Using Remote Tracking Technologies to Audit and Understand Medicine Theft

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Medicine theft is a leading cause of inadequate healthcare. Audits of public health supply chains suggest that up to a third of medicines go missing in low income countries, disproportionately affecting those facing greater health risks and poverty. Despite much investment, policymakers struggle to identify and prevent theft due to the opaque and highly distributed supply chain in most low-capacity health systems. We propose a technology-based audit tool – a "remote tracking audit" – to address these challenges and to provide new insight into the causes and consequences of theft. We evaluate this tool in Malawi, a context where over two-thirds of communities have observed the illegal sale of medicines. We partner with the Ministry of Health to place electronic tracking devices in 2,387 medicine boxes. The devices provide real-time data on medicine locations and provide some of the most comprehensive estimates to-date on the scale, timing, and consequences of medicine theft. We estimate that 35% of medicines go missing. Most theft occurs after deliveries, presumably by public health staff. However, supply chain error is the most common cause of missing medicines. We show that patients experience higher stock outs and pay more for medicines near facilities with more theft. These findings confirm that theft is a severe public health problem, but suggest policymakers could productively redirect anti-theft investments towards closing supply chain gaps. The study also illustrates how remote tracking technologies can be an effective tool in the anti-theft arsenal.

corruption | health systems | drug theft | monitoring | Malawi

Medicine theft is a leading cause of preventable disease and has been linked with increased mortality in many low income countries (1–3). In Malawi, where our evaluation takes place, Ministry of Health officials estimate that 29% of spending on medicines and medical supplies disappears due to theft alone (4). Our own survey work indicates that 75% of all communities in Southern Malawi have observed the theft of medical supplies. While Malawi is one of the world's poorest countries, these estimates are similar to estimates in other countries with low-capacity health systems (1, 5–13).

Medicine theft costs governments and donors many billions each year between lost medicine and spending on supplemental supply chain oversight (9, 14–19). Medicine theft and other health sector corruption has been linked to higher infant mortality, maternal mortality, HIV transmission and poverty (17, 19–21). Further, the burden of this theft falls most heavily on vulnerable individuals, who have fewer resources with which to acquire needed medicines (19).

The persistence of widespread medicine theft is partly due to the difficulty of detection (14, 22). Traditional detection technologies – like audits and hotlines – struggle to detect theft within the kind of distributed and opaque supply chains that exist in many low-capacity health systems. Thus, officials often face little risk that theft will be detected – and therefore punished. Further, without accurate detection, communities and policymakers cannot determine the scale and consequences of theft, precluding effective theft mitigation strategies. Indeed, despite the consequences of medicine theft, global and national estimates of theft and its consequences vary to the point of often being unusable for policy (15).

Why is detection so challenging? In its reduced form, a "traditional audit" involves human auditors inspecting government records to identify gaps and anomalies and then assessing which of these gaps and anomalies are attributable to corruption. There are at least three challenges with these traditional detection technologies in the context of public health and other opaque and geographically distributed supply chains.

First, audits rely on the accuracy of official records (i.e., the auditable "paper trail"). In many low-capacity health systems, the accuracy of such records depends on officials with little technical training. Moreover, checks in the system are often insufficient to ensure compliance with documentation requirements and dishonest or incomplete records are often the norm. Officials who steal medicines can protect themselves by deleting or introducing inaccurate information to cover their theft (23–25), making theft a low-risk/high-reward option (26, 27). For instance, a 2019 audit in Malawi found discrepancies in the stocking records of 96% of audited clinics (28).

Second, traditional audits struggle to detect theft at multiple points in the supply chain and differentiate theft from error. Medicine supply chains are inherently complex, encompassing a variety of products, extensive geographic spread, and numerous organizations (1, 29). Many traditional audits only aim to identify whether medicines intended for a clinic actually arrive (detecting what we call "upstream theft"). Yet, as we show, most medicine theft happens downstream from the point of delivery: for example, clinic employees will resell medicines to private pharmacies. Such "downstream theft" is often difficult or impossible for existing audit technologies to detect. Relatedly, traditional audit technologies also struggle to distinguish between theft and error (e.g., mistaken deliveries) (30, 31). As we show below, the primary reason medicines are not delivered correctly in Malawi is error rather than theft. Technologies that rely on end-to-end monitoring – e.g., using scanners and QR codes – have mitigated this problem (26, 32). However, end-to-end monitoring is not feasible in many low-income contexts due the capital, skill, and infrastructure required for such solution to work, and remains prone to error and manipulation, particularly after the point of delivery.

Third, traditional audits cannot provide data at scale or in real time. Because of their expense and effort, traditional audits tend to happen weeks (or months) after a medicine delivery occurs and only target a very small proportion of health facilities. Low-scale audits

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mean that perpetrators can often avoid detection by shifting theft to places more difficult to audit. Lack of timely data makes it hard for oversight bodies to follow-up up on irregularities or address supply chain loopholes through policy. (33).

In this study, we propose and evaluate a corruption detection approach that addresses all three of these traditional audit weaknesses. Through this approach, we also contribute new and accurate data on the scale and patterns of medicine theft. Specifically, we adapt an automatic identification and data capture (AIDC) system that combines GPS and Bluetooth tracking units placed throughout the medicine supply chain. We then perform a multi-stage "remote tracking audit" to detect the scale and points of diversion,[*] as well as the ultimate destination for the diverted medicines. This approach is more scalable, timely, and cost effective than traditional audits.[†] Further, our approach allows us to detect forms of diversion that go undetected in traditional audits and distinguish between error and theft.

We conduct a scaled evaluation of the remote tracking audit approach in Malawi, a country that has persistently struggled to secure its medicine supply chain. Malawi is a particularly compelling case to examine how low administrative capacity confounds traditional audits.[‡] We cross-validate the remote tracking audit data with survey data and outdated traditional audit data to show that remote tracking audits appear to correctly characterize the probability of medicines going missing. We also demonstrate that remote tracking audits can identify points and forms of diversion that are invisible to traditional audits. To our knowledge, we are the first to deploy electronic tracking technologies as a tool for conducting independent audits of medicine theft in developing countries.[§]

We use data from these remote tracking audits to shed new light on patterns and persistence of medicine theft. Perhaps most consequentially, we show that medicines are much more likely to go missing after delivery is complete (downstream diversion) – rather than during the delivery process (upstream diversion). Downstream diversion is unlikely to be detected or deterred by traditional audit and anti-corruption interventions. We also use the remote tracking audit data to differentiate between supply chain error (i.e., inadequate or inaccurate supply chain management) and definitive theft: we estimate that supply chain error – rather than theft – explains almost all the diversion that would be picked up by a traditional audit, implying that existing studies overestimate and misidentify patterns of corruption.

Remote Tracking Audits

Our theft detection approach was developed in collaboration with the Malawi Ministry of Health, the Malawi Drug Theft Investigations Unit, and a technology company – OnAsset Technologies (USA). The approach was designed to audit the medicine supply chain from the Central Medical Stores Trust (CMST) warehouse to health facilities in Malawi's Southern Region. In an upstream remote tracking audit, we placed tracking devices in 2,387 medicine boxes being delivered to Malawi's Southern Region health facilities (N=174 facilities).[¶] In a subsequent downstream remote tracking audit, we audited a representative sample of 104 of the recipient health facilities, 143 private pharmacies and markets, and 40 health facilities that should have received redeliveries from district health offices (DHOs). This multi-level remote tracking audit provides a real-time snapshot of the entirety of the medicine supply chain, allowing us to identify diversion during the delivery process (upstream diversion) and after delivery is complete (downstream diversion). Figure 1 shows a map of the remote tracking audit activities.

The audit protocol involved two types of OnAsset tracking devices:[‖] (1) SENTRY 500; and (2) SENTINEL. The SENTRY 500 is a cellular and GPS tracking device. It is the "parent" device. The SENTINEL is a "child" Bluetooth device automatically read by any SENTRY 500 within its transmission radius (300m). Each SENTRY 500 unit captures and transmits data from itself and all surrounding SENTINELS to the server at regular intervals. Cellular and GPS technologies of this sort were intended to provide real-time monitoring of distributed supply chains. We are the first to adapt this technology to measure corruption.

Upstream Remote Tracking Audits. The upstream remote tracking audits were intended to identify medicines that are diverted during the delivery process (Upstream Diversion). These audits occurred in October and November of 2021. Using health facility orders provided to us by the Ministry of Health, and drawing on survey and interview data, we sampled eight medicines that are both commonly ordered and commonly diverted (Table 1). At most facilities, we tracked all orders of these medicines.[**]

In partnership with the Ministry of Health, we accessed the warehouse that is responsible for delivery of medicines to public health facilities in the Southern Region. A team of 14 people from a third-party logistics company, overseen by our research team, placed SENTINEL tracking devices in the packaging of targeted medicines during the normal shipment preparation process. Medicines were intended for delivery to 170 facilities, ranging from large district hospitals to small local health centres. The devices were attached to pill bottles or placed in boxes for non-bottled medicines.[††]

The SENTINEL devices were covered with a sticker stating each device was a "SHIPPING TEMPERATURE & HUMIDITY MONITORING DEVICE" and property of the Ministry of Health. The sticker also instructed officials to not remove the device from the packaging.[‡‡] These instructions were intended to discourage officials from disposing of devices.

In a parallel process, the same team placed two SENTRIES on each delivery truck.

Table 1. Tracked Medicines

Medicine Description	Number of Tracked Boxes
1. Amoxicillin: Bottle of 1000 250mg capsules	89
2. Aspirin: Bottle of 1000 300mg tablets	402
3. Ibuprofen: Bottle of 1000 200mg tablets	786
4. Insulin: Bottle of 10 ml of 100 IU/ml zinc suspension	3
5. Paracetamol: Bottle of 1000 500mg tablets	519
6. Phenobarbital: Bottle of 1000 30mg tablets	166
7. Syringe: 10ml	235
8. Syringe: 5ml	170

[*] Throughout this manuscript, we use the word "diversion" to refer to an instance of a medicine being located somewhere other than its intended public health facility. We reserve the word "theft" for use in instances where we can confirm a diverted medicine is found in a private business or home.

[†] See the SI for cost details.

[‡] See the SI for a discussion of the health system and the institutional challenges in the Malawian context.

[§] For a review of other ways mobile technologies have been adapted to prevent corruption in the health sector see (26).

[¶] 86 devices could not be tracked due to entry error or device failure; so our final sample includes 2,299 devices.

[‖] See the SI for images of the devices.

[**] Officials were instructed to place devices on a maximum of 30 units intended for clinics and 50 units intended for district health offices. This usually encompassed the entire order.

[††] All prescribed medicines are repackaged at dispensaries, so no tracking devices ever ended up in the hands of patients or went missing due to prescriptions.

[‡‡] See the SI for images of the stickers.

Downstream Remote Tracking Audits. After all deliveries were complete, two audit teams began in-person, anonymous, downstream remote tracking audits. The goal of these downstream audits was to validate deliveries and to determine whether tracked medicines had gone missing after the point of delivery.

We conducted downstream remote tracking audits at three kinds of facilities. First, auditors visited a randomly sampled 138 of the 170 public health facilities that should have received deliveries of the tracked government medicines. These audits were intended to determine whether medicines that had been correctly delivered upstream remained at the correct facility in the following weeks. To audit each of these public health facilities, auditors placed a SENTRY inside a generic backpack. The auditors then slowly walked around the facility, pausing for 10 minutes at all pharmacies, dispensing, and warehousing areas.

Second, auditors visited 144 private pharmacies and markets near each public health facility.[§§] The goal of these audits was to identify instances of theft: where medicines were being sold for a profit in private facilities. During these audits, the auditors were likewise instructed to circle the facility, pausing at all areas where medicines were possibly being sold.

Finally, auditors visited 40 public health facilities that requested medicines from their district health office (DHO) rather than directly from CMST.[¶¶] Such peer-to-peer orders are a common way for smaller, more remote public health facilities to obtain needed medicines. In interviews, public officials identified such redeliveries as a common point of theft, in part because paperwork for such redeliveries is often incomplete and easy to falsify. The goal of these audits was to identify how frequently medicines go missing through peer-to-peer channels.

Data from SENTRY devices were monitored in real-time to ensure sample and protocol compliance.

Health Facility Surveys

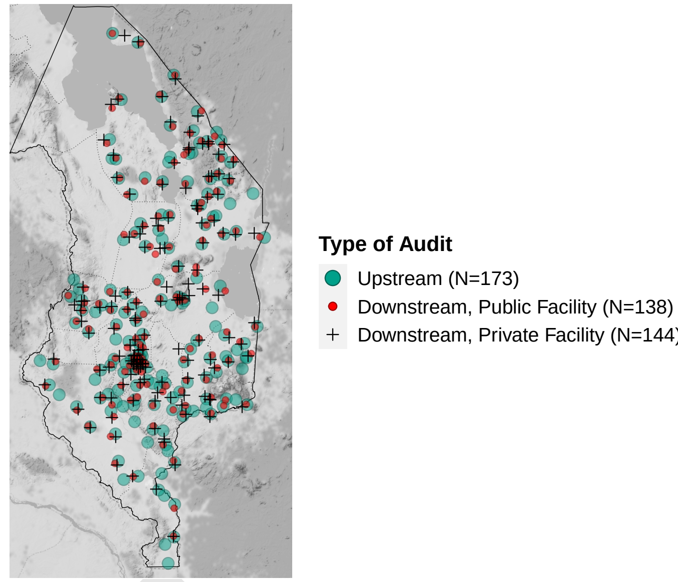
Prior to beginning our audit, in January-March 2019, we conducted an in-person survey with Malawian citizens in the catchment areas of a random sample of 97 health facilities in Southern Malawi. The surveys were conducted in person with trained Malawian enumerators and available in English and Chichewa. At each sampled health facility, we recruited two distinct groups of participants for the survey. First, the enumeration team completed a random walk sampling protocol to recruit 35 individuals living within 10 km of the health facility. This resulted in a sample of 3,360 individuals who completed a survey containing 61 questions regarding patient experiences at the facility, focusing on their observations and perceptions of theft, as well as a list experiment to measure the prevalence of public medicine resale and 14 questions for the enumerator about the survey context. Second, the enumeration team used a purposive sampling procedure to recruit three individuals affiliated with the facility's citizen oversight committee (the Health Centre Advisory Committee). This resulted in a sample of 281 individuals who completed a survey containing 20 questions regarding the operations and activities of the committee.

These survey data confirm that theft is a significant problem. An estimated 50% (± 5%) of respondents across 79% of facilities have observed the illegal sale of medicines that should have been provided for free.

