample. From each participant in our control cohort, we randomly sampled one to two mECGs from the study window to include in our control sample. Users in the study and control cohorts were randomly assigned to either training, validation, or test sets in a 7:1:2 ratio. Therefore, no unique users could have mECGs in more than one of these sets, preventing artificially inflated performance.

We were interested in determining the optimal AI-enabled AF screening window. In a clinic, we would not have any information about when a patient with suspected AF had their last AF episode. We needed our model to be able to infer AF/no AF without the use of such temporal information. Therefore, we first validated and tested our model where study samples came from ±0−30 days of an AF event. Then, to identify an optimal screening window, we stratified our test set's study mECGs temporally into three sub windows. We chose ±0−2 day (2-DAY), ±3−7 day (7-DAY), and ±8−30 day (30-DAY) windows from the associate AF event because we hypothesized that clinically important structural changes would be most pronounced shortly before, and immediately after, an AF event, and that these changes may be detected by our model (see Figure 2.3 Panel B). We coupled the control ECGs in test sample to the study test set corresponding to each subwindow for these our secondary results, as the control mECGs do not surround a case mECG and are rather sampled from the entire study period (see Figure 2.3 Panel A).

We also performed secondary analyses to determine whether AF events could be predicted

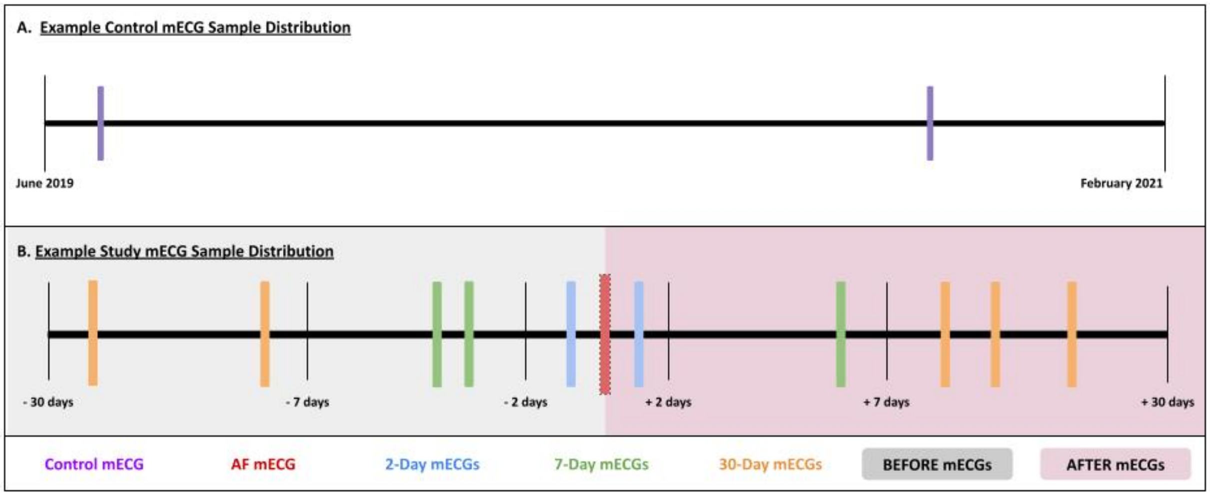


Figure 2.3: **Panel A** contains selected mECGs from a user in the control cohort. These are two randomly sampled mECGs from all mECGs recorded by this healthy user on the AliveCor device from June 2019 to February 2021. **Panel B** contains ten sampled mECGs from a user in the study cohort. To collect these mECGs, first, one of their AF mECGs was sampled (marked in red). Then, mECGs were randomly sampled from the ±30 day window surrounding the AF event for inclusion into the study sample. These mECGs are then subdivided temporally for the secondary evaluations described below.

prospectively or retrospectively with higher fidelity. We divided the test sample into 2 cohorts: all mECGs collected in the days preceding the AF event (BEFORE); and all mECGs collected in the days following the AF event (AFTER) (see grey and pink sections in Panel B within Figure 2.3). Lastly, we examined model performance by age group and sex.

Findings Across the entire cohort, there were 73,861 included users with corresponding 267,614 mECGs. Overall, mean age was 58.14 ± 14.61 years; 25,991 users (35.1%) were female; and the mean number of mECGs contributed per user was 3.62. Of these users, 18,661 individuals (25.3%) and

160,957 mECGs composed the study cohort. Mean age of the study cohort was 60.46 ± 14.55 years; 6,098 users (32.7%) were female; and the mean number of mECGs contributed was 8.62 ± 6.44. The control cohort included 55,200 users (74.7%) and 106,657 mECGs. Mean age of the control cohort was 54.64 ± 14.01 years; 19,893 (36.0%) were female; and the mean number of mECGs contributed was 1.93 ± 0.25 (see Figure 2.4 for user inclusion and exclusion).

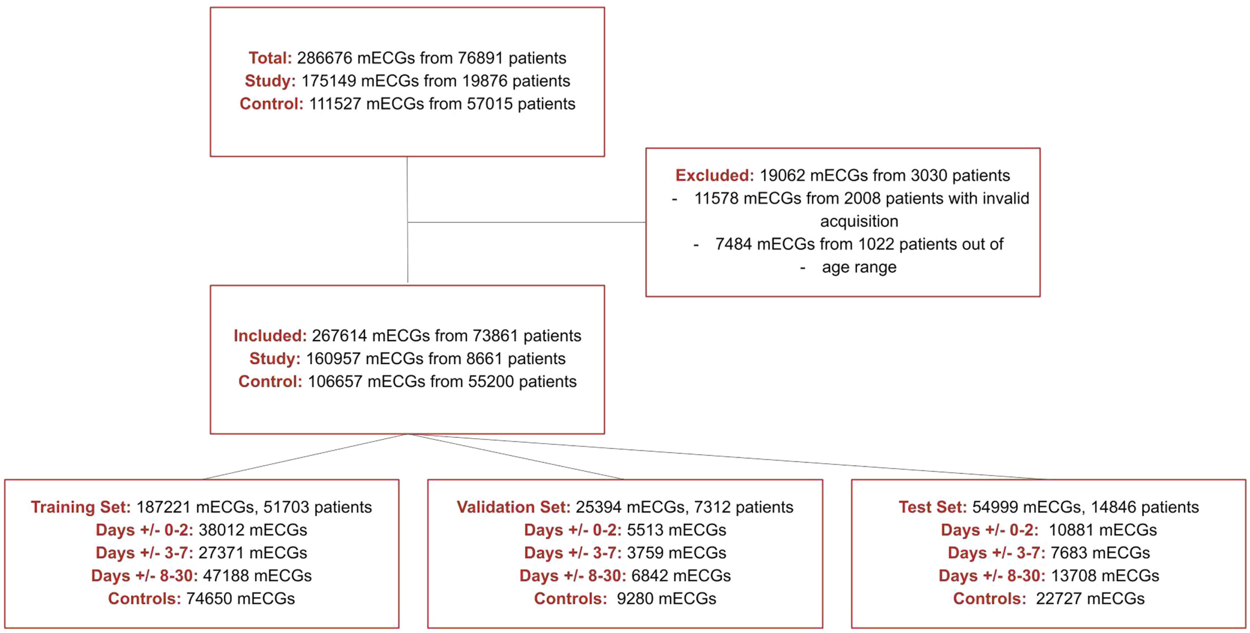


Figure 2.4: Participant Inclusion Exclusion

In total, 51,703 users and 187,221 mECGs were allocated to the training set, with 38,012 mECGs from the 2-DAY window, 27,371 mECGs from the 7-DAY window, 47,188 mECGs from the 30-DAY window, and 74,650 mECGs from the control sample. A total of 7,312 users and 25,394 mECGs were allocated to the validation set, with 5,513 mECGs from the 2-DAY window, 3,759 mECGs from the 7-DAY window, 6,842 mECGs from the 30-DAY window, and 9,280 mECGs from the control sample. A total of 14,846 users and 54,999 mECGs were allocated to the test set, with 10,881 mECGs from the 2-DAY window, 7,683 mECGs from the 7-DAY window, 13,708 mECGs from the 30-DAY window, and 22,727 mECGs from the control sample. Users with AF contributed

60.15% of the mECGs in our study. Median amount of time between the first and second mECGs randomly sampled from each user in the control cohort was 238.4 days.

Study	Sensitivity (95% CI)
Overall Test Set	0.760 (0.758–0.760)
2-DAY subsample	0.711 (0.709–0.713)
7-DAY subsample	0.708 (0.704–0.710)
30-DAY subsample	0.688 (0.685–0.690)
BEFORE subsample	0.713 (0.710–0.716)
AFTER subsample	0.695 (0.691–0.700)

Table 2.1: Comparison of model performance stratified by mECG date

Our model achieved an overall area under the curve (AUC) score of 0.760 (95% CI 0.759–0.760), sensitivity of 0.703 (95% CI 0.700–0.705), specificity of 0.684 (95% CI 0.678–0.685), accuracy of 69.4% (95% CI 0.692–0.700), and F1 score of 0.694 (95% CI 0.694–0.700) on the test set comprising control samples and study samples from all three windows of interest. This exceeds hospital-grade CVD screening tests including B-type natriuretic peptide test for heart failure (AUC 0.60–0.70) and CHA2DS2-VASc score for stroke risk (AUC 0.57–0.72) [ANLJ+19].

Model performance on the temporally stratified secondary test sets was best on the 2-DAY window (sensitivity 0.711; 95% CI 0.709–0.713) and least good on the 30-DAY window (sensitivity 0.688; 95% CI 0.685–0.690), with performance on the 7-DAY window falling in between (sensitivity 0.708; 95% CI 0.704–0.710). There were 14,268 BEFORE mECGs and 18,004 AFTER mECGs in the test set. The BEFORE and AFTER studies performed similarly to each other, with sensitivity of 0.713 (95% CI 0.709–0.717) and 0.695 (95% CI 0.692–0.699), respectively. See Table 2.1 for all aforementioned results.

When we examined model performance by age group, the test set (including both control and study samples) contained 10,098 users (68.0%) less than 65 years old contributing 33,908 mECGs (32.0%) and 4,748 users greater than or equal to 65 years old contributing 21,091 mECGs.

The model performed marginally better in adults greater than or equal to 65 years old (AUC 0.748; 95% CI 0.744–0.750) compared to adults < 65 years old (AUC 0.743; 95% CI 0.742–0.745). When we examined model performance by sex, the test set (including both control and study samples) contained 10,252 male users (69.0%) contributing 36,436 mECGs and 4594 (31.0%) female users (31.0%) contributing 18,563 mECGs. Performance was similar for men (AUC 0.765; 95% CI 0.763–0.767) and women (AUC 0.747; 95% CI 0.746–0.751) (see Table 2.2).

Group	**AUC**	**Sensitivity**	**Specificity**	**Accuracy**	**F1**
Overall Results					
Test set	0.760 (0.758–0.760)	0.703 (0.700–0.705)	0.684 (0.678–0.685)	69.4% (69.2%–70.0%)	0.700 (0.694–0.700)
Age (y)					
18–64	0.743 (0.742–0.745)	0.615 (0.613–0.618)	0.750 (0.746–0.751)	68.0% (67.9%–68.2%)	0.679 (0.678–0.681)
64–99	0.749 (0.745–0.750)	0.807 (0.804–0.808)	0.508 (0.503–0.510)	72.0% (71.3%–71.9%)	0.715 (0.711–0.717)
Sex					
Male	0.765 (0.763–0.767)	0.714 (0.713–0.715)	0.674 (0.670–0.678)	70.0% (69.6%–70.0%)	0.700 (0.698–0.700)
Female	0.747 (0.746–0.751)	0.680 (0.678–0.686)	0.694 (0.691–0.696)	68.6% (68.4%–68.9%)	0.687 (0.685–0.691)

Table 2.2: Comparison of model performance stratified by Age and Sex. 95% confidence interval given in parenthesis.

2.4 Critical Insights

This work centers CHWs' schedules, skill levels, and infrastructure constraints to build an AI model that can infer underlying AF from resting mECGs captured on low-cost hardware within a 60-day window of an AF event. Our model achieves an AUC score similar to other CVD screening tools, extending AI-enabled AF risk assessment beyond AF-present mECGs towards scalable screening at the margins.

Chapter 3

Understanding Phone Use by Rural Farmers & Entrepreneurs in Tanzania

3.1 Introduction

The growth of mobile phone penetration in Sub Saharan Africa (SSA) has unfolded in three distinct phases. In the first phase, lasting until the early 2000s, mobile phone ownership was low and predominantly male, with access largely restricted to large cities before gradually expanding to other urban centers [Ngu10, SBJ+22]. In rural areas, where mobile services were available, users faced significant challenges in charging their phones and affording mobile plans [MUT08a]. At this stage, mobile phones offered basic functionalities, such as voice calls and text messaging [1]. This set the stage for the second phase, spanning the late 2000s to early 2010s, which saw the emergence of multiple service providers that drove down the cost of mobile plans, significantly boosting mobile phone ownership. During this period, financial services like M-Pesa (2008) and Tigo-Pesa (2011) were introduced, relying on Unstructured Supplementary Service Data (USSD).

[1]The literature refers to such phones as *basic phones*

USSD, a widely used protocol in SSA, enabled users to access information on basic phones via simple shortcodes without requiring the Internet. The third phase, from the mid-2010s to 2020, witnessed the gradual adoption of smartphones, leading to a steady but significant increase in Internet access. Affordable data bundles fueled the popularity of apps like WhatsApp for social communication and multimedia sharing. This, in turn, made mobile platforms integral to business communication and advertising as well as information services provided by both governments [Bir21]. By 2021, Tanzania's mobile phone penetration had skyrocketed from 0% in 2000 [wor20] to approximately 90% [oFP22, MUT08b], with 48% of inhabitants reporting smartphone access or ownership [Int21] and 35% of adult men and 17% of adult women reporting internet usage [Row19]. While these statistics highlight the rapid expansion of mobile phone adoption across the three phases, they obscure disparities in access and usage between urban, periurban, and rural areas in SSA. This gap is further reflected in the HCI literature, which lacks a granular examination of mobile phone ownership in these regions. Given that phone usage is shaped by social, economic, and geographic factors, a deeper understanding is essential for developing mobile tools that effectively serve SSA's diverse and evolving technology landscape.

To bridge this gap in the literature, I began by conducting a quantitative survey to examine mobile phone ownership and usage among 1,014 rural farmers from 100 villages in Kagera, Tanzania. In my scoping fieldwork in Tanzania, farmers' firsthand accounts revealed vast differences in mobile phone access, comfort, and use. To systematically capture such demographic-specific differences in phone use, we carefully designed survey questions to include whether phones were used to support farming, use of USSD-based information services, comfort using with technology (defined by the amount of help sought to carry out common actions on the phone), and support seeking through wakalas (local retailers who facilitate the use of USSD-based mobile banking services). Overall, our survey revealed how device ownership, usage, and digital literacy vary across demographics in rural Tanzania, equipping researchers and policymakers with insights to design more effective agricultural tools tailored to this socio-technical context.

To complement the quantitative survey and add further nuance to our understanding of mobile phone use in SSA, I conducted qualitative focus groups (FGs) exploring the practices of smartphone-supported entrepreneurs (SSEs) who rely on mobile phones to operate micro and small enterprises (MSEs) in periurban Bukoba, Tanzania. Through in-depth FGs with 46 SSEs, I explored three key research questions: (1) how modern messaging technology enhances business dynamics and networks, (2) what environmental and societal factors contributed to the rise of smartphone-supported businesses, and what spillover effects there are on the surrounding market due to these new businesses and (3) what specific gender-based opportunities and challenges arise for SSEs. This research revealed the endogenous mechanisms through which SSEs leverage smartphones to launch and expand businesses with minimal initial capital or assets, enabling women to gain economic agency otherwise constrained by patriarchal norms.

The following chapter details both studies, which have been published in CHI and COMPASS [RME+24, RKM+23]. This work was done in collaboration with Cornell University and Institute of Rural Development and Planning, as a precursor to a large randomized controlled trial examining the economic impacts of introducing an agricultural information technology across Kagera (described in Chapter 4).

3.2 Related Work

A substantial body of literature recognizes that mobile phones hold significant potential to support farmers in SSA [VKK+15, Ake11, AM10, CS15, BO15, DvR13, JHW08, Ove06]. The cost of obtaining information through mobile phones is substantially lower compared to other sources [Ake11, AM10, CS15], and the uncertainty associated with travel delays and changes in demand for goods is decreased, thereby avoiding costly stock outs, unproductive trips [AM10, BO15, DvR13, JHW08, Ove06], and over-reliance on middlemen to set the terms of trade [DD17, CS15]. Taking a broader lens, phones have been shown to impact price dispersion, information asymmetries, and overall market performance in SSA [Jen07, Ake10]. However, even when phones are available, Chaudhuri et. al. shed light on how "technologies are often expected to create a direct link between users and information", but "illiteracy, low levels of education, gender, class and caste inequalities, and other social endowment gaps become significant barriers" [Cha19]. Similarly, Oreglia et al. debunk "free" information flows enabled by mobile phones [OS20]. Therefore, it becomes imperative to move beyond access and understand demographic-stratified trends in technology use by farmers and entrepreneurs in SSA. In this regard, the first part of my work creates nuance through a large scale survey on phone ownership and use in rural Tanzanian farming communities.

There has also been scholarship on the interaction between basic phones and MSEs in the region [Don04, DE09a, DE09b, KRN12, K+15, GMY21, QSB+21, Jen07]. This work primarily supports the hypothesis that basic phones can enhance the efficiency of MSEs and strengthen business owners' relationships with their existing networks. For instance, Donner and Escobari (2009) [DE09a] found that entrepreneurs effectively used basic phones to improve marketing and sales outcomes while minimizing travel time. However, their findings revealed limited evidence that phones facilitate the establishment of new enterprises or new contacts. They noted, "there is currently more evidence suggesting changes in degree (more information, more customers) than for changes in structure (new channels, new businesses)." Similarly, Jagun et al. (2008) concluded from a Nigerian case study that basic phones primarily reinforce trust-based relationships initially developed through face-to-face interactions, rather than expanding business networks to include new contacts.

As smartphone adoption increases in these contexts, literature has emerged describing how MSEs operating in large urban areas integrate smartphones into extant entrepreneurial practices [OWLN18, KA22, STK+22, RC18, VVPD20, VPV22, VVD21, PGEE+19, DDJ22, GMPT22, BRMH10].

In contrast to Jagun et al., Modak and Mupepi list marketing and promotion to solicit new customers as common uses of WhatsApp by small businesses in India [JHW08, MM17]. Further, Wyche et al. note that the use of the Facebook app through smartphones can result in an expanded market beyond one's geographic area [WFYS13]. My qualitative work with SSEs explores how with the growth of one's business networks online, existing trust-building practices must be reimagined. For example, in Tanzania, *mali kauli* refers to trust-based credit transactions sealed by verbal agreements between middlemen and MSE owners. Small scale vendors from rural and peri-urban areas used to visit and ascertain trustworthiness of middlemen (typically located in larger cities) to gain products on credit, considering the range of products sold, stability of product type per vendor, restocking behavior, source of obtained products, etc. [Oga05, Oga06, Brü14, MAS+15, MAKS16]. In middlemens' role as creditors, they decide whom to trust with products, waiting to receive payment until the goods are sold to collect payment, providing entrepreneurs with the chance to build capital [Oga05]. While this trust has traditionally been established by convening in the same physical place, we show how WhatsApp groups of middlemen and entrepreneurs extend SSEs' networks to include new potential creditors, creating a reimagining of trust in these digital spaces. In this way, our work uncovers how smartphones can lower barriers to *starting* new businesses (instead of just expanding old businesses as previously documented).

Evidence suggests that the adoption of mobile technologies for personal or entrepreneurial reasons in LMICs is often self-taught and conducted on shared devices [SS10a, WM12a]. One's perception of their authority to use technology impacts its usefulness in marginalized segments of society. For example, women traditionally have less access to technology across LMICs [IRA+19, BE10, Roo13, SC12, DB18, SGSD18, WSO19]. These challenges with access intersect with broader societal and structural constraints, such as social norms that limit women's entrepreneurial opportunities. Studies have shown that women entrepreneurs often balance familial responsibilities with business demands, while also contending with negative societal perceptions of women earning independent incomes [MMM14, KM17a]. Lambin and Nyyssölä argue that government policies aimed at improving female employment often fall short due to women's lack of assets, dual work-home responsibilities, and limited education [LN+22a]. Despite these barriers, mobile technology has proven to be a valuable tool for enabling entrepreneurship. Encouragingly, Kapinga et al. demonstrated the benefits of a smartphone app connecting women entrepreneurs with their customers in Tanzania [KSMM19]. Similarly, studies from Uganda and Kenya show that mobile phone use has enhanced women entrepreneurs' competitiveness and information flow, leading to improved business outcomes [GMY21, K+15]. Nyajeka et al. (2022)found that vulnerable women farmers in Zimbabwe mitigated livestock-related risks through mobile phone use [ND22]. My work contributes to the ICTD and HCI4D literature by describing impacts of the smartphone-supported business paradigm on how women view labor, capital and ability to engage with entrepreneurship, and by examining how gender dynamics intersect with evolving definitions of trust and creditworthiness in the expanded social networks enabled by smartphones. Building on Tanzanian scholarship [MMM14, KM17a, LN+22a], we introduce a new narrative, showcasing how women achieve entrepreneurial success and economic freedom through smartphone-supported enterprises.

3.3 Quantitatively Characterizing Mobile Phone Use by Rural Farmers

To sample farming households (HHs) for our quantitative survey, our collaborators at Cornell sought the help of a team of twenty Tanzanian enumerators. These enumerators used a heavily specified random walk strategy wherein right and left turns were determined randomly in advance of their visit to a given village. As they walked through the village, they visited one HH, proceeding to screen and enroll the head of the household by asking their age and if the HH had a working cell phone. Then, they skipped six HHs before arriving at the next HH to screen. This is a sampling strategy we believe to be uncorrelated with underlying structural characteristics of the villages. The team of enumerators repeated this process in 100 villages across Kagera. The survey data was manually cleaned (duplicates dropped, incorrect information investigated and replaced) and subsequently verified by the authors and collaborating economists. Descriptive and inferential statistics (in the form of ANOVA significance tests for categorical variables and t-tests for numerical means) were calculated to support inferences from the survey.

Sampling across Kagera yielded 1014 HHs from 100 villages. Average participant age was 51.41 years (sd = 15.41 years), and 44% of participants were women (n=446). On average, men (mean age=48.41 years, std=15.24) were younger than women (mean age=55.22 years, std=14.80). Of the 1014 HHs sampled, only 7.1% reported having a smartphone, and 92.9% reported having a basic phone. When asked whether the HH's home was connected to the electric grid (to understand the ability to charge phones), 83.2% of participants said no, while 16.8% said yes. Almost all participants (99.51%, n=1009) reported use of their phone to support their farming. The predominant use-case was to place phone calls to other farmers or extension officers to discuss planting decisions. Participants were asked if they used any USSD-based services on their phone, with M-Pesa offered as an example of a USSD technology. 68% reported use of USSD, and 32% reported non-use. Women who did not use USSD exceeded men by 10.2 percentage points (37.7% vs. 27.5%, respectively). HHs that reported use of USSD were asked about their comfort level when using USSD-based and similar information applications, with answer options as follows: (1) *Very Comfortable*, "I don't need help," (2) *Somewhat Comfortable*, "I rely on help on occasion," (3) *Somewhat Uncomfortable*, "I rely on help often," and (4) *Very Uncomfortable*, "I need help most of the time or always." 46.2% of HHs reported being very comfortable with USSD, whom we refer to as "Comfort Group A," and the remaining 53.8% reported needing help on occasion (29.3%), often (11.0%), and always (13.5%).

We refer to these participants collectively as "Comfort Group B." A demographic breakdown of the participants grouped by self-perceived comfort is shown in Figure 3.1. Table 3.1 shows the overall distribution of comfort.

People	**Group**	**Comfort**
Non-Users: 32%	-	-
Users: 68%	A - do not need help	Very Comfortable: 46.2%
	B - do need help	Somewhat Comfortable: 29.3%
	B - do need help	Somewhat Uncomfortable: 11.0%
	B - do need help	Very Uncomfortable: 13.5%

Table 3.1: The distribution of USSD use and comfort in our sample.

Self-reported comfort using technology differed with age and gender according to an ANOVA test (P « 0.001), with younger and male gender participants reporting higher comfort. However, differences in comfort were less significant for the < 40 age group, suggesting that the younger generation might be bridging the gender gap in comfort with technology (> 40 years: P = 0.020; < 40 years: P = 0.099). The pattern of males being more comfortable than females is statistically significant (P « 0.001); however, though men exceeded women in the Comfort Category 1 by 13.3 percentage points (37.3% vs 24%), women and men were proportional in categories 2-4. There were distinct subgroups of comfort for both males and females (one group with higher comfort and one with lower), and of the collected variables, age is the most explanatory for the observed bimodality in comfort (P = 0.065). District and village were not associated with comfort (P = 0.073), indicating that perhaps there was no peri urban/rural split in comfort with technology.

All HHs (including non-users of USSD) were asked how often they visited a wakala, a Tanzanian mobile money agent [2]: 50.7% said less than once a month (n=565), and the remaining 49.3% reported at least once per month; 31.5% said exactly once a month (n=322), 10.1% said once each week (n=90),

[2]Wakalas are defined and discussed in more depth in Chapter 5

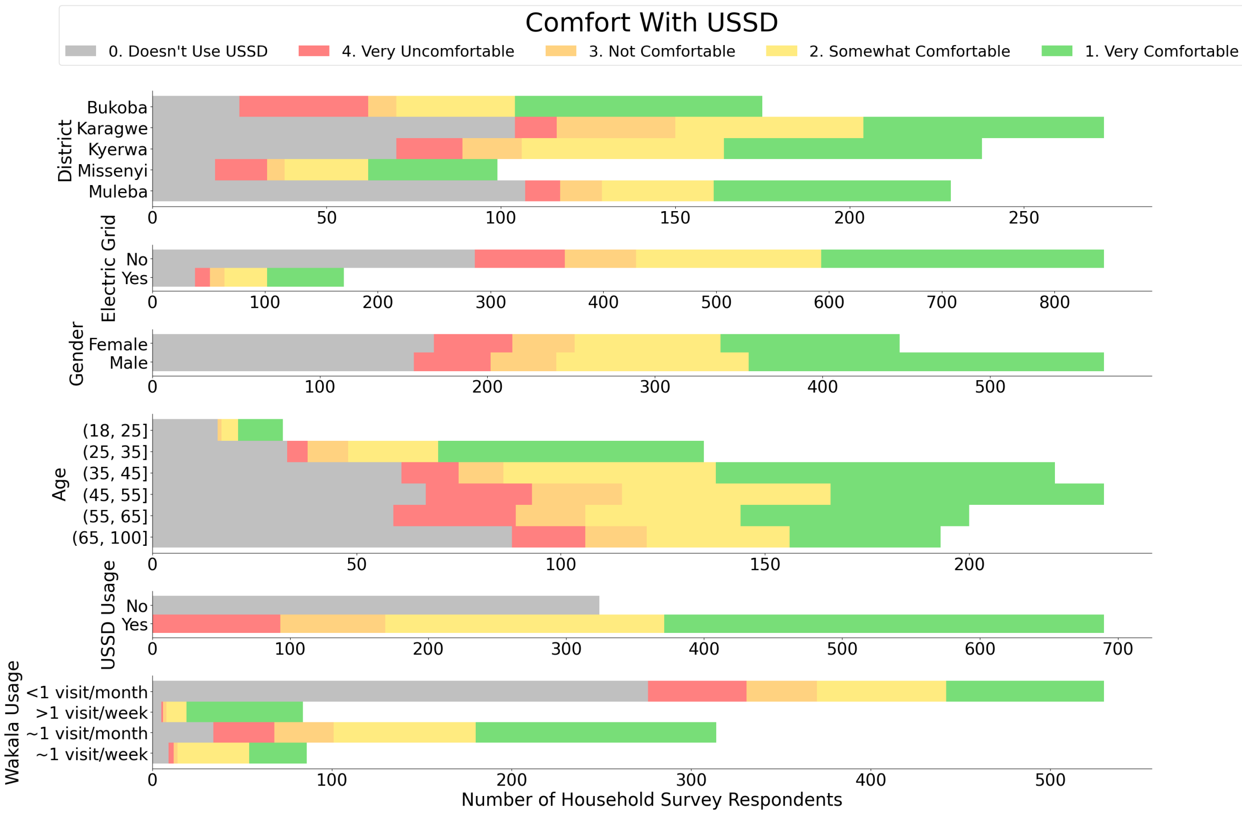


Figure 3.1: Demographics stratified by comfort using USSD. Women are less likely to use USSD and fall into Comfort Group A; however, men and women are equally proportioned in Comfort Group B. Older people in our sample are less likely to be users of USSD and less comfortable on average. Over half of those in Comfort Group B visit wakalas at least once a month. District (signaling proximity to a periurban region) and grid connectivity are not correlated with comfort.

and 7.7% said multiple times a week (n=86). Interestingly, HHs that report being very comfortable using USSD visit the wakala more often than those who are somewhat or very uncomfortable. This may indicate that comfortable USSD users have increased engagement with information services like M-Pesa, causing them to visit walakas more frequently to deposit or withdraw cash. 60% of those in Comfort Group B visited a wakala at least once a month.

Summary. *In general, we find low smartphone penetration (7%) in this rural population. Although a large majority report using their phone for calling and texting, 30% report non-use of USSD and 53.8% need support using USSD. There is general heterogeneity in comfort even though age and gender are associated with comfort. This underscores the importance of designing USSD technologies with increased usability and the challenges with selecting one subsection of the population to provide potential intermediation or support for new technologies.*

3.4 Qualitatively Characterizing Mobile Phone Use by Peri-urban Entrepreneurs

Our FGs with smartphone-supported MSE owners took place around Bukoba, a small city within the Kagera region of northwest Tanzania, bordered to the west by Rwanda, to the north by Uganda, and to the east by Lake Victoria. The region has around 2.2 million people, of whom 74.9% claim farming as their main occupation. Bukoba's open market contains vendors that sell vegetables, clothes, pots and pans, etc. The town has one central post office where people can retrieve packages, but this is not a typical activity for most households. Instead, the standard way for goods to travel is in the storage hold of public buses, where people can deposit items for a nominal fee and the recipient can collect them at another bus stop. This mechanism enables shipment of goods from Mwanza and Dar es Salaam (among other cities) to Bukoba. In the Kagera region of Tanzania, more than twice as many people are found to move from rural villages to towns or small cities like Bukoba than to large cities like Dar es Salaam [CDWT13]. This makes periurban areas surrounding Bukoba an ideal location to study technology access and use between rural areas and small cities.

We followed a mixed-methods approach to our FGs. We recruited participants with the help of two Tanzanian collaborators as well as two Tanzanian staff of an affiliated project. Each of the four recruiters posted a WhatsApp status describing our research questions (statuses are described below) through which they solicited participants. In addition, they looked through the business-related WhatsApp statuses they saw, and asked those business owners to be a part of our survey, as well as requested that they repost the status soliciting others on their own feed as a means of snowball sampling. Inclusion criteria were currently operating a smartphone-supported MSE that participants started at least 6 months prior to the survey and being based in the peri-urban areas surrounding Bukoba. Once recruitment was complete, a phone-based screening was conducted to collect quantitative data from each participant. In addition to age, marital and family status, the survey asked about income, whether the respondent has a bank account, and employment status prior to starting their smartphone-supported MSE. For those who had converted from a physical to a mobile business, questions on changes in customer base, profit levels, and productivity were posed. Post surveys, we asked participants whether they would consent to participating in an FG to discuss smartphone-based businesses. Forty-five people agreed to participate, whom we divided them into three FGs of female SSEs, and two groups of male SSEs to promote open discourse on more sensitive topics, such as gender. Open ended discussion topics included initial motivation to start a mobile-supported business, sourcing products, advertising, support networks, and challenges faced. All surveys and FG questions were translated into Swahili before administration. Transcripts of the FGs were translated into English and thematic coding was undertaken, highlighting new or changed internal mechanisms and external networks. The quantitative survey data and thematic analysis were corroborated to look for any trends or outliers.

A sample of 46 participants were successfully recruited (35 women and 11 men), and we received survey responses from forty-five of them (34 women and 11 men). Participants received a 5,000 TSh incentive ($2.14 USD) for engaging in the focus group. Hereafter, each participant is identified by coupling their focus group, (e.g. Group 4 is noted as G4), and their random id, (e.g. Participant 8 is noted as P8) to maintain anonymity. Gender is listed after the identifier to give context where necessary.

We organize our findings into the following sections. *Growth of MSEs* describes the rise of smartphone-supported MSEs with diverse internal mechanisms. Each subsequent section describes how individual SSEs interact with the broader market. *Social Networking* explores how WhatsApp groups enable new paradigms of logistics and relationship maintenance. *Trust* describes how the new practices combined with *mali kauli* test and morph traditional dynamics of trust. *Gender* details how opportunities and achievements in mobile-supported business differently impact women and men. *Limitations of Technology* describes the challenges that people face with current technologies supporting their enterprise.

Growth of MSEs As smartphones become less expensive, and internet connectivity becomes more expansive, WhatsApp is becoming an integral way to communicate with friends, share emotions, pass on photos, etc., in peri-urban Bukoba. G2P8 says: *"I have a phone and can see diverse kids' clothes through WhatsApp status and on TV. But all kids in Bukoba are wearing the same clothes from the (nearby) market."* She aspires to own different clothing for her children but her peri-urban market does not offer a diversity of options. Therefore, WhatsApp creates a growing desire for differentiated products, and as a carrier of community dialogue, it is uniquely positioned for new entrepreneurs to showcase new goods in response to the increasing demand. The SSEs we interviewed cite the primary use of their smartphones as interfacing with customers: advertising products through WhatsApp statuses and taking orders through messages and calls. WhatsApp statuses are photos and captions uploaded to the app, visible to all contacts for a duration of twenty-four hours. All SSEs use their smartphones as cameras to take photos of their goods, some even using apps like Snapchat to apply filters before they post as many statuses as they like of different products. As G1P1 said, *"It's not easy to tell everyone that you are doing a certain business by word of mouth. Posting everyday creates customers."* G1P7 noted how sharing photos has been a part of marketing in Bukoba prior to smartphones: *"My mom has been a decor person since way back before smartphones existed; and it has always been important to "see" businesses. [...] We used to have photo albums that display décor projects she has done over time. The only difference now is that lots of work is done with a phone with less weight, so we term this as advancement from the past."* Thus smartphone-based business integrates with practices indigenous to the community that are being adapted to a new socio-technical context.

The next most salient use of smartphones is to join WhatsApp groups to source and market products. While some business owners make or grow their own products, with artisans hand making bags and dresses and farmers and livestock owners growing their own poultry or *senene* (grasshoppers), products such as clothing and car parts are sourced by some SSEs through WhatsApp groups from as far away as Dar es Salaam and Kampala, Uganda. Goods come to these large cities from Turkey, China among other countries. This shows WhatsApp's role in substituting travel, whereas before entrepreneurs would have to take the bus or the train to a big city to select wares to resell. Therefore, WhatsApp groups enable businesses to see and source products from much farther away than prior business modalities. In tandem with using their phones for procurement, many SSEs report using their phones to contact *boda bodas* (motorbike taxis) to help with local delivery logistics. Finally, most participants report using their smartphones for M-Pesa and other financial apps which allow them to transact digitally.

Beyond these commonalities, there is a great diversity in how the smartphone-based business model has been adopted by entrepreneurs. Some SSEs are also street vendors, carrying their wares to office buildings, using their phones to amplify advertisement and decide their routes for the day; some SSEs have stores that they own or rent while using WhatsApp purely for procurement; and some SSEs are fully mobile business owners, meaning that they use their phone to procure, show off their wares and interface with customers. The range of products and business strategies available through smartphone-supported MSEs is truly remarkable, especially when we take into account that each SSE sources their own goods and distributes them in the absence of a central online marketplace or postal infrastructure, with each SSE's advertisements through WhatsApp status being limited to their own contacts and obtaining goods being limited to buses that move between bigger cities and their peri-urban area.

Although people in Bukoba can now more readily access lower cost smartphones, electricity, and Internet, we recognize that we describe the choices of people who want to do business and are able to purchase a phone. For context, our SSEs report monthly incomes ranging anywhere between 20,000 TSh (USD 8.57) to 1,500,000 TSh (USD 642.92). From our discussions with street vendors to large-scale car dealers, we find that renting a stall and stocking a variety of products to conduct business is prohibitively costly. Several SSEs in our FGs mentioned that they purchased a smartphone to circumvent these barriers when beginning an enterprise. G2P6 said *"I used to go shopping and find nice products that I couldn't afford to bring back to customers. If I came back and told people about the products, they wanted to see them. I couldn't show them because I had no smartphone. People advised me to get a smartphone, so I bought one and started posting statuses."* Owning a smartphone therefore allowed SSEs to display goods and services to people without committing the capital to stock them before they are ordered by a customer, underscoring that adopting technology proves a cost-effective way for resource constrained individuals to *begin* new businesses. Per G4P3, having a smartphone and posting a status that received several replies was what gave him the idea to start a business: *"One day I saw a car and I really liked it so I* *took its picture and made it my status; every viewer was asking what is this car, how can I get it, and how much in case I need it… then I saw status as a business opportunity."* Here we see that risks are mitigated through smartphones enabling SSEs to find clientele without committing to beginning an enterprise. Recognizing the potential of smartphones, some SSEs report saving for a smartphone over time and sharing phones with family and friends in the interim. Per Artisan G2P4, *"I had no smartphone, I used a basic phone. I used smartphone through my sister, she liked posting and posting. She posted her products and named the price of the product. I was inspired too, so I started trying to post."* When sharing devices wasn't a possibility, some participants noted that they circumvented smartphone costs by buying counterfeits, known as "copy phones." Per G2P6: *"Funny enough, they look exactly the same, copy and the original, no difference".*

The adoption of phones into peoples' business practices has had a significant impact on their business outcomes. 100% of participants report that their income and customer base have grown since incorporating smartphones into their business practices. As G5P6 says, *"I was selling 50 trays of eggs before phone business but now I can sell 500 plus trays of eggs a week."*, and G2P8 notes: *"I had no shop. I reached a stage where I could stay online. Through the phone I saw no need to rent a stall because I could sit and collect 60,000 or 100,000 TSh ($24 to $40 USD) in a day posting statuses of my products."* Therefore, we see that the smartphone-supported business model allows for sizable entrepreneurial growth of existing businesses in this area. These effects are magnified for those that were previously engaging in manual labor with little returns. G1P5 describes the physical exhaustion that was mitigated by saving up for a smartphone, *"I started my business as a street vendor; I used a lot of strength walking from place to place displaying my product. After some time at the end of each of day, I ended up so tired."* The reintroduction of images into marketing, as well as their easy transport through WhatsApp to many viewers, changed how our SSEs view entrepreneurship. Per G1P2, *"You can't make a cake with no eggs, so it's more like no mobile no business."*.

Social Networking The underlying theme of participants' use of WhatsApp is communicating ideas to large numbers of people. Verbal greetings are extensive in Tanzania, which translates on WhatsApp to people sending "Hello, good morning" messages or posting such statuses regularly. Further, the practice of saving everyone's phone number upon meeting leaves people with hundreds, sometimes even thousands, of contacts on their phones. This makes it easier for SSEs to make and maintain connections to market to. About half of the participants we interviewed mentioned that their contacts help amplify their messages on WhatsApp to keep new customers coming. As G2P5 notes, *"Our daily customers or people close to us will direct customers to my phone number."* This mechanism of smartphone-supported MSEs is therefore a product of a unique combination of societal factors that are easily amplified using technology.

Beyond messaging, calling, etc., which are accessible to people with basic phones, and beyond posting statuses, WhatsApp allows its users to join groups of up to five hundred people. These groups take different shapes in Bukoba, starting from self-organized groups of business owners who support one another. For example, as G2P1 notes, *"You sell perfumes and I sell clothes. I give you my business and you give me yours."* Other groups with external admin ask business owners to pay a fee to the admins (5,000 TSh/week ($ 2.14 USD) and follow rules that involve posting on behalf of other sellers. According to G2P8, *"There are new groups formed with 100 businesses. Each day, admins will select 10 businesses. Each business owner in the group is required to post a status about those 10 businesses to all of their contacts. You are supposed to meet the requirement and post everyday; if you don't post, you are removed or told to pay a fine."* This unique form of mutually aggrandizing social networking is interesting as it exposes SSEs to new markets and new customers without paying for paper advertisements, which participants say are ineffective. G1P2 says, *"I don't read ads when I pass by various places. [...] It's simpler to buy a bundle compared to paying for those print ads which involve Tanzanian Revenue Authority (TRA)."* Finally, there are groups for individual businesses that resemble rotating savings and credit associations (ROSCAs) [MAR+19], collecting fees through mobile money and giving participants products on a weekly or monthly basis. As G1P4 says, *"There is this girl who creates WhatsApp groups based on geographical locations of customers. 1000 TSh is collected from each participant weekly, and each Saturday one participant receives kitchen utensils of her choice."* This example shows an SSE leveraging a subscription working through a ROSCA model on WhatsApp groups to deepen customer relationships and renew sales.

Trust & Privacy In FGs, we explored relationships that demand trust in the entrepreneurial setting, and how these notions have changed given the adoption of smartphones. The first relationship is *between distributor and seller,* which often takes the form of *mali kauli* in Tanzania. Previously, inbound or outbound logistics were handled by an SSE who would travel to the city to establish trust with a wholesaler, viewing goods first-hand. This incurred costs in the form of both bus tickets and time. Some of these costs were mitigated by the use of a basic phone. Now, given WhatsApp's ample groups containing both sellers and wholesalers, owners can view pictures of new products from faraway middlemen and begin procurement with lower cost and greater ease. They can message these vendors directly on Whatsapp and form long-lasting relationships.

People wanting to start a smartphone-supported MSE in areas without *mali kauli* would need to buy a phone and subsequently pay up-front for goods. In Bukoba, sellers can leverage *mali kauli* to launch new businesses, getting their initial batch of products on credit while they build capital. Per G1P3, *"My reason to start a mobile business is lack of capital. I just posted screenshots of statuses from a wholesaler without owning the products or even having the money to buy them. When I got five orders from customers, I ordered those products through a WhatsApp group I joined; a bigger wholesaler sends the products based on mali kauli. After I sell them to customers, I pay the vendor back. In the long run, this is how I secured capital."* We observe that with smartphones alone, business owners may be unable to subvert their lack of assets and pursue entrepreneurship.

However, in the presence of a cultural system that helps low-capital SSEs launch businesses, mobile technology can amplify efforts and begin partnerships to groups of creditors. Therefore, smartphones not only increase information availability but also increase the potential assets that SSEs have access to when they become part of the groups of wholesalers.

However, this “efficient” online system of sourcing can lead to unintended consequences. Some sellers reported negative experiences with online-only wholesalers, with a few saying that they still preferred to vet goods in person before they made purchases. G2P6 notes spending significant money to buy sheets and duvet covers after viewing them on WhatsApp, only to see that they were very small and of poor quality when delivered to her. G2P5 says, *"We lost our money to [Tanzanian distributor]. Tanzanian middle people are thieves."* Thus, in this new paradigm, it is hard for SSEs to know whom to trust, raising the need to uncover ways to ascertain the legitimacy of bigger sellers online.

Next, we consider the *trust between seller and customer*. Participants report that phone-based interactions raise issues in cases where pictures may fail to adequately represent products. For example, G2P1 says, *"There is this customer. I delivered the scarf to her; she said in the pictures she saw a different pink color. And I came back with my scarf."* This respondent spoke about how she suffered losses on transportation due to this and other such exchanges. While making sales through posting statuses helps business owners build credibility over time, they suffer losses when customers have alternate expectations of products based on picture quality. Business owners say that “return-related" loss, while inevitable, is especially hard to absorb when the commodity they are trying to sell online is perishable (such as *senene*). Just as SSEs need to build trust over time with wholesalers, customers take time to trust SSEs’ statuses. Some of the reckoning with online images might be cultural. Per G5P1, *“Some customers don’t trust status business due to fear of fraud. For example, if I post a car on my status, people won’t believe that I sell cars; but if I take a physical car outside my shop, everyone will believe that I am selling it. I am ignored because we Africans* *don't trust and believe in online business."* So, though SSEs can get their products out to many more people, current culture regarding seeing items firsthand might keep customers from making purchases.

To create trust, SSEs often expose their identity online. In the words of G1P7, *"Among the very best strategies to do business online is to show your face. When you advertise with the products and expose your face, this creates a sense of trust for a customer to be eager to purchase a product from you."* However, this greater visibility can have grave repercussions. Government officials from the TRA now use WhatsApp to find unregistered businesses. Per G4P2: *"I sold a car over status, so I decided to post a status thanking the buyer. Then I received a call asking for a meet up to talk about the car business, and I gave the "customer" directions to where I was. After a short time, TRA agents came along asking why I sell cars without a license."* Though a similar interaction could have occurred if a TRA agent walked by a vendor, there is amplified exposure that WhatsApp statuses pose, given that people repost one anothers' statuses and provide contact details of business owners to anyone that enquires. As to why SSEs would not simply register themselves with the TRA, businesses incur a cost to register, and not all businesses qualify given rules surrounding registration. Some of our respondents shared how the registration process was confusing to navigate, and therefore they feared being exposed to significant risk (such as heavy fines) if their statuses were viewed by the authorities. This is a negative impact of advertising mechanisms enabled by WhatsApp groups stochastically expanding networks.

Gender When asked about the owners of smartphone-supported enterprises in Bukoba, 97% of women and 100% of men stated that women are more likely to start a mobile-supported business. For context, 58% of all shop owners are men, and in particular, 57% of all of the physical businesses associated with a smartphone are owned by men (these statistics are from our collaborators' survey which is forthcoming). The fact that more men own smartphones, yet more women seem to start smartphone-supported MSEs directly contrasts the idea that access is equivalent to use. Even though we attempted to sample SSEs without gender constraints, our participants ended up being 75% women. We were curious about why more women seem to adopt the WhatsApp-based business paradigm, given that women are often less likely to adopt and feel authority to leverage new technology.

First, women noted that using smartphones was a key way to begin low-capital businesses. Per G2P1: *"I used to like doing business, but I had neither capital nor a stall. If I was a man, he would take those things and put them in a stall and start doing business. Because he has a lot of capital. But because I had low capital, I decided to start posting; it's very rare to see men posting."* This difference in start-up capital between men and women was referred to by thirteen women and six men in survey responses as a reason that women could not begin a business through traditional pathways. In our study population, the average upfront cost incurred to start a business was 100,000 TSh (50 USD) for women and 200,000 TSh (100 USD) for men. G2P8 describes the cultural underpinning of this difference: *"I can wake up in the morning and buy bananas and start selling them in my street. That is difficult for a man. Do you understand? A man starts their business with big capital. It isn't shameful for me to be cooking, selling bananas or doing other activities."* Further, we see that 94% of our women SSEs primarily use smartphones to run their business, whereas only 36% of men primarily use smartphones, indicating that men are able to rely partially on physical stores to display their products and advertise. This underscores that women are more likely to run fully mobile-based MSEs.

Second, both male and female participants report that they trust women more than men, and this plays out in the form of who benefits from *mali kauli*. G2P8 (female) believes that *"Men are not trusted because they take risks when it comes to money. It is simple for a man to go away from his home, but a woman with kids cannot run; instead, she will take her whole family. It's very easy for a man to risk and say give me 10 million, and the next day he is not there. [...] Because women* *are emotional, they don't think only about themselves. They will think of the kids, husband, the mother, the father and relatives, but for men they will be thinking only for themselves. They will say, "I have taken 10 million and am shifting, am going to Uganda, and we won't see you, and you get married to another woman."* Interestingly, this sentiment was echoed by men, as G5P1 (male) notes *"Men are brave so it's normal for them to disappear and destroy their contact number after collecting contributions from group members… How can a woman leave a place so simply? Women aren't as mobile as men."* Motherhood is referenced by women as an example of why they are to be trusted, but it also seems to be a reason in men's eyes that mothers are employees rather than owners. In the words of G4P3 (male), *"Most women, especially family women who take care of their family, don't have time to open shops in town, but they do their business via their phone by simply posting. It's a normal thing..."* In this way, we see that women aren't primarily using smartphones to be able to communicate while they are away from the home, as was seen as the main "mobility" affordance of basic phones when compared to landlines. Rather, they use smartphones to circumvent immobility that is caused by household responsibility, i.e. smartphones allow them to stay within the home and still carry out complex business activities.

While both men and women agree that women are the bigger forces behind smartphone-supported MSEs, many of the reasons men gave to support this phenomenon differed from those given by women. For example, G5P2 (male) says, *"It is because a woman has a lot of idle time; she doesn't get occupied by a lot of responsibilities like a man does."* and G5P3 (male) concurs, *"Most of a woman's time is spent on the phone compared to us men. My Instagram account for my business is operated by my wife because my wife has time and opportunity"* G5P4 (male) cites WhatsApp groups being primarily filled with women: *"Something like twenty women agree to post a certain business altogether, so women are supporting the business in operation; that's why they are more"* he adds, *"but shops are owned by men, so we as men believe that [...] women are there to invite and attract customers to make profit."* When referencing WhatsApp groups to advertise business, G5P1 (male) says, *"No, personally I don't know such groups ... men do like to struggle on their own to solve their own issues."*

While many women feel encouraged by their spouse or parents to start a business, some feel curtailed by spouses that do not allow them to do so. Three women cite social pressure in response to our survey questions about why women are less likely to start a physical business in Bukoba; no men cite this as a response. Per G1P6 (female), *"There are those women that are married, and their husbands don't want them to even go outside. They ask their friends to do business on their behalf so that their husbands don't know."* Per G1P4 (female), *"Before we got married, my husband promised to support me in opening a business. But after we got married, he said he gives me all the basic needs, so there is no need for me to work. But I had my important needs, and I wanted to depend on myself."* These quotes reveal that many women aspire to start businesses and achieve economic independence; further, per G2P8 (female): *"it's because of the kind of men we have these days; we have no option. We have to go outside and work. The man leaves no money at home. You can buy a single plantain and start selling it on the street. We must do that to sustain the family."*

Crucially, businesswomen report exploitation and harassment from both customers and wholesalers. G4P5 (male) notes, *"Most of the middle personnel are men."* Therefore, traditional patriarchal dynamics along gender lines continue to prevail in interactions between strangers over the phone. G2P4 (female) says, *"When I order my materials in Mwanza, I choose the colors I want for sewing thread. [...] When the order arrived, I found they had sent me wrong colors. And they took me for granted. They knew I was a woman and said she can't say a thing because she is a polite girl."* The same is true for interactions with customers; per G2P1 (female), *"There was this man who bought things for his wife from me. [...] When you remind him of the debt, he becomes so furious. So what I did was I got another man to talk to him about my money, [...] you can't believe he paid all the money. And I thought he did all that because I was a woman."* These issues prove that social context can minimize a women's agency while exploiting her labor. The female business owners themselves feel this deeply, as G1P7 says, *"One thing I can say, and I don't say this because I'm a woman, [...] many businesses are owned by women but are not acknowledged or recognized. Women are working so hard in Bukoba"*, and several women in the group agreed.

Limitations of Extant Technology There were several challenges raised with using WhatsApp and related smartphone technologies. Cost-related barriers included phone price and quality. Participants reported difficulty obtaining a smartphone that would take good quality pictures, and they mentioned that copy phones (counterfeits) may not serve their purposes. Lack of formal technological understanding makes it hard for some participants to decide what phone will serve their purposes within their budget, and whether the phone they are buying is genuine. G1P7 described how she uses her airtime to view statuses of her inspirations to learn new techniques to post her products and to follow up with customers. Thus, bundle costs cover day-to-day business costs as well as "training," or the cost of improving the quality of one's own posts. Participants posited that if bundle costs decline or they could post with no bundle (through a free wireless network), it would help them engage more with their network and improve their posts. On top of bundle costs are those associated with charging phones, which has gotten cheaper with the expansion of electricity.

When participants described limitations of WhatsApp as a platform for business, the most common concern was that posted statuses last for only 24 hours, meaning that every day, business owners must use their data bundle to re-upload images to ensure persistence. Further, WhatsApp does not allow people to search through statuses or groups. For example, there is no way to find statuses selling used cars. Therefore, SSEs face challenges connecting to consumers who may be looking for their products. On the other hand, when viewing statuses, as one contact's statuses finish, the next contact's statuses follow immediately. G4P4 (male) says, *"I have Muslim sheikhs as contacts on WhatsApp, but they are not interested in my photos."* Per Int1: *"How is this different from* *those who decide to have physical stores?"*, and per G4P4: *"Someone knows exactly what they are going there to buy before visiting the shop. But in statuses, we force people to see things that are not for them."* Therefore, this feature may show contacts unexpected products or advertisements that they do not intend to see. Another challenge with status images is plagiarism, says G4P1, who sells his art on WhatsApp: *"When I post on WhatsApp, someone can steal my business. Let's say as I post, my friend reposts them in his account and takes my clients."* Copying statuses and posting them as one's own prevents customers from being aware of the creator of the product, who took time to generate the images or source the products.

Unlike the Western context, businesses in Bukoba do not typically rely on any centralized online resources. This is innately a challenge to this nascent form of entrepreneurship. For example, Google Maps is not commonly used by SSEs or customers. This is cultural, in part, as respondent G4P1 (male) says, *"White people travel just by Google Maps [...]. This is not an African culture. [...] I decided to have a website for my business for white customers."* Int1: *"It is for whites so you decided to apply whites' behavior on it?"* G4P1: *"Yes."* This remark shows awareness among participants of how technology supports businesses in the West, and simultaneously an acknowledgement of how it doesn't inherently fit the African customers' expectations. Another example, as mentioned by G2P6 (female): *"One day I came across an app and decided to join it to sell my products. [..] I had no knowledge of how to use it, and people asked for my products but I didn't know how to answer. To continue owning it, I was supposed to pay for services by Visa. I couldn't, so I stopped using it."* Her quote, and comments from other participants, describe the multiple challenges in using available online marketplaces that are not designed for indigenous peoples, who may be unused to operating apps and online storefronts. G1P7 reports using Instagram for Business with success, but G2P6 cites it as a very expensive way to post. Many participants showed a willingness to pay for an online marketplace, but not by credit card and not at the amounts that Instagram charges. That many of these products were designed in the West, and quote prices in USD, enforce a distance between people and the technology; as G5P4 says, *"I think because e-payment on business account are directed on US dollars, and here we have a wrong idea that every amount of money presented in US currency is high, so people do not bother to know it will be how much and how it works."* When asked about how technology is integrating into the population, G5P4 notes, *"our environment in Africa doesn't show us a way out; all of these medias we are using and networks are not ours; they came from white people and we are only influenced to use it."* This indicates a lack of identification with the technology and its creative use due to necessity rather than by choice.