[§§]The auditors inconspicuously asked at each clinic where the nearest private market or pharmacy was where they could purchase medicines, and subsequently visited all identified locations. Additionally, an auditing team visited five facilities identified during the upstream remote tracking audit as potential locations for diverted medicines.

[¶¶]With the assistance of the Ministry of Health, we identified all facilities that requested tracked medicines in 4 out of the 11 districts in Southern Malawi. See the SI for details.

Fig. 1. Map of Remote Tracking Audits



Note: This is a map of all audited facilities in Southern Malawi coded based on the type of remote tracking audit conducted.

Findings of Upstream Remote Tracking Audits

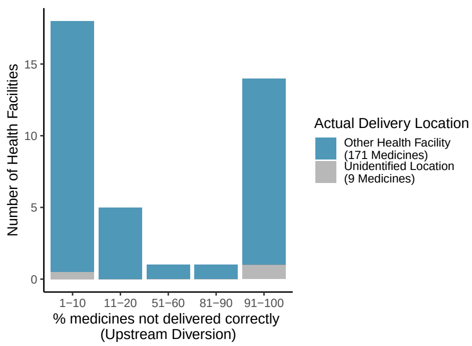
Using the upstream remote tracking audit data, we create the variable *Upstream Diversion*. This variable equals zero if a medicine box was correctly delivered to the health facility that ordered the medicine and equals one if a medicine was delivered somewhere else. We are able to identify deliveries for 2,060 medicines (90%). The delivery status of the remaining 10% of medicines could not be determined precisely, primarily due to poor cellular and GPS coverage (see the SI).

Our upstream audits reveal interesting patterns in upstream diversion at the facility level. The vast majority of health facilities (77%) experienced no upstream diversion. Still, 23% percent of facilities (39 out of 173 facilities) experienced some upstream diversion, meaning they did not receive their entire delivery of medicines. Within this set of facilities that experienced at least some upstream diversion, it affected either very few medicines (18 facilities) or almost all medicines (14 facilities): Figure 2a provides a histogram of Upstream Diversion calculated at the clinic level. Many of the facilities experiencing higher rates of Upstream Diversion are in remote or border areas. This is consistent with generally lower levels of service delivery in remote areas of Malawi (34).

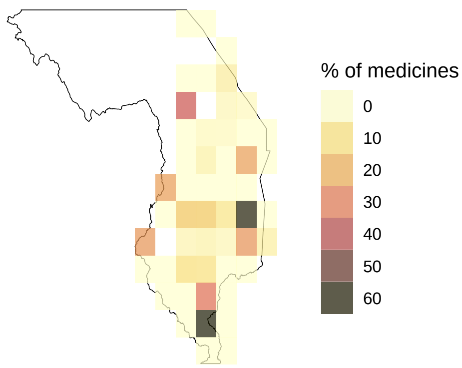
In order to differentiate between theft and error, we classify upstream diversion into cases where a medicine was plausibly delivered at a public health facility versus cases where a medicine was most likely delivered at a location that was not a public health facility (Figure 2a). Nearly all (95%) instances of Upstream Diversion were cases where the medicine was likely delivered to a public health facility, just not the intended one. Only nine medicines were likely not delivered to a known public health facility. While delivery to a public health facility does not preclude theft, these data suggest that most cases of Upstream Diversion are due instead to supply chain error.[***]

[***]We code a medicine as delivered to a health facility if there was a health facility within the confidence interval of the final delivery coordinates. Since this is an estimate, we expect a small amount of classification error. Thus these data are also consistent with *all* deliveries occurring at a public

Fig. 2. Patterns in *Upstream Diversion* (Medicines Missing During Upstream Remote Tracking Audit)



(a) Histogram of Upstream Diversion



(b) Map of *Upstream Diversion*

Note: The top panel shows the distribution of *Upstream Diversion* percentages by health facility (excluding cases of no diversion). Blue indicates the share of medicines that likely went to the incorrect facility. Grey indicates the share where we could not determine the location due to the lack of a proximate health facility at the delivery location. The bottom panel shows a heat map of *Upstream Diversion* percentages for each 30km area.

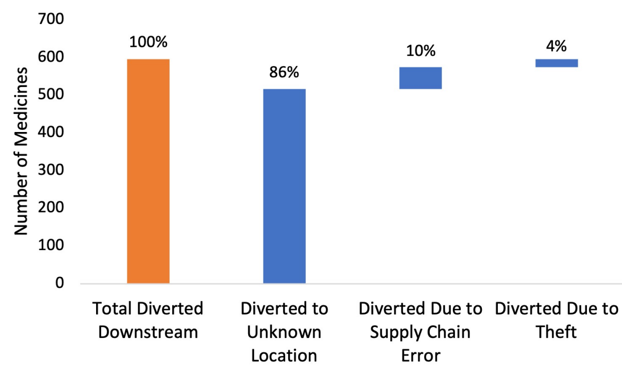
Findings of Downstream Remote Tracking Audits

Using the data from the downstream remote tracking audits, we create the variable *Downstream Diversion*. This variable equals one if a medicine was correctly delivered to its intended public health facility (i.e., not diverted upstream) but then was *not* subsequently found at that facility during the downstream remote tracking audit. It equals zero if it was correctly delivered and then found at that same facility during the downstream remote tracking audit.

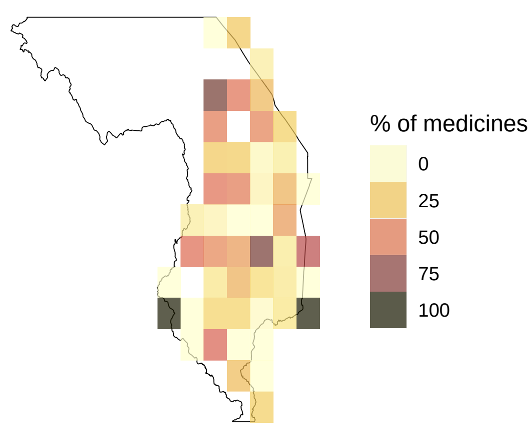
We find 566 instances of Downstream Diversion, which amounts to 32% of the medicines that were not diverted upstream. 80 of the 133 health facilities audited during the downstream remote tracking audit experienced some downstream diversion, meaning that more than half (60%) of facilities were affected by downstream diversion. As with Upstream Diversion, we find some geographical clustering of Downstream Diversion, particularly around facilities in border and remote areas (Figure 3b).

Based on the downstream remote tracking audits, we can glean some information about the destinations of these medicines diverted downstream. Figure 3a disaggregates the set of medicines diverted downstream into three categories: those that were not found in the downstream remote tracking audit, and are therefore in unknown locations; those that were found at other (incorrect) public health facilities, and whose diversion is most likely due to supply chain error; and those that were found in private businesses or homes, and whose diversion is most likely due to theft. Out of the 573 medicines that were not located during the downstream remote tracking audit, the majority (86%) of these could not be found. Out of those that could be found, 71% were found at at an incorrect, but still public, health facility. Only a minority – 29% of the downstream diverted medicines that could be found and a mere 4% of the downstream diverted medicines overall – were found at a private facility and therefore were plausibly stolen. We also provide a mode complete summary of the final location of all tracked medicines in the Sankey diagram in Figure 5.

Fig. 3. Patterns in *Downstream Diversion* (Medicines Missing During Downstream Remote Tracking Audit)



(a) Final Destinations of Downstream Diverted Medicines



(b) Map of *Downstream Diversion*

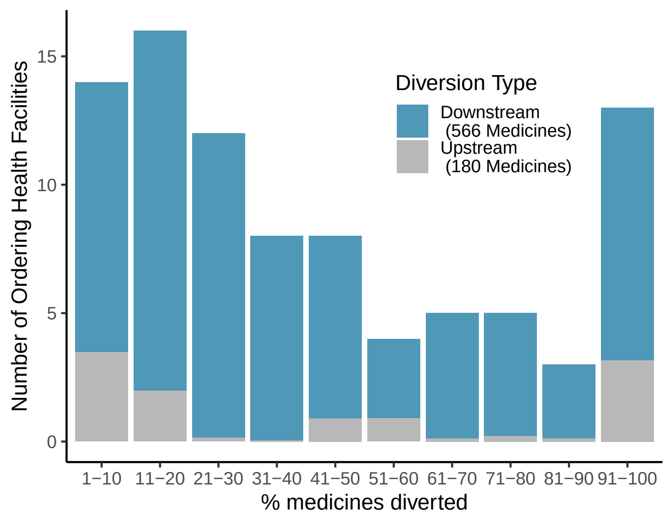
Note: The top panel shows a breakdown in final destinations of the medicines diverted downstream. The orange bar represents the total set of medicines diverted downstream and the blue bars show the subset of diverted medicines for each of three destinations: unknown locations; other public health facilities; private businesses and homes. The bottom panel shows a heat map of *Downstream Diversion* percentages for each 30km area.

We find more evidence of downstream diversion than upstream

health facility. See the SI.

diversion. In Figure 4, we plot the percent of medicines diverted by clinic and diversion point (downstream vs. upstream). Out of the 746 medicines diverted, 76% (566) went missing downstream: after having been successfully delivered. In total, upstream diversion only explains about 20% of the clinic-level variation in total diversion ($R^2 = 0.20$). Though we emphasize that some public health facilities are experiencing upstream diversion of almost all of their medicines (the far right bar in Figure 4).

Fig. 4. Histogram of Diversion: Downstream vs. Upstream



Note: This figure shows the percent of diverted medicines by number of health facilities (excluding cases of no diversion). Blue indicates the share of medicines that went missing due to downstream diversion. Gray indicates the share of medicines that went missing due to upstream diversion.

Medicine Diversion After Redelivery. As discussed above, medicines are sometimes redelivered from district health facilities (usually hospitals) to other health facilities. Our data suggest a high risk of theft in these transactions: In the four district in which we audited redeliveries, we identified 39 tracked medicines which were eligible to be redelivered.[†††] We were only able to locate 7 of these (18%) at the correct receiving facility (see the SI).

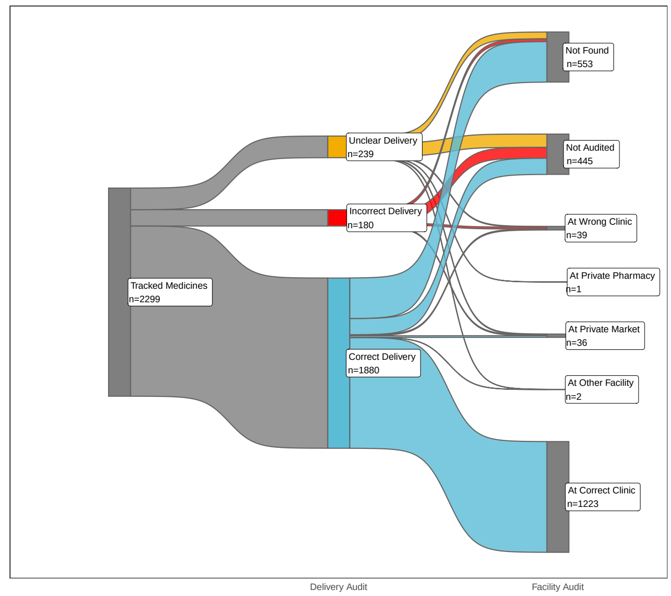
Validation of Remote Tracking Measures

Our measures of diversion correlate with alternative measures of theft. First, we compile data from facility-level audits conducted by the Malawi Ministry of Health and show that our measures of diversion predict the number of medicines missing in these traditional audits (see the SI). Second, we validate using data from our facility survey: we observe positive correlations between our measure of medicine diversion and indicators from the baseline survey with citizens, including an index of theft perceptions, in which higher values indicate greater signs of theft by respondents (see the SI). For instance, we observe a strong correlation ($\beta = 0.82$, $p = 0.03$) between the percentage of medicines patients believe were stolen from their facility and the actual percentage of medicines diverted.[‡‡‡] We summarize these correlations in Figure 6.

[†††] We did not audit all redelivery facilities outside these four district so it is possible we misclassify some medicines as missing which were actually redelivered. Less than 2% of the remaining sample was eligible to be redelivered; so any such bias would be very small.

[‡‡‡] We asked patients to describe the last ten medicines requested from a clinic and the share of those that were missing due to stock outs or theft. See the SI.

Fig. 5. Sankey Flow Diagram of All Tracked Medicines



Note: This figure shows the status of all tracked medicines from upstream remote tracking audit to downstream remote tracking audit.

Diversion and Public Health

Our survey data also suggest detrimental public health consequences of diversion on healthcare access. Respondents report that 26% of needed medicines were unavailable at their health facilities. Respondents attribute about a third of these stock outs to theft.[§§§] In Figure 7 Panel A, we compare citizen reports of stock-outs to observed rates of diversion at the facility level. At facilities above the median in stock-outs (where less than 61% of requested medicines were available), we observe 68% more diversion relative to facilities below the median.

In addition to going without medicines, patients often respond to stock outs by purchasing medicines at private facilities. As shown in Figure 7 Panel B, in facilities where the median respondent has paid for non-clinic medicines, we observe 75% higher levels of diversion.

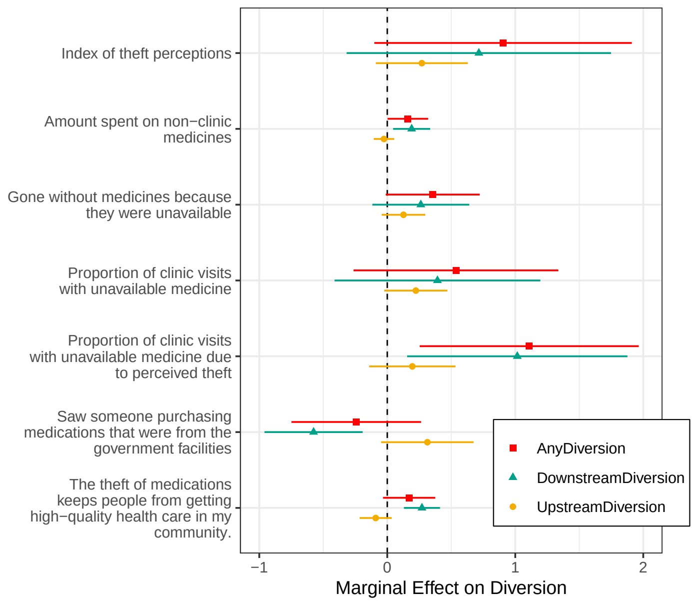
Discussion

Our study offers several policy implications. First, despite substantial investment and funding in supply chain security, medicine diversion is common. Based on the findings of our remote tracking audits in Southern Malawi, 35% of tracked medicines are diverted upstream or downstream in the supply chain. In particular, many facilities in remote areas receive few or none of their intended deliveries, or experience the diversion of medicines after delivery.