3.5 Critical Insights

The mobile technology landscape in SSA is evolving, with varying access, use, and comfort across different geographies. Our survey of 1,014 rural farmers in Tanzania reveals that broad narratives of increasing mobile phone adoption obscure significant heterogeneity in basic phone and smartphone access and use. Neither age nor gender reliably indicate comfort using phones, making it challenging to use demographic-based digital literacy interventions. There is a need for localized, adaptive intermediation strategies to assist diverse rural users that are entering or navigating the mobile phone landscape. Our focus groups with 46 entrepreneurs show that while smartphones are not being used in rural areas, they serve as an important mechanism for women to bypass traditional capitalist structures and launch new businesses and re envision existing businesses in periurban Tanzania. The emerging WhatsApp-based business model drives significant economic growth, creating ripple effects that have reshaped the broader entrepreneurial landscape in this region. Together, these insights emphasize that emerging ICTs must be designed to accommodate both feature phone users who will remain a substantial user base for years to come, and smartphone users who are already making highly sophisticated use of mobile tools.

Successful digital interventions must be multiplatform in response to the fluid and stratified nature of technology adoption in SSA.

Chapter 4

Building and Deploying a Dual-Platform Agricultural Directory in 100 Villages

4.1 Introduction

Establishing robust, sustainable, and equitable food systems is imperative to nourish an anticipated population of 10 billion individuals by 2050 [RWSH18]. Agricultural information tools may support and amplify the labor of farmers in achieving this objective by providing critical insights into crop management, market access, and climate adaptation. In Tanzania, 65% of adults are smallholder farmers. Although these farmers are accessing feature phones and smartphones at historically high rates, they face challenges finding a robust network of agricultural contacts. For example, one widowed subsistence farmer in a remote area depended entirely on a single transporter to buy her surplus harvest. Despite owning a feature phone for eight years, she lacked the contacts of alternate transporters and therefore couldn't use her phone to support her agricultural pursuits, forcing her to accept unfairly low prices. To bridge this gap, in 2015, Blumenstock et al. created, printed, and disseminated a paper telephone directory of nearby agricultural businesses in central

Tanzania titled **Ki**tabu **cha Bi**ashara (*Kichabi*) [BDA20]. They conducted a randomized controlled trial to measure the causal effects of having access to nearby contacts on farming households (HHs). They found that "enterprises listed in the directory saw increases in customer contact, sales, and employment [...] and agricultural HHs that received directories were more likely to rent land and hire labor, had lower rates of crop failure, and sold crops for higher prices."

Although there were significant gains associated with Kichabi, the paper directory was hard to distribute and keep up to date, showing promise for a mobile phone based agricultural information service that could scale and adapt to the changing business landscape. Building upon Blumenstock et al.'s work, Weld et al. piloted a USSD-based directory *eKichabi* in 2018 housing 500 businesses deployed to 107 feature phone users [WPA+18]. While the eKichabi pilot demonstrated the feasibility and potential for USSD technology to support an agricultural directory, challenges with USSD-based information services *at scale* remain unexplored, i.e., usability challenges with a growing number of diverse users (deployment scale) and development challenges with a larger set of firms listed (application scale).

Since the 2018 eKichabi pilot, smartphone ownership has grown in Sub Saharan Africa (SSA), with 48% of SSA inhabitants having smartphone access in 2021 [Int21]. Chapter 3 shows the use of smartphones by periurban Tanzanian entrepreneurs to create and enhance their MSEs. In response to the growth of smartphone use, governments and developers are increasingly creating smartphone apps to disseminate agricultural information. Numerous affordances of smartphones — such as image capture, global positioning systems, Internet connectivity, and touch screens — show promise to support users with differing levels of comfort navigating digital services. Currently, developers build either smartphone apps that leverage affordances available to an increasing proportion of users *or* feature phone apps that forego such affordances to serve the majority of users.

Recognizing the need to cater to both feature phone and smartphone users from our scoping work, we design and develop eKichabi v2, a searchable, *dual-platform* directory of 9833 agriculture-related enterprises accessible via feature phones (a complete redesign of Weld et al.'s pilot agricultural USSD app) and smartphones (through an offline-accessible Android app). We report on usability and trust-building adaptations discovered through user testing, and describe inherent divergences, limits and capabilities between USSD and Android applications. This work, published in CHI 2024, identifies the advantages, obstacles, and critical considerations in the design, implementation, and scalability of information systems tailored to both feature phone *and* smartphone users in SSA [RME+24].

4.2 Related Work

Research has explored the aptness of varied basic phone technologies for disseminating information in SSA — Short Message Service (SMS), SIM apps, USSD, etc. The SMS interface has been considered for web search and agriculture information services [MPB+11, CSB10, SRR05, YMP08], but it was found to have limited impact [BO15, FM12]; the technical challenges, (SMS is error-prone and subject to delays [PPPA15]), costs and a lack of inherent sessions, make it unsuited for stateful interactions [WS16]. Solutions such as SIM apps and SIM overlays require costly custom hardware development and distribution and have therefore been discarded.

USSD technology has been instrumental in mobile money systems such as mPesa (used by 57 million SSA residents in 2023 [Dep23]) and for providing government services such as MSeva in India [SJG19, BV15]. It offers advantages, such as: a session-based protocol that supports multi-step operations and stateful interaction; familiarity among users through their existing experience with mobile money systems; compact packet size, leading to faster delivery than SMS; and message order guarantees with higher security due to persistent sessions. As the Tanzanian technology landscape changes, and more than 2.6 billion USD has been invested in network infrastructure improvements [FI22], new device owners stand to benefit from USSD-based information services. Previously, development was limited by carrier control, requiring negotiations with individual carriers to implement a third-party USSD service. However, the number of third-party USSD providers (such as Niafikra) has increased in recent years, with stable gateways available in Kenya, South Africa, Tanzania, and Nigeria leveraged by existing work [WPA+18, PDA15, WM12b, SJ18]. The previous eKichabi project demonstrated the feasibility and potential for USSD technology to support a directory with 500 businesses, having ~2,000 sessions and ~10,000 screen views [WPA+18]. We add to this body of work, testing the boundaries and capacity of USSD technology to serve as the foundation for a much larger application scale (directory of ~10,000 firms) and a significantly increased deployment scale (user population of 1014 farmers) than has so far been attempted for an information service. Because ICTs in agriculture are not typically conducted on such a large scale, it has been challenging to distinguish variations in use across sub-populations [AB15, AM10]. Our work analyzes use by the 1014 users stratified by several demographics factors, including self-assessed comfort with technology.

Smartphone technologies have also been shown to hold great potential for economic interventions given affordances absent in feature phones [SJ18, ALK21, FI22]. A plethora of Android-based agriculture applications in India showcases the benefits of a GUI, sensors, bigger screens, increased processing, and more [KD18, MPNdS+20], which motivate expanding the limited research on direct use of smartphones for agricultural interventions in rural regions such as those in northwest Tanzania. One extant app is Ugani Kiganjani, a simple and affordable mobile and web-based digital agricultural extension service available for weather, crop calendars, nutrition, livestock and fishery sub-sectors in Tanzania, created and maintained by the Food and Agriculture Organization (FAO) [FO21]. Recent HCI research shows the smartphones' effectiveness in supporting women entrepreneurs and farmers [RKM+23, KM17b, LN22b, Mas14, ND23] with the caveat that it can make them more vulnerable to economic exploitation when they are not taken into account during the design of applications [RKM+23]. An HCI survey on smartphone usage for African populations [BSSNMA+21] found that when designed to prevent problematic overuse and encourage face-to-face interaction, mobile applications can have a positive impact across a wide age range and varying professions and levels of education. At the same time, the disproportionate cost of smartphone data compared to the low income of significant populations in Tanzania mean that lower income individuals see less benefits of smartphone applications and, from an HCI perspective, care must be taken to provide cheap solutions and understand/design to support the varied use patterns [MUT08c]. We enrich this literature by creating acknowledging the benefits of smartphone applications by making an Android app available that mirrors our USSD app functionality while leveraging smartphones' affordances. We report on design challenges and the complexities in use enabled in the smartphone-accessing population while building on findings from existing literature, e.g., the importance of offline functionality [ALK21].

Despite the increasing number of platforms that offer agricultural information, the use of these services and access to subsequent extension services are mixed due to socio-technical challenges [MMK14, SMHT16, ML19, Mwa19, QSN+20, Kat21, MDMSB22, AB15]. In SSA, mobile phone use is hampered in some sub-populations by the cost of acquiring phones, charging the devices, maintaining airtime, repairing phones, and network coverage issues [AGR+16, WM13, WDSA15], as noted in Kenya [ONJ+14, WSO16], Uganda [MA11], and Malawi [SWCC15]. Another limitation is the farmers' lack of technical literacy [WS16, MM21, Nya21] and lower trust in ICTs [AGB16]. Aker et al. [AGB16] review various attempts to use agricultural ICTs in Africa and offer sociological and anthropological insight into how these platforms alter the relationship between the provision of information and trust. For rural communities in Tanzania, trust takes different forms [MGA14, AADES20, Rap16]. Our work documents localized ways to confer trust through design that we learned through iterative user testing.

4.3 Iterative Design & Development

This joint research undertaking entailed a survey of firms and a survey of HHs across Kagera, followed by development, user testing, and deployment of the dual-platform technology. Working with collaborators at Cornell allowed our reach to extend to a larger scale than otherwise achievable; however, it also limited our contribution to some methodological components (e.g., collaborators had already established power calculations and sampling strategy for households being surveyed in relation to their chosen economics outcomes) or downstream analysis (e.g., collaborators will measure long-term impacts, changes in agricultural productivity, etc., due to the agricultural information service). Below, we provide in-depth descriptions of the methods and results of the design and development processes.

4.3.1 Designing and Developing for Scale

I moved to Kagera, Tanzania in May 2022 to begin study activities. In June 2022, collaborators designed and implemented a firm survey in 100 villages in the Kagera region to collect contact information, goods sold, and other relevant information from 9833 agriculture-related businesses across 100 villages in Kagera. This survey formed the basis of our digital directory. We built an entirely new directory architecture with USSD and Android components, scaling the application data 20x and the deployment user population 10x across 20x the amount of villages in comparison to Weld et al.'s 2018 work [WPA+18]. Our iterative app design and deployment processes involved several rounds of informal and formal user interaction and testing with the USSD and Android apps between May and August of 2022. We convenience sampled participants for these user tests with the help of a local guide during the administration of the firm survey. This yielded 56 participants across 4 villages. During each user testing session, an enumerator and I met with groups of 4 participants. We first explained the project and led participants through two example use-cases on the USSD and Android apps: ("Imagine you need to find a transporter for some goods; this is how you'd do it using our digital directory." AND "Imagine you need the phone number of *"Specific Shop"* in your village center; this is how you'd find it."). We asked participants for to come up with one alternative use-case and observed their independent use of the tool. Participants were then asked questions about searches and UI preferences that informed specific app design choices. For example, they were told to imagine a village grocery store and asked how they would identify the store (by the business name, owner, location, storefront, etc.). Finally, enumerators answered questions, inquired about ease of use and perceived utility of the tool, and let participants know that the service would be started in November 2022.

USSD Application To access our USSD application, users dial a shortcode on their phone to initiate a session with their mobile network operator (MNO). The MNO then requests a “screen" from the USSD server consisting of up to 160 characters of plain text to display on the user's phone screen. While the session is active, the user can respond to each screen with text or numbers and be served a new screen in response to each input. A MySQL server is queried through the Django ORM to generate dynamic screens based on user inputs (e.g., for text searches), and these screens are then cached in memory when possible. Once the user has navigated through 6-8 screens (depending on the path of the search tree they traverse), they arrive at a list of businesses corresponding to their search.

Through user testing, we optimized the search functionality to increase ease of navigability. When asked whether having multiple screens in a shortcode application deters their use, 46.4% of users in our testing groups agreed. Therefore, we decided to break categories of businesses into logical subcategories where necessary, while limiting the number of subscreens where possible. Though Weld et al.'s pilot had crops, livestock, and agricultural products [WPA+18] grouped together during search, we chose to split them into individual categories to allow users to be specific about their search, eliciting the following user feedback - *"Search through the menu is easy to avoid confusion on what you want, since you go direct to your need/concept using the specific choices."*

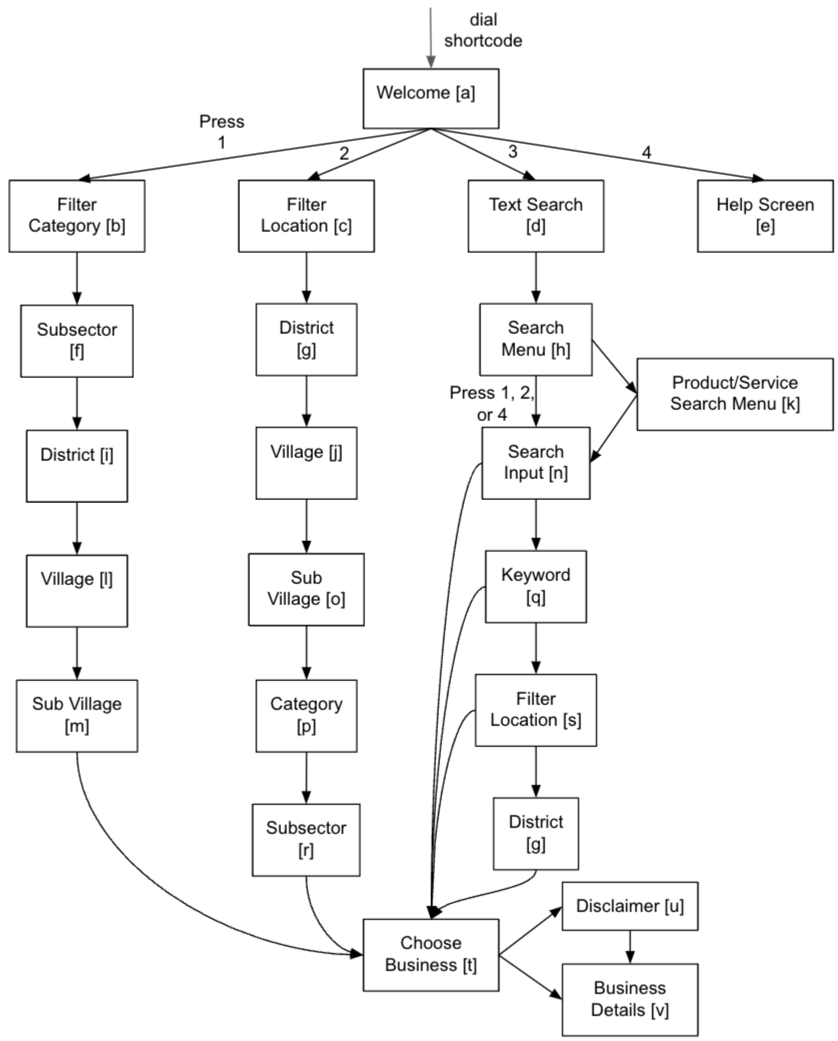


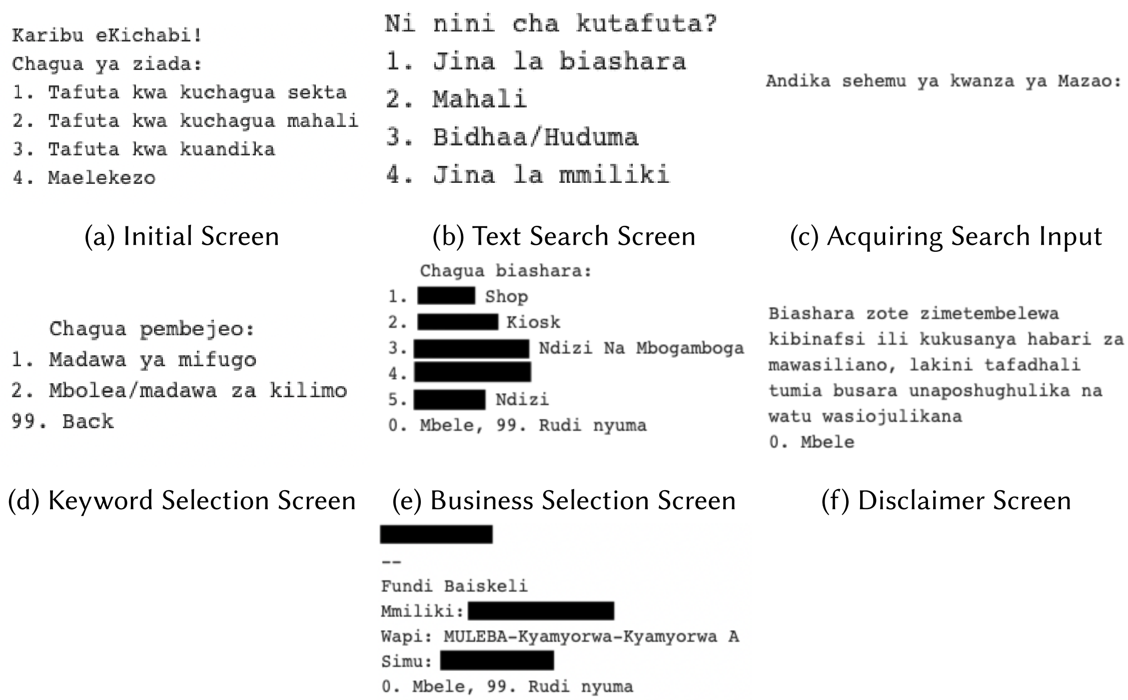
Figure 4.1: Users must navigate through USSD screens using numerical or alphabetical inputs until they arrive at a business details screen.

Splitting into subcategories also eliminated the occurrence of "too many results" screens for many categories of searches as our application scale grew. The final main menu screen offered 4 options: (1) *filter by category*, which prompts the user to select a sector, sub-sector, geographic district, village, and subsequently sub-village, (2) *filter by location*, which does the same as option 1 but starts with geographic filter options followed by sector and sub-sector filters, (3) *text input search*, which lets users enter a string that corresponds to a sector, sub-sector, product, or location, bypassing the need to navigate through any USSD screens before seeing a list of relevant businesses, and (4) a *help screen*, which walks users through available search options. Filter options are suspended and jump directly to a list of matching businesses when prompted by the user or when 10 or fewer businesses match the previous filters. Figure 4.1 shows the flowchart of USSD screens for the eKichabi application.

Several users expressed interest in the typing-based search to avoid narrowing their search through menus. However, spelling challenges prevented this from being as useful as anticipated - as reported during feedback sessions: *"If you mistake of some spells you may end up get wrong information, eg Korogwe vs Karagwe, Kyera vs Kyerwa."* To circumvent this problem, a "keyword" selection screen was added after text searches to let users choose from a list of close matches, reducing the occurrence of unhelpful "no matches found" screens that were prevalent in Weld et al.'s pilot [WPA+18]. Figure 4.2 provides a walk through of text based search through the directory.

User observations underscored that fast application performance was necessary to avoid MNO-implemented timeouts that reset users to the first screen - as one user said: *"Some search took so long to display, I had to start from the beginning"*. This presented a steep technical challenge since our database grew from 500 to around 10,000 businesses. To address this, we performed database optimizations, including: implementing a Redis cache for session information, changing the session storage format from pickles to compact strings, adding lazy loading for search results to reduce computational overhead, caching pre-computed screens, adding proper database indexing for fuzzy search, and using MySQL instead of SQLite to handle concurrent connections. Collectively, these significantly boosted performance, with request times dropping from 5+ minutes of server computation when using Weld et al.'s implementation [WPA+18] to ~400 ms using our new system.

This signified an average performance improvement across a single session of more than 7000x as indicated by benchmark and stress tests.



(a) Initial Screen (b) Text Search Screen (c) Acquiring Search Input

(d) Keyword Selection Screen (e) Business Selection Screen (f) Disclaimer Screen

(g) Business Detail Screen

Figure 4.2: A few screens from the USSD application demonstrating what a first time text search traversal could look like with phone numbers obscured for privacy. **A:** The first screen displays the 4 menu options - category search, location search, text search, and help. **B:** After selecting the 3rd option, the user has 4 text search options - business name, location, products/services, or owner's name. **C:** The user is prompted to spell part of what they are looking for. **D:** If there are many matches, or no matches for the provided spelling, the user is prompted to select the keyword that most closely matches what they were looking for. **E:** After selecting, the user will either be prompted to further filter by location, or in the case of few results, be prompted to select businesses to view. **F:** The first time a business is selected, the study disclaimer is shown. **G:** Finally, users see a detailed overview of the business name, economic sector, owner name, location, and contact phone number. They can move to the next business in their search by pressing 99, or go back by pressing 0.

Android Application The Android app was developed as a GUI-based directory. After users download the app, they are shown a short tutorial followed by a list of all businesses in the directory, through which they can freely scroll. The app provides filtering options based on geographical locations at district, village, and sub-village levels, as well as sectors and sub-sectors. Text search dynamically displays relevant results after the user inputs their query. Additionally, the GUI features convenient buttons for actions, e.g., accessing the list of favoriting businesses, calling businesses directly, and adding businesses to the user's contacts (see Figure 4.3 for the different screens described).

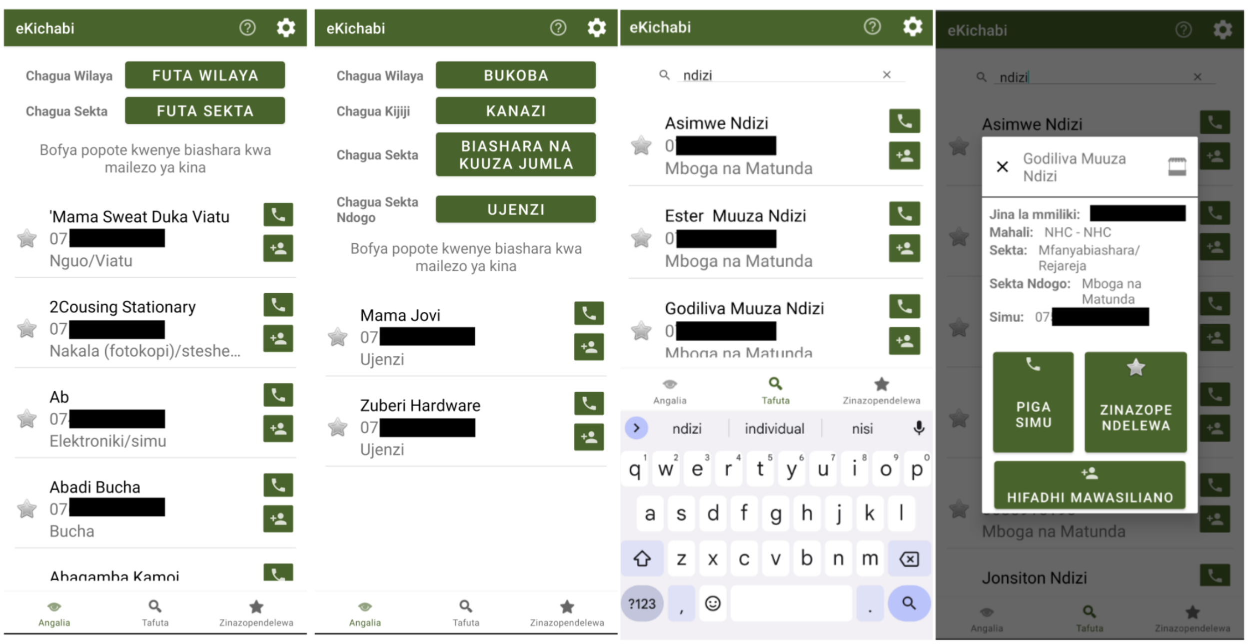


Figure 4.3: A few screens from the Android application with phone numbers obscured for privacy. **A:** The user can scroll through the businesses, favoriting, adding to contacts, calling and viewing more details, as desired. **B:** The user can filter the businesses by district, village, sector and sub-sector to make results more relevant. **C:** The user can find businesses via text search: a scrollable list of businesses dynamically appears as the search is being narrowed. **D:** The user can click on a business name to open a screen showing business name, owner name, phone number, location, sector, and sub-sector.

We made many improvements over the course of Android user testing. These include optimizing images and assets for faster loading, adjusting colors to work well in bright light, creating a more robust help screen, adding animated GIFs to explain features, and general bug-fixing. The Android app relied on the same server and database as USSD, centralizing the data and making it easier to keep it current as well as reducing costs associated with scaling by removing the need to maintain two separate server instances. The main challenge encountered in Android app development was making it work without an internet connection. We chose this as a design principle because most users reported having an internet connection in the village center but not in their homes. We considered several solutions, one of which had the Android app fall back on a USSD app when no internet was available and augmented data appearance through the GUI, but this was deemed too unreliable for deployment due to (1) limitations in different Android operating systems' support of USSD connections, and (2) the USSD gateway's inability to accept payloads through Android applications. The final design kept a local copy of the phone directory (only 1.8 Mb). Any subsequent directory updates are efficiently performed when the device has an internet connection: an endpoint was created to check if the directory is up-to-date so it need not update its local copy unless necessary. Internet connection is therefore required only for the initial app download and user authorization. We stored usage logs in a custom binary format for compactness because offline storage space and online data transfer were limited resources. Logs returned to our server are limited to 100 KB local storage before uploading, which is sufficient for 6250-20000 actions each given our custom formats. Our final app was 6.73 Mb of data. In 2023, 6.73Mb of data cost ~67 TSh or $0.02 USD.

Both our Android and USSD applications form parts of a unified software architecture supporting the dual-platform service (see Figure 4.4).

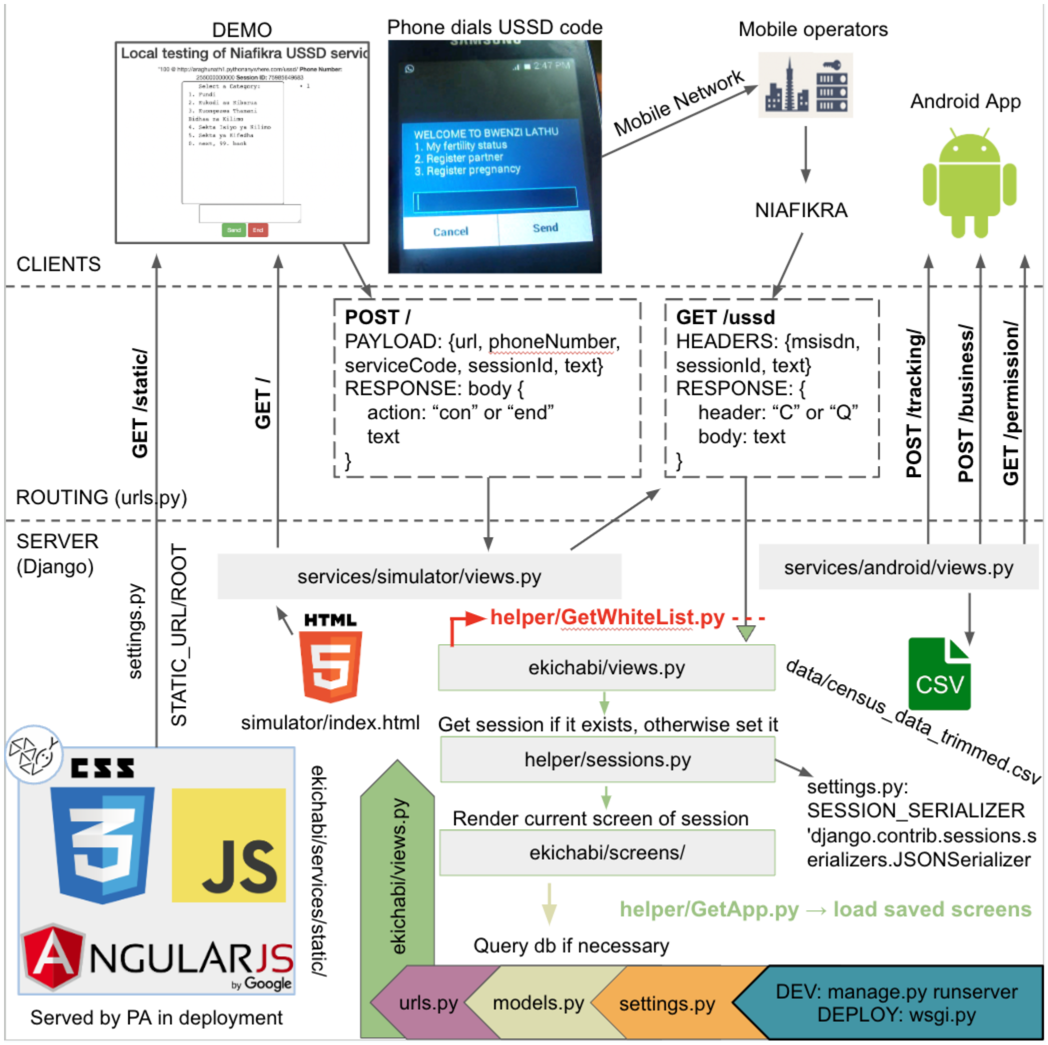


Figure 4.4: Software components the architecture serving our our dual-platform service. Client side pieces of the developer demo, USSD app, and Android app are at the top, with routing and server components below.

Whitelisting Both the USSD and Android apps needed *whitelisting* mechanisms (i.e., the ability to allow only the phone numbers in our study to access the intervention) to enforce specific treatment groups and villages as needed by the collaborators. Whitelisting was implemented based on a common server endpoint that standardizes the phone number format and then compares against a hashset of pre-approved, formatted phone numbers. One challenge in authenticating users for the Android whitelist presented due to the technical limitations of the previous versions of the Android SDK and older hardware, which were common in this context (such as dual SIM implementations, older SIM security systems, and lack of support on old Android operating systems). This created barriers to accessing phone numbers programmatically. To maintain compatibility with the hardware commonly found in developing regions, we decided to treat phone numbers as one-time passwords rather than as 100% reliable identity providers through hardware, collecting phone numbers from users to grant them access to the service. Although other solutions, such as sending one-time access links, were considered, they were eventually discarded since they did not offer significant security benefits and would have posed a barrier to use for less tech-familiar demographics. We settled for allowing the user to input their own phone numbers, trusting that they would not share them with others who were not whitelisted. Analysis of the Android logs showed no anomalies, suggesting that login with one's phone number was a valid method of authentication.

4.3.2 Designing for Trusting Interactions

Trust was a significant factor in acceptance and use of the app and arose repeatedly in user testing. As researchers have found, text message or USSD-based scams are becoming commonplace in this area [RJMA23]. Several users questioned why they should trust the phone numbers in the directory, what recourse they had if they were conned by a contact they made through the directory, whether the app would validate the businesses, and so on. One user asked: *"What if I call a transporter through the directory and he comes and kills me?"* We made three changes to the app training protocol and the technology to inspire trusting interactions, as follows.

1. **Users were skeptical about our incentive when creating and disseminating the directory. In addition, they wondered how we selected businesses to include in**

the directory. In our training materials, we explained our research study and goals and mentioned the prospect of handing over a similar project to the government of Tanzania. We also made clear that the information in the directory was assembled by our research team through a survey that we conducted when we worked with the support of local village extension officers (VEOs) to collect information. Every business listed in the directory was visited by one of our team members to gather information in person.

2. **Users were accustomed to building trust by meeting face-to-face. The new potential for interactions inspired questions as to whether we guaranteed transactions as part of our role in maintaining the service.** We modified the training to encourage continuation of face-to-face meetings even when people make initial contact through eKichabi. We added a disclaimer the first time either app was used, alerting users that they should take care when contacting individuals and that we did not guarantee transactions: *All businesses have been visited in person to collect contact information, but please use discretion when transacting with unknown individuals. It is possible that some businesses will close this year or change their business practices. But we hope and expect that the directory will remain very relevant for years to come.* User feedback gave us other ways to improve this mechanism in later iterations of this study. For example, one user said *"You can also think of adding village officials to each contact listed on the last screen in any case one wants to contact the official person for verification of the business since those officials knows well people around their area of administration."*

3. **Users would trust the directory if national tax IDs were collected from businesses and added to the directory.** Until user testing, we listed only business name, contact information, and sector in the directory. Understandably, not all businesses are registered in Tanzania, and national IDs are too sensitive to include in the survey or directory. Once we

understood that Tanzanians do not typically identify businesses by their names but rather consider the business owner as representative of the business, we added owner names to the business information we provided in the directory. We created an associated search pathway to allow searches through owners. Although this modification added technical complexity, user engagement grew during testing sessions when users saw their friend's or family's business in the directory, and the sense of legitimacy granted by these interactions was extended by users to other businesses listed in the directory.

4.3.3 Divergences between Platforms

Though we designed both USSD and Android apps to present the same service across different platforms in similar ways (filtering, text search, etc.), there were unique and inherent advantages of each, as listed in 4.1.

Theme	**USSD App**	**Android App**
Navigation	Users navigate through USSD screens with numerical input corresponding to selections. To go to the previous screen, they enter 99; to go to the next screen, they enter 0.	The Android app leverages the smartphone touchscreen to move back. 'Next' is not a necessary function since all relevant businesses can be scrolled through at once.

Visibility of Businesses	Users must navigate a minimum of 6 screens before businesses become visible and open business details screens individually to see more than the business name.	The Android app displays the list of unsorted businesses as soon as the user opens the app (see 4.3 Panel A), with business name, owner phone number, and economic sector/product type available without clicking on the business details screen.
Search	Screen size and character limits limits put a ceiling on the number of business names displayable on a single screen, i.e., typically 5 to 6 businesses. This means there can be tens of pages of responses for some queries that the user must traverse sequentially.	Android search is dynamic, and the list of businesses updates as the search is being narrowed. As many businesses as are applicable appear during the search.
Additional functions	Users must physically write down contact numbers from the final business screen since feature phones do not allow text copying and pasting. Use of the help screen requires returning to the first page of the app.	Android users can favorite businesses (which then appear on a separate tab), save phone numbers to contacts, and call businesses through the app. The help button can be toggled from any screen.
Costs	No costs are incurred when users dial the USSD app.	Android users exhibit reluctance to download the app, citing data costs.

Authentication	The USSD app automatically authenticates users with their phone number since it has access to that information from MNOs.	Operating system version challenges on popular smartphones cause users to self authenticate as opposed to using a hardware-based guarantee from sims.
User Experience	USSD has strict character limits of 160, and on feature phones, it is often necessary to scroll down to display a single screen. This makes USSD more laborious to navigate. Further, feature phones have no way to increase screen brightness or increase text size.	The Android app displays more data while remaining readable and having a more intuitive user interface. Further, smartphones can increase screen brightness and text size to suit users and the environment.
Potential Interruptions	If network is spotty, the USSD connection fails, and the user must resume from the beginning when the connection returns.	Once the app is downloaded, there is no connection necessary unless the directory changes and new businesses must be downloaded.
Trust	Trust is built through a disclaimer and the addition of business owner names to the directory. There is no easy way to corroborate information validity given the number of steps needed to find a business.	Trust is perceived to be greater: although a similar disclaimer is presented, familiar businesses can be located with ease.

Table 4.1: Differences between the USSD and Android apps.

During all user testing sessions, our USSD and Android apps were tested by smartphone owners (SPOs), while USSD alone was tested by feature phone owners (FPOs). When we used smartphones with beta versions of the Android app already downloaded to SPOs for trial purposes, the Android app fared much better than USSD across groups (76.9% of SPOs in these groups preferred Android over the USSD app). Preferences for the smartphone app were magnified when there were network connectivity issues impacting USSD since the app works completely offline. Confusion with USSD concepts, such as selecting "next" and "back" numbers to navigate between screens, further enhanced the preference for the more intuitive smartphone app navigation.

However, when we asked SPO groups to download the app onto their own phones, we witnessed significant reluctance, which limited their ability to experience the app's additional features. SPOs explained that data on Androids was harder to gain access to and that they were accustomed to using USSD, which they understood to be free. Therefore, *there was an overall preference for USSD by both smartphone and feature phone users.* Interestingly, both FPOs and SPOs preferred using the USSD app on a smartphone compared to a feature phone, citing increased usability. Their main rationale included complaints about eyesight and text readability on feature phones. The USSD screens of ~160 characters took multiple pages (and therefore required scrolling) on the small displays of feature phones but appeared on one page on smartphones, with displays that could be pinched to increase font size. Therefore, the affordances of the smartphone impacted the USSD application positively.

From the perspective of trust and usefulness, more SPOs reported that the Android app appeared trustworthy and useful. This might be due to faith in the new smartphone technology they have already purchased or to the immediate visibility of businesses and owner names without much upfront navigation, as is required by the USSD app. In final rounds of user testing, participants offered the following benefits of our app used on their platform of choice:

1. It makes it easier to sell and buy when you know about the area businesses. No middle men are needed; you can directly contact the supplier/buyer and so increase profit when selling and reduce cost when buying.

2. You can contact the business to gain an assurance about goods and service availability before making an order or visiting a buyer/supplier.

3. For smaller business and service providers, especially in the local area, it is an easy way to access larger business buyers/suppliers that are always not found in the local area.

4. It can be used for service provider job recruitment or to display sales information because qualifications or notes can be added to the business detail screen.

4.4 Deploying to 100 Villages

Our collaborators partnered with Niafikra (a third-party USSD provider) in June 2022 to obtain a USSD code from the Tanzanian government. Once the USSD and Android apps were developed, logging and whitelisting mechanisms were appended before the apps were deployed. The logging system collected all USSD server hits and all actions such as favoriting, calling, and searching on the Android app. Deployment began in November 2022, concurrent with the household survey, where users gave consent and were trained to use the applications. Here is a summary of the training script used to onboard users. The process began with a standard introduction of the purpose of the study:

> We are very grateful for your assistance with this study. I would like to tell you more about this project. We are interested in learning whether some additional information about businesses in Kagera would be useful for farming households. To

> better understand this, we are giving some of our participating households access to a phone-based telephone directory. There is no specific reason that your household was chosen to receive this directory – my computer randomly tells me at the end of the interview whether a respondent is eligible to access the directory service.

The system of the menus was introduced with the scenario of a farmer wanting to find a transporter for farm produce. Navigation was taught step by step, beginning by dialing the shortcode (*149*26#), showing the the initial screen containing 4 options, including the three ways to search. The first way was by navigating menus (by selecting a sector or a location (options #1 and #2)) or typed search (option #3). There was also a help button, (option #4).

To find a transporter, the enumerator first selected option #1: Tafuta kwa kuchagua and showed that there were six main sectors in the following USSD menu (wholesale traders; retailers, including shops and kiosks selling all kinds of goods; transporters, including boda bodas, lorries, and others; agricultural processors, such as those with milling machines; skilled tradespeople (fundi), including tailors, carpenters, mechanics, and others; and businesses that provide services, such as restaurants, salons, wakalas, and financial institutions). They mentioned that users could select #0 for the 'next' page and #99 to return to the previous page at any time. The walkthrough then describe how the directory was constructed by the research team, emphasizing how this work was done with the local village executive officers. The script continued to encourage different uses of the directory:

> Let me give you some examples of potential uses of this directory. First, suppose you are interested in learning whether a certain kind of seed is available for purchase. Instead of traveling to a business to find out, you can look up the phone numbers of businesses that sell agricultural inputs, and call them first. You could call a few different businesses in nearby towns, to see if they have the seed in stock, to ask the

> price, and to see if they stock other products that you need.

and then continued with another specific example of finding a seed shop by searching on business type. A third example was used around selling crops, with the motivation of finding the best price through calling different types of businesses such as wholesale traders and retail shops. The script then had the participants explore that application and ask questions. The first discussion was strictly about the USSD application, and it was then emphasized that the USSD shortcode can be used completely free, without consuming airtime credit.

At this point the smartphone application was introduced, mentioning that it does not need connectivity to be used after it is downloaded. The final part of the script returned to the logistics of the study:

> The USSD service and the Android app are only available to participants in this study. It will take us about a week to add your phone number to the system, so that you can access these services. We will send you a text message when the services are available to you.

Enumerators then talked about the actual study and the need to collect usage data and the confidentiality policy. An information sheet on both apps was then given to participants. All households were directed to use whichever they preferred and could access.

Dual Platform Application Usage

Once deployed, user logs were cleaned by identifying outliers from box-plots (1.5 interquartile range from the first and third quartile), investigating their cause and dropping data that came from sources that did not fit the study parameters, e.g., testers and author usage logs, failed sessions from non-whitelisted phone numbers, and so on.

USSD Application Use The USSD application received 122,000 actions over 2939 sessions, with 266 unique HH users of the 1014 whitelisted households. Usage statistics—such as session duration, number of sessions, retention, use of back buttons, and text search—were highly correlated with number of businesses visited ($p \ll 0.001$). The final business screens, which offer the payload of information that the service aims to provide, can thus be seen as tied to the value provided by the service to the user; 782 business screen were visited over the uptime.

The overall mean number of businesses visited by males was 1.046 (s.d. = 6.128), which breaks into two distinct groups, as described below. The first had a mean of 0.27 business visited (s.d. = 0.98), and the second had a mean of 25.17 businesses (s.d. = 24.60). The female group fell between these, with a mean of 0.38 business visited (s.d. = 1.68). ANOVA analysis shows lack of significance in the number of businesses visited between genders ($P = 0.086$); thus, both men and women navigated searches and achieved a similar amount of value from the application.

The only significant predictor of the number of businesses visited is user age ($P = 0.006$). Males were generally younger in our sample, with a mode age group of 35-45 years compared to females, who were between 65-100. Interestingly, the bi-modality within the male group is explained by age since the group with more business visits had a lower average age of 39 years compared to that with fewer visits (average age 49). The pattern that younger people visited more businesses held for both genders (All: $P = 0.006$; Male: $P = 0.014$; Female: $P = 0.026$).

The number of businesses visited did not differ across districts ($P = 0.937$), indicating that there was no peri-urban/rural split in relation to use. However, the number differed significantly across whitelist dates ($P = 0.012$), indicating that seasonal farming practices have a large impact on use of agricultural information dissemination systems.

Notably, the number of businesses visited did not differ across comfort levels ($P = 0.556$). However, Comfort Groups A and B show interesting usage differences (see summary in Table 4.2). For example, all Android application users came from Comfort Group A. In addition, Comfort

Group A had a larger number of sessions, made greater use of the back code (0), ended up on more final business pages, and had longer session durations through ANOVA analysis, with a significance level of 1% .

Android Application Use Android use peaked at 42 active devices. Of the 42 downloads, 40 unique users accessed the application. Android logs tracked 7 different action types: favoriting/un-favoriting businesses, calling a business from within the application, adding a phone number as a contact, opening the business detail screen of a business, searching with filters, and searching with text. Favoriting was used by 12.5% of Android users, with 40 favorite/unfavorite actions. There were also 51 call actions from within the app. Similarly, 15 businesses were added to phone contacts. When stratified, the user population was not sufficient to observe significant differences in use across comfort or demographics.

Contributing Percentage	from Comfort Group A	from Comfort Group B
eKichabi USSD users	21%	12%
eKichabi Android users	0.3%	0.0%
Total Sessions	488	205
Average sessions per user	7	5

Table 4.2: Differences in use by comfort level.

Comparison use Across Platforms Android app use was more complex and fostered higher user retention than the USSD app. There were 22 actions per user on Android (874 total) compared to 42 USSD inputs per USSD user who used the app at least once. Though this appears to indicate greater engagement on USSD, each USSD input confers less "valuable" information, with 6-8 actions needed before viewing the business screen; the Android homepage presents all businesses for the user to scroll through before any actions are taken (see Table 4.1). In addition, there was an average of 5 views of business detail screen actions per user (193 total) on Android compared to an average of 3 open business screen actions for USSD (1785 total). This suggests that Android users were keener to know more about the businesses they browsed through or had easier access to businesses, encouraging increased exploration.

Another significant difference between USSD and Android was in filter actions: Android had 462 browse actions (about 12 per user) compared to USSD's 0.2 browse by category or location actions (126 in total). Thus, filtering through businesses was substantially easier and more frequently done on Android. Likewise, Android had 85 text search actions (about 2 per user) compared to USSD, which had less than 0.5 text search actions per user (288 in total). Further, Android users returned to the app on an average of 2.65 different dates compared to each USSD users' 1.72 different dates, suggesting that the Android app may have been more helpful to its users.

4.5 Critical Insights

This study presents the design, development, and deployment of a dual-platform agricultural directory in 100 villages in Tanzania, containing a USSD component to serve basic phone users, and an Android app to serve smartphone users. For such an ICT to be successful at improving human outcomes, we need to be able to scale our services on mobile tools that people access and use comfortably. Our rigorous engineered USSD application, while broadly accessible to people in this region, is constrained by its linear interaction model, short session limits, and small character limits per screen, making it difficult for users to engage with increasing quantities of new information. Scaling to include information on 10,000 businesses for 1,014 users and over 239,000 interactions stretches USSD to capacity. In contrast, the Android application offers a more interactive and intuitive user experience, enabling people who choose to download it to access information new information more deeply and efficiently.

Chapter 5

Proposing & Piloting DFS Agents as Intermediators of eKichabi v2

5.1 Introduction

In the Global South, ICTs have the potential to promote inclusive and equitable access to information and services, particularly in areas where existing market structures leave significant gaps. However, research has shown that over time, ICT performance often falls short of expectations or fails to be sustained due to several factors, including limited access, infrastructural challenges, low digital and language literacy, cultural barriers, high costs, and inadequate training and support to help users navigate these systems effectively [AGB16]. As highlighted in Chapter 3, there is considerable variation in how comfortably individuals in rural Tanzania engage with mobile technologies. Additionally, Chapter 4 underscores a substantial disparity in the effectiveness of different technologies in providing meaningful access to essential information to Tanzanian farmers. In an attempt to bridge some of the aforementioned sociotechnical gaps, *intermediation*, or the use of technology with the help of a trusted, local agent, has shown promise in resource-constrained areas [SS10b, SCTN10]. For example, [KA15a] recognize youth as helpful intermediary to ASHAs (community health workers) using digital health tools in India; [MTS+19] find parents intermediating educational technology on behalf of children with the goal of improving their literacy; [OOTD19] discuss the intermediated learning of technology by formerly incarcerated individuals; and [WSF11] describe religious groups as intermediaries in Indonesia.

The proliferation digital financial services (DFSs) in rural SSA is another successful, widespread example of ICTs leveraging mobile money agents (or *wakala* in Swahili [1]) as intermediaries to bridge access and ability gaps [DB22, PR09, BCG+18, CCG+20]. Wakalas are typically local MSE owners who also convert physical cash to digital value and perform crucial technology tasks, such as on-boarding millions of customers onto DFS and supporting them with the subsequent use of mobile banking USSD and Android DFS tools.

The effectiveness of the wakalas led to their growth in strength to over 100,000 agents in Tanzania by 2021, with 60% of Tanzanian adults successfully enrolled and active on DFS. Despite this, competing business interests emerged between wakalas and DFS providers (DFSPs) who were vying to recruit as many agents as possible to deliver ubiquity and convenience to customers [EJ17]. Worryingly, most local agents work in a franchise-like model [ULPB19], with agents compensated based on reaching targets rather than by earning fixed salary. This lets the DFSPs increase labor without assuming the fixed cost associated with agent network expansion. Paradoxically, the better the wakala network got at enrolling new customers, the they needed to compete against each other for the increasingly limited numbers of new customers, heavily straining their incomes.

In addition, DFSPs are increasingly creating digital payment systems that enable the use of mobile money for various transactions, such as paying for meals or electricity bills. This declining cash activity means fewer opportunities for wakalas to earn commissions on DFS to

[1]We refer to the plural form of wakala as wakalas in the text for easy readability, although the correct term in Swahili is *mawakala* when referring to more than one wakala

cash transactions (or vice versa). Between 2012 and 2021, the amount cashed out from every dollar that was deposited into mobile money accounts dropped from 88 cents to 67 cents, and the mean monthly volume of cash withdrawals and deposits made by agents in sub-Saharan Africa declined from $11,700 in 2016 to $9,900 in 2021 [Bai22, Eco22]. Amidst increased competition and low profitability, wakalas are needing to compensate for the loss in their mobile money based revenue [GSM22, Emi19, Koc18].

In SSA, mobile tools are being designed to facilitate easy and fast access to information and services in urban and rural areas, e.g., digital platforms in agriculture grew through the framework of the GSMA mAgri tracker [MAG16], with projects including Tigo Kilimo (T-Kilimo) (operated by Tigo), Vodacom Kilimo (from Vodacom) and T-Hakiki (from Tanzania Telecommunications Corporations), which leverage USSD and SMS to provide critical knowledge about weather patterns, crop prices, and new agronomic techniques to small-scale farmers. Recently, the Tanzanian Ministry of Agriculture introduced Mobile Kilimo (M-Kilimo), an interactive mobile agriculture platform to improve communication between extension officers and farmers in rural areas. Extension officers, farmers, fishermen, breeders, and business people can meet on M-Kilimo, share information and advice on agronomic practices, and access input/output markets. Developers intended these innovations to increase farmers' access to market information and consequently improve farm productivity. Although these tools have not been evaluated publicly, the Tanzanian National Sample Census of Agriculture statistics show that access of ICT-based extension services have persistently remained low [oCGS21]. The percentage of households receiving extension service on crop production decreased from 67% (2007-2008) to 7% (2019-2020). Similar declines were observed for livestock keeping, where extension services received by households decreased from 55% (2007-2008) to 9.1% in (2019-2020) [oCGS21]. These precipitous declines raise questions about the interest in additional agricultural information, perceptions about phone capability to deliver said information to non-technical or illiterate users, and the ability of rural communities to trustfully use ICTs in East Africa [WDG15, AGB16].

This work explores the potential for the wakala network to extend their intermediation services to increase the utilization of emerging ICTs, such as our dual-platform technology in Chapter 4. We ask RQ1: Given the changes in the DFS ecosystem, what are current wakala intermediation practices in their communities? and RQ2: What key factors influence wakalas' interest and ability to intermediate for different ICTs that remain underutilized? To answer these questions, we conduct FGs with community members and wakalas across 5 villages in Kagera, Tanzania, exploring the intermediation offered; among our findings, we highlight the intricacies in defining who needs sustained support with both new and old ICTs, and challenges in how support & trust is enacted within different corporate incentive schemes. Finally, we run a small scale pilot study with wakalas across 5 villages intermediating our eKichabi with farmers that self-report low comfort using USSD technologies. Through this work, published in COMPASS '24, we contribute an in depth analysis of the opportunities and obstacles that accompany the potential expansion of the wakala human infrastructure to become general ICT intermediaries [RJMA23].

5.2 Related Work

Star and Ruhleder, in their seminal work on infrastructures [SR96], say:

> "What is infrastructure? Common metaphors present it as a substrate: something upon which something else "runs" or "operates: such as a system of railroad tracks upon which rail cars run. Infrastructure in this image is something built and maintained, sinking then into an invisible background. Such a metaphor is neither useful nor accurate. [...] We hold that infrastructure is fundamentally and always a relation, never a thing [...] and focusing on relations (e.g. between railroads, timetables, and management structures in bureaucracies) [...] reveals how choices and polities

embedded in systems become articulated components. Substrate becomes substance"

A key concept is ICTD and CSCW research is highlighting the contingent and continuous work of human actors in maintaining an infrastructure, whom Lee et al. and many others refer to *human infrastructure* [LDM06, SPVP22, SJ21, JPK12, DNKB19, AJMS14]. From identifying the role of Anganwadi workers in India [SPVP22] to trust in biometric infrastructures [Mas18], this body of work promotes the need for the ICTD researcher to prioritize both the technological *and* human systems that support the artifacts we observe. Infrastructures depend on multiple structures, embody standards, and invisibly support tasks becoming visible upon decay. [SR96, STA99a, KB18].

Particularly relevant to our research is the view of mobile money and other DFSs as infrastructures [GO20, KMMV11]. In a study of the expansion of DFS aimed at extending access to loan products, [GO20] describe the complex and seamless interaction of the wakala infrastructure and the loan repayment infrastructure, highlighting the indispensable human work that makes the provision of loan services possible [GO20]. Though research on DFSs has always recognized the importance of intermediaries in supporting financial inclusion ([Emi19, JN18, Koc18]), it has also consistently highlighted the precariousness of this model ([Koc18, CBA+16, JN18, ULPB19]). The model's viability and long-term sustainability is limited by (1) the nature of costs, (2) (reachable) population size, and (3) demand for intermediation [Nel72].

Here, we introduce two additional systems that leverage human infrastructures for intermediation, the District Health Information System (DHIS2) and Mobile Vaani, to demonstrate the highly complex interaction between a technology's market, the goals of its creators, and the social and financial incentives that shape the infrastructures of intermediaries.

DHIS2 is a prominent open-source Health Management Information System used by national health information systems in LMICs for data management, health program monitoring, logistics management, and disease surveillance and reporting [BS21]. It has roots in action research by

HISP, a collaborative program involving the University of Cape Town, the University of Western Cape and a Norwegian researcher, that aimed to address the information management challenges of the fragmented healthcare system in post-apartheid South Africa. At the heart of DHIS2 growth is its supporting community, which includes the HISP global network of users, developers, funders, and researchers that use DHIS2. As the project grew, it sought to "engage students from both the health and informatics disciplines in a collaborative way in the development of health information systems in their own countries" [CFN+17]. Today, DHIS2 makes continual and concerted efforts to build its global community of users and intermediators through the DHIS2 Academy, which has built its' human infrastructure (of 6,000 experts) through a combination of online courses and in-person training, which promise to create a ready-to-go, directly compensated (non-volunteer) DHIS2 expert consultant who can leverage the model to support any organization.