However, our findings also suggest that theft is less common than reports based on traditional audits may assert. Our upstream audits suggest almost all missed deliveries are due to error rather than theft. Consistent with this pattern, we find in downstream audits that 10% of diverted medicines were located at other public health facilities and only 4% were found at private facilities. This suggests that

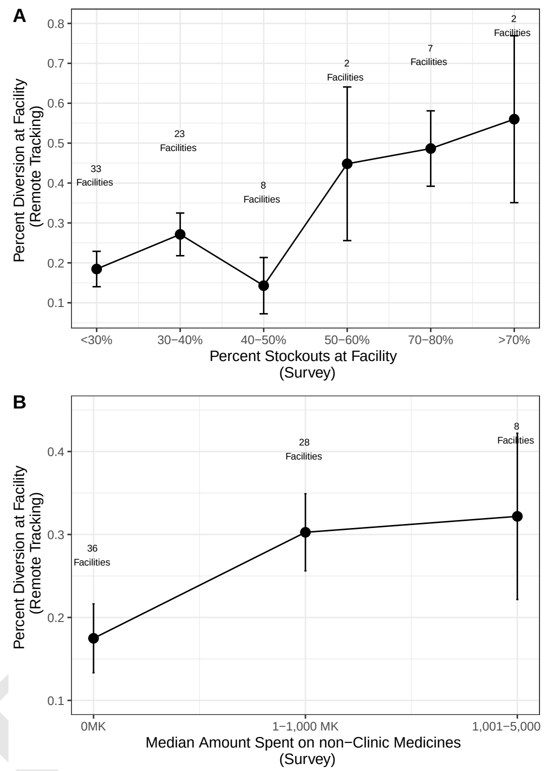
[§§§] Respondents claim 38% of unavailable medicines are missing because they believe “someone stole the medicine.”

Fig. 6. Comparing Diversion and Survey Measures of Theft



Note: This figure shows the coefficients and 95% confidence intervals from separate linear regressions of diversion on each variable listed on the x-axis. The sample includes all tracked medicines. We cluster errors errors on facility and include district and facility type fixed effects.

Fig. 7. Relationship Between Stock Outs, Perceived Theft and Diversion



Note: Panel A compares observed diversion rates (on the y-axis) to patient observations of stock-outs (on the x-axis) with 95% confidence intervals on the level of diversion. Panel B compares the facility median level of expenditure on medicine (the x-axis) to the observed rate of diversion (the y-axis) with 95% confidence intervals.

interventions to improve supply chain operations may be as effective in improving health system outcomes as interventions to combat theft.

Additionally, the results imply that existing anti-corruption interventions focused on theft during delivery are likely to be ineffective. Most interventions in Malawi and elsewhere – e.g., parallel procurement systems, citizen oversight, and physical audits – try to raise the costs of theft during medicine delivery. We find little evidence that such theft represents a significant share of medicine theft or diversion. Efforts to address gaps in accountability and oversight at the facility level and between facility staff are likely to be more effective.

Finally, our research illustrates the value of remote tracking audits for the anti-diversion arsenal. In particular, such tools address many of the weaknesses of traditional audits: remote tracking audits are less prone to manipulation and displacement, more effective at measuring downstream diversion, capable of distinguishing between theft and supply chain error, and more cost effective. This approach is also efficient in a crisis environment when physical audits are impossible (this study was partly motivated by the challenges of physical audits during COVID-19). By offering a low-cost, low-interaction, and easily fielded detection technology, the protocol we developed could be scaled up in similar contexts facing similar health crises.

Materials and Methods

Implementation. This project benefited from partnerships with two government offices in Malawi. The Drug Theft Investigations Unit (DTIU) is a donor-funded government agency housed under the Malawi Ministry of Health responsible for monitoring corruption (specifically theft) in public health supply chain. DTIU leadership were consulted throughout the lifespan of this project, and DTIU officials were particularly involved in the intervention design and execution. In addition, high-level leaders at the Malawi Ministry of Health and the Malawi Central Medical Stores Trust participated at critical junctures of the project, including in the design of the tracking strategy, the supervision of the intervention, and the dissemination of results. Project implementation occurred between November 2018 and April 2022.

Data Availability and Pre-Analysis Plan. Anonymized data files and replication code have been deposited on Harvard's dataverse at https://dataverse.harvard.edu/dataset.xhtml?persistentId=XXXX. This study was pre-registered on the American Economic Association's RCT Registry at https://www.socialscienceregistry.org/trials/3684.

This project was approved by the London School of Economics Science Research Ethics Committee (000790). The Malawi National Health Sciences Research Committee reviewed and approved the project twice: once for the original design in March 2019 and once for the redesign in July 2021.

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1. O Onwujekwe, et al., Corruption in anglophone west africa health systems: a systematic review of its different variants and the factors that sustain them. *Heal. policy planning* **34**, 529–543 (2019).

2. KS Mooketsane, MB Phirinyane, Health governance in sub-saharan africa. *Glob. social policy* **15**, 345–348 (2015).
3. R Gaitonde, AD Oxman, PO Okebukola, G Rada, Interventions to reduce corruption in the health sector (2016).
4. H Mphande, Massive Drug Theft Hits Malawi Hospitals. *Nyasa Times* **Sept. 04, 2017** (2017).
5. R Bate, K Hess, L Mooney, Antimalarial medicine diversion: stock-outs and other public health problems (2010).
6. M Bouchard, JC Kohler, J Orbinski, A Howard, Corruption in the health care sector: A barrier to access of orthopaedic care and medical devices in uganda. *BMC international health human rights* **12**, 1–9 (2012).
7. W Savedoff, Transparency and corruption in the health sector: A conceptual framework and ideas for action in latin american and the caribbean (2007).
8. KR Hope Sr, Contextualizing corruption in the health sector in developing countries: Reflections on policy to manage the risks. *World Med. & Heal. Policy* **7**, 383–401 (2015).
9. P Ferrinho, W Van Lerberghe, Managing health professionals in the context of limited resources: a fine line between corruption and the need for moonlighting (2002).
10. M Lewis, Governance and corruption in public health care systems (2006).
11. B McPake, et al., Informal economic activities of public health workers in uganda: implications for quality and accessibility of care. *Soc. science & medicine* **49**, 849–865 (1999).
12. B Hwang, et al., Stock-outs of antiretroviral and tuberculosis medicines in south africa: A national cross-sectional survey. *PLoS One* **14**, e0212405 (2019).
13. WC Hsiao, Disparity in health: the underbelly of china's economic development. *Harv. China Rev.* **5**, 64–70 (2004).
14. T Vian, Anti-corruption in the health sector: Preventing drug diversion through supply chain management. *U4 Brief* **2006** (2006).
15. PJ García, Corruption in global health: the open secret. *The Lancet* **394**, 2119–2124 (2019).
16. T Bruckner, The ignored pandemic: how corruption in healthcare service delivery threatens universal health coverage (2019).
17. B Jones, A Jing, Prevention not cure in tackling health-care fraud. *World Heal. Organ. Bull. World Heal. Organ.* **89**, 858 (2011).
18. WH Organization, , et al., Public spending on health: a closer look at global trends, (World Health Organization), Technical report (2018).
19. M Hanf, et al., Corruption kills: estimating the global impact of corruption on children deaths. *PLoS One* **6**, e26990 (2011).
20. KA Muldoon, et al., Health system determinants of infant, child and maternal mortality: A cross-sectional study of un member countries. *Glob. health* **7**, 1–10 (2011).
21. A Fitzpatrick, The impact of public health sector stockouts on private sector prices and access to healthcare: Evidence from the anti-malarial drug market. *J. Heal. Econ.* **81**, 102544 (2022).
22. JC Kohler, D Dimancesco, The risk of corruption in public pharmaceutical procurement: how anti-corruption, transparency and accountability measures may reduce this risk. *Glob. health action* **13**, 1694745 (2020).
23. DW Brinkerhoff, Accountability and health systems: toward conceptual clarity and policy relevance. *Heal. policy planning* **19**, 371–379 (2004).
24. C Sant Fruchtman, et al., The complexity of scaling up an mhealth intervention: the case of sms for life in tanzania from a health systems integration perspective. *BMC health services research* **21**, 1–11 (2021).
25. J Barrington, O Wereko-Brobby, P Ward, W Mwafongo, S Kungulwe, Sms for life: a pilot project to improve anti-malarial drug supply management in rural tanzania using standard technology. *Malar. journal* **9**, 1–9 (2010).
26. TK Mackey, RE Cuomo, An interdisciplinary review of digital technologies to facilitate anti-corruption, transparency and accountability in medicines procurement. *Global Health Action* **13**, 1695241 (2020).
27. SM Zuma, Assessment of medicine stock-outs challenges in public health services (2022).
28. TG Fund, Audit report: Global fund grants in malawi, (The Global Fund), Technical report (2019).
29. T Vian, Review of corruption in the health sector: theory, methods and interventions. *Heal. policy planning* **23**, 83–94 (2008).
30. T Vian, Implementing a transparency and accountability policy to reduce corruption: The gavi alliance in cameroon. *U4 Brief* **2013** (2013).
31. Y Zamboni, S Litschig, Audit risk and rent extraction: Evidence from a randomized evaluation in brazil. *J. Dev. Econ.* **134**, 133–149 (2018).
32. A Swartz, AE LeFevre, S Perera, MV Kinney, AS George, Multiple pathways to scaling up and sustainability: an exploration of digital health solutions in south africa. *Glob. Heal.* **17**, 1–13 (2021).
33. NHZ Leung, A Chen, P Yadav, J Gallien, The impact of inventory management on stock-outs of essential drugs in sub-saharan africa: secondary analysis of a field experiment in zambia. *PloS one* **11**, e0156026 (2016).
34. RS Jablonski, B Seim, What politicians don't know can hurt you: The effects of information on politicians' spending decisions. *Am. Polit. Sci. Rev.* (2023).

Supporting Information for

Using Remote Tracking to Detect and Deter Medications Theft in Malawi

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Supporting Information Text

1. Malawi Public Health System Context

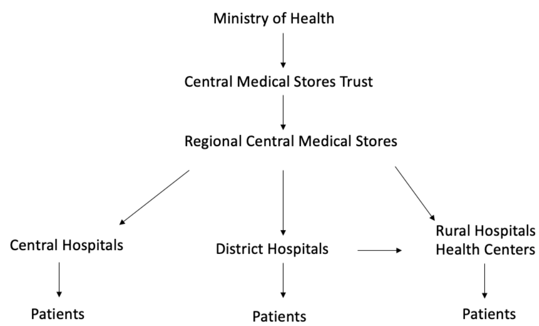
Malawi has a government-sponsored healthcare system which consists of four types of health facilities: Health Centers, Rural Hospitals, District Hospitals, and Central Hospitals. Health Centers are facilities located at villages and responsible for primary care. These clinics have limited staff, composed of three employees: a nurse/midwife, a medical assistant, and a pharmacist. Together with Rural Hospitals, they are responsible for most of the health care in Malawi. They provide outpatient, maternity, and antenatal services. Secondary care is provided by the 26 District Hospitals across the country. In addition to primary care, District Hospitals are more equipped and staffed to provide other medical services, such as x-ray, ambulance, and laboratories. Finally Central Hospitals are the top tier of healthcare in Malawi and have more specialized services. There are only four of them in the country.

Health facilities are connected by a patient referral system. For instance, if patients cannot receive adequate treatment at local health centers, they will be referred to District Hospitals. Health facilities also share the same health commodity supply chain. They buy medicines and other medical supplies from Central Medical Stores. The Central Medical Stores Trust, established by the Malawian government in November 2010, is responsible for processing orders for medicines and medical supplies. CMST has three regional medical stores. We worked with the CMS South, located in Blantyre in the South Region.

Each central medical store processes orders for medicines and medical supplies from District Health Offices responsible for district hospitals and health facilities under its charge and Central Hospitals within their regions of operations. Health facilities send requests to the District Health Offices, and then the offices send the procurement orders to Central Medical Stores. The orders are shipped directly to health facilities.

There is a flow of information and health commodities between central medical stores and health facilities, as illustrated in the picture below. The Malawi Health Commodities Logistics Management System, the Ministry of Health's medical supply system of inventory management and recording for all medical supplies, is responsible for organizing the movement of health commodities. Health commodities are moved from the CMS to the regional medical stores, where they are packed and shipped for each health facility. The movement of health commodities is not only vertical. For example, health centers can also buy directly from District Hospitals. It's a common practice given the shortage of drugs in the country. However, because of issues with administrative capacity or collusion between corrupt health officials, many drugs often end up in clinics where they were not supposed to go. In section C.3, we discuss in more details how redeliveries work.

Fig. S1. Movement of Health Commodities to Patients



Malawi faces a critical issue: the lack of essential medicines in government health facilities. Stock-outs are common across health facilities and patients, who depend on the public health system, are often sent to buy drugs at private pharmacies and clinics. Many patients end up not receiving medication. According to a report by Oxfam, poor families spend up to 10% of their annual income on health care (1). In the same study, Oxfam finds that only 9% of local health facilities in the country provided a full list of essential drugs for treating 11 common diseases. Our baseline survey indicates that 42% of respondents were told in the last months that their clinic could not provide needed drugs.

The reasons for drug shortages in Malawi are varied. Doctors and health authorities have blamed the centralized health delivery system, insufficient funding for drugs, the devaluation of the kwacha, lack of administrative capacity, and more recently the disruption of global system by the pandemic. In addition, drug theft has also been common and considered one of the main reasons for the acute drug shortage experienced by the country.

To address issues in the supply chain system and ensure access to medicines, in 2012, the Government of Malawi and donors developed a joint strategy for integrating the parallel supply chains into one supply chain managed by Central Medical Store Trust. The goal was to reform CMST to create the "necessary capacity and expertise to enable it to procure, store and distribute all essential medicines through one integrated supply chain system. (2)"

Donors and the government have established several initiatives to improve the delivery of medicines in Malawi. One of these is the campaign "I Speak Out Now", which encourages citizens to report drug theft via a hotline. Another is the Health Centre Advisory Committees (HCACs), a community-based program created by UKAid-funded Malawi Health Sector Programme Technical Assistance. The HCACs are groups of volunteers from the local community who monitor and oversee drug deliveries (3). However, despite these efforts, drug and health commodities theft remains a problem in Malawi. The situation has become even more critical during the COVID-19 pandemic, with drug shortages becoming more common (Kateta, 2022).

To address this issue, the Ministry of Health established the Drug Theft Investigations Unit (DTIU) in 2016. The DTIU is a government agency funded by the DFID, tasked with ensuring the security of public health procurement. Its primary strategy is to reduce drug theft by conducting audits, monitoring visits, and investigating those suspected of stealing drugs. The DTIU also collected and analyzed information provided by the hotline to target specific localities and support subsequent enforcement actions. Between August 2016 and April 2017, the DTIU investigated 62 individuals suspected of stealing and selling medicines from the public health system (Global Fund). Of those, 16 were public health workers subsequently prosecuted for theft of medicines, according to a report by the Global Fund.

Despite the DTIU's efforts, it has had limited success due to insufficient resourcing and non-compliance with procurement regulations by local officials. Collaboration with the judicial system has also been challenging. To address these issues, we partnered with the DTIU to design interventions that do not require broad institutional reform or significant financial resources.

2. Timeline of Activities

This timeline outlines the sequence of activities conducted during the project in Malawi. Our study combined remote tracking data from an field experiment with survey and administrative data. As shown in Figure S2, baseline data collection started in

March 2019. Our initial remote tracking data collection started a year later, in March 2020. However, due to the pandemic of COVID-19 activities had to been suspended. We redesigned the intervention to avoid in-person activities and rolled it out again in September 2021 alongside the remote tracking audit activities. The remote tracking audits lasted from October 2021 to January 2022. We completed the field activities with an endline phone survey with health officials.

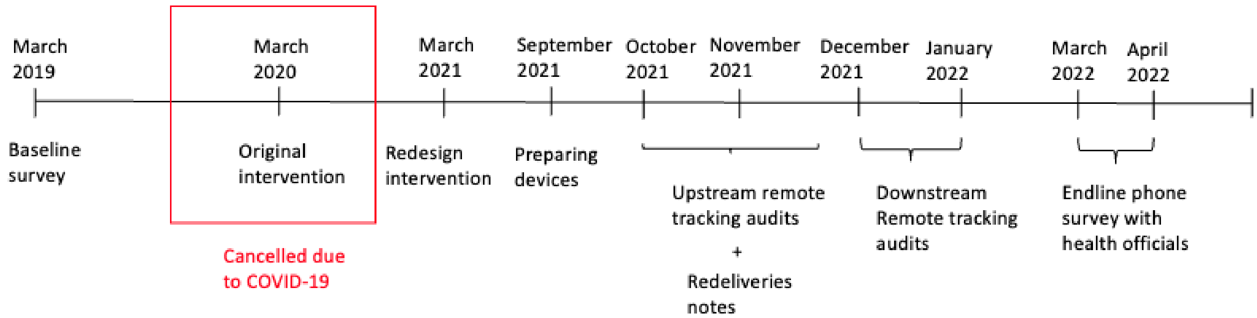


Fig. S2. Timeline of Activities

3. Remote Tracking Audits

We conducted several tests in Malawi using different tracking devices to determine which would perform best for the project. We found that the OnAsset product was the best option for several reasons: (1) it was the most reliable product in terms of connectivity and communication; (2) it was easy to place and hide the OnAsset devices due to the design and size; and (3) the tracking protocol allowed for easy access to the API and data download.

A. Tracking Technologies. We use two types of tracking devices to track medications: (1) SENTRY 500, which is a cellular and GPS tracking device, and (2) SENTINEL, which is a bluetooth device that is automatically detected by any SENTRY 500 within its transmission radius of 300 meters. Figure S3 shows the devices. No installation is necessary for the devices, and they can simply be included in a shipped package. The SENTINELS were placed inside cartons or boxes of medications, while the SENTRY 500 units were placed inside trucks and used during follow-up mobile audits.

The SENTRY 500 devices used Malawi's cell phone network to communicate and send location data. The SENTRY units capture and transmit data from itself and all surrounding SENTINELS to the server at regular intervals of 15 minutes. A technician consultant was responsible for running tests to improve the use of the devices during the experiment. These tests included calculating estimates such as how close the SENTRY needs to be to a SENTINEL in order to confirm the SENTINEL's existence with certainty and how long the devices' battery last. Additionally, we tested if different materials around the devices could affect the SENTRY's reading capacity. While the SENTINELS' batteries can last more than one year, SENTRY devices face a trade-off between battery life and reporting intervals. The battery can last up to three days after fully charged when using reporting intervals of 15 minutes. In our case, the SENTRY devices were only deployed for several hours when in delivery trucks, which did not exceed their battery life.

One challenge we faced was connectivity in Malawi. The SENTRY devices use both cellphone network and radio communication. Although many parts of Malawi do not have good connectivity, the SENTRY devices can store information and transmit the data to the server once they connect to the network. Thus, we were able to detect if the box/device arrived at the clinic at some point. For the audits of health facilities during the follow-up visits (Section E), we also piloted tests with SENTRY devices in a backpack and SENTINELs within a box in an enclosed room.

B. Placing Tracking Devices in Government Warehouses and Delivery Vehicles. Prior to the placement of devices, all labels and identifying information were removed from SENTINEL devices. All SENTINELs were then relabeled with stickers identifying them as "Temperature and Humidity Monitoring" devices and noting that they were property of the Malawi Ministry of Health and that the devices should not be removed (see example sticker in Figure S4). The stickers also provided a phone number which health officials could call with questions. The phone was manned by the Malawi Ministry of Health Directorate of Technical Services. We received only a couple calls, almost entirely from individuals who had found SENTINELs under suspicious circumstances.

The devices were attached to medicine boxes in the Malawi Central Medical Stores (CMST) warehouse in Blantyre. The placement of devices was completed by a team of 14 people from a third-party logistics company (9), the warehouse (1), Malawi Ministry of Health (1), and the research team (3) during the course of normal packing operations.

Prior to the placement of the devices, all 14 people participated in a full-day training. The training explained how officials were to place the devices and introduced them to the cell phone application that they were to use in recording medicine and delivery details. With the exception of the research team and a manager from the Malawi Ministry of Health, none of the

Fig. S3. OnAsset Technologies Devices. The device in green is the SENTRY and in yellow SENTINELS.

Fig. S4. SENTINEL Sticker during Auditing Deliveries

officials involved in the placement of devices were aware that the SENTINELs recorded location information or were intended to measure corruption. Officials were told (honestly) that the devices would record temperature and humidity and were part of a research program to improve medicine shipping and storage.

The deployment of the devices occurred during the normal medicine delivery cycles of October[*] and November of 2021. Using health facility orders provided to us by the Ministry of Health, and drawing on our pre-experiment survey and interview data, we sampled eight medicines that are both commonly ordered and commonly diverted (Table S1).

Officials were instructed to place SENTINELs on the lowest level of medicine packaging in an unobtrusive manner. In the case of pills, such as Amoxycillan the SENTINEL were taped to individual pill bottles. Where medicines were boxed (as in the case of syringes), SENTINELs were placed inside the box. An example of the device placement can be seen in Figure S5.

During the placement of the SENTINELs, officials were required to complete out a survey on their phone. This survey required the officials to read a QR code on the device and then provide the details on the medicine, including the batch number, destination and medicine type.

After the placement of SENTINELs, medicines were packaged into larger cardboard boxes and labeled for specific facilities. After all such boxes were sealed and labeled, the boxes were placed on trucks for delivery by a logistics company under contract with the Malawi Ministry of Health Central Medical Stores Trust. Pictures of a delivery truck and the CMST warehouse are shown in Figures S6 and S7.

For redundancy, officials were told to place two SENTRY devices at the rear of every delivery truck. These SENTRY

[*] These deliveries were delayed and were actually delivered in November.

Table S1. Tracked Medicines

Medicine Description	Anticipated Number of Tracked Boxes
Amoxycillin,250mg,capsule,1000	89
Aspirin,300mg,tablet,1000	402
Ibuprofen,200mg,coated tablet,1000	786
Insulin zinc suspension (lente),100 IU/ml,10ml	3
Paracetamol,500mg,tablet,1000	519
Phenobarbitone,30mg,tablet,1000	166
Syringe Luer,10ml,disposable,hypoluer	235
Syringe,autodestruct,5ml,disposable	170

Fig. S5. SENTINEL device placement

devices were placed prior to the loading of any medicine boxes. Each delivery truck was restricted to a particular delivery route. Typically this encompassed a single district, though sometimes trucks visited multiple smaller districts.

C. Upstream Remote Tracking Audit Protocol. We accessed OnAsset API to download the data sent by the SENTRY devices. We have information when a SENTINEL was read by a SENTRY device, the SENTRY id, location, battery level, humidity, and luminosity. We conducted analysis at the SENTINEL level.

At the end of every day, we collected reports from the OnAsset portal with details on all the SENTINEL sightings identified by SENTRY devices for that day. There are two types of reports: (1) a sentry-sightings report, that shows the sightings for the SENTRY's last report, and (2) a sentry report, that contains a list of reports for each SENTRY device for every 15 minutes. For each report, we downloaded sightings that refer reports from SENTINELS. In other words, the reports contain information about every SENTINEL identified by the SENTRY devices with reporting time in the course of the trip. It also stores statistics by SENTINEL, such as battery, humidity, light, temperature, and rssi.

D. Downstream Remote Tracking Audit Protocol. After the devices were sent and active in the ground, we ran follow-up visits to health facilities to find the exact location of the devices. Starting at the end of November 2021, our enumerators visited thirty nine health facilities in ten (10) districts namely Blantyre, Zomba, Thyolo, Phalombe, Mulanje, Machinga, Balaka, Mangochi, Neno, and Nsanje to check and verify if indeed the drugs that were ordered reached the facilities.

Upon arrival at the facility (but before entering the facility), enumerators informed time and identity of the facility. They placed charged and active SENTRY in a backpack and turned the SENTRY on. During the visits, they filled out a form with information about the district, the name of the facility, the location and the time. Then, they walked slowly around the health facility, completing a circle around the following areas, pausing for at least 10 minutes in each area:

1. All facility pharmacies

2. All areas where doctors or pharmacists are dispensing medicines

3. All warehousing facilities

Fig. S6. Delivery Vehicle

Once the visit to the facility is complete, they immediately turned the sentry off, completed the remainder of the form, and sent a a message to the WhatsApp group with the time that enumeration at the clinic was completed. They were also requested to ask a receptionist or similarly employed official at the health facility about any locations where they might purchase medicines. Additionally they located all pharmacies and markets within 2 km of the facility and followed a similar protocol.

At the end, they were required to send a text to the whatsapp group with the time they left the area and submit the survey. Finally, we closely monitored the SENTRY reports. A research manager provided a report on the whatsapp group with details on all the SENTINEL sightings for that day. The report also mentioned if sighting information from ANY of the health facilities for that day are still missing.

E. Redelivery Remote Tracking Audit Protocol. To complement our analysis, we also obtained the full set of delivery notes from the District Health Offices (DHOs) for the months of October and November. These notes contain information on redeliveries, i.e. medications that were ship to a second facility. Health facilities can buy medicines directly from District Hospitals. In this case, the medicines go from Central Medical Stores to District Hospitals and, then, are sold to health facilities. The records detail the shipments from the DHOs to smaller health centres.

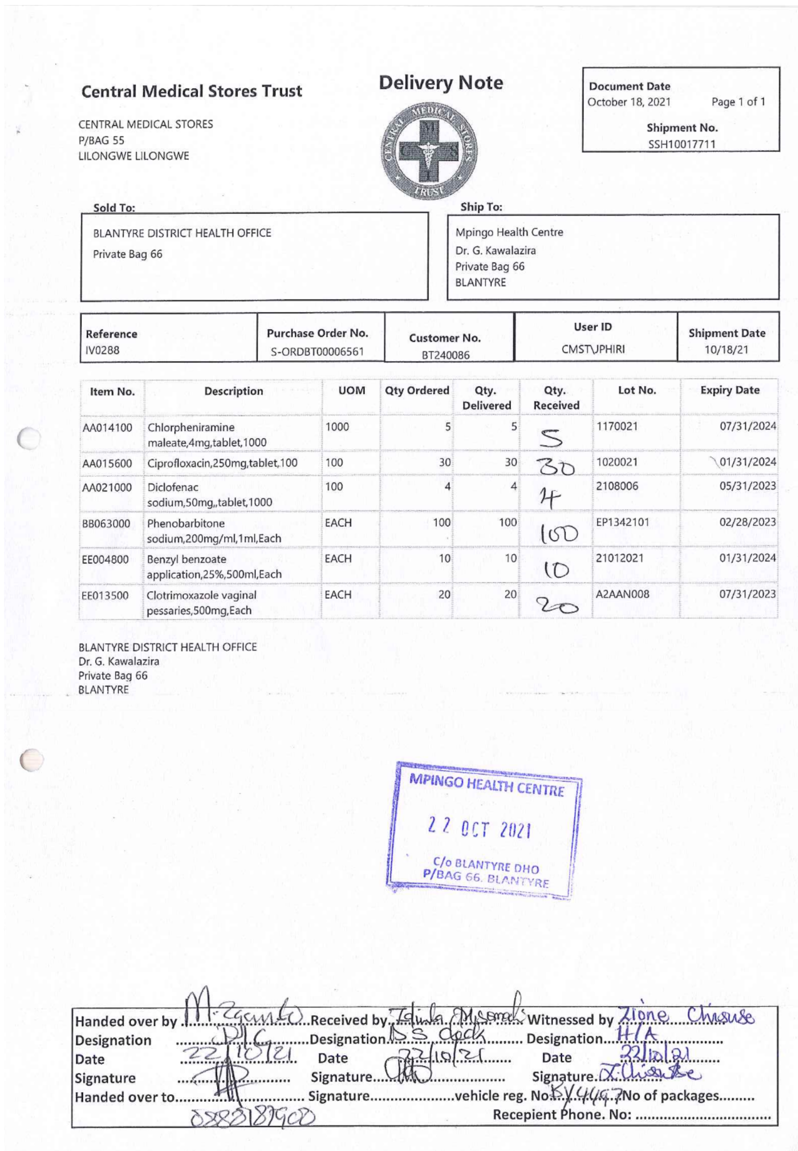
These 101 records were provided to us as scanned PDF documents. Figure S9 displays an example of a delivery note. To incorporate them in our analysis, we transcribed all the information from the reports to a spreadsheet and we merged with others datasets.

After collecting these delivery notes, we sampled 40 facilities that were identified as having received redeliveries. We then visited each of the 40 facilities and conducted a physical remote tracking audit using the protocol discussed in Section . This allows us to identify whether medicines identified has having been redelivered ended up in the correct facility.