Mobile Vaani is a community media platform based on interactive voice response (IVR) that was created by the Indian social enterprise Gram Vaani (GV) with the goal of "empowering poor and marginalized community to create their own local media" [MKS18]. It was then popularized in different regions by its volunteer intermediators or *community mobilizers*. In 2015, GV began to introduce financial incentives to its community mobilizers to reward them for their mobilization activities (i.e., the number of users they recruited to the platform). In tandem, GV launched a referral system to track new user acquisition instead of relying purely on self-reported data. However, this structure faced significant problems due to misreporting, an abuse observed in Mobile Vaani's recall metrics [2], which dropped from 25% to 5% [MKS18]. "The referral system was therefore discontinued, but it led to anger and resentment of honest volunteers who were making legitimate referrals and (importantly) had begun to rely on the additional income for their livelihoods" [MKS18]. After a failed attempt to design a financial incentive mechanism for volunteers, the GV team realized that "managing a large team of community mobilizers, dispersed

[2] These recall metrics captured the percentage of referred users that called into Mobile Vaani.

in remote pockets and motivated by different incentives, was a far more complex challenge than developing the technology itself! Volunteer selection criteria, internal accountability through measurable indicators, and group dynamics resilient to social conflicts were all important aspects that needed fixing" [MKS18]. Eventually, GV changed the organizational structure of Mobile Vaani from a state-level platform to a smaller federated platform managed by a tiered *volunteer club* working based on a new financial incentive structure: a *group* incentive tied to volunteer club performance that was shared among club volunteers; an *individual* incentive based on each volunteer's contributions; and a *self-reported individual* incentive based on the number of community workshops that a volunteer conducted. Further, the volunteer selection process became more rigorous, requiring at least three months of effort in supporting Mobile Vaani before a user could graduate into a role. [Set22] believe that this combination of group and individual incentives has allowed GV to manage the trade-off between social and monetary incentives and ensured that altruism was not deprioritized by lucrative tasks.

Both of these infrastructures of intermediation elicit the following observations: First, intermediation tends to be a highly specialized activity attuned to community needs, a technology's complexity, and the intermediary's 'elasticity,' i.e., responsiveness to both financial compensation and their expected workload. Second, successfully intermediating a technology at scale, especially if the technology's users are geographically dispersed, requires significant investment in human resources management. Third, even with open-source software and open specifications, no two technologies are alike: two forks of technologies created by the same organization can lead to significant development and management overhead that requires more intermediation to coordinate. In such cases, trade-offs must be made between complex, feature-rich technologies that require significant expertise to intermediate and simple, highly standardized applications with a potentially lower technical barrier to entry.

Despite the importance of intermediaries in ICT delivery and uptake, government systems and literature have explored moving beyond agents to create sustainable ICTs. [RSN+22] find that "dishonest and unfair intermediaries" were "a hindering factor for the slow acceptance of financial systems in the context of Bangladesh," and the Aadhar framework in India was standardized to minimize the role of intermediaries and thus limit corruption in the last mile delivery of government services [SJ21]. Our work adds nuance by uncovering how intermediary incentives could change given different market structures, how technical systems could be strengthened to afford intermediaries and community members a more robust ICT ecosystem, and how Tanzanian intermediaries' skills and trust relationships could be scaled and translated to promote adoption of ICTs beyond DFS.

5.3 Focus Groups Findings & Themes

For our focus groups (FGs) held between October and November 2022, we employed local enumerators to run 12 FGs in Swahili, encouraging them to amplify the voices of women and the elderly, and offered compensation and beverages to all participants. In total, enumerators held FGs with 70 people: 5 FGs that included *30 community members* and 7 FGs that included *40 wakalas* from 5 villages. Wakala sampling within each village was conducted by a local guide who introduced us to wakalas, making sure to select some from the center or main road as well as some from internal areas. HHs were sampled systematically with the help of local enumerators, who walked through the village, visited one HH, and skipped six others before arriving at the next HH to screen, a sampling strategy we believe to be uncorrelated with underlying structural characteristics of the villages. When arriving at a HH, the enumerator screened the head of the household by asking their age and if the HH had a working cell phone. Table 5.1 presents details about our FG samples.

Our FGs with community members centered on questions about comfort and interest in using USSD, experiences with intermediation, and discussions on future intermediation modalities. Each

FG began by soliciting examples of ICTs ato ensure a common understanding of terms. In our FGs with wakalas, we presented the following hypothetical about new ICTs being introduced in a community: *Imagine that a government/institution asks you to teach community members how to use a specific new system of mobile technology and encourage them to use it, just as you are now doing for DFSPs. Please share whether you would be interested in participating in this work. How can we design this new modality together?* FG questions also addressed how wakalas run their business, the training and organization infrastructure that supports them, and discussions on future intermediation modalities. All FGs were transcribed and translated into English by two Tanzanian enumerators with a combined 30 years of research and translation experience. I analyzed FG transcripts and developed a codebook both inductively and deductively and analyzed quantitative data using Python. To preserve the privacy of FG participants, we use **W#** (e.g., W10) to refer to specific wakalas and **C#** (e.g., C12) to refer to specific community members in the remainder of this paper.

Village	Wakala Headcount	Household (HH) Headcount
Rwagati	4	7
Kanazi	6	5, 6
Izigo	9	6
Ngadi	5, 4	-
Bunazi	5, 7	6
Total	40	30

Table 5.1: Focus group participation by village and role.

Below, we describe four types of relationships extracted from themes we generated during our FG iterative coding: *community and technology relationship* (community interest in ICTs and who needs intermediation to access them), *community and non-wakala intermediary relationship* (alternate intermediaries the community uses), *community and wakala relationship* (how intermediation occurs and the change in trust dynamics given organizational policies), and *wakala and organizational relationship* (challenges to human infrastructure stability). Finally, we address how the community and wakalas envision intermediation if it were structured to serve all involved parties more equitably. All wakala FGs mixed freelance and mobile money wakalas (explained further below).

Community and Technology Relationship.

Generally, participants related their belief that *technology had the power to make their lives easier once they understood how to use it*, and the vast majority demonstrated an interest in ICTs. For example, C22 mentions, "If it's late and you want to buy electricity credit and shops are closed but you have money in your phone, you can just buy it right there at home with LUKU, and the electricity will stay on." C16 notes that "M-Pesa saves the time of walking towards a bank or anything; you can just do it right where you are. I really enjoy it." Even those who did not actively use digital technology acknowledged that it has changed the landscape of Kagera. When asked what technologies they were using, FG respondents mentioned *few services other than the most common* DFS (M-Pesa, Tigo Pesa, Airtel Money) *and mobile payment* services such as LUKU. Figure 5.1 shows common manifestations of DFS technologies seen during fieldwork. One FG member, C13, knew of USSD codes for microfinance banking companies that provided solar equipment loans. C30 notes that awareness of ICTs distributed by the government was limited: "Most people know about Facebook and WhatsApp, but when you talk about other services, they don't know them."

Learning to use new technologies and ICTs came to community members with time and many participants mentioned *teaching themselves how to interact with new technology*. For example, C6 states: "Those days, new phones were given with a manual, so I learned most of the operations through that." This approach was shared regarding learning and use of new technology: C16

Figure 5.1: Images captured during fieldwork. **Panel A** shows a cafe advertising Tigo wakala services, and **Panel B** shows an M-Pesa poster with fees associated with different DFS transactions.

stated that “Yes, I can [use new ICTs]; with a clear understanding of the previous systems, new systems can’t be a problem," and C15 noted that “Recently, I have gained experience with this service compared to the past, so with a new system, I will continue to learn it a little bit step by step.” However, others mentioned that the lack of ICT ’training wheels’ provided hindered their ability to adopt them; per C9: "Buying airtime is challenging; there isn’t enough information concerning the services.”

We asked if there were salient characteristics of community members who often seek intermediation: wakalas characterized people requiring intermediation by first mentioning *gender*; male and female wakalas both stated that more women came to them for help. Some perceived this as an innate difference in capacity, as W14 notes: "Women are carrying a lot of problems in their head nowadays, so it’s easy for them to mix or forget even the simple process of withdrawing the cash from their phones. Men’s heads are quick at adopting and managing things.” Some participants externalized the gender gap as a result of the technology itself; for example, W5 states: “100%

of the things that are in this phone favor men and not women.... it doesn't make sense for a grown woman like me to be playing with my phone, but most men do that." Further, per W6: "Women spend their day doing household chores, so they don't have time for that." However, many FG members mentioned that educated women were likely to be able to use technology without assistance. *Age* was another factor common in those who sought help. Per W24: "Youth who do not have enough knowledge on how to operate their phones. We still have youth who cannot read and write, too." This was underscored in the quantitative findings (see Chapter 3), which showed variance in the correlation between age and comfort using USSD technology. However, adults often rely on their children to ask questions and get things done on their behalf. As W38 notes: "They send kids to us with a memo of instruction." Older people with lower vision were cited as often being unable to access technologies on their phone without help. Similarly, populations with *lower literacy* were characterized as needing intermediation. Relatedly, an understanding of Swahili or English alone was not always sufficient. Per W4, "What I know is a person may be educated and know English, but the language used in the phones can be a challenge for him/her to understand." Rural areas with differing dialects posed another challenge, as W20 reports: "Yes, because we have a lot of foreigners in this area, so most of them can't use our services, so they come to us for help." Overall, *there is consensus among wakalas and community members that a lack of agency or understanding is not limited to one type of person; diverse people request help with different aspects of technology.* Per W27: "Yes, regardless of age, gender, occupation and financial status when it comes to helping others because people of all kinds may have problems using phones." Community FGs underscored this heterogeneity, with self assessments of the ability to use M-Pesa and similar common USSD applications by oneself ranging from 20-70%.

A minority of community members felt complete agency towards using technology, and the remaining state that they require help from time to time when using their phones. Some respondents opted out of tech even with intermediation due to their lack of understanding; e.g., C23 shares: "I asked for help when I didn't have my own phone, but now I have it, but still I don't ask for help because I don't use my phone often firstly...because I don't have much use for it and secondly I don't have a lot of knowledge about it." However, interaction with new technology was sufficiently daunting for some who could potentially benefit from it to avoid using it; per C14: "I have never asked for such help [...], and I don't use a smartphone either because it has a lot of things hard for me to take unlike a normal button phone" and W10: "There are others [community members] who are just afraid to withdraw money on their own."

Some peoples' lack of agency in using the technology is due to*infrastructure limitations* rather than difficulty in understanding the technology itself. C6 states that: "There are challenges, especially during a bad network; you may buy credit several times without response, and when things are back again, you find that you have purchased triple times." C23 notes: "While I am in the middle of the services, the codes are stuck, then it becomes very hard for me to get the service. They are completely stuck, even if you want to withdraw or to send money from your phone, you can't." This shows that exogenous infrastructural factors beyond challenges with individuals' relationship with ICTs continue to fuel the need for intermediation.

Community and Non-Wakala Intermediary Relationship.

Because there is often no training and coaching, community members seek help from a variety of human relationships. We next review their use of friends and family, customer service hotlines, and government officials.

Friends and family members are the first point of contact for many who experience trouble with ICTs. All FG participants mentioned at least one such trusted individual assisting them. For example, C23 states that: "My child wanted to go to the university, so I asked my neighbor for help, and he use (sic) his phone to search for the joining instruction form in that university website." C31 reports, "When I bought my first phone, my brother taught me how to use a phone in general, such as how to write and send messages and to make phone calls, serving contacts, looking for contact and so on." However, the intermediation that such others could provide was constrained by the ICT's complexity.

Many reached out to *customer service hotlines* for help, which was effective at times when family fell short. As C6 notes: "For example, [with] Vodacom you dial 100, then you get help, like reversing a wrong transaction or in case you have blocked a sim card." However, talking to someone over the phone had its own limitations. Per C15: "Understanding customer service is around 50% because talking to some[one] on phone differs from face to face talk; you cannot see who you are talking to, and always they have faster conversation than what I prepare myself to respond to." The existence of customer service and telephone-based feedback also opens doors for scams under the guise of technology intermediation. Per C13: "...sometimes you may receive a call from someone pretending to be M-Pesa customer care (or any network agent) giving...false news about winning a prize for your excellence on using M-Pesa or topping up credit, but for you to receive your prize he asks you to carry out several procedures and change your M-Pesa language from Swahili to English. You end up sending him money. So the thing is if your phone operations are set in Swahili and someone [asks you about] changing to English means he/she wants you to press the buttons without knowing what you are doing."

Although the *Village Extension Officer* (VEO) and their team are trusted and educated members of the community, most community members felt like they could not ask them for technology-related help. In one FG, everyone burst into laughter when asked if this was a feasible option. When asked about their laughter, C26 responded that it was "because the work of VEO is very different, so in terms of phones, he absolutely can't help us." When asked who had tried to get help from local government officials about his/her phone, all respondents said "No one." *Only in cases of ICT-based fraud was it deemed acceptable to contact government officials* for help with technology. Per C6: "I can go [to the VEO] if I pick up a phone somewhere to surrender it to him, or if I have received any threat through the phone." C2 notes that "Personally, I cannot ask a ward executive for any help on the phone, whether mechanical or operationally, because a ward executive is not there for such tasks; maybe in case of lost or theft of phone you can seek their help. But issues like how to access a certain service on the phone and so on, I can't personally involve them." Notably, trust in the VEO extended to trust in the agents that they recommended; C25 notes: "I think... using VEO will also help us to know that the agents can be trusted. It will prevent the issue of illegal SIM card registration." We were told of only one successful instance of someone soliciting ICT-related help from government officials. C19 volunteers that: "Yes, there was information I was looking for about a certain university, so I went to the government office, and the officer helped me to write certain codes, and the information I was looking for appears (sic)."

Wakala and Community Relationship.

In every village we visited, wakalas were a necessary cog in the finance networks. C22 shares that "You can't put money in your phone without the help of an agent; maybe in case the money is already in my phone and I want to send it to someone else that I can do without going to the agent, but if I have them in cash without the agent, I can't send them." Hence, all people in the village visit wakalas, even if not for intermediation services.

FG participants described two main types of wakalas, each serving a different role: (1) *mobile money agents*, and (2) *freelance SIM card registration personnel*. Per C11: "The difference is the [mobile money] agents have an office, but the ones who register SIM cards are freelancer agents who move from one place to another." Mobile money agents are paid a commission when they conduct mobile finance transactions on behalf of customers, and freelancers are paid upon reaching targets of selling mobile cards, vouchers, etc.

For many respondents, agents are the main, if not only, intermediary for technology. C30 notes that "I have never asked for help from anyone else except the agent," while C11 states that "I went to the agent because he is the one who knows about phones." When asked why friends and family members could not help, C11 remarked that "even they ask help from the agent." For those needing intermediation who do not visit wakalas, the issue is often accessibility. Per C25: "[I do not go to the agents] because the place that I live in I can't access the agent easily."

For most FG respondents, *wakalas introduce new ICTs or features of existing services (to reduce learning challenges).* C24 notes: "I asked one agent to help [me] take a loan from M-pawa services. But I asked him to lend me money, but he helped me get a loan from my own phone." Wakalas help community members interact with new technology in many ways, including: unlocking phones, troubleshooting network services, sending and receiving money, onboarding to new USSD services, enrolling and troubleshooting on social media, placing bets, fixing internet connections, using calculators, searching for prices, searching google for solutions to problems and fixing them using the phone. Community members report that wakalas also commonly help them block unwanted callers, check a USSD code for a national identification number, retrieve their passwords, unlock their phones, make online payments, open Gmail accounts, download WhatsApp, and access mobile bank services, such as checking their mPesa balance.

We found *confusion about free vs paid services that wakalas provide.* Some FG participants report avoiding wakalas due to fear of charges. However, many agree that wakalas offer several free or inexpensive intermediation services. Per C24: "I was registered for a different service on my phone that I used to use, but I forgot the codes of those services; ... the agent helped resolve that without even asking me for money." C18 notes: "I first went to an agent to ask about pay by M-Pesa service because I heard that there was a means of cashing out money with small deductions."

However, *from the wakalas' perspective, offering free help can interfere with getting paid for work-related tasks.* W31 shares: "There are services that customers have to pay for, like swapping phone numbers, but when you told a customer payments are required, he or she doesn't understand." Wakala FG participants noted that most of the "free" tasks they perform could be done by community members themselves. Per W4: "When a person accidentally changes his/her profile without him/her knowing what to do, he/she will come and ask me while it was something he could do by him/herself. Or a customer may have a phone that can use two SIM cards, but he wouldn't know how to block one SIM card in order to use the other, so he would came (sic) to me for help."

Wakalas negotiate rates and charge people at different rates for those tasks that may not have an established cost since this keeps people coming to them. Per W28: "Most of people whom we help without care about their financial status are older and disabled people." W21 notes that "Phone setting most of the time I do it for free, but when the work takes longer than expected, I charge for it." W34 adds that "The only free service I provide to the customer is helping with the air time, but other services, like Personal Unlocking Key (PUK) issues and resetting passwords, we negotiate."

In general, *even those with a solid understanding of technology visit wakalas for help with higher order problems.* Per C19: "[If] I think that's something that can't be avoidable in terms of mobile network, I might go twice a month, and at those time I might have ruined something in the system, so I will have no choice but to go to the agent. When asked if he went to the agent only to fix things and not to send/withdraw money, for example, C19 replied: "Those are the things I can do myself through the phone."

How Help Happens. How intermediation occurs between the wakala and community members involves several decisions on the wakalas' part. *Intermediation occurs either on the user's or wakala's phone*, through teaching the customer, or by acting on the customer's behalf. For example, per C23: "[The wakala] didn't teach me, but he helped me." Acting on behalf of the customer meant that several community members had no idea what the wakalas were doing with their phones, as C26 notes: "He just asked me if I have the card. I showed it to him. I don't know where he clicked, and suddenly my phone was working." C6 adds that "When he returned my phone, I found my SIM card unlocked. So I can't explain what exactly happened." Wakalas report that *they decide whom to teach vs on whose behalf to work*. Per wakala W13: "It always depends on looking at the age and appearance of a person. I can decide to assist the person directly by taking his/her phone, or I can direct him or her on what should be done." W33 shares that "If they don't know how to read or write, teaching them won't help." Some wakalas prefer to err on the side of teaching, as W17 reports: "If that person is somehow knowledgeable, I always assist them directly from their phones, or otherwise I am always fixing problems by myself." W32 adds that "The services that doesn't (sic) require a customer to use agents work I normally teach them so that next time when it happened (sic), the customer will be able to solve without my help, and also it gives them a chance to help other people who will be facing that same problem in the future."

Customers are also sensitive to being taught or having tasks performed for them. As C21 observes: "...I was the one holding [my phone]; he only directed me so that in upcoming days, I would be able to do it by myself. And I wrote it down so that when I need it one day, I don't have to bother him anymore." W24, an agent, notes that "I normally position myself closer to the customer so he/she will also see what I am doing, and in case...any question needed to [be] asked, he/she will be able to answer it," while some leave it up to the customer. Per W14: "It's the decision of the customer; some are interested in knowing, and others do not care; as long as the problem is solved, it's okay with them."

Trust. We next examine trust dynamics between customers and wakalas through their positive and negative experiences seeking intermediation. We start with those community members who mention fully trusting mobile money wakalas. Per C16: "I have never heard of someone complaining about them, and personally I have always got what I wanted from them; ....mostly they give us a simple and cost effective way of cashing out or sending money, like pay by M-Pesa."

This *trust might be enhanced by the wakalas' role in providing small or micro loans to community members, whereby they share some risk.* Per C23: "I only trust those MPESA agents where I can ask them for some cash, let (sic) say 20,000/=, they lend it to me, then the next day I return it to them." Such shared risk extends beyond established agent/customer relationships. C19 notes: "I went to a certain MPESA agent shop, and I asked him to lend me some cash so that I can pay certain people who were waiting for me, but he asked how can I lend you money while we don't know each other. How will I get it back? But I told him you just give me your number and the money will be sent to you; so he gave me the cash. He gave me 25,000/= I made payment to those people, and I sent his number to a person who sent him money." *Bidirectional trust* is an established mechanism for daily transactions. Per C16: "I also had help from one agent for my kid's school fees; I went to pay for school fees with insufficient amount, but an agent lent me some, and I repaid the next day." Occasionally, trust arises from helping community members purchase an item from their shop. As C6 relates: "When we don't have enough amount to cover the cost of buying a phone from them, they can accept partial payment and allow you to bring the remaining on the other day you agreed with, but only if you are closely related."

From the wakalas' perspective, it is challenging to do business without providing loans or supplementary, free intermediation. Per Jaston: "I offer loan[s] to the customer I trust because sometimes it is hard to do business without offering a loan to about 60% of customers; but they pay it back at the end of the month after they receive their salaries, and some other customer may not pay it back. That is very challenging." This demonstrates the material risks that wakalas assume. However, *negative experiences in these relationships demonstrates the fragility of trust.* For example, customers use their national ID number to register for SIM cards and get initial phone-related support, and freelance wakalas walk around the village to service those who are not serviced by stationary wakalas in the town. However, mistrust arises because freelancers have been known to reuse their customers' national id numbers several times and therefore sign a single customer up with multiple phone numbers rather than the single one that they requested. Per C24: "What I am suggesting is, like 70% of these agents can't be trusted. They are hungry for money, and it's the hardship of life."

Some wakalas mention that this practice might be due to company-designed pay and incentive structures (discussed below), which often conflict with goals of establishing consumer trust. Per C26: "Sometimes, you may be called by an unknown number and told to send money to that number, but you don't know that person at all." C25 adds: "...multiple SIM cards can be registered [to your national id number] without you knowing," and C21 states that: "You may have lost your phone and all your registered SIM cards, but when you go to them and tell them I want a registered SIM card, they will give you one without even using your national ID number to register it." In these cases, freelance wakalas often cannot be tracked down due to their constant mobility. Per C12: "Because these [freelancers] have no permanent office, you can go to raise your claim against them, but they are confident to do anything unlike other agents with a physical shop." This feeling is echoed by freelance wakalas themselves, who face the negative consequences of loss of customer trust; per W29, "I am always moving from one market to another trying to find customers. There is a group of people using this opportunity improperly, so it's hard now getting a customer." Such lack of trust has led to violence against wakalas in some areas, as W9 states: "There are others who are not trustworthy; for instance, we went to a certain place wearing M-Pawa t-shirts; the people of that place almost beat us up because there were some other freelance wakalas who stole from them. But we explained ourselves until they understood us."

The relationship of intermediation is one where trust is necessary due to the sensitive nature of the transactions and information that wakalas glean from customers. Per C24: "If someone wants to withdraw money from an agent, they can do all the process by himself near the wakala. But if the person can't write or read, then the wakala will ask that person for some information, like what is your password and the amount you want to withdraw, etc." Further, the lack of understanding surrounding passwords causes some customers to inappropriately disclose their information; per W18: "75% of customers can't create their own password. You help him create the password, and later on you teach him how to create one himself so that he can change it. So is it possible they allow you to create a password for them not because they trust you, but just because they don't know how to do."

This was echoed several times by community members. It is clear how *passwords could be misused* by wakalas, but *their customers' naivete can lead to negative consequences for the wakalas,* as well. Per W33: "What I do to make sure that I continue to maintain the trust I have built is to not help customers with password issues unless that customer is my loyal customer whom I know for sure doesn't get service from other agents, and he or she is old or can't see; but for every other customer, I don't do that because that has caused countless problems, and it may lead...the trust you have built to die." The inability to see who is misusing a password may thus lead to a loss of trust and therefore of customers.

It is evident that customer trust in wakalas is therefore directly linked to wakala livelihood. *Wakalas use proxies to measure customers' trust and loyalty in order to ascertain how well they are doing* in a given month. Per W25: "I know that a customer trusts me when they call me and ask me about other services [I offer] and if there is any change he should be aware of." W39 adds that he knows he is trusted "because some of them [customers] leave their money with me so that I could send it to them when I have credit in my phone." Many wakalas report that customers form loyalties with one wakala in the area; W35 states that "They are loyal to me; when I am not around, they will wait until I return to get services."

How the wakalas foster trust varies. However, each employs intermediation strategies to keep customers coming back for paid services. *Some wakalas follow up with customers;* W27 notes: "I normally take my customers' number so after a month I call them, and they are still using the same SIM card I sold to him; so that gave me the sense that my customer trusts me." *Others rely on* *their uniforms, proximity to customers and working daily in the same places* as a means to maintain customer loyalty. Some offer *financial discounts,* like W35: "[I] sometimes provide the services with a discount price" in order to gain customers. Some cite a *common language* as a means to reach customers who may not otherwise enter the system; W9 notes: "The language I use to communicate with them helps them trust me."

The Wakala Infrastructure.

Wakalas work within a complex infrastructure that includes their mobile network operators (MNOs). We next describe their experiences becoming and serving as intermediaries.

Training experiences to prepare themselves to become intermediaries varied greatly. *Formal training was through seminars,* as W17 notes: "These companies have been providing different seminars on how to provide this service. But those seminars are very few. I don't even remember the last time I attended." They also learn through *shadowing an existing employee.* Per W33: "Before, it wasn't easy to get this job. You needed to be at least a form four graduate every time we went to the field so that he could teach me how to work." Agents also reported *learning their trade through phone conversations*, as W20 notes: "Through phone calls and sometimes face to face when I failed to understand some things." Informal training was more common since some wakalas acted on behalf of their employers, who owned the kiosk and were formally registered. Per W35: "I taught myself; I observed how others worked." W5 shares: "I was taught by my daughter; she taught me how to send and withdraw money." W4 adds: "My boss taught me."

As with any technology, all ICTs that the wakalas intermediate for change from time to time, sometimes without clear notice given to wakalas or community members. *Many wakalas expressed challenges in informing customers of these ICT changes due to the lack of communication from the MNOs to the customers.* This impacts customer trust in their services. For example, per W13: "When one customer tells others that I am reducing their money, then they stop coming to my shop. This is due to lack of education on the withdrawal costs introduced by the government. These telecommunication companies like Vodacom or Tigo can solve this problem by providing education." W11 adds: "Media advertisement...on increase of charges done by the government should start as soon as the day the announcement is given out."

In addition to straining trust relationships, the increase in charges also directly impacts a wakala's ability to solicit new customers. Per W9: "The more charges there are, the less likely a customer is to come to the agent for support." In the same vein, as wakalas are the face of the technology to the community, if the technology fails, some blame the wakala. W24 notes that: "I may send money to the customer, and he doesn't check if the money is in his account; then, after two to three days, he returns to me and said I didn't see the money. I will then have to call the headquarter to ask for that money, but the charges of sending that money to the customer account will be deducted from my pay."

Further, there is *a lack of education regarding the ecosystem of scam messages* and how to differentiate real from fake messages sent by the MNO. For example, per W32: "Sometimes, a customer can receive a scam message that shows him or her that he or she received money and asks you to help him or her to withdraw the money, but when you try to do that you find out he or she doesn't have money in the account; so when you told him..., it is hard for him to understand what is a scam; ... it once caused a customer to report an agent to the police station." To our participants' knowledge, there is little support for ICT-related fraud via police or other authorities. W11 notes that "There are many thieves with new techniques, and when reported to the police, it can even take you seven months making follow-up on the same matter; we are losing our money." W23 adds: "When I register a customer SIM card, and another agent unregister[s] it, it's very challenging," as this registration would fail to count towards his quota.

Given economic vulnerabilities due to scams and unethical practices, *wakala compensation is low, especially for freelancers.* Per W33: "You may walk a long distance to find a customer, but still payments are very low." For those using transport to reach more distant customers, agents mention that this consumes a significant portion of their earnings. Per W27: "The day of payment, he or she will just be paid the amount he took from his own pocket."

Compensation for freelancers occurs after they achieve their MSN-derived targets; therefore, financial insecurity is high until they reach that goal. For mobile money agents working for more than one MNO in our groups, the salary was about TSh 200,000-400,000/month (USD100 - 200) for working 50 hours a week. Further, wakalas are not compensated for many forms of intermediation they provide to retain customers; though this is really a form of advocacy for their MNOs, they do not receive the same level of support in return.

Some wakalas *use systems to give feedback to their employers* about challenges they or their community members face in using their technology. Some simply *call customer service lines for their company*, like W19: "Yes, we have numbers for reaching out [to] customer cares in case of any problem." Some *call or visit their superiors*, and a select few have morning meetings before starting work to talk with employers about the challenges they faced the day before. One agent mentioned that they use *a WhatsApp group* to communicate feedback to employers. While some believe their feedback makes a difference to the technology, like W18 ("Yes, because I believe challenges reported to my bosses are being shared to the top management and lastly to the government."), *the vast majority know of no mechanism to give feedback to their employers.* As W21 remarks, "Personally, there is no system for me to give feedback."

We asked wakalas and community members to share their perspectives on how they envision changes to intermediation if the government were interested in providing community-based support for new ICTs. All community members agreed on the need to *increase intermediation support* to improve access to digital tools, even if they manage to use technology by themselves. Per C24: "Few of us manage to do it alone, but the Government started the adult school; they can also start something like that which will be able to educate people on phones." Per C5: "People to train us are important because we differ in terms of understanding and of understanding each other, but having specific agents where you can direct people for better understanding sounds good." Per C15: "I will be happy if they come to teach us because there are things I don't know. To me, I think the availability of the people to train us will be able to learn a lot of things at a time. Let people come to train us and also keep instruction in the system itself." Some felt that having *more mobile agents* (freelancers) would help reach remote areas where understanding and use of services is low. Per C8: "I think having an agent will be helpful, especially the freelancer ones because they will be able to reach even the people who won't be able to go to town and get help. To understand something, people must be there to guide us. When you send a child to school, a teacher should be there to teach a kid to understand, so there should be people to teach us a new system, too."

We asked wakalas how likely they were to stay in their current role. Some mentioned not staying for more than a year; per W28: "I personally don't see myself staying longer in this job. There are a lot of challenges. We don't have contracts, so we are being paid less but you have worked hard." W32 adds: "Right now if I get a better job, I won't do this anymore." Some described how they supplement their wakala job income with other work due to a lack of customers; per W5: "We aren't that busy. It gives us time to do other things; apart from the agents' work, there is agriculture." The level of job stability agents felt is influenced by several factors. W4 notes that "It depends on *the area you are working at*," while W3 observes that "It depends on the *customers you have at the moment*." Only a few agreed that they are likely to stay in the role for another 5 years. However, most shared that they would be interested in participating in additional work similar to that they already do, with the following caveats: (1) *better compensation* (W3: "...I shouldn't do [more intermediation] if there is no profit in it."), (2) *localization* (W21: "If I can work from my office, it won't be a problem."), (3) *time* (W39: "It depends on if it will contradict my working hours or not. I don't want any confusion to arise between my current work and that."), and

(4) *new customers* (W7: "This has became a district, and population is increasing so [additional responsibilities re intermediation] will be an opportunity to get customers.") However, some wakalas mentioned that they are too busy to take on additional work beyond their current jobs; per W37: "Based on what I am doing, I can't add something else to it because it needs attention. Even if I will be at home, my work continues because customers come to me."

If they were to disseminate new ICTs, agents would like to see a number of changes made. First, they thought there should be a *robust channel of communication to customers directly from ICT creators* to prevent them from being the only face of the technology and risking loss of trust when tech updates were made. Per W1: "People need education on the charges they should expect and how the technology should function. [ICT creators] can provide seminars, advertise in different media." In tandem with this was the *design of safeguards in the technology* to support intermediation activities; per W10, "Introduce a special application which will be used on correcting all challenges and other information." From both wakala and community perspectives, the need to couple intermediation with the *availability of easy instructions in the app or online* was raised. C9 noted: "I prefer the agents to be available, but I would also advise that instruction of that service should be available in Google because now the number of people using smartphones is larger." Wakalas also suggested a *customer service line* that could operate when they were not available.

Most wakalas prefer a *hybrid training model* if they were to be taught how to use new ICTs, i.e., a combination of in-person training and online support. Solely online training was not the preference of several wakalas, who noted that it is difficult to understand and follow instructions without a person who can clarify questions. Further, they recommended creating *WhatsApp groups for follow-up after training ends* in case they encounter problems. They also recommended *compensating for transport* to/from training. At a higher level, they insisted on *involving the community from the start.* Per W26: "I think it will be good to make an announcement in the community that certain agents will be providing certain services before we start talking to the community people." To this end, *allying with the government* was suggested during training and beyond, as W27 shares: "While providing the training, we should be with government officers so that when the training is over and we start to talk to people in the community,... government officers will be able to identify us." This was part of how wakalas wanted to foster and maintain community trust.

In addition to intermediating for existing ICT users, wakalas shared that they could *promote new ICTs to customers that seemed likely to benefit from them.* This was already part of their current work; as W14 mentions, "Yes, I do always tell customers about the availability of useful programs found in their phones." Agents seemed to conduct such promotions especially when new features favor customers financially, even if that means that customers are less likely to come to them for subsequent transactions with physical cash. For example, per W25: "I encourage them to use mobile payment systems like buying LUKU and paying different bills through [the] phone if they are not doing so." W4 adds: "I encourage the customer to use [a] new system when that system happens to be cheaper than the previous one." Sometimes, new product promotion occurred at the will of the company. W33 notes that "We only emphasize [promotions to] customers based on what we have been told by the upper authority. Right now, our main emphasis is to tell customers about the shift from 4G to 5G Vodacom network."

We asked wakalas about *compensation* for intermediating new ICTs. Two prominent models emerged based on their work experiences. The first was a *commission-based method* through which they would be paid for meeting targets or based on their level of engagement. Per W40: "I would like to be paid according to my work performance." For this method, agents would want to be told how much they had accrued in terms of salary at the end of every work day. The second was a *fixed monthly payment*; per W35: "I prefer contract payment because it gives you an assurance of being paid compared to commission." In addition to monetary preferences, agents also requested *phones, company identification, and uniforms.* Overall, wakalas felt that their jobs would be easier if the surrounding tech infrastructure were strengthened. W35 observes that "[The] main challenge is [the] network. Some customers may need a certain service but at a time the network won't be working." They requested that the *technology infrastructure be improved* to incent them to conduct further intermediation.

5.4 Intermediation Pilot

Our small scale pilot study aimed to assess the utility of wakala-led intermediation in promoting eKichabi acceptance and use in low-comfort users (see Chapter 3 for more demographics associated with this user type). Between December 2022 and January 2023, we located and enrolled ten wakalas and thirty one pilot HHs (pHHs) in five randomly sampled villages in Kagera. pHHs in each village were chosen through random walks and were screened by asking about their comfort with USSD. Those who responded as being *very comfortable* with USSD were excluded, and those remaining were included. The protocol for the pilot began with an enumerator individually training each pHH and wakala on the USSD app. The same protocol was used as in the larger deployment described Chapter 4. In addition, the pHHs were told that they could contact wakala who would help them use the USSD app if they were interested. The wakalas were given phone numbers of the pHHs under their purview. They were asked to text the pHHs once to offer help and send a reminder text sometime over the subsequent 3 weeks. Wakalas were asked to keep count of people who asked for help, and what kind of help was asked for. They were compensated at their average pay for an estimated 2 hours of work per week across 4 weeks, amounting to 10,000 Tsh (4 USD) per wakala for the duration of the pilot. Following the one-month pilot, we conducted an endline phone survey with wakalas and participants, which included quantitative and qualitative feedback on the experience. We inductively coded qualitative feedback in Atlas.ti. The codebook contained the following codes: interaction with wakalas, interaction with community members, trust, benefits of intermediation and challenges with intermediation. We used Python to analyze quantitative responses. Further, we compared usage logs between wakala-intermediated pHHs and HHs in the larger deployment described in Chapter 4 that were similarly (un)comfortable with USSD to identify differences in use with and without intermediation.

Wakala adherence to offering their intermediation to pHHs by sending the first text was high at 90%, but this number dropped to 50% for sending the reminder text. Despite lower adherence to the second text, 54% of pHHs asked for help, with 27% of the pHHs meeting wakalas in person for assistance, 18% speaking to wakalas via phone, and 9.1% using text messages. Of the pHHs that did not reach out to wakalas for help, some said they could use the app on their own and some tried by themselves so that they could learn without others' help. Those that reported needing help were not from one demographic, i.e., both young/old women and men accepted wakalas' help in using the app. Seventy percent of the wakalas were asked to clarify how to use the app or for more information regarding its trustworthiness. For example, wakalas were asked how to: navigate through different categories of service; login to the system; get the USSD code when users did not remember; scroll when finding names since some HH members could not see well, and more. Our qualitative results indicate that fostering trust met with uneven success: some pHHs extended their trust in the wakalas to trust in our tool, i.e., wakalas lent legitimacy to the ICT. For example, wakalas reported that pHHs asked them about the origins of the intervention, how to contact the app owner for more information, etc. One wakala reported that two people not enrolled in the pilot came and asked for information on how to access the app and how it could help their farming. However, one wakala reported facing some resistance, saying "It is hard to make people understand the program because people think that we are thieves." Despite some mistrust, several users shared that they perceived the app to be useful, in particular to the business community as well as those who need services from the community. There were some challenges that the wakalas could not help users overcome, for example, one user mentioned "We need more stable network connection in our community to use the service."

Here, we present a comparison of use between pHHs and low comfort users (bHHs) from our larger deployment (see Section 3.3 in Chapter 3 for the definition of low comfort users or "Comfort Group B") as context to our qualitative findings. By all metrics, pHHs used the tool more than the bHHs, and use by pHHs was more complex. For example, the proportion of unique users significantly differed in each group, with 44 unique users (12%) from the 371 bHHs and 10 unique users (33%) from the 31 pHHs. On average, pHHs had significantly higher engagement per user: 371 bHHs engaged in 205 sessions, and 31 pHHs had 38 sessions. pHHs also had more sessions per whitelisted number, indicating a higher retention rate than bHHs and significantly longer session durations (175 seconds on average, compared to 30 seconds on average in bHHs), with more sessions using the back button option. Most importantly, pHHs visited significantly more businesses, i.e., had more successful traversal through the search tree (while bHHs visited 2+ business screens in less than 20% of sessions, this was 60% in pHHs). Both groups had a comparable number of text and category-based searches. Use of the exit and home functionality and advanced search behavior (like additional filter by location) was low & insignificant in both groups.

5.5 Critical Insights

DFS agents, originally designed to facilitate mobile money transactions, can serve as effective ICT intermediaries, helping users navigate USSD-based agricultural tools by leveraging their existing technical expertise. Intermediation is not merely a workaround for low digital literacy but a fundamental mechanism for scaling digital interventions, as DFS agents provide trust, technical assistance, and interpretation of complex digital interactions for rural populations. Sustainable intermediation models require rethinking incentives, as DFS agents' willingness to support broader digital tool adoption is shaped by financial viability, social capital, and institutional recognition of their expanding role in rural digital ecosystems.

Relationship Type	Main Themes
Community and Technology Relationship	Limited knowledge and lack of training hinders ICT uptake.
	Gender, age, literacy, access, and infrastructure differentially impact demand for intermediation.
Community and Non-Wakala Intermediary Relationship	Family/friends, customer service hotlines, and Govt are relied on for ICT support in differing degrees and with limited impact.
Wakala and Community Relationship	From loan services to password management, wakalas provide a host of uncompensated support beyond digital banking services.
	Scams and ICT breakdowns negatively impact customers' trust in wakalas.
	Wakalas use their often uncompensated loan service as a mechanism to build trust with customers.
Wakalas and Their Organizations Relationship	Limited training for wakalas complicates the work of intermediating software changes for customers.
	A target-based compensation model creates a perverse incentive structure for wakalas.
Community Thoughts on Extending Intermediation	Community members are interested in expanding intermediation to more ICTs. Freelancers are seen as potentially having more impact in hard to reach areas.
Wakalas' Thoughts on Employment Stability	Some wakalas want additional stability and compensation. Others want more opportunity for well-compensated intermediation work, more structure in their work, and the ability to interact with new customers.

Table 5.2: Summary of findings.

Chapter 6

Designing Accurate & Acceptable Care-giving Chatbots in Urban India

6.1 Introduction

The lack of healthcare professionals in marginalized areas has prompted the consideration of medical chatbots as a means to expand access to timely, high-quality medical care. The prevailing method of equipping bots with medical knowledge is by finetuning large language models (LLMs) (e.g. [SAT+22]) on knowledge corpora consisting of internationally recognised, clinically-validated guidelines. Strict adherence to these guidelines is emphasized during chatbot development and often demonstrated by achieving high scores on standard exams, such as the United States Medical Licensing Exam [SAT+22, NKM+23]. The underlying assumption is that once chatbots achieve sufficient accuracy, patients will adopt them to access quality medical advice, potentially improving their health outcomes.

However, there are several regions where such bots may be rejected because their clinically validated advice conflicts with patients' treatment expectations that were formed through their interactions with the local health system. In the Indian context, medical treatments have been widely documented to deviate from clinically validated guidelines. For instance, a 2024 study in urban India found that 44.8% of prescriptions across 13 tertiary care centers did not comply with standard treatment recommendations, with approximately 10% containing unacceptable deviations [SKT+24]. In this work, we focus on three common deviations: the overuse of antibiotics, injections and antidiarrheal medications.

Several studies in India have found that antibiotics are widely overprescribed for conditions where they offer no therapeutic benefit, such as viral infections [NTM+19, HCP+22]. For example, a 2020 National Center for Disease Control study found that antibiotics were given prophylactically (as opposed to having a therapeutic indication) in 55% of patient interactions across 20 Indian tertiary care centers [SBP+20]. A study of pharmacists in Telangana and Haryana revealed that this overprescription practice has caused patients to develop incorrect associations between their symptoms and antibiotics. One pharmacist said, "You go to the doctor and they prescribe you at least one antibiotic when you can be treated with a simple paracetamol. So the patients that come for self-medication straightaway ask for antibiotics." The pharmacists also indicated that alternative medicine practitioners prescribe strong antibiotics, amplifying patients' beliefs that antibiotics are effective for many conditions [KJL21]. This systemic overprescription of antibiotics has serious consequences: a Lancet study found an estimated 1.27 million deaths attributable to antimicrobial resistance (AMR) in 2019, making it one of the leading causes of mortality worldwide [XCH+21]. Studies project that AMR could cause 10 million annual deaths globally by 2050 without intervention, with India among high-burden nations [TS19].

The false association between injections and superior therapeutic impact when compared to oral medications has also been widely studied in India. For example, researchers in Maharashtra found that 61.6% of outpatients across 11 districts received injections despite only 5 - 10% having a clinical indication, with rural and tribal communities experiencing an even higher rates of 73%

and 86% respectively [Tim09]. A qualitative study for determinants of injection use reported that the practitioners themselves often initiate injection prescriptions. This preference stems from beliefs that injections provide "stronger" or "faster-acting" treatment [JBMA16]. Overuse of injections when they aren't indicated can also have severe consequences as practitioners often reuse hypodermic needles after inadequately boiling them, "exposing thousands of patients to the risk of contracting Hepatitis B, HIV/AIDS and other diseases" [Tim09].

Finally, the underuse of Zinc supplements and the improper (sometimes contraindicated) use of antidiarrheal medications has also been documented in Indian children. Despite Zinc and ORS being clinically endorsed treatments for childhood diarrhea, antidiarrheals appeal to parents seeking to quickly stop loose motions. As a result, a study in Uttar Pradesh found that 80% of children with diarrhea visiting private practitioners received antimotility drugs or antibiotics, while only 17% were given Zinc supplements [FWTL+16]. Beyond the direct risks of prescribing antidiarrheals, such as trapping harmful bacteria or toxins inside the body, leading to organ bloating or failure, such prescriptions also increase treatment costs and the likelihood of preventable adverse drug reactions.

There is strong evidence to suggest that patient treatment expectations in the Indian sociocultural context may not align with clinically validated advice provided by medical chatbots. As we use these bots to expand access to care, carefully nudging patients towards safe practices could help bolster initial uptake and mitigate the aforementioned adverse consequences. This thesis chapter describes my mixed-methods work, conducted in collaboration with Microsoft Research India, on designing LLM-enabled chatbots that simultaneously achieve the competing goals of accuracy and acceptability in marginalized regions. To tease apart this tension, we carried out a two-phase experiment in Bangalore, India.

First, we asked **RQ1**: In a setting where medical advice varies significantly, do patients prefer a chatbot that follows vetted medical guidelines over one that does not? With physicians, we created three hypothetical patient profiles and symptom scenarios (around common cold, tension headaches, and viral diarrhea). In Phase 1, 100 participants reviewed transcripts of simulated interactions between each hypothetical patient and two chatbots: *Verity* and *Max*. Both bots reached the same, correct diagnosis, but Verity offered treatments based on clinical guidelines, while Max suggested an overuse of medication and/or injections. Our findings show that a slight majority of participants (54%) preferred Max (the overprescribing bot) over Verity (the clinically validated bot). Participants' bot preference was strongly associated with their educational attainment: being in the Lower Education subgroup indicated a significant preference for Max's overprescription ($p < 0.001$, $t(98)=3.83$, Cohen's $d = 0.78$).

Given this understanding, we developed **RQ2**: Can a *contextually-aware nudge*, i.e., wrapping verified medical advice with extra information that is aware of the context in which it's being interpreted, shift patient preferences towards clinically validated advice? In Phase 2, a new cohort of 100 participants was introduced to Max and another chatbot, *Clarity*, which mirrored Verity but incorporated a context-aware nudge after Verity's clinically validated advice. A significant majority (85%) of participants preferred Clarity over Max across both education subgroups ($p < 0.001$). Across both stages, we collected qualitative rationale explaining participants' chatbot choices, uncovering that medical reasoning and chatbot-related factors influenced their selection of Max, while the context-aware nudge improved participants' trust in Clarity.

6.2 Related Work

Chatbots are increasingly being used to disseminate health information across diverse domains, such as combatting COVID-19 vaccine hesitancy [KSK+24], educating women about breastfeeding [YMDS19], and promoting adolescent sexual and reproductive health [RRT+21, WGS+22, NNMB+23]. Other studies have explored chatbots' role in providing medical guidance in waiting rooms [LGC+24], supporting mental health interventions [ISS+18], and assisting with pre- and post-operative care [RSG+24]. Many factors, including performance expectancy, perceived risk, and anthropomorphism, influence chatbot adoption in India [WPHvB24, RCB21, SBFG22, WHWKN23]. Finding different ways to adapt and respond to the local sociocultural context can also improve acceptability. Studies have shown that healthcare professionals tailor communication based on patients' health literacy levels to improve comprehension [WFKB18]. Similarly, a sexual health chatbot in Bangladesh adopted culturally responsive design strategies to encourage scientific health practices while addressing local beliefs [RRT+21]. TeachAIDS, a culturally adapted AIDS awareness program in India, demonstrated how respectful and creative messaging can enhance acceptability, particularly in stigmatized communities [SSL+17].

There is expansive literature on nudges, i.e. subtle, non-coercive ways to influence human beliefs or behaviors [TS21, BK20]. Integrating these nudges into chatbot design may also enhance acceptability and influence patient decision-making. Nudges have been studied in behavioral economics [TS21, BK20], and are closely linked to persuasive technologies that aim to change user behavior through engagement and feedback [Fog03, HKP14]. A systematic review surveyed 71 articles related to nudging and distilled 23 distinct nudging mechanisms that leveraged different cognitive biases [CKGC19]. Another study reviewing 73 digital nudges found that field experiments, like those in this work, were less common than purely online experiments [BDBH22]. This study explores how well designed chatbots can nudge users toward safe and clinically-validated practices.

6.3 Methods

In July 2024, participants were sampled from Microsoft Research in urban Bangalore, India. This setting, with 1,000+ staff members, was selected for having employees with diverse socioeconomic backgrounds, educational attainment and familiarity with health technologies. We convenience sampled 100-participant cohorts for each phase of our experiment, encompassing staff of both Higher Educational Attainment (people with Bachelors, Masters, PhD, MBA or other degrees, who were mainly employed as engineers, research interns or scientists) and Lower Educational Attainment (people that had attained grades four through twelve, who mainly served as custodial staff, kitchen employees, security workers, etc.). Inclusion criteria were being an employee of the institution in July 2024, over the age of 18, and speaking English, Hindi, Tamil, or Kannada. Recruitment occurred across eight days, where we reached out to potential participants face-to-face. We recruited at different times of day, at different parts of the institution, working to mitigate skew in the cohorts that may be caused by convenience sampling.

The experimental setup was co-designed by three researchers and two physicians with a combined 40 years of experience practicing general medicine at large government and private hospitals in Bangalore. We curated a list of prevalent diseases in India from the medical literature [TRP15] and selected common cold, pediatric viral diarrhea, and tension headache to use for patient profile creation in our experiment. These diseases were common, and had associated treatment practices that were not clinically validated but widely documented in the literature. For each disease, a hypothetical patient profile with a given set of symptoms was constructed by the physicians. The physicians then generated two treatment plans for the hypothetical patient: one that was strictly based on clinically-validated guidelines, and another was the common and incorrect prescription.

Bot	Treatment Style
Verity	Presents verified medical guidance
Max	Over prescribes drugs or interventions
Clarity	Presents verified medical guidance with a context-aware nudge

Table 6.1: Bots and Their Treatment Styles

Using the patient profiles, diseases, and treatments from the physicians, the research team simulated conversations with three chatbots, namely **Verity, Max and Clarity**. The bots were all anonymous when presented to participants; the names are only to simplify the narrative in this paper. We created nearly identical conversations in which the patients described the exact same symptoms to each of the bots. All three bots were designed to come to the same diagnosis after asking similar clarifying questions. The only difference in the conversations was that Verity concluded by prescribing the treatment that was based on verified medical guidelines, Max ended the conversation by overprescribing treatment, and Clarity ended the conversation with the same treatment as Verity with an additional message that contained a context aware nudge (see Table 6.1). The context-aware nudge was carefully created in collaboration with the physicians. They were aware of local medical practices, common misinformation in the minds of patients, and medical literature that has characterized these dynamics. The nudge was a concise, logical appeal that aimed to proactively counteract misconceptions which may cause participants to think of Max's overprescription as the correct treatment. See Table 6.2 for the responses and nudges related to each disease.

Disease	Bot	Treatment
Cold	Verity	You don't need any medication for now, but if you have a fever above 100 degrees, take Crocin every 6-8 hours after food. Do regular steam inhalation. Rest and drink fluids.
	Max	Take an antibiotic (like Azithromycin) for 5 days (1 tablet daily after breakfast). Do regular steam inhalation. Rest and drink fluids.
	Clarity	Note that the following prescription is preferred to antibiotics. Antibiotics are used to treat bacterial infections as opposed to common cold. You don't need any medication for now, but if you have a fever above 100 degrees, take Crocin every 6-8 hours after food. Do regular steam inhalation. Rest and drink fluids.
Diarrhea	Verity	Give Electral ORS solution till the loose stool persists. To reduce diarrhea, either give Zinc supplements (like ZN20), 5ml once a day, for two weeks, or eat zinc rich food like curd, dal, etc. daily.
	Max	Give Electral ORS solution till the loose stool persists. Give a medicine (like Loperamide) to instantly stop the loose motions - 1 teaspoon 3 times a day after food for 4 days.
	Clarity	Note that antidiarrheal medication can stop diarrhea quickly, but it is not recommended for children below 2 years of age. Hence I am not prescribing that. Give Electral ORS solution till the loose stool persists. To reduce diarrhea, either give Zinc supplements (like ZN20), 5ml once a day, for two weeks, or eat zinc rich food like curd, dal, etc. daily.
Headache	Verity	Take a tablet of pain medicine (like Dolo 650 or Naxdom 500) in case of severe pain. Eat meals on time. Maintain good sleep hygiene. Drink fluids.
	Max	I will prescribe you a Paracetamol injection to ease your pain. Rest and drink fluids. Eat meals on time. Maintain good sleep hygiene.
	Clarity	Take a tablet of pain medicine (like Dolo 650 or Naxdom 500) in case of severe pain. Eat meals on time. Maintain good sleep hygiene. Drink fluids. Note that this medication could be administered via injection, but that is only recommended in acute cases.

Table 6.2: Treatment recommendations for diseases by Verity, Max, and Clarity

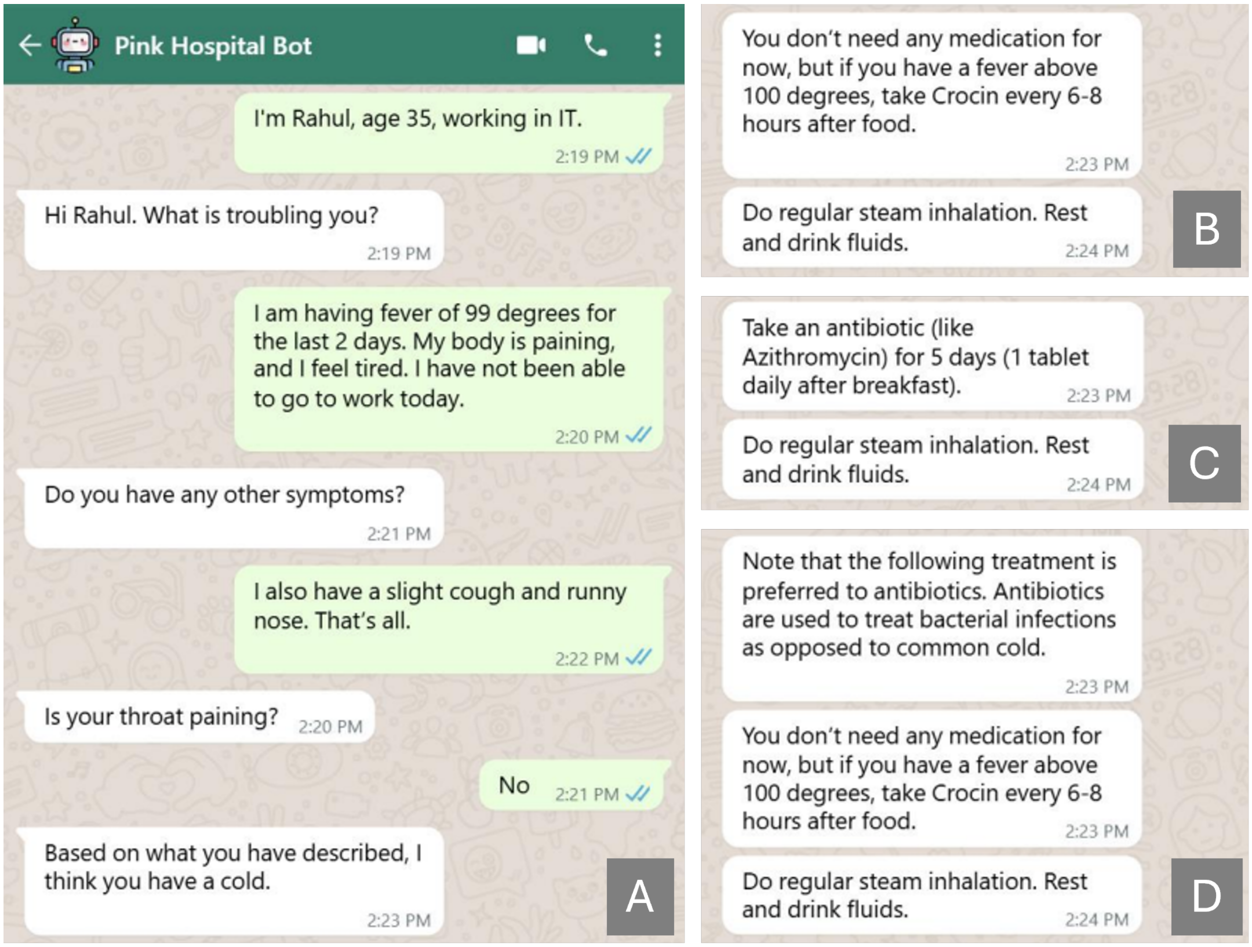


Figure 6.1: **Panel A** depicts a common message that was shown to participants across bots for the Cold scenario. On the right, **Panels B, C and D** shows Verity's, Max's, and Clarity's treatment messages respectively.