Fig. S7. CMST Warehouse

figures/cmst warehouse.png

Fig. S8. Photo taken During Follow-up Visits



Central Medical Stores Trust

CENTRAL MEDICAL STORES
P/BAG 55
LILONGWE LILONGWE

Delivery Note

CENTRAL MEDICAL STORES TRUST

Document Date October 18, 2021 Page 1 of 1

Shipment No. SSH10017711

Sold To:
BLANTYRE DISTRICT HEALTH OFFICE
Private Bag 66

Ship To:
Mpingo Health Centre
Dr. G. Kawalazira
Private Bag 66
BLANTYRE

Reference	Purchase Order No.	Customer No.	User ID	Shipment Date
IV0288	S-ORDBT00006561	BT240086	CMST\PHIRI	10/18/21

Item No.	Description	UOM	Qty Ordered	Qty. Delivered	Qty. Received	Lot No.	Expiry Date
AA014100	Chlorpheniramine maleate,4mg,tablet,1000	1000	5	5	5	1170021	07/31/2024
AA015600	Ciprofloxacin,250mg,tablet,100	100	30	30	30	1020021	01/31/2024
AA021000	Diclofenac sodium,50mg,,tablet,1000	100	4	4	4	2108006	05/31/2023
BB063000	Phenobarbitone sodium,200mg/ml,1ml,Each	EACH	100	100	100	EP1342101	02/28/2023
EE004800	Benzyl benzoate application,25%,500ml,Each	EACH	10	10	10	21012021	01/31/2024
EE013500	Clotrimoxazole vaginal pessaries,500mg,Each	EACH	20	20	20	A2AAN008	07/31/2023

BLANTYRE DISTRICT HEALTH OFFICE
Dr. G. Kawalazira
Private Bag 66
BLANTYRE

MPINGO HEALTH CENTRE
22 OCT 2021
C/o BLANTYRE DHO
P/BAG 66. BLANTYRE

Handed over by M. Zgambo Received by Tsala Msamal Witnessed by Zione Chisuse
Designation DIC Designation DS clerk Designation HA
Date 22/10/21 Date 22/10/21 Date 22/10/21
Signature Signature Signature Z. Chisuse
Handed over to Signature vehicle reg. No KY 4467 No of packages
0888189900 Recepient Phone. No:

Fig. S9. Example of a Delivery Note

4. Survey Activities

To better understand patterns of medicine theft, we conducted two complementary surveys: 1) an in-person survey of citizens and health centre advisory committees; 2) a phone-based survey of health facility officials.

A. Baseline Survey of Citizens and Health Centre Advisory Committees. In January-March 2019, we conducted an in-person survey with Malawian citizens in the catchment areas of 97 health facilities. The 97[†] health facilities were randomly sampled from a list of all of the health facilities in the Southern Region, excluding facilities that were affiliated with the Christian Health Association of Malawi (CHAM) and the Malawi Military, as these health facilities have additional, overlapping procurement processes.

At each sampled health facility, we recruited two distinct groups of participants for the survey. First, the enumeration team completed a random walk sampling protocol to recruit 35 individuals living within 10 km of the health facility. This resulted in a sample of 3,360 individuals. Second, the enumeration team used a purposive sampling procedure to recruit three individuals affiliated with the facility's Health Centre Advisory Committee. This resulted in a sample of 281 individuals.

The Health Centre Advisory Committee (HCAC) is a government-mandated oversight committee that is supposed to exist at each health facility in Malawi.[‡] They are typically 10-member elected bodies that serve a social accountability function on behalf of the citizens in the facility's catchment area, though there is variation in their ability to hold health facility officials accountable, partially driven by variation in integration with other accountability structures (3). They have four official duties: (1) bridging the communication gap between community and health staff, (2) inspection of facility conditions and drug stock, (3) formulating recommendations on facility equipment, and (4) complaint management (3).

The two survey instruments were similar, and both were conducted in person with trained Malawian enumerators and available in English and Chichewa. The citizens survey included 61 questions for the participant regarding their experiences at the facility, focusing on their observations and perceptions of theft. It also included a list experiment to measure the prevalence of public medication resale and 14 questions for the enumerator to collect information about the survey context. The HCAC survey included 20 questions for the participant regarding the operations and activities of the HCAC and 7 questions for the enumerator.

B. Endline Phone Survey of Health Facility Officials. In March and April 2022, we executed a phone-based survey of health facility officials. At each of the 97 facilities included in the baseline survey, the Malawi-based research managers used snowball convenience sampling to conduct a phone interview with two individuals: a pharmacist and one other official involved in medicine stocking and/or disbursement at the facility. Contact information could not be obtained for 12 facilities, so the final sample includes 172 officials from 85 facilities. The survey included 30 questions for the participant regarding their experiences at the facility, focusing on their observations and perceptions of theft, as well as four questions for the enumerator to collect information about the survey context. Surveys were conducted in English.

C. Descriptive Findings from Survey Data. One of the primary contributions of this project is to provide descriptive evidence regarding medications theft. In this sub-section, we present the findings of the baseline survey of citizens and Health Centre Advisory Committees and the endline phone survey of health facility officials.

First, we consider citizens' overall perceptions of theft at their local health facility. Figure S10 shows the results of a list experiment designed to anonymously elicit the probability that respondents have observed the sale of medicines in their community that should have been provided for free by government facilities. The results suggest that an estimated 50% of all citizens have observed the sale of medicines that should have been provided for free. Moreover, at approximately 80% of all health facilities, at least one citizen has observed the illegal sale of medicines.

One consequence of medicine theft is that citizens are unable to access medicines that they need. We asked citizens to estimate how often they are unable to access needed medicines from their health facility. On average, approximately 45% of needed medicines were unavailable at health facilities. We also asked this question of health facility officials and get a similar estimate (37%), though the correlation between the estimates from the citizens and officials is not statistically significant ($p = 0.21$). We show the distribution of perceptions of medication (un)availability in S11.

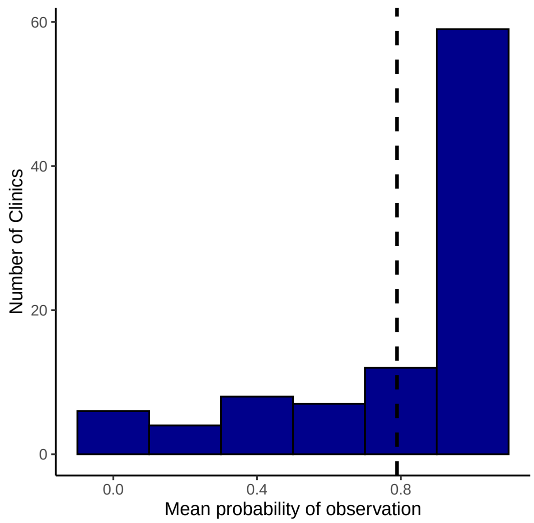
Of course, there are a number of reasons why medicines may not be available, and Malawi has suffered from chronically insufficient public health financing. Nonetheless, it is clear that many citizens attribute medicine unavailability (often called "stockouts") to theft. In Figure S12 we show the geographic distribution of perceived medicine unavailability (stockout) rates and perceived theft rates. It is clear that areas with higher stockout rates are also the areas where citizens perceive the highest rates of theft.

We also asked citizens a number of questions about the reasons that officials might engage in theft. Citizens perceive information and capacity gaps to be a main constraint. Fifty-three percent of citizens said that they lack effective ways to report the diversion of medications and cited this as a primary reason officials choose to steal medications in Malawi. Another reason cited was that patients simply have no way of knowing whether medications in their health facility were stolen.

In addition, it seems that formal accountability institutions are weak. For instance, Health Center Advisory Committees have been ineffective in overseeing deliveries of medicines. Figure S13 shows that nearly three-quarters (74%) of interviewed Health Center Advisory Committee (HAC) report witnessing a delivery at the health center in the past three months. However,

[†] We originally sampled 100 facilities but three facilities were inoperable at the time of data collection.
[‡] In reality, not all facilities mobilize HCACs, let alone utilize them.

Fig. S10. Probability of Theft Being Observed

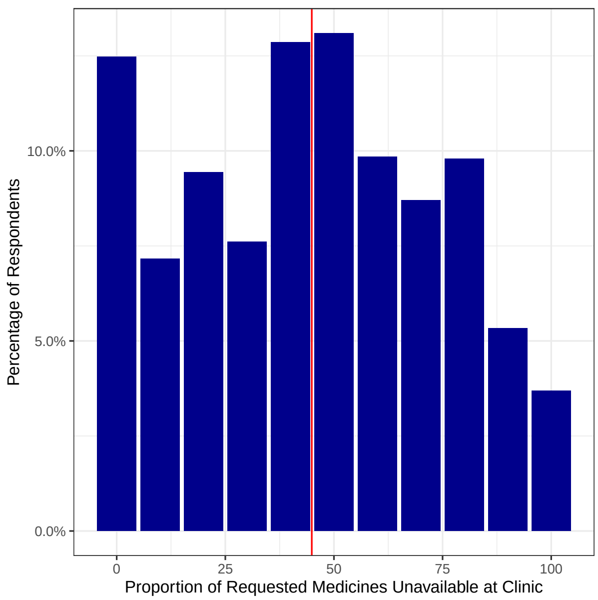


Note: This figure shows estimates of the facility-specific probability that the illegal sale of medicines has been observed. The figure is derived from a list experiment asking whether respondents have observed the sale of medicines that should have been provided for free.

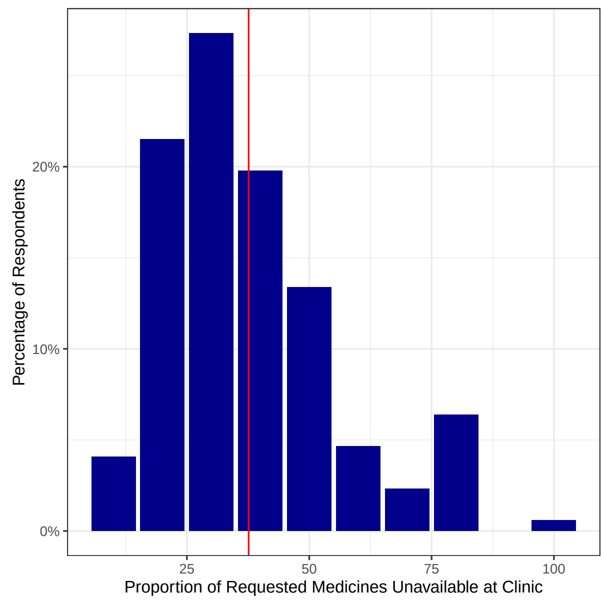
very few witnessed three or more deliveries in three months, despite a mandate to witness each monthly delivery. Furthermore, approximately one-quarter (26%) of HAC respondents report witnessing no deliveries in the past three months.

Despite recognizing the weaknesses of accountability mechanisms, more than half of citizens believe that officials that steal medicines are highly likely to be caught and highly likely to face consequences (Figure S14a and Figure S14b). Among the officials, however, we observe a different reality. The median perceived probability of getting caught and facing consequences according to health facility officials is 51-75%. Only 20% of health facility officials perceive a 75-100% chance of getting caught, and 30% perceive a 75-100% chance of facing consequences (Figure S14c and Figure S14d).

Fig. S11. Perceived Rates of Medication Unavailability by Citizens and Officials

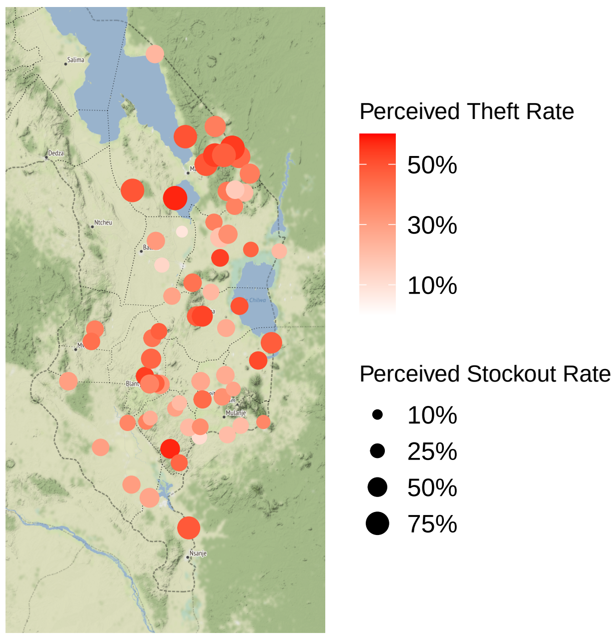


(a) Citizens' Perceptions of Medication Unavailability



(b) Officials' Perceptions of Medication Unavailability

Fig. S12. Perceived Rates of Theft and Stockouts



Note: The Perceived Stockout Rate indicates the percentage of times on average patients were unable to obtain needed medicines from their health facility in the last three months. The Perceived Theft Rate indicates the share of those unavailable medicines that the patient believed were stolen by public officials.

Fig. S13. Health Centre Advisory Committees (HACs) Attendance at Deliveries

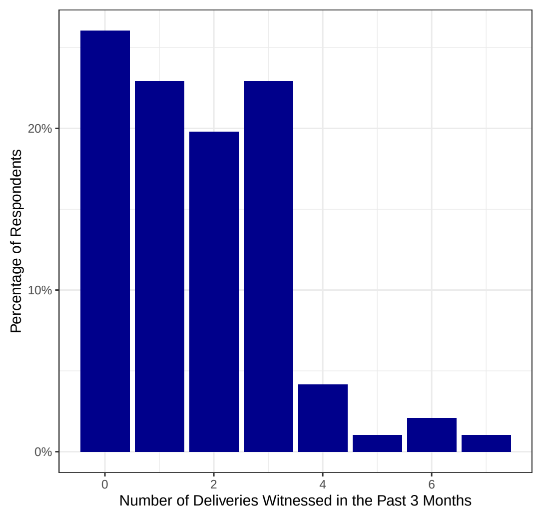
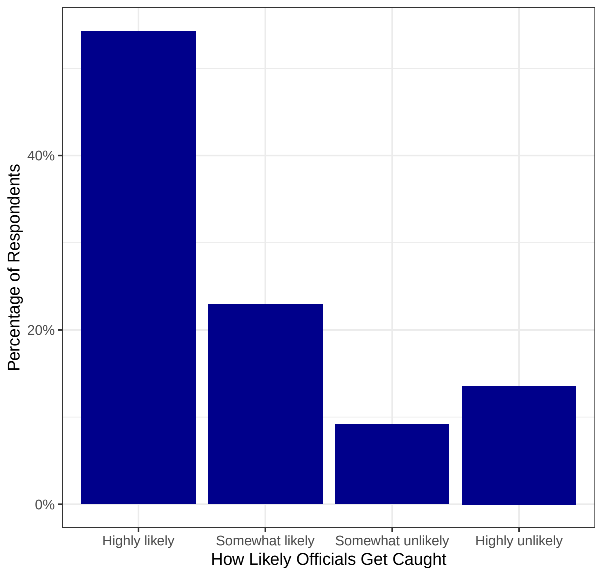
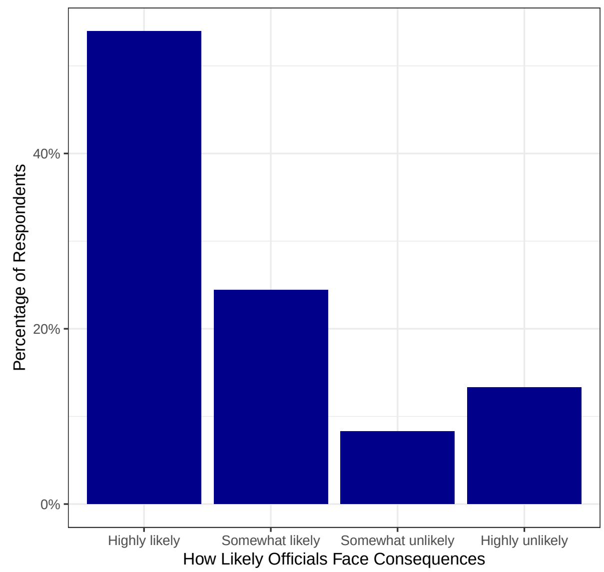


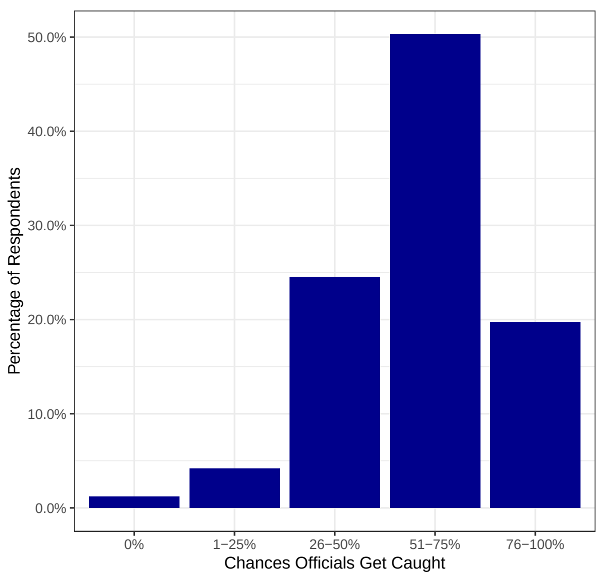
Fig. S14. Perceived Rates of Theft Detection and Punishment by Citizens and Officials



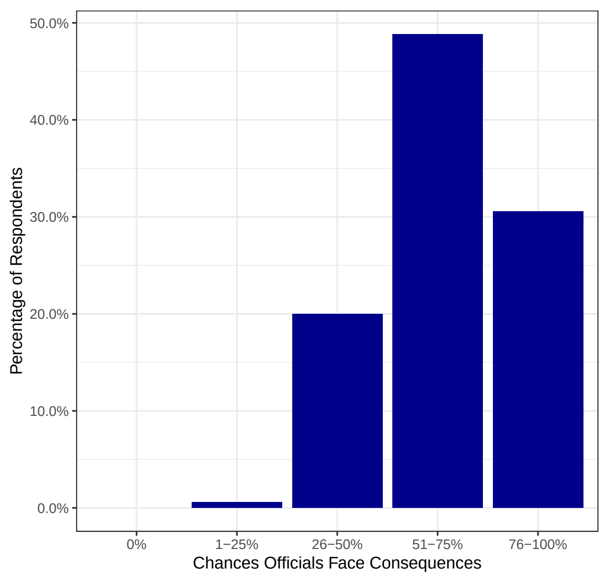
(a) Citizens' Perceptions of Theft Detection



(b) Citizens' Perceptions of Theft Punishment



(c) Officials' Perceptions of Theft Detection



(d) Officials' Perceptions of Theft Detection

5. Administrative Data

Our partners in the Ministry of Health and the Drug Theft Investigations Unit (DTIU) also provided administrative data on medicine procurement and traditional audits:

1. Facility-Level Shipment Records: We obtained the full set of shipment manifests that were used to prepare the October and November deliveries, and used these records to construct variables regarding the volume and density of medicines during the shipment periods.

2. Delivery Notes: We also obtained the full set of delivery notes from the district health offices (DHOs) for the months of October and November. These records detail the shipments from the DHOs to smaller health centres (i.e., "redeliveries").

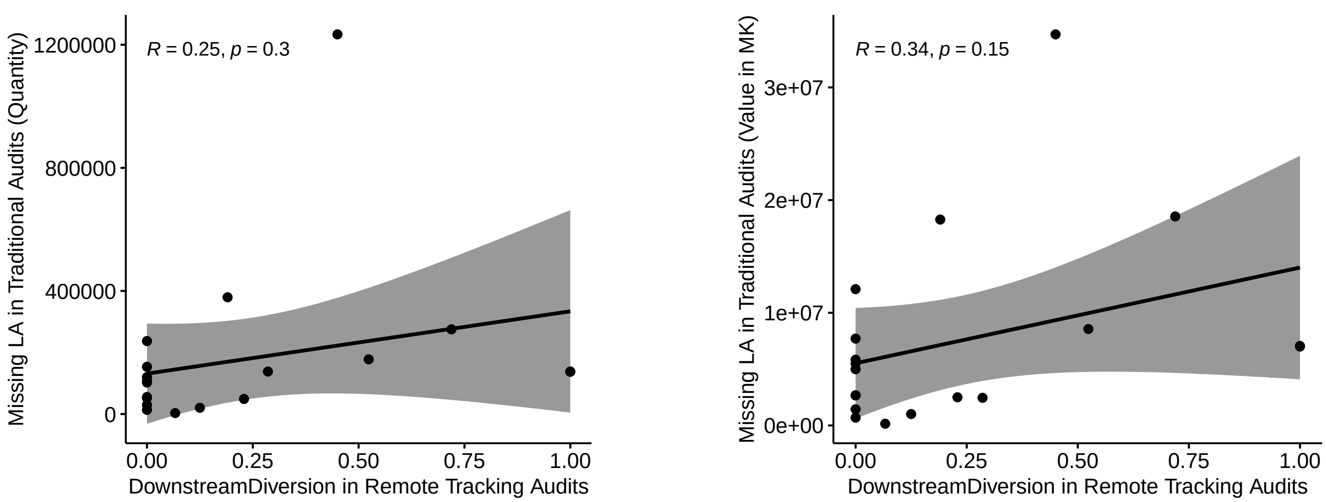
3. DTIU Audit Records: DTIU provided us with: a) traditional audit reports at the health facility level for 2016-2018; b) one-off reports of theft collected through the tipoff hotline for 2017-2019. See Section **??** for a discussion of how these audit findings correlate with the remote tracking audit findings.

A. Traditional vs. Remote Tracking Audits. As discussed above, we received tipline, investigation reports, and audit data from DTIU in 2018 and from MoH in 2023. We are uncertain whether we received all of the tipline, investigation reports, and audit data that exist, but we likely did not. (For example, the tips are numbered sequentially but we are missing some of the sequence of numbers.) This means we cannot really interpret a facility not being reported via a tip or not being audited as the absence of theft at that facility.

We subsequently coded these data to generate pre-study indicators of theft to compare to the remote tracking audit data at the health facility level. Tipline data were only included if they named an existing health facility. Many tips did not (and instead referred to a market or private shop). We have data on 27 tips for 24 named facilities in the Southern Region, all coming into the tip line between 2017 or 2018. Whether or not a tip ever came in about a health facility is not correlated with our facility-level measures of downstream theft ($r = 0.112$, $p = 0.2547$).

Similarly, audit data were only included if it was from an existing health facility. We have data on 45 audits for 45 facilities in the Southern Region, all likely occurring in 2016. In addition to concerns about missing audit data as described above, the scope of each audit is unknown. At each audited facility, at least one (and sometimes more) medicines are reported as missing. It is not clear if medicines that are *not* listed are not missing or were simply not audited. It is also not clear what the stock of the medicine was supposed to be (i.e., what percentage of the medicine stock is missing). The most commonly audited medicine was chloroquine phosphate (aka "LA"). There were no audit reports that did not include a line to report missing LA. Therefore, we base our analysis of the audit data on the quantity of LA missing and the value (in Malawi Kwacha) of this missing LA. (Note that this amount was not always provided.) These indicators positively correlate with our facility-level measures of downstream diversion, though the relationship is not statistically significant. Once one particularly high-diversion outlier is removed, however, the p-value on the correlation coefficient is under 0.2 for both variables (Figure S15a and Figure S15b).

Fig. S15. Comparing Remote Tracking Audits Downstream Diversion Rates and Traditional Audits Missing Chloroquine Phosphate (LA) Rates



(a) DownstreamDiversion and Missing LA Quantity

(b) DownstreamDiversion and Missing LA Value

B. Remote Tracking Audit Costs. Table S2 includes all of the costs associated with running our remote tracking audits, estimated based on Malawi administrative data and project records. We note that the items "Equipment-Trackers" and "Printing Costs -

Trackers Stickers" are startup costs: now that they have been paid, these costs would not need to be incurred again.[§] In total, the total estimated costs of a remote tracking audit are US$119,700, or US$19,531 without the costs of the tracking devices and their stickers included.

Table S2. Remote Tracking Audit Costs

Cost Description	Unit	Unit Cost	Number Units	Total Amount (in MK)	Total Amount (in USD)	Notes
Communications	Total Cost	MK1800000	1	1800000	2222	Airtime for minutes and data used to coordinate the audits
Equipment - Trackers	Total Cost	US$98274	1	N/A	98273	80 parent tracking devices and 2400 child tracking devices
Printing Costs - Trackers Stickers	Total Cost	MK1536000	1	1536000	1896	Stickers for the tracking devices
DTIU Director salary	Monthly Cost	MK610000	0.75	457500	565	3 months of quarter-time work to coordinate the audits
DTIU/MOH officer salary	Monthly Cost	MK490000	8	3920000	4840	2 months of 4 people working full-time to execute the audits
CMST manager salary	Monthly Cost	MK812000	0.75	609000	752	3 months of quarter-time work to coordinate the upstream audits
Vehicle maintenance costs	Monthly Cost	MK300000	4	1200000	1482	Maintenance for 2 months of 2 vehicles
Fuel costs	Total Cost	MK6500000	1	6500000	8025	
Training costs	Total Cost	MK1070000	1	1070000	1321	Training DTIU/MOH officers on audit execution
DTIU office space	Monthly Cost	MK350000	0.75	262500	324	Overhead for DTIU office space for audit coordination and execution

[§] This does not take into account some reasonable loss rate for the tracking devices. In our remote tracking activities, the SENTRY loss rate was zero, but the SENTINEL loss rate was much higher.

6. Outcome Variables

Below we describe the coding of each of our outcome variables. Note that, primarily for reasons of clarity, we deviate slightly from out pre-analysis plan in the coding of these variables (see Section **??**).

A. Identifying Incorrect Deliveries from Upstream Audit (*Upstream Diversion*). We define a successful delivery as one in which the medicine reached the facility for which it was intended during the delivery period. Specifically, we create a variable $UpstreamDiversion$ which equals one if a SENTINEL is not delivered by the designated delivery truck to its intended destination. It equals zero if it was delivered elsewhere and is coded as missing if the delivery could not be confirmed.

More specifically, as discussed in Section B, in the SENTINEL placement process, each SENTINEL was coded to a particular medicine and intended health facility destination while packing the medicines for delivery. We determine whether a medicine reaches this intended destination using the following procedure:

1. Using the OnAsset API, we determine the geographic coordinates of the final SENTRY sighting of the SENTINEL associated with the medicine. Since each SENTRY was associated with a delivery truck, this final SENTRY sighting is the location at which a medicine left the delivery truck.

2. We then measure the distance between the final sighting determined in step 1 and the intended destination of the medicine. If this distance exceeds an uncertainty range (as defined below), we code this medicine as not delivered to its intended destination ($UpstreamDiversion = 1$). If this distance falls within the uncertainty range, we code this medicine as delivered to its intended destination ($UpstreamDiversion = 0$).

3. In cases where we lack sufficient data to identify the final location (e.g., due to a lack of cellular connectivity), we also rely on the downstream audit data. We code a medicine as having been delivered if we find during the downstream audits that one or more medicines intended for the same facility and delivered at the same time were found in the correct facility during the in-person audits. That is, if we can confirm that other medicines delivered at the same time and place were correctly delivered, we assume that all medicines delivered at the same time and place were correctly delivered ($UpstreamDiversion = 0$).[¶]

One challenge with coding deliveries is that the coordinates of the final SENTINEL sighting cannot always be precisely determined. At any given sighting, each SENTRY provides coordinates based on GPS or cellular triangulation. Since satellite and cellular coverage in remote areas of Malawi is often incomplete, this means that we are sometimes unable to determine the location of the delivery; or we are only able to identify the delivery imprecisely (e.g., because of weak signal strength or triangulation off of few satellites or cellular towers). If we cannot obtain location coordinates, we first attempt to use the most recent valid coordinates as a way to identify the location of the delivery. In the case of 9.7% of tracked medicines, we cannot find a valid coordinates within 90 minutes of the delivery. We code such deliveries as indeterminate.

A related challenge is determining whether a medicine was delivered to the intended destination or another location. Because location coordinates are sometimes imprecise, we cannot always be confident that a delivery occurred in the location of the sighting. To address this challenge, we estimate the uncertainty associated with each SENTRY sighting. To derive context-specific estimates of uncertainty, we first created a training dataset of all SENTRY sightings where the true location was precisely known.

Using these data, we create a variable D_{ij} which measures the logged distance between the known true location (i) and the triangulated location (j) provided by a SENTRY (i.e., the precision of the location estimate). Our goal is to estimate the distribution $\hat{D_{ij}} = E(D_{ij}|X = x)$ where X are the characteristics of location i which we expect to matter for the location precision, D_{ij}. To estimate this equation we rely on a quantile regression forrest estimator (4), which provides a non-parametric way to estimate the expected value of different quantiles of $\hat{D_{ij}}$. Our vector of predictors, X include the density cellular towers in range of the true location, the signal strength of the SENTRY connection, the type of signal (GPS or cellular), the altitude of the true location, and the altitude of cellular towers.