The conversations we designed between patients and the bots were simulated on WhatsApp (see Figure 6.1). Screenshots were taken of these simulated conversations, forming the experimental apparatus.

Experimental Design

Phase 1 was designed to quantify the degree of preference for bots that provide clinically validated advice (comparing Verity and Max), while Phase 2 was designed to determine whether context-aware nudges could shift these preferences towards clinically-validated advice (between Clarity and Max). Across both phases, once consent was obtained from the participant, we explained the study procedures and collected demographic information. Then, each participant was shown chat conversations with Verity and Max, or Max and Clarity (determined based on Phase) for each of the 3 disease scenarios. Variants of the experimental apparatus were created to control for the potential confounding effects of 1) ordering of presenting Max and either verified bot, 2) minor conversational differences between Max and either verified bot, and 3) order of presenting the three diseases. No statistically significant differences were seen in bot preferences in these tests, hence we do not report them in the results.

If the participant was comfortable reading by themselves, they were asked to read each pair of conversations independently. If they were not comfortable reading, Author 1 would read the conversation to them in Hindi, Tamil, or English. Once the conversations for each disease were known to the participant, they were asked to state Q1 (preferred bot): "Which bot's advice do you accept?," Q2 (Rationale): "Please provide a one sentence justification for your selection" and Q3 (Exposure): "Have you or a close relative experienced <disease> in the past 6 months?" Participants were allowed to ask clarifying questions to the research team at any point during the study procedures. The entire study procedure took under 10 minutes per participant. They were not compensated for their time due to institutional policy and local norms.

Analysis

In Phase 1, we counted the number of times that the participant chose Verity across the three diseases. This value, Total, is continuous, with a minimum of 0, and a maximum of 3. Total was mapped to the participant's overall Preferred Bot in the following manner. If Verity was chosen 0 or 1 times by the participant, the participant's Preferred Bot was designated as Max. If they chose Verity 2 or 3 times, their preferred bot was Verity. In Phase 2, we performed analogous coding based on the number of times that the participant chose Clarity across the three diseases. Preferred Bot was our binary dependent variable in each Phase. Independent variables were Educational Attainment (binary, defined as "Lower Educational Attainment" representing grades four through twelve, and "Higher Educational Attainment" representing participants with Bachelors, Masters, PhD, or MBA degrees), Gender (binary, Male or Female), Exposure (binary, Yes or No), and Parent Status (binary, Yes or No).

For both phases, we followed the same statistical analysis plan. To test whether participants chose Max more often than the bot providing clinically-validated advice, we used the one sample t-test to compare the mean total to random chance. To understand the effects of education, gender, and other demographic subgroups, we used independent samples t-test and measured effect size with Cohen's d. For sub-analyses with individual disease scenarios, we again used the t-test to understand the differences between the selection of Max and the selection of the bot that provided clinically-validated responses. To measure the impact of context-aware nudges on bot preference across phases, we used the independent samples t-test. The two-way ANOVA test was used to understand the main and interaction effects of each pair of independent, between-subjects categorical variables (one selected from the demographics and the other being Preferred Bot).

We used Braun and Clarke's thematic analysis method to identify themes and subthemes after which salient quotes were identified for inclusion. Participants' quotes are anonymized and attributed to their unique identifier (ex. P67). We focused coding on rationales given for preferring Max, as we were interested in shifting the preference away from Max through our intervention.

All study procedures were carried out after obtaining Institutional Review Board clearance from Microsoft Research India, and written consent was obtained from individual participants. Using screenshots of the chat, as opposed to care seekers talking to a chatbot in real time, could be seen as a threat to ecological validity. However, this was a deliberate choice made so that treatments that weren't clinically valid were not shown to people that were currently making decisions about care. This choice also led to easier comparisons across participants because standard conversations were shown to all participants. To negate any potential impacts of showing Max to participants, we let them know which treatment is clinically valid for each disease scenario at the end of the study, and spent time answering follow up questions if they arose.

6.4 Findings & Themes

The Phase 1 cohort had a mean age of 30.17 years (std 9.56 years, range 20 - 58 years), 68% participants identified as male, 33% participants were parents, and educational attainment was split evenly between Lower Education (50%), and Higher Education (50%). In Phase 2, our sample of 100 participants had a mean age of 29.98 years (std 7.67 years, range 20 - 49 years). 72% participants identified as male, 37% participants were parents, and educational attainment was split almost evenly between Lower Education (47%), and Higher Education (53%). Participants in both phases were distinct.

6.4.1 Phase 1 [Verity vs Max]

Quantitative Responses

At the baseline, a statistically insignificant majority of participants (54%) preferred Max, i.e., they selected it on at least 2 of the 3 occasions. Of these, 23% of participants strongly preferred Max, selecting it on all 3 occasions, while 31% narrowly preferred Max, selecting it on 2 of the 3 occasions. Of the remaining 46% of participants, 11% strongly preferred Verity, and 35% narrowly preferred Verity.

While strong preference for Verity amounted to a low proportion (11%) across both education groups in Phase 1, there was a significant difference in Preferred Bot between Higher and Lower

Education subgroups ($p < 0.001$, $t(98)=3.83$, Cohen's $d = 0.78$). Where 0 represents Max and 1 represents Verity, the Higher Education subgroup had a mean preference of M = 0.64 (SD = 0.48) while the Lower Education subgroup' mean preference was M = 0.28 (SD = 0.45). Both subgroups individually had means that were significantly different from random choice (Higher: $t(49) = 2.04$, $p = 0.047$, $c = 0.41$; Lower: $t(49) = 3.43$, $p = 0.001$, $c = 0.69$). No other demographic factors (Exposure, Gender, or Parent Status) significantly impacted bot preference.

Qualitative Responses

Participant rationales shaping their preferences for Max fell into two themes: medical reasoning (wanting to shorten convalescence, incorrect beliefs, and perceptions of known medication) and bot-related reasoning (perceptions of Max's personality and comparing Max to one's doctor). Below are representative examples of user responses that illustrate these themes.

Medical Reasoning: Shortening Convalescence Most participants mentioned that medication would allow them shorter convalescence. For example, P78 commented, "All problems can go away quicker with medicine," while P41 remarked, "Action is better than doing nothing. [Verity] is too passive." Panic about delaying care was especially acute in the case of the pediatric viral diarrhea scenario. In the words of P57, "Children will need to go to a special hospital if something happens, so can't wait [...] Need to take medicines instantly," while P69 added, "With children, it is an emergency situation." Similarly, P48 said, "Give them anything to feel better quickly."

Medical Reasoning: Incorrect Beliefs Several participants believed that antibiotics were a necessity: as per P53, "Taking antibiotics is needed, without that, fever never goes away. My doctor always gives antibiotics for fever, it is required." Some participants also saw antibiotics as a panacea. P64 asserted, "Antibiotics are a guarantee," while P81 believed antibiotics are "effective for almost anything." Some specifically extended this belief about antibiotics to viral infections, as P25 stated, "Even if viral, we [the patient] can take antibiotics, it will help. [...] the antibiotic will bolster the immune system." Notably, only two participants (n=100) in Phase 1 made references to antibiotics not being applicable for viral diseases as part of their rationale for selecting Verity in the cold scenario. Finally, they also believed that antibiotic use had no negative consequences, e.g., as P94 noted, "Antibiotics are cheap [...] there will not be any issue if you take them. If you don't, then there will be a problem." Similarly, participants cited prior experience having received injections for pain or fever at clinics or government hospitals, holding misbeliefs about injections' long lasting effectiveness in comparison to oral medication. P60 remarked, "Injection is a permanent solution, whereas pills you have to keep taking now and then."

Medical Reasoning: Perceptions of Known Medication Most participants recognized medications that the bots mentioned, like Crocin or Dolo 650, and associated them with common use in the Indian context. P18 commented, "I know Crocin, it is a general purpose medication." Trust was tied to the prescribed medication having been previously given by a doctor, as P19 pointed out, "Can't trust a bot if I haven't heard of the medication it gives." However, Crocin's familiarity, somewhat counterintuitively, got some participants to not trust the bot that recommended it. For example, P99 said, "If I am going to the doctor I will want them to give something serious and not just say Crocin." A small group of participants held incorrect beliefs about common medications, which influenced their preference for Max. P34, for instance, stated, "Dolo is stronger than Paracetamol, so seems more severe than taking a paracetamol injection," while P70 incorrectly claimed, "Crocin and Dolo are banned in other countries, only in India it is still allowed."

Bot-Related Rationale: Perceptions of Max's Personality Participants often rationalized their preference for Max using their perception of its intelligence or empathy. Notably, the experiment tested variants where the conversation prior to the treatment was interchanged between Max and Verity, but we observed no quantitative difference in preference. Nevertheless, some participants who chose Max rationalized their choice using personality attributes that were in fact consistent across both bots, calling Max "smarter overall and more human" (P14), "more understanding and trustworthy" (P6) and "more empathetic" (P33). These perceptions were strong enough to override some participants' acceptance of Verity's prescription. For instance, P19 commented, "Zinc tablets for diarrhea are known, but still [Max] seems smarter so I will follow that."

Bot-Related Rationale: Comparing Bots to One's Doctor Participants commonly expressed the belief that a conversation with a medical expert (both bot or doctor) should result in a prescription. P47 mentioned his thoughts in the context of a doctor's visit: "We can take rest by ourselves. If you say no to [prescribing] a tablet, and just go home, why would I take time from work and go to the doctor." This expectation of receiving a prescription led participants to reject Verity when it failed to prescribe. For example, P36 criticized, "[Verity] starts off with 'you don't need medicines,' [...] seems like a scam," while P72 noted, "If it's [Verity], I need to go to another doctor afterwards for some real treatment, that bot is useless." Some participants thought that not prescribing medication made Verity less smart, with P37 mentioning, "If the bot knows stuff, it should be able to recommend medications." In addition to not prescribing medicine, participants also felt that Verity's advice which allowed more room for patient decision-making, felt unfamiliar and less trustworthy. P5 commented, "[Verity] gives more options to the patient which makes it seem unlike a typical Indian doctor and therefore not really believable or serious." P98 added, "[Max] sounds more like a doctor giving [a prescription with] a big medicine name."

6.4.2 Phase 2 [Max vs Clarity]

Quantitative Responses

After the incorporation of context-aware nudges, the majority of participants (85%) showed a significant preference for Clarity ($p \ll 0.001$) compared to Max. Only 2% of participants strongly preferred Max, selecting it on all 3 occasions (compared to 23% in Phase 1), while 13% narrowly preferred Max, selecting it on 2 of the 3 occasions. In contrast, 43% of participants strongly preferred Clarity (compared to 11% preferring Verity in Phase 1), and 42% narrowly preferred Clarity.

When comparing the demographic subgroups, preference for Max occurred in only 3/53 participants in the Higher Education group and 12/47 participants in the Lower Education group. Both Higher and Lower Education subgroups significantly preferred Clarity over random choice (Higher: $t(49) = 13.84$, $p < 0.001$, $c = 2.71$; Lower: $t(49) = 3.81$, $p < 0.001$, $c = 0.79$), although there still existed a significant effect of Education on Preferred Bot ($t(98)= 5.19$, $p \ll 0.0001$, $c = 0.74$). Gender, Prior Exposure and Parent Status did not significantly impact preferences.

Qualitative Responses

Participant rationale fell into three broad themes in Phase 2: 1) Building Trust Through Explanation, 2) Building Trust Through an Efficient Authority and 3) Alignment with Personal Beliefs.

Trust Through Explanation Many participants who chose Clarity rationalized their selection because of it's nudge, which created a conversation that had "more coherent, more detailed replies" (P5). P98 clearly stated, "More reasoning is more trustworthy," perhaps alluding to the fact that a nudge of any kind could have enhanced participants' trust in a given bot. For some participants, the nudge helped understand Clarity's reasoning (as P16 noted, "[Clarity] is upfront that injection is not a good idea, gives me a sense for what they are thinking about when coming to a decision") and critically evaluate the recommendations (as P57 mentioned, "context can be cross-checked.") Others valued Clarity's nudge for its educational potential. P49 emphasized, "We need people to sit with us and tell us right and wrong, we do not know." P82 noted that Clarity's reasoning made it "seem personable and kinder. Doing the reasoning is important and makes it seem less mechanical. It can educate us."

Trust Through an Efficient Authority Those who chose Max trusted the bot because they believed in authority figures (doctors, technology) as inherently correct, dismissing or disliking extra details. For example, P77 said "Why is [Clarity] giving extra information? If it is a technology, it will not say wrong things." P79 felt Max sounded "more like a doctor in India, short and crisp." The added context being missing in the doctor's office seemed apt to P77, who mentioned, "How can we judge a doctor's advice? I would take an injection if the doctor says," and P88 concluded, "[Max] is more layman-oriented which is what I am." P100 felt overwhelmed by the nudge, saying, "I think honestly there is too much information in this [nudge] for me to even focus on what it is saying." These participants preferred Max for having shorter chats compared to Clarity.

Alignment with Personal Beliefs Participants' rationale was also shaped by their existing beliefs and personal experiences with treatment. Some participants who rejected Clarity mentioned doing so explicitly because the nudge it provided conflicted with their prior experiences. For example, P85, for example, had always relied on tablets for colds, so he distrusted Clarity's suggestion otherwise. P17 held a strong belief in antibiotics, stating, "Antibiotics never have side effects whereas other medicines do. Will not trust this [Clarity] bot because of personal experience with this condition." For others, Clarity's nudge was easy to trust as it confirmed their existing beliefs. In the words of P52, "As a parent, it is easy to believe that the antidiarrheal medicine is not needed. Long term solution is to suggest foods [...] not just medicines medicines medicines."

6.4.3 Comparative Analysis across Phases

In Phase 1, participants did not show a clear preference between Verity and Max. In contrast, in Phase 2, participants significantly favored Clarity to Max. There is a significant difference in preferences across Phases with $t(198) = 6.33$, Cohen's $d = 0.90$, $p = 1.619e\text{-}09$.

A two-way ANOVA was conducted to examine the interaction between Education (Higher vs. Lower) and Phase (Phase 1 vs. Phase 2) on preferred bot. We found no statistically significant interaction ($F(1,196) = 1.91$, $p = 0.17$), indicating that the difference in preference across Phases was not influenced by education. Similarly, a two-way ANOVA examining the effects of Exposure (exposed vs. not exposed) and Phase (Phase 1 vs. Phase 2) on bot preference found no significant interaction ($F(1,196) = 0.76$, $p = 0.38$), indicating that the effect of phase on correct choices was not influenced by past exposure to the disease.

6.5 Critical Insights

Our two phase experiment showed that patient trust and adoption of LLM-enabled medical chatbots are shaped by treatment expectations and cultural norms rather than clinical validity. Participants associated treatment effectiveness with the prescription of medication regardless of clinical indication, and many were skeptical of chatbot-generated advice that did not align with their previous medical experiences in the local healthcare context. However, context-aware nudges that foregrounded local treatment practices while guiding users toward safe medical choices improved acceptability, suggesting that medical chatbots must be designed to actively contend with local medical misbeliefs if they are to succeed in expanding quality care to the margins.

Chapter 7

Comparing the Imaginaries and Realities of AI-enabled Healthcare at the Margins

7.1 Introduction

A growing body of research explores the use of ICTs to enhance healthcare delivery by both skilled and unskilled health workers [FE13]. This includes AI-enabled health interventions designed to augment CHW-delivered NCD care at the last mile such as that described in Chapter 2 and Chapter 6. While individual AI applications have shown promise in converting health data into screening or diagnostic results, they often stop short at the standalone evaluation of these AI-enabled mHealth tools without examining how they can be effectively integrated into LMIC health systems. The select few mHealth interventions that measure human outcomes have struggled to link AI-enabled tools to better states of health. For example, the First Look study invested millions of US dollars in integrating point-of-care ultrasound (POCUS) technology in rural clinics across five LMICs, only to find no significant impact on morbidity or mortality outcomes.

Nevertheless, health systems are beginning to conceptualize CHW-led, AI-enabled care pathways as a means to improve healthcare delivery at the margins. These emerging agendas can be understood through the lens of sociotechnical imaginaries (SIs)—"collectively held, institutionally stabilized, and publicly performed visions of desirable futures attainable through, and supportive of, advances in science and technology" [JK09]. Several works, including Toyama's amplifier theory, establish that the ability of any technology (such as AI-enabled healthcare devices) to deliver peoples' imagined future is heavily contingent on the technology tying back to the intent and capacity of the existing sociotechnical systems. To learn what it will take for AI-enabled care to deliver the improved outcomes its champions imagine, we ask: **RQ1**: How do Nepali health leaders believe that AI-enabled tools will impact healthcare at the margins? and **RQ2**: What socio-technical realities in the health system may impede leaders' imaginaries from manifesting as improved human outcomes?

Through 14 interviews with Nepali government officials, community health leaders, and senior health practitioners, we outline 8 collectively held and institutionally stabilized futures of AI-enabled NCD care in Nepal. To understand the rollout of such an AI-enabled tool, we create a technology system that centers a generic AI-enabled NCD diagnostic, and ensconce it in interviewees' lived socio-technical realities working at the margins of the Nepali health system. In characterizing the gap between the current state of the system and the imaginaries of an AI-enabled future of health, we discuss whether and when AI-enabled care could deliver improved and expanded care to all Nepali people.

7.2 Related Work

HCI literature has defined a sociotechnical imaginary (SI) in three ways: (1) an imagined form of social life reflected in a technology [Jas15, CM22], (2) a desired outcome of the use of a technology [Jas15, CM22], or (3) an undesired outcome or fear associated with a technology [SB22]. All three definitions allude to the human perception of the capabilities of a technology and the realization of these capabilities. SIs are widely context-dependent, and the stakeholders, novelty, and cultural environment push SIs to be positive or negative [SB22, SRD19, KSS22, HC21, OKDV21, BAIA22, BAS+22], while speculation, critique, and performance has led to preventive policy or exacerbated "hype" that manifests individually or collectively [Jas15, HC21, AC22]. Below, I use the example of electronic health records (EHRs) to interweave related work on SI theory with examples of the incorporation of eHealth, mHealth, and most recently AI-enabled health into LMICs' national and subnational care infrastructures.

Technological solutionism is a common SI that has encouraged the deployment of health applications in the Global South to amplify the values that were found to enhance and empower individual rights in the Global North [Kar22]. The literature has documented several such instances of trying to use technology to "solve" healthcare challenges within the LMIC context [BCP+11, FE12, WS05, GW04]. The introduction of EHRs is the first and therefore most extensively reviewed eHealth application, which promised to scale, organize, and centralize vast amounts of patient data in a cost effective manner [BCP+11, FE12, WS05, GW04, GPW+09, BPC+19, Jus17, NNSS22, EES88, TUU22, BAIA22]. Across LMICs, there was substantial hope that EHR technology would organize and consolidate the diverse, incomplete, and fragmented data sources to afford better health surveillance and therefore better health. District Health Information System (DHIS) is the world's largest EHR system, hailed as a global eHealth success story. Its use in 80 LMICs is attributed to its scalable and decentralized nature [dhi, SRD19, BH11, AGNSS19, NNSS22, KMKN18], countering the disproportionate control of patient data by any singular private entity. The most notable example of DHIS's success was in South Africa, as the strong drive to incorporate DHIS into the nation's healthcare system came from understanding health system gaps post-apartheid [BH11, AR19].

Sociotechnical gaps are inevitable misalignment between the promised imaginary of a technology and the context it is applied to. Despite an imagined good, there are several recorded examples of failures or misaligned expectations caused by the digitization of health [Hee06, Kar22, AC22, EMS+22, TUU22, BAIA22]. Although DHIS was successfully integrated in South Africa, scholars have contested EHRs' ultimate utility towards bettering human lives, citing examples of mass digitization leading to messier data management and murkier accountability for human actors in health systems [BPC+19, Hee06, SSK+21, SRD19, TUU22]. It is challenging to gauge a priori whether people's positive SIs of a technology will materialize in a given socio technical environment or be prevented by sociotechnical gaps. In a move to create a different system like DHIS, England designated 2 billion British pounds to create the then largest civil technology that aimed to incorporate EHRs into their National Health System (NHS). However, after eight years, and the expenditure of over 12.8 billion Pounds, the NHS dismantled the initiative citing that it was challenging to manage, difficult to maintain and repair, failed to meet expectations of clinical staff, provided little functionality and increased costs [Jus17]. Together, the failure of this system and the success of other eHealth interventions, measured by the difference between the intended effects with realized effects, is contingent on the importance of foregrounding the needs of diverse actors in the extant health system.

In more recent efforts that focus on patient empowerment and healthcare accessibility in LMICs, work on mobile health (mHealth) technology has boomed, presenting a new set of futures. While eHealth initiatives showed promise to foster accessibility and support for healthcare in marginalized and fragmented systems, proponents of mHealth have imagined a novel democratization of the healthcare system, advocating for a "digitally-empowered" patient population and "demystified" medicine [Cor14, AC22]. mHealth technologies have promised increased communications between patients and experts, granting them new levels of accessibility, allowing users to record, track and share their symptoms while learning more about their own health [BPL+18, KA15b, AC22, EMS+22]. For example, Feldacker et al.'s efforts in two-way texting demonstrated the usability of mHealth in support of delivering HIV health services, and the subsequent impact of these services on patient satisfaction, comfort, time and money [FHM+20, BBM+20]. Beyond communications and information dissemination, another expectation of mHealth is the abilities of mobile applications and tools to do what was once only attainable by hospital-grade machines [TUU22], including expanded diagnostic capabilities and patient personalized care. These complex tasks are made possible via AI-enabled mHealth [OKDV21, TUU22]. For example, AI models have aided health workers in making assessments in fetal ultrasonography [LWC+23], or provided patients with high-quality answers for personal, specific medical questions [SAT+22]. Our work conceptualizes a generic AI-enabled, mHealth based screening system, taking pieces from the WHO Classification of digital health interventions v1.0 [Org18], and adding specific AI-related components. This system helps us contextualize technology in the current health infrastructure to understand the futures of health that can be realized.

The literature has juxtaposed the intended effects of these emerging mHealth and AI-enabled health technologies with the realized effects [Hee06, Kar22, AC22, EMS+22, TUU22, BAIA22], attributing the gaps to region-specific factors, bureaucrat interactions, and adaptability [SRD19, SSK+21, TIK+22, Sta99b, NS15, EMS+22, TUU22, BAIA22]. For example, CHWs in Kenya were tasked with managing digital payments for appointments, but the dream of a so called "techno-optimist" vision quickly fell apart as CHWs would frequently be unable to follow up on missed payments or access payment records due to the inaccessibility of the technology and financial and technical illiteracy [Kar22]. Integrating Whatsapp into the communications of nurses in South India and their higher-ups failed to serve the socio-technical imaginary of a higher form of efficiency in healthcare, and rather resulted in nurses needing to work off-shift [Kar22]. A recent study on the usage of AI for pediatric ultrasound interpretation in South Africa found that while clinicians were eager to use AI-based assistance, there is still a larger need for tools that make ultrasound more accessible in the first place [EMS+22]. Finally, further investigation into the calls received by a Telephone Crisis Helpline in Bangladesh revealed that the root of many mental health issues had more to do with the country's broader structural issues such as unmet UN sustainable development goals [BAIA22].

There has also been debate about the best way to measure and define socio-technical gaps as the intended or perceived success of a digital health tool may be subjective [LX23, BAIA22]. In 2023, Liao and Xiao argue that model evaluation should make a discipline that takes up understanding and narrowing the socio-technical gap, proposing that real world field testing maximizes the context and human realism [LX23]. Our work takes this one step further, outlining current and future socio-technical gaps in the integration of AI-enabled healthcare delivery by foregrounding lived experience from hidden human infrastructures that will interact with technologies to create ecosystems of care.

7.3 Findings & Themes

We conducted 14 interviews with healthcare-associated leaders in Nepal to understand their perceptions and imaginaries of AI in healthcare (see Table 7.1). After eliciting imaginaries, we provided specific examples of AI-enabled care to ground the discussion in practical realities. For instance, we described tools such as a handheld ultrasound device that uses AI to generate a list of characteristics of a baby or an AI-enabled smartphone app designed to assist CHWs in diagnosing lung diseases based on entered symptoms. Once a common understanding of AI-enabled care was established, we asked whether the interviewees would advocate for the use of such tools for the screening of NCDs in their specific contexts. We inquired about factors that may amplify or limit success of such interventions, making specific attempts to understand any lived caregiving realities in integrating and sustaining new tools in their communities.

ID	Education	Career	AI Awareness	Area
A1	PhD	Professor of Computer Science	**Medium** - Supervised multiple mHealth projects. Used AI in a limited capacity.	R & U
A2	PhD	Researcher using AI to predict and improve health outcomes for patients.	**High** - Career focuses on using AI for health	R & U
A3	PhD	Researcher using mHealth for disease management.	**Medium** - Personally uses mobile apps for fitness and dietary activities.	U
A4	PhD	Public health professional in maternal and child health	**High** - Worked on mHealth projects that integrate AI in decision-making for diagnoses.	R
CL1	MD	Physician with an international organization	**Low** - Helped design an app to increase awareness of Dengue, no experience with AI.	R
CL2	BScience	Field officer for a nutrition advocacy organization.	**Medium** - Extensive personal use of mHealth. Some awareness about AI for health.	R & U
HP1	MD	Pulmonologist	**Low** - No direct experience with AI but understanding of its use cases.	R & U
HP2	MBBS, MPH	Physician & field coordinator for international organization	**Low** - Very little exposure to AI	U
HP3	PhD	Researcher & health practitioner working on NCD management.	**Medium** - Some familiarity with mhealth and how AI is being used in health contexts.	R & U
HP4	MD	Administrator in health policy	**Low** -Working on digitizing the health system of provincial hospitals via a medical registry.	R
PL1	Undisclosed	Policy maker	**Low** - Uses smartphone and smartwatch with health-related apps, no awareness of AI	R
PL2	MBBS	Policy maker	**Low** - Uses mHealth apps extensively. Advocate for mHealth in their professional work.	U
PS1	MBBS	Works at an international organization that makes digital tools for CHWs.	**Medium** - Extensive work on digital tools for CHWs, strong knowledge of mHealth but no direct experience with AI.	R & U
PS2	MPH	Works at an international organization on community approaches to education and healthcare. On several Nepali health commissions.	**Low** - Consulted on digitizing healthcare tools for CHWs.	R & U

Table 7.1: Participant backgrounds. In the Area column, R = Rural, U = Urban

7.3.1 Interviewee Understanding of AI

Interviewees' self-reported familiarity with AI varied widely. We intentionally avoided presenting technical definitions at the start of interviews, allowing participants to express their unfiltered views on AI and AI-enabled futures. Although all interviewees are stakeholders in the proposed transition towards AI-enabled health in Nepal, awareness of AI ranged from low to medium, with the lowest reported awareness among policymakers. Many interviewees' conceptions of AI extended beyond what is typically considered AI-specific capabilities by the research community. Some used the term interchangeably with general mHealth tools. For instance, A1 said: "Many use the name AI; I don't know much about AI. [...] Years ago, video conferencing from remote villages due to geographical barriers seemed like a significant achievement, but now there are apps where you can define your symptoms and select relevant doctors to make an appointment with the help of AI." Similarly, HP2 referred to AI while discussing the use of demographic data to create unique patient IDs, while HP3 suggested AI could be used to send push reminders for blood screening. Closer to a technical definition, CL1 mentioned AI's role in continuous monitoring of chronic conditions. A2 imagined AI as connecting critical patients with devices that alert the doctor in the case of abnormalities. HP1 demonstrated a more nuanced yet still distant understanding: "AI is a term that everyone has been using but no one understands what that actually stands for and how that is going to be used. If somebody tells me that I have got a huge amount of data and I have to make an algorithm and try to figure the data out and yeah I see AI can be used, isn't it? But then if it involves first time interaction [with a patient], I don't really see how AI is going to work with that. If you have tabulated data that is where AI comes easily into play but if you are trying to obtain data for the first time, AI is not going to work at that time."