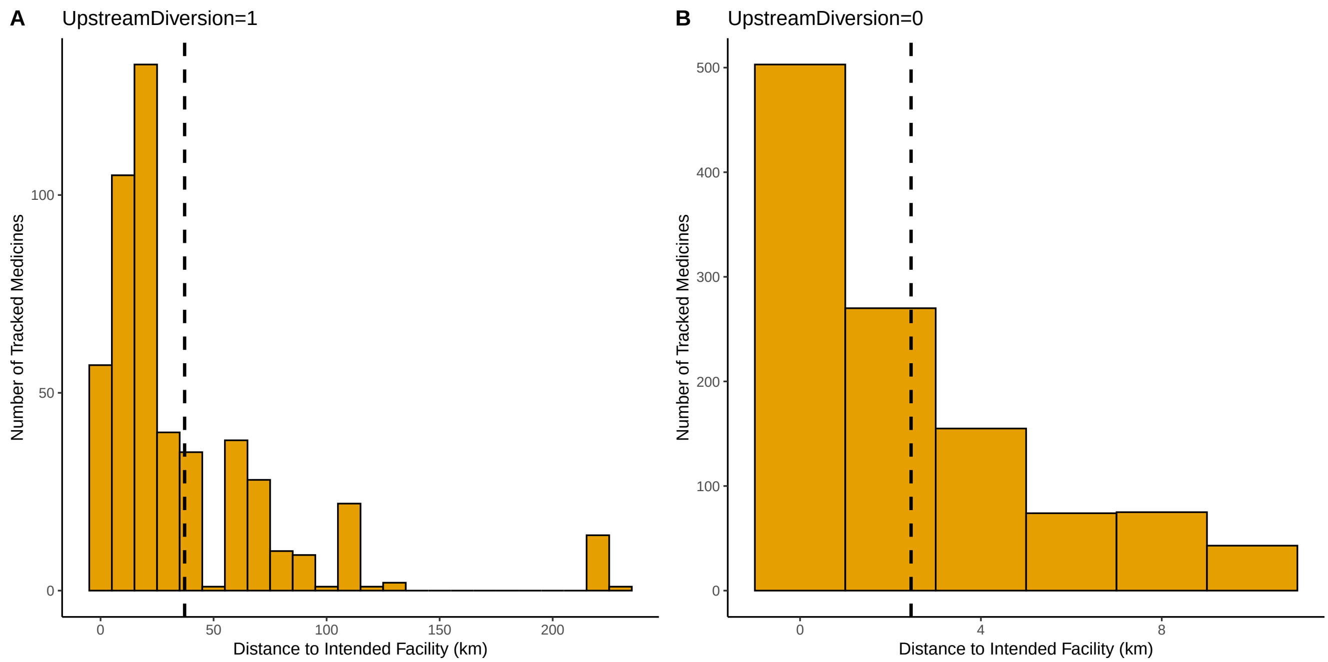
Using the weights estimated from the quantile regression, we can estimate the likelihood that a triangulated location corresponds to a correct delivery (i.e., no upstream diversion). Formally, let a be the location of the intended delivery. Let b be the triangulated location provided by the last SENTRY sighting of a medicine's SENTINEL. We assume that the expected distribution of the distance between a and b can be well approximated by the prediction $\hat{D_{ab}} = E(D_{ab}|X = x)$ provided by our bagged sample weights. We code a correct delivery ($UpstreamDiversion = 0$) as one where $\hat{D_{ab}(95)} - D_{ab} >= 0$. Here $\hat{D_{ab}(95)}$ is the value within which our model predicts 95% of the values of D_{ab} to fall under the assumption that the delivery occurred at a. We code an incorrect delivery ($Upstream\ Diversion = 1$) as one where $\hat{D_{ab}(95)} - D_{ab} < 0$.

This estimated level of uncertainty appears to correctly characterize the true precision of triangulated locations. In out of sample tests, the mean of our prediction correctly explains 42% of the variance in D_{xy}. Further, D_{xy} is larger than $\hat{D_{xy}(95)}$ in less than 1.3% of cases. This suggests that our Type II error (where we code a delivery as not delivered to its intended location when it actually was) will be less than 2%.

In Figure S16 we plot the distance between intended and triangulated locations for deliveries that are coded as correct and incorrect. The number of cases where a Type II error is possible is exceedingly low: on average, cases where $Upstream\ Diversion = 1$ are delivered 37 kilometers away from their intended destination.

[¶] Note this does not preclude some medicines from a delivery being misdelivered (this happens regularly). The assumption here is instead that if we can locate one or more correctly delivered medicines, we assume that other medicines in that same delivery, and *that share the exact same delivery time stamps*, were also correctly delivered.

Fig. S16. Distances between intended and triangulated locations (D_{ab}) for medicines coded as delivered and not delivered



Note: This figure shows the difference between intended and triangulated locations (D_{ab}) of final medicine deliveries. Panel A shows the range of D_{ab} where deliveries are coded as incorrect (*Upstream Diversion*=1). Panel A shows the range of D_{ab} where deliveries are coded as correct (*Upstream Diversion*=0).

We are also concerned about the possibility of Type I error (where we code a delivery as delivered to its intended location when it was actually delivered elsewhere). This might be a particular concern if diversion is happening very close to the intended health facility and within the level of precision of the triangulated location. While this is possible, we don't see evidence that this represents a large proportion of the diversion in our study. In Table S3 we show how our estimates of *UpstreamDiversion* vary under different levels of estimated precision, $\hat{D_{ab}}$. If diversion was occurring nearby to intended delivery locations, we would expect that we would find higher rates of diversion where we can more precisely identify diversion. However, we see no evidence of such a pattern.

Table S3. *Upstream Diversion* for different levels of location precision, $\hat{D_{ab}}$.

Mean *UpstreamDiversion*	$\hat{D_{ab}}$	N Medicines
0.01	1 km	416
0.07	1.5 km	830
0.09	2 km	1311
0.10	2.5 km	1530
0.10	3 km	1760
0.11	3.5 km	1829
0.11	4 km	1858
0.12	4.5 km	1932
0.12	5 km	1935

Note: This table shows the mean delivery diversion rate (*UpstreamDiversion*) for samples of tracked medicines that are more or less precisely coded to a final delivery location.

A final concern is that the rate of diversion might differ in cases of deliveries that are indeterminate (e.g., if officials steal at more remote locations at a higher rate). One way to evaluate whether indeterminate deliveries are more likely to be diverted is to compare the proportion of determined and indeterminate deliveries that were found in the downstream remote tracking audits. Of the 682 deliveries which could not be determined from coordinates alone, 531 of them were supposed to have been delivered to locations where we conducted a downstream remote tracking audit. Out of these 531 medicines, 361 (68%) were actually found at the correct location during the downstream audit. In comparison, of those medicines with determinate delivery locations, 65% were found in the downstream audits. This suggests that indeterminate deliveries are not substantially more likely to be diverted.

B. Assessing whether a medicine is delivered to a valid health facility. For medicines that are not correctly delivered, we also attempt to identify whether the actual delivery location could have been a valid public health facility (see Figure 2 in the main text). To do this, we adopt the same procedure from Section A above used to validate deliveries for correct locations.

Specifically, let A be a vector of all health facility locations in Southern Malawi. Let b be the triangulated location provided by the last SENTRY sighting of a medicine's SENTINEL. For each $a \in A$ we calculate $\hat{D_{ab}}(95)$ using the quantile regression procedure described above. If $\hat{D_{ab}}(95) - D_{ab} >= 0$ is true for *any* $a \in A$, we assume that the delivery most likely went to a valid health facility. If $\hat{D_{ab}}(95) - D_{ab} < 0$ is false for *all* $a \in A$, we assume that the delivery most likely went somewhere other than a valid health facility. Consistent with our coding rules above, we also, code a medicine as going to a valid health facility if the medicine was found at a valid health facility during the downstream audit.

While our conclusions are those most consistent with the data, there is a risk of misclassification in this estimator. An important assumption that we make is that if it is consistent with our data that a delivery *could* have happened at a valid public health facility, then it actually happened at a public health facility. We cannot rule out the possibility, for instance, that deliveries occurred proximate to a public health facility, but not at the public health facility. Likewise it is possible that deliveries far from valid public health facilities, nonetheless happened at a public health facility. On average, deliveries classified as *not* at a public health facility were 5.2km from a facility. Deliveries classified as being at a public health facility were 2.6km away. Since we expect a small amount of error in our estimator, it is possible, but unlikely that some of these deliveries actually happened at a public health facility.

Since downstream audits rarely overlapped with missed deliveries, it is difficult to validate this estimator directly. One indication of the potential for misclassification is the extent to which our results vary under alternative confidence intervals for $\hat{D_{ab}}$. If we use a 90% confidence interval rather than a 95% confidence interval, our estimate of non-valid deliveries increases from 5% to 11%. If we use an 80% or 70% confidence interval, our estimate increase to 31% and 41%. Thus, even under these more relaxed assumptions, supply chain error — rather than theft — seem to explain the majority of missed deliveries.

In Section C.3 below, we discuss some potential reasons for this high rate of incorrect deliveries.

C. Identifying Diversion from Downstream Audit. We are interested in whether medicines that arrive at the correct facility remain at that facility in the weeks following the delivery. As discussed in Section E, audit teams conducted in-person tracking audits at a random sample 144 health facilities that were supposed to have received deliveries or redeliveries of tracked medicines.

C.1. Downstream Diversion. Using data from these audits, we create a variable called ***Downstream Diversion***. This variable equals one if a medicine was delivered to its intended destination (*Upstream Diversion = 1*) but was then not found in the in-person audits at the correct location, or at a redelivery location. It equals zero if the medicine was found at the correct location, or at a redelivery location. It is missing in cases where a medicine was not confirmed as correctly delivered, or when an intended facility was not audited.

C.2. Private Theft. In addition to identifying whether a medicine was diverted, we attempt to determine why a medicine went missing. In most cases, the reason why a medicine a medicine went missing cannot be determined since we fail to track their SENTINEL in any of our auditing activities. However there are specific cases where we can identify what happened.

One such case is when medicines are re-sold to private markets and pharmacies within the local community. As discussed in Section E, we conducted remote tracking audits in the nearest private pharmacy and market to each of the 104 health facility included in the Downstream Remote Tracking Audits. Since not all health facilities have nearby markets or pharmacies, we audited a total of 143 private markets and pharmacies. It is important to note that we can only identify cases of theft that occur within these sampled facilities. It is possible (and likely) that private theft occurs through other channels.

Using these audits, we code *Private Theft* equal to one if medicine which is missing at the correct health facility was found at one of the audited private facilities. We code *Private Theft* as zero if the medicine is missing for another reason. Note this means that *Private Theft* is missing where *Upstream Diversion* or *Downstream Diversion* equals zero.

Private theft can occur as a consequence of either upstream or downstream diversion, depending on the likely perpetrator of such theft. We attempt to distinguish between these two channels in the main text. We conclude that most instances of private theft occur as a result of downstream diversion.

C.3. Supply Chain Error. A second reason why medicines might be diverted is that they went to the wrong facility due to error. There are multiple reasons why this might be the case. In some cases it seems likely that delivery teams made an error in the delivery process and provided medicines intended for one facility to another. This can happen, for instance, due to the mislabelling of medicine boxes during the loading process or errors identifying boxes during the unloading process. It is also possible that some of this error is due to intentional or intentional substitution of similar medicines by delivery teams. Due to the lack of cross-checking of paperwork, errors of this sort are easy to overlook.

There are other potential sources of error. As we discuss in Section , medicines are also sometimes redelivered from one facility to another. Such redeliveries are supposed to be documented in redelivery notes held by District Health Offices (DHOs). However compliance with these regulations are sometimes spotty and delivery notes are frequently incomplete. When this is the case, a medicine can end up a facility which made no official order was made.

It is also possible that medicines end up at the wrong facility as part of coordinated theft. For instance, corrupt officials may seek to divert medicines to those facilities that are particularly prone to theft. It is difficult two rule this out. However we are aware of no accounts of such coordination between delivery and clinic officials.

To code supply chain errors, we create a variable *Supply Chain Error* which equals one if a missing medicine is found at a facility which was not the original ordering facility and was not a facility for which we have a documented redelivery request. *Supply Chain Error* equals zero if a medicine is missing for another reason. This means that *Supply Chain Error is missing in cases where Downstream Diversion* equals zero.

D. Identifying Diversion during Redeliveries. As discussed in Section C.3, medicines that are delivered to district health offices and hospitals (DHOs) are sometimes redelivered to other health facilities. To audit these deliveries, an audit team collected the delivery records (delivery notes) from all district health offices in the Southern Region. From these delivery notes, we identified 150 health facilities that had ordered tracked medicines from 11 DHOs and hospitals in October and November. We visited 97 of these facilities in the downstream audits. Our sample included all redelivery facilities in the districts of Balaka, Blantyre, Mangochi and Neno.

We are interested in what happens to these medicines eligible to be redelivered. To measure this, we first identify the sample of tracked medicines that were correctly delivered to the DHO, but were later found to be missing in the Downstream Remote Tracking Audit. This provides us with a sample of 81 medicines.

To identify which of these medicines were likely redelivered we attempt to match each of these 81 medicines with an entry on the delivery notes. Unfortunately there are no unique medicine serial numbers on medicines or delivery notes, so there is no way to identify exactly which medicine was redelivered. However by matching on medicine type, batch number and DHO name between our list of tracked medicines and transcribed delivery notes we are able to identify 66 tracked medicines which were eligible to be redelivered. While we cannot confirm that all these medicines were intended to be redelivered, this is the full population of tracked medicines which could plausibly have been redelivered according to this official documentation.

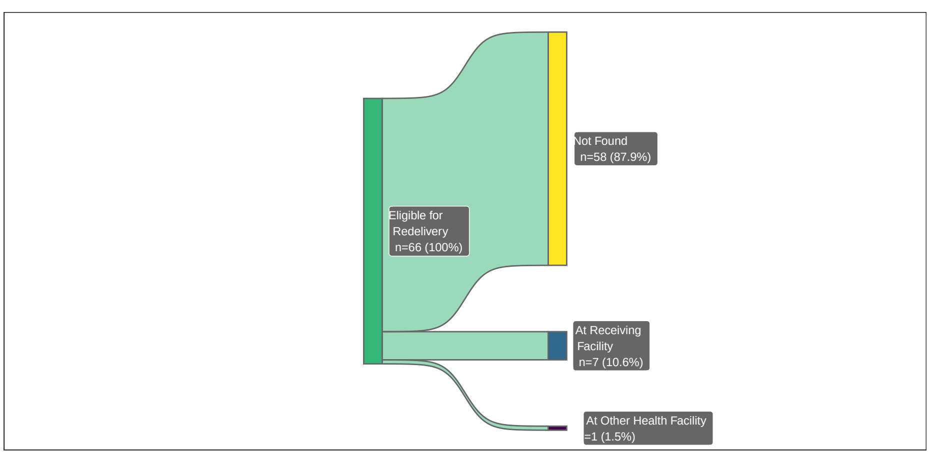
We summarize what happens to these 66 medicines eligible to be redelivered in Figure S17. Only 7 (11%) of these medicines actually reach an official ordering facility. 1 was found at facilities which were not on the delivery notes. The remainder were not found. As we show, in S18, if we focus on the four districts where we visited the population of redelivery-eligible facilities, we observe a slightly higher rate of redelivered medicines (17%).