Despite limited awareness of AI's capabilities, interviewees generally had positive impressions, with many believing that other countries were already using AI to support their health systems.

However, three interviewees raised concerns about the potential downsides of AI for NCD care in Nepal. PL2 expressed concern about misinformation, stating, "AI should be kept a bit away for now because we have other authentic, up-to-date apps like Medscape, PubMed [...] We cannot rely on AI in the present context." HP1 questioned AI's utility, noting that while mHealth could assist with history-taking, it fell short for examinations, saying, "Maybe 40% of the time I would be able to reach a conclusion by [AI-enabled] mHealth, and 60% of the time I will not."

7.3.2 Needs and Associated Imaginaries

Interviewees shared several anecdotes highlighting the rise of NCDs, e.g. CL2 noted increases in conditions like hypertension, diabetes, and gastritis in their community, saying "There are so many NCDs and I can't say exactly which disease needs to get prioritized first." Below, we explore the health system's needs and interviewees' visions for AI-enabled screening and care in NCDs.

AI will Enable Improved Diagnostics and Early Detection Several interviewees' imaginaries of AI-enabled NCD care futures focused on improving diagnosis and screening in primary health centers (PHCs). In semi-urban and rural areas, low availability of skilled health workers impedes quality diagnosis and screening. A2 noted, "There is an absence of good doctors in rural areas due to geographical barriers and so the ratio between doctors and patients is very low," and HP1 added, "there are 10-12 pulmonologists in Nepal, all based in Kathmandu." The lack of skilled professionals makes diagnosing prevalent NCDs like rheumatic heart disease (RHD) difficult, as A4 said, "RHD needs to be detected from an earlier age… diagnosis needs very well-skilled professionals." Here emerges the imagined future of AI enabling early identification of NCDs and therefore reducing NCD-related morbidity and mortality - PS1 said, "If [AI-enabled screening] becomes a success, it can be used to detect RHD early at schools." HP4 mentioned how AI can help peripheral doctors diagnose life-saving conditions: "[With AI], it can be analyzed, diagnosed, and the emergency situation can be easily solved." A2 shared and expanded this imagined future to reemphasize how the lack of diagnostic capacity causes avertable mortality: "If we can utilize IT technology and make infrastructures then we can bridge the diagnostic gap. In rural areas, we can observe that due to lack of simple care, there has been death, for example, if there is a case of trauma and a person falls down, we need to do an MRI to identify where the clot has been and to do such things it is difficult to treat - but if we can take to nearby health post and find where the clot has been [using tools], we can connect the rural health professional to the urban doctors then we can protect people from dying." This line of reasoning leads to further imaginings of expanded diagnostic possibilities with the help of AI. A1 mentions "Machines could interpret health information and provide feedback, AI could be used for full-body scanning and provide insights into potential diseases."

AI will Enable Support for Skilled Health Workers When skilled doctors do visit rural areas, they are expected to handle all types of conditions. HP1 described their experience: "In the villages, I was handling cases from pediatrics to orthopedics to gynecology." This expectation of diverse knowledge coupled with the high volume of patients leads to skilled health workers being overburdened, and HP2 observed that overworked staff have less motivation, which "may indirectly affect clinical decision making." Building upon this, PS1 said, "I think that makes sense because if you have connected any digital device, the information is going to be correct. But if a doctor interacts with a patient, it has to be done strategically," implying that the AI will be more likely to be correct in comparison to a doctor that may only see the patient for a few minutes. AI is envisioned to support skilled workers by also acting as an error-checking tool at the margins, as A1 mentioned: "where human errors may occur, tools could be used to correct them."

AI will Enable Simplified, Accessible Tools for CHWs The lack of time and energy in skilled healthcare workers causes more and more care delivery to be shifted to by CHWs. A2 noted that CHWs only cover 56% of Nepal's geography. PL2 said, "The problem is so big, primary health services are not staffed, doctors aren't ever there. The initial paramedics or CHW have to run the health centers and they give the prescription." HP1 showed how challenging this becomes for CHWs - "In Nepal, actually CHWs too are overburdened. Everyone is targeting them. If you teach them one specific thing they will be able to do good at it but then if you try to teach them 15 different things, it becomes a problem. You don't expect them to be good at 15 different things." As the labor shifts to CHWs, lack of adequate training for each individual skill is a significant barrier, and equally (yet opposingly) are attempts to saddle CHWs with several training sessions about a variety of new conditions and tasks. Specific to NCD screening, A4 mentions cervical cancer that is eliminated in high income countries, "but in Nepal, only 8% of women have ever been to cervical cancer screening. In our country, we cannot use [PAP smear] due to resource constraints. Another method is accepted by the government, but the Nepal government provides 5 days training to health professionals, and it is still difficult to conduct [in the clinics] as they perform the test using apples during training." The imagined future is one where AI simplifies decision-making for minimally trained CHWs. A4 mentioned a program where AI helps auxiliary midwives interpret ultrasound images that they previously couldn't handle themselves. PS2 noted that AI could streamline CHWs' workflow by allowing them to make faster decisions: "the first point of contact of patients is with CHWs and there can come any questions. In general CHWs can provide referral, but while providing primary care there may be unexpected things, and it may take time to handle. If the decision tool is inbuilt then we can select from the options, it makes it possible to complete by just clicking and making the work easier. Since AI supports this we can say that AI is building our future." A3 underscored that AI tools in local languages that are easy to use will be readily taken up by CHWs: "it should be just like a yes or no option."

AI will Enable Increased Quality Time with Health Workers Interviewees envisioned an AI-enabled future where health workers could spend more quality time with patients if menial tasks were automated. CL1 reflected that AI could make a significant impact at the margins: “If this technology was implemented before in the hilly region, we could have done better to avoid mortality.” This time-saving potential applies across all cadres of health workers, reducing the workload and improving patient outcomes.

AI will Expand Access to Low-cost, Doctor-Free Care Delayed care seeking was highlighted by interviewees which led to delayed NCD diagnosis. A2 said, “Our cultural mindset is such that we reach the hospital only after being seriously ill or collapsed.” For many rural patients, economic barriers prevent them from seeking care. CL1 pointed out that “they are living in a hand-to-mouth situation, and are concerned about making their stomach full [..] It is all due to their economic condition. For them, all those things (like visiting doctor) are luxurious, which is the basic thing.” However, CL2 mentioned traditional healers sought before visiting facilities by people of all economic backgrounds: “In our rural areas the number one priority visit is at Dhami Jhakri [local healer] whether the person is rich or not. Even my mother-in-law does such things whenever she falls ill she goes to Dhami Jhakris before visiting the hospital. The second priority of people especially those who are poorer is the local community health post as less money is required there [than the hospital] and they can get free medicine too. If they are not cured then they visit the clinic and at last they go to the teaching hospital.”

Delayed care seeking at facilities can also be attributed to fear: both of a diagnosis or of the following stigma. CL1 noted, “Nowadays, who doesn’t know about checking their blood pressure? Everybody knows. But there’s a difference between knowing and actually taking the initiative to visit a hospital and get their blood pressure checked. People hesitate because they fear the test results. "What if something is wrong with me?" This fear is already demotivating. It takes a lot of effort for someone who is ready to take the initiative." HP3 said, regarding people with stigmatized conditions, "First of all people with HIV don't want to come out. Some people are so afraid of society that they will never go to the clinic or even at the traditional healers."

Overall, the lack of facility-based care seeking left CHWs with an outsized responsibility for NCD caregiving at the margins. In response, some participants imagined that AI could enable CHWs to carry out cost-effective diagnoses in patients' homes. Many participants went further, to imagine doctor-free care that patients can access from their homes without addition burden on CHWs. As a usecase relating to stigmatized conditions, PS1 said, "Nowadays, people go for mental health counseling, and even there, they have trouble opening up. Suppose I go to counseling willingly but can't express my innermost thoughts; then what's the point? But when we talk about apps, the person becomes less conscious of being judged. So, apps can seize this opportunity and make progress."

This form of AI-enabled care would support CHWs indirectly by helping manage load in the CHW-led clinics or hospitals. A1 said, "I believe this approach is essential because for minor issues, there's no need for patients to visit a hospital. This can save time and reduce the risk of contracting additional illnesses during hospital visits. For instance, if a patient enters their symptoms, the app would recommend a medication like acetaminophen. This allows patients to easily find and use medication that is readily available at home, saving time and hassle. Only in cases where physical examination is necessary should the patient visit a hospital." HP3 agreed, mentioning that integrating AI would help reduce footfall in the hospital, lowering the volume issue from the source - "All kinds of health workers and health facilities may not be able to reach [rural areas]. If people have those services in hand then they can get immediate support like if someone is facing fear of a heart attack and if the mobile tool consists of authentic information then it will definitely help him." PL1 agreed, saying "I think there is a huge scope."

AI will Enable Data-Driven Health System Optimization There are significant data gaps in understanding the state of population health, as PL2 noted: "I asked about the number of patients with hypertension in Nepal, but they didn't have it. We talk about evidence based policy but where do we bring the evidence from? First phase of policy making is to collect the data, services should be provided on the basis of need. If we get the data, we can find out which disease has more expenses and that can be prioritized." Therefore, interviewees' AI imaginaries involved tools enabling better health data collection, informing policy decisions, and allowing for longitudinal follow-up of NCD patients. PS1 and HP4 mentioned how digitization could provide transparency and ownership over health data, "which in the long-run can also be integrated with the disease-specific data, hospital-based registration and will be helpful to drive evidence-based policy development." PL2 envisioned a future where national health identification systems could integrate with AI tools to collect detailed health information for planning and resource allocation. HP2, in relation to the longer term impacts of collecting and storing data, said, "As the data stored can be stored for a long time, different generations can know about their grandparents health and about hereditary risk factors. It will be beneficial for planning in the long run." HP1 emphasized that there were some shortcomings of relying on EHR systems alone for follow up, mentioning, "One of the biggest drawbacks of HMIS/DHIS2 is that every data comes in a cumulative way and not an exact count. So, we won't be able to tell whether a patient is controlled, uncontrolled, missing, dead or transferred out. So, basically mhealth/AI will be a stepping stone for analyzing the data and continuous monitoring."

AI will Enable Efficient Resource Management Several interviewees made reference to the fact that currently, resource management in Nepal's health system is poorly aligned with patient needs. PL2 described how inefficient resource distribution leaves some hospitals with unused ICU beds while others are overwhelmed - "Referrals come from around the country to Kathmandu and the government hospitals cannot take all the load. But if you see private hospitals you will see empty beds, empty operation theaters, the equipment are there but aren't used so this is all due to improper management. [...] Whereas in teaching hospitals the beds are never empty for which I get so many calls everyday. This is all because of lack of understanding about the gaps. Either specialist should be sent there or all that equipment should be centralized again and redistributed on the basis of need." The imagined AI future creates centralized information systems that ensure proper resource allocation. As PS2 mentioned, AI could also guide patients on where to seek care, improving access to services. This system-wide improvement could accelerate care-seeking, as CL2 highlighted: "If we can access mobile health services and know where and whom to visit, we can get care easily and faster. So thinking about the future I think it has a great scope."

7.3.3 Realities

Upon understanding the capabilities enabled in the interviewees' imagined futures of AI-enabled care, we created a technology system that centers and supports a generic AI-enabled NCD screening tool using the WHO Classification of Digital Health Interventions v 1.0 [Org18]. The WHO classification scheme names and describes components in a generic digital health intervention. We selected components involved in the AI-enabled care pathway, added additional new components where necessary, and grouped components into the phases of the AI development, implementation and integration lifecycle. Further, we interlinked components where there were inter dependencies across phases. This technology system is presented in 2 ways: the first being Table 7.2, that details each technology component. The "Software Interfaces," column alludes to the connectedness between individual components that is needed to carry us from the creation and maintenance of an individual screening tool to the eventual care delivery that can impact outcomes. The last column, "Human Interfaces," describes the main human actors that use that component. Below, we describe each of the components, and ensconce them in the lived realities of working at the margins as shared by our interviewees.

Cohort Data Collection Cohort data collection is crucial for ensuring that AI models are unbiased and accurately incorporate locally-relevant risk factors. This is the only way to build applicable tools to local contexts. The data collection process not only helps improve the model's performance but also offers a foundation for understanding health status a priori and comparing outcomes after an intervention in the case of a smaller study. However, data collection presents challenges, particularly in defining what data to collect and how to collect it. A3 highlighted, "When providing mHealth, the data pool is haphazard and ununified. There is no centralized system [...] it is difficult to formalize." Additionally, data collection efforts often fall on already overburdened CHWs, who face resistance from rural people wary of sharing personal information. As CL2 noted, "If we are [providing some information], but there is some seller who calls and says that it's time to do service for your car, we really don't like it. Isn't it? When we tell the patient that [data collection] is something we are going to do and they agree to it, have they actually agreed to being a part of that [AI]? That is the problem that is going to happen when we are going to scale things up." Further complicating matters is the digital divide. Some patients, particularly in rural areas, lack the necessary familiarity with technology, making mobile-based data collection less effective. As PS1 explained, "For them, a mobile phone is only to say hi hello and nothing more [...] Even the youth don't utilize it properly so there are no chances of mothers and elderly people using it [to provide data]."

Model Development & Validation Model development in AI-based care requires robust hardware and software systems to process large datasets and train models and carry out clinical validation studies. Developing models locally is essential to avoid dependence on black-box

	Component	What	Software Interfaces	Human Interfaces
A	Cohort Data Collection	Collect & validate datasets from diverse cohorts with features explicitly or implicitly linked to NCDs	D, C	Data managers, CHWs, Patients
B	Model Development & Validation	Build and evaluate AI models that screen for NCDs based on highly localized risk factors	A, E, J	Engineers, Data managers, Doctors
C	Model Deployment & Governance	Analyze & monitor the creation and performance of tools deployed across the health system	B, E, G, J	Government officials, Data Managers
D	Patient Data Collection	Collect patient information at the clinic through software and devices	E, G, H, I	CHWs, Nurses, Doctors
E	Risk Stratification	Screen for the NCD using patient information	D, F, K, G	CHWs, Nurses, Doctors
F	Triage & Referral	Triage and refer patients to appropriate care	E, K, G, I	CHWs, Nurses, Doctors
G	Health Record Maintenance	Maintain persistent patient records	E, I, C	Health workers, MoH employees
H	Patient Outreach	Identify and attract diverse patients to clinic	A	Health workers, MoH employees
I	Patient Followup	Identify and reachout to patients with low adherence or loss to followup	E, F	Health workers
J	Provider Growth	Train, supervise, and assess health worker use of tools	F, J	Health workers, MoH employees
K	Inventory	Understand the state of software, hardware and devices, as well as medication and materials	F, J	Health workers, MoH employees
L	Health System-Level Analysis	Measure impact of the interventions over time	A, G, I	MoH employees, CHWs

Table 7.2: Components in a generic AI-enabled screening system

tools, which can have significant health implications. Cost is a barrier in this aspect as well - A2 mentioned, “In a developing country like Nepal, to bring highly accurate technology may be difficult but if there is a cheaper technology that gives 85% affordability then it can be considered.” but then pulled back, saying "We can say false positives but one small mistake can lead to someone’s death [...] after creating [the tools], we need to test it locally." However, the lack of local resources often leads to outsourcing data for model development, raising concerns about privacy. PL2 pointed out, "So many things are there which patient’s can only share with the doctor such as diseases related to private parts, STDs. In these cases we must be able to maintain privacy. If we look at it holistically, the Government takes the ownership but Nepal doesn’t have its own servers. All our data is stored in servers of India or any other third country. To bring that in Nepal and strengthen it more is needed.” Successful model development demands coordination between diverse stakeholders, including healthcare professionals and IT specialists. A2 emphasized, "It requires a combined effort by an IT specialist and a healthcare specialist. If everyone stays together, defines a mutual goal and works together then there is no problem in the technological aspect."

Deployment & Governance Deployment and governance systems ensure the safe and effective use of AI tools by selecting appropriate sites, setting appropriate thresholds and monitoring model performance. These systems constantly analyze whether interventions are working as expected, and when necessary, they signal reconfiguration or retirement of tools that are not performing adequately. Governance challenges are significant, especially when policies are decoupled from their implementation. A1 highlighted, "The government has designated hospitals and health posts in all areas, but who is there to check it? Is there a doctor? A new nurse? With AI, there are many things we could do, such as recommendations - but who checks? Policies alone won’t work; there should also be monitoring and evaluation." Customization needs across diverse geographies within a country complicates deployment. As A2 mentioned, "If the Nepal government makes a generalized system that works in every ward [...] then I think it will be durable." Scaling a governance system also requires strong coordination, which is often lacking. A2 likened it to growing a flower, stating, "We need trust, collaboration, coordination, and mutual understanding [...] The most difficult aspect is managing the technology, innovation aspect, healthcare, and raising awareness in the public."

Patient Data Collection The patient data collection component at clinics or through CHWs' devices in peoples' homes are essential last mile tools for documenting patient conditions and feeding that data into the risk stratification models. However, the material issues of technology availability and provider time present themselves yet again in this part of the process. CHWs often face practical challenges when required to use multiple apps for different health needs.The CL1 highlighted, "If I have to open separate apps [...] I'd become overwhelmed and probably wouldn't open any apps at all." For these systems to be effective, they must streamline data entry and be designed with the CHWs' workflow in mind, reducing their burden and increasing the sustainability of the screening process.

Health Record Maintenance Maintaining health records allows providers to track patient progress, particularly for those who screened positive for NCDs, and ensures that patients receive proper follow-up care. Despite the benefits, budgeting for health record systems poses a significant barrier. A2 noted, "The conclusion was that it requires money [...] the province government is not ready to pay for that, and the local government is not ready to take ownership because of budgeting issues."

Risk Stratification The risk stratification component involves clinically validated AI models that analyze patient data to offer recommendations based on established policies. A major challenge lies in determining which healthcare workers should use these tools. For instance, CHWs, who are often overburdened, may require firm thresholds and limited decision-making authority. Ethically, it is challenging to leave them with flexibility in disease scenarios that they may not be used to encountering and treating. While it seems dicey to put them in this position in the first place, for most people in remote areas, the alternative to CHW-led, AI-enabled care might be no care at all. On the other hand, more experienced doctors may benefit from flexibility baked into AI tools. As HP1 stated, "We should have flexibility in terms of decision making for health workers who can use their clinical expertise and experience." Risks and thresholds are acted on differently by different workers, and therefore coordination with users is crucial, and A3 highlighted the importance of creating tools that are easy to understand: "Tools in AI-based approaches should be simple to operate [...] It should be simple, minimal, and understandable throughout."

Triage & Referral Triage and referral systems manage the next steps for patients screened as positive. These systems ensure that patients are referred to appropriate care facilities and may include creating appointments or suggesting interim lifestyle changes. However, geographical disparities complicate this process. A1 explained, "A single strategy won't work for all seven provinces [...] we would have to apply different strategies based on the conditions of the province." The ethics of screening without sufficient follow-up infrastructure is also a concern. Some interviewees questioned whether AI systems should be allowed to screen patients if there is no downstream capacity for treatment in some of the provinces.

Patient Outreach Patient outreach systems support health workers in reaching out to patients who need to be screened first time or followed up on for a rescreening after adequate time. Automatic SMS systems were discussed that reach out to patients en masse and invite them for screening. However, text message notifications may also cause unintended stress or fear among patients. A3 highlighted, "We cannot assume that nothing bad will happen. While sending a SMS we assume there will be no mental stress, but it could be. If we talk about such a policy there should be ethics." Outreach can be particularly difficult in rural areas, where many individuals lack access to or familiarity with mobile technology. HP3 pointed out, "There are so many people who cannot use mobile phones, who do not know how to use Viber, WhatsApp, and other forms of technology. That is one of the challenges that might come ahead especially when we think of implementing it in the rural part of our country. People there are not so educated, and the health literacy is very low there. So, especially limited access to the internet and affordability of technology will cause inequality. M-health is the important component I believe that has to be launched for the research projects but how you judiciously use it in different contexts is a very crucial part." This alludes to the lack of equity in technology access and how the introduction of AI-enabled screening tools without proper patient outreach structures will further magnify health disparities and outcomes. To combat these effects, users need to be reached in person, causing significant additional labor to CHWs.

Patient Followup Follow-up systems track patients who have been screened as positive, ensuring they receive the necessary treatment or lifestyle interventions. As A3 mentioned, "Challenges after the screening are in behavior modification," which alludes to a set of arduous tasks that some last mile health workers must take on with each patient in the system who needs support. This process requires frequent contact with patients, and peer-to-peer communication has been highlighted as an effective strategy. One participant noted, "Peer-to-peer communication was very strong [...] we observed 76% acceptability of information with peers, but we also did random sampling where the health workers used to communicate with the clients, and we only observed 54% acceptance. I think we should work on how to capitalize the networks and enhance the use of technology." Part of the art of following up is understanding why people may not be receptive to follow up, therefore spending resources designing follow-up systems that accommodate diverse populations is also essential. Some patients may struggle with typing, and as such, several interviewees suggested that voice-enabled features could enhance accessibility for older individuals.

Provider Training & Growth Monitoring Provider training systems ensure that healthcare workers are prepared to use AI tools effectively, respecting the labor that goes into screening. Interviewees mentioned how challenging training is and that training must be tailored to the specific needs of health workers. A1 highlighted, "There's a lack of training. But whom to train? While working on a project, I was told, "Sir, there are lots of training programs like these." There are many training programs, but where is the improvement? There's a massive investment in training, but what has changed?" Therefore designing training in itself is complex and labor intensive. Once the training is complete, there needs to be supportive supervision of tool use over time. New tools are taxes on health worker time and energy so there is inherent inertia in workers that are overburdened. In the words of A3, "We bring the concept of "volunteer" to support maternal child health. I am not very fond of the term volunteer. We are calling them volunteers but we are giving every policy and program to them. They also should be motivated professionally. There should be different cadres and we have to train different cadres because we can't remunerate them much and there will be workload. I feel like it is exploitation of resources if we do it that way. If we are bringing any program to the community they should have motivation to learn because if there is no motivation program will fail. Their literacy, motivation, background support and help make any program to be successful." One way to support the CHWs through this form of system (after creating a broader structural way to compensate them) is to create avenues that bear witness to the professional aspirations. PS1 said, "We provide everyone, including CHWs, with a dashboard. It allows them to track their own performance, such as how many houses they've covered, what diseases they've screened for, and how much work remains. This is the accountability for them. There is another dashboard for health facilities, municipalities, and the federal government, which provides them with feedback. If health facilities consistently check the dashboard, they can easily monitor which health workers are actively working and assess their performance. Similarly, municipalities can track health facility performance. However, it has its challenges. Theoretically, this all sounds good, but in reality, the dashboard often remains unused. People would rather open Facebook than the dashboard, and when asked about it, they claim there was no internet. So, who is responsible for maintaining this accountability?"

Inventory Inventory systems ensure that health facilities and AI tools have the necessary supplies and functionality. Proper inventory tracking helps ensure that AI tools themselves are running optimally. This includes ensuring software updates are regularly installed and hardware is maintained to prevent breakdowns. Inventory management systems must be up-to-date with patient care pathways, especially in resource-constrained settings where stockouts are frequent. Proper tracking and restocking procedures will play a crucial role in determining the long-term success of AI tools in impacting outcomes.

Overall, as can be seen in the imaginaries, there is a web of interconnected hopes and dreams that AI systems will overcome challenges and limitations with the current health system. However, as in the words of A3, "The system is such that if you want to change it, the system itself makes it difficult for you." Each component in the technology pipeline needs to be created and maintained within the same human and technology infrastructures that are currently in place. Even in light of all of these challenges, all interviewees had the belief in a technology enabled future of health. As PS2 put it, "When we think about alternatives there are not any, so being hopeful is mandatory. There have been so many hopeless situations, we feel that it could have been much better but it didn't happen. [...] But from a leadership point of view what I see is that there is a wonderful opportunity after decentralization and that there has been built of local accountability. [...] If we think of health technology as replacing paper with mobile and computer, then we will consider that paper is more convenient. We have no idea about what the change can do and by utilizing the tools how high we can reach."

7.4 Critical Insights

Health leaders in Nepal envision AI as a transformative tool for expanding healthcare access, particularly in diagnosing and managing non-communicable diseases, yet their expectations often exceed the current technological and infrastructural capabilities. This interview study juxtaposes the imaginaries of AI-enabled care with on-the-ground health system constraints, providing a structured approach to assessing the feasibility and potential impact of AI-driven interventions before scaled deployment into an extant healthcare system.

Chapter 8

Conclusion

This dissertation takes a careful, iterative approach to building, contextualizing, and scaling mobile and AI-based ICTs that can support the improvement of health & economic outcomes in LMICs.

My work in AI-based diagnostics (Chapters 2, 6, and 7), begins by building a community health worker centered AI model that can help expand atrial fibrillation screening to rural areas lacking dedicated cardiovascular care. Moving beyond simply providing an accurate diagnostic output, I study an LLM-based diagnostic chatbot in context to understand how patients would react to clinically validated diagnosis and treatment where it is not the norm in the surrounding healthcare landscape. Through a two phase experiment with Indian adults, I find that a majority of our participants reject bots providing clinically validated advice, limiting the potential for these bots to expand access to quality care in their current form. However, appending context-aware nudges into the bots' dialogues shows promise to bridge the gap between accuracy and acceptability in the Indian healthcare context. To explore scaling the impact of such ICTs, I analyze interviews with Nepali health officials to understand how such diagnostic tools may fit into health systems at large. By identifying officials' imaginaries of such tools, and juxtaposing them with health system realities, I contribute a methodological tool to evaluate whether AI-enabled ICTs can better health outcomes in a given sociotechnical context.

My work in agricultural information systems (Chapters 3, 4, and 5) begins with a large, scoping survey and focus groups to understand mobile technology access and use by rural farmers and periurban entrepreneurs in Tanzania. With cognizance of the nuanced landscape, we build a dual-platform agricultural directory through which farmers can access information on 10,000 agricultural businesses. Deploying our directory to 1000 farmers in 100 villages helps us contextualize use (and non-use). We identify that the vast majority of farmers (even smartphone owners) choose to use our USSD app even though its user experience is limited at scale due to the underlying protocol. In response to these findings, we reconceptualize mobile money agents as general ICT intermediaries due to their fluency in navigating USSD tools. Through the creation of this intermediary infrastructure, we pave the way to broaden our ICT's impact to the most vulnerable farmers that would otherwise still be unable to access critical information they need to improve their economic outcomes.

Taken together, these two bodies of work contribute a nuanced perspective on when, where and how ICTs can (and cannot) drive meaningful, scalable impact on human outcomes at the margins.

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