In sum we think these data suggest a couple things about this delivery channel: First, the discrepancy between intended and actual locations of redelivery eligible medicines imply large errors in official records. One explanation that this discrepancy is due to falsification of entries in delivery notes. Such falsification could be an attempt to hide corruption. However this falsification may also be an attempt to hide a general lack of compliance with official record-keeping regulations. One plausible scenario is that delivery notes records were completed *after* rather than *before* the audit visit was announced. Such post-hoc compliance is consistent with the high proportion of these medicines that are in fact redelivered, but to locations that are not noted in official documentation. This suggests that official delivery notes may have been compiled after the audit request based on incomplete sources of data.

However there does seem to be evidence that the redelivery channel is a particular target for corruption. Compared to direct delivery channels, a higher proportion of medicines in this channel goes missing or ends up in private facilities. This is consistent with more anecdotal accounts of theft during redeliveries.

Some caution is warranted in the interpretation of theses data since the sample is small. Also, since we lack unique identifiers, we cannot confirm that all medicines in this analysis were intended for redelivery.

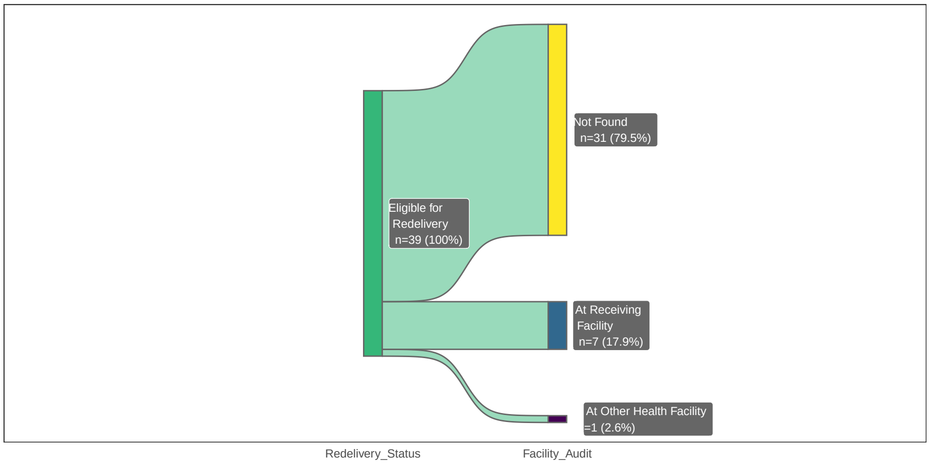
Fig. S17. Location of medicines eligible for redelivery



E. Index of Theft Perceptions. For the construction of the one-factor confirmatory factor analysis (CFA) index presented, a set of relevant variables was carefully selected from our Baseline Citizen Survey. These variables were chosen based on their theoretical relevance to measure perceptions of medicine theft. The variables are the following:

1. Did the clinic provide you or your family with these medicines?

Fig. S18. Location of medicines eligible for redelivery in Balaka, Blantyre, Mangochi and Neno



2. In the past 3 months, has the clinic ever been unable to provide medicines that your family needs?
3. In general, how effective do you think clinic is at providing medicines that this community needs?
4. Agree or Disagree with the following sentence: The theft of medications keeps people from getting high-quality health care in my community.
5. Number of visits when you needed a medication and it was not available for you at the clinic pharmacy, and you believe it was because someone stole the medicine.
6. In the past 3 months, have you or someone in your household ever gone without medications because they were not available from clinic?
7. In the past 3 months, approximately how much in kwacha have you or someone in your household spent on purchasing medications that were not available at clinic?

Prior to analysis, variables were transformed into binary variables, with the exception of the last variable, which is an ordered variable that varies from 1-6. Each number refers intervals of money spent on medicines. These preprocessing steps were applied to maintain the compatibility of the variables within the CFA framework.

The resulting factor loadings from the one-factor CFA analysis were used to construct the index. Each variable's loading on the latent factor was treated as its weight in the index. The index score for each participant was calculated by summing the products of their individual variable scores and the corresponding factor loadings. This procedure yielded a single numerical value for each participant, representing their position on the latent construct. Then, we calculated clinic-level averages of the index, which were used in the analysis.

7. Summary Data

A. Summary of Outcome Variables. In Figures S19, S20, S21, S22 below we plot the distribution of our main outcome variables.

Fig. S19. Distribution of *Downstream Diversion*

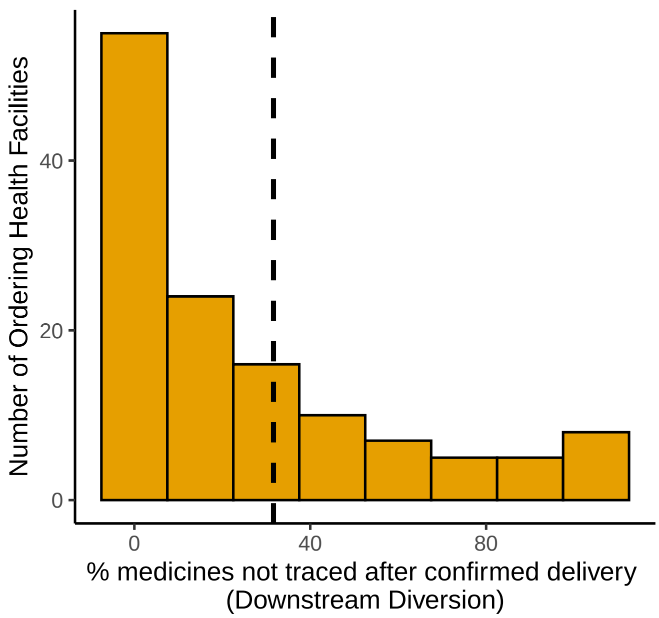


Fig. S20. Distribution of *Upstream Diversion*

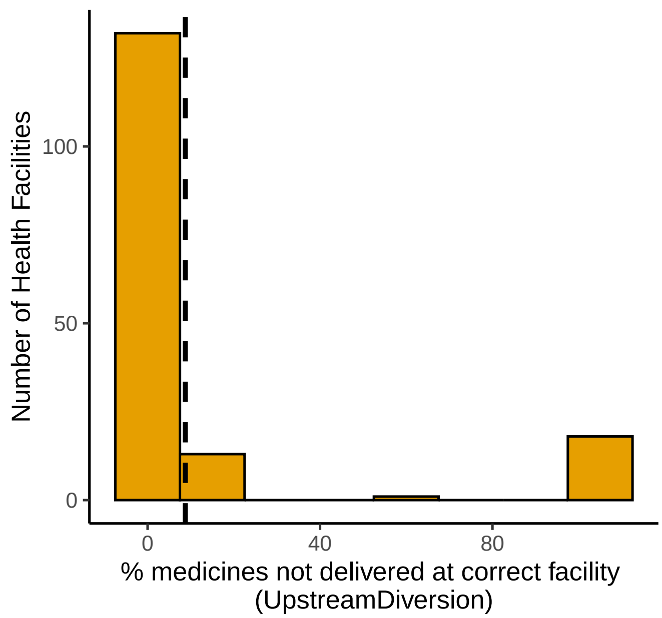


Fig. S21. Distribution of *Private Theft*

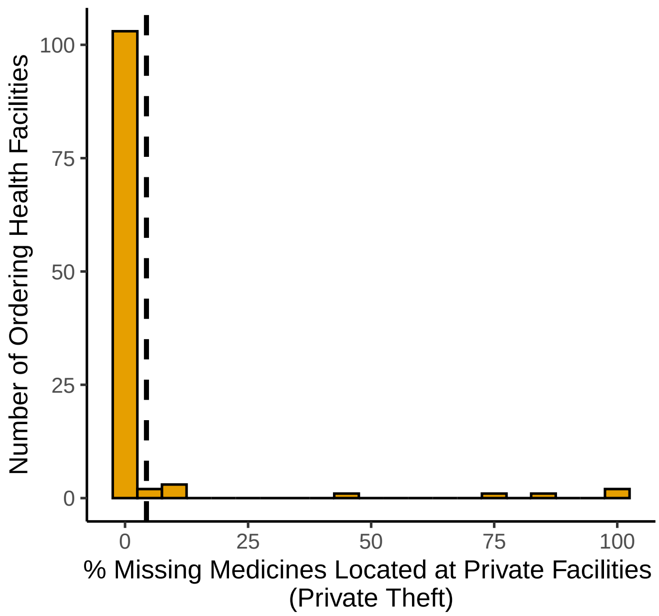
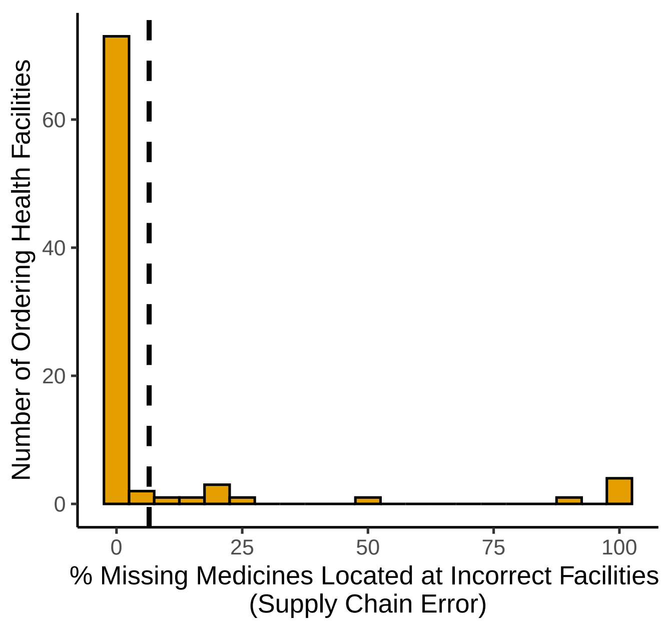
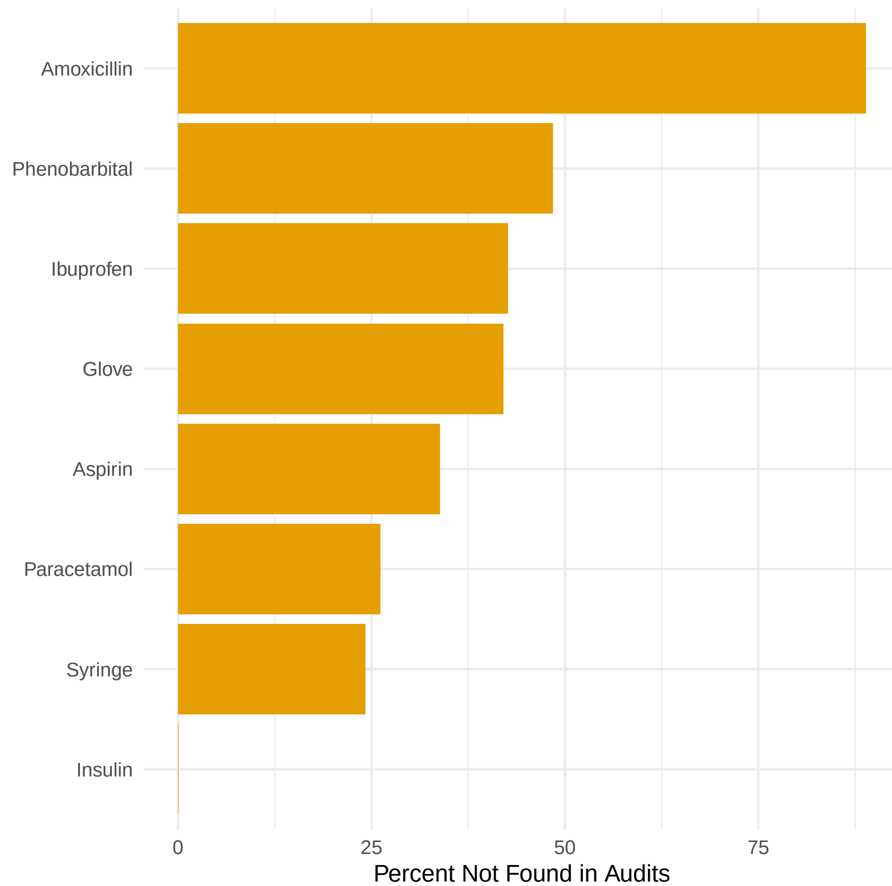


Fig. S22. Distribution of *Supply Chain Error*



B. Diversion by Medicine Type. In Figure S23 we show the percentage of medicines diverted by medicine type. Amoxicillin, a common antibiotic, is the most commonly diverted medicine by far (over 88% diverted), followed by phenobarbitone and ibuprofen.

Fig. S23. Rate of diversion by type of tracked medicine



C. Diversion by District. In Figure S24 we show the percentage of medicines diverted by district. The most medicines were diverted in Zomba, followed by Balaka and Neno.

8. Experimental Intervention

The remote tracking audit activities described in the main manuscript were executed as part of broader impact evaluation with the goal to experimentally identify the deterrent effect of procurement oversight. As the COVID-19 pandemic prevented our originally designed intervention from proceeding, we redesigned the intervention to avoid in-person activities and rolled it out alongside the remote tracking audit activities described in the main manuscript. The large time lapse between baseline survey data collection and intervention rollout was not ideal, though unavoidable.

Specifically, across a random sample of approximately 2,400 boxes of medicines (the same sample as those tracked in the remote tracking audits), we randomly assigned half ($n = 1,258$) to a top-down monitoring message intervention. We placed a prominent and government-branded sticker containing information to be read by public officials involved in health services delivery (Figure S25). The remaining $n = 1,112$ boxes were randomly assigned to the control group, which did not receive a sticker. The goal of the intervention was to inform recipients that a particular box of medicines is being tracked by the Ministry of Health. Building on behavioral theories of crime, we expected that recipients of this intervention would update their beliefs regarding the probability and costs of interdiction and would be less likely to divert the medicines. The experiment results will be analyzed in a separate paper, but our pre-analysis plan with more details can be found at [LINK TEMPORARILY REDACTED FOR AUTHOR ANONYMITY].

Ethical review for this project took place in 2018 at the London School of Economics and Political Science, and the project was approved in December 2018. In addition, the Malawi National Health Sciences Research Committee reviewed and approved the project twice: once for the original intervention design in March 2019 and once for the intervention redesign in July 2021.

Fig. S24. Rate of diversion by district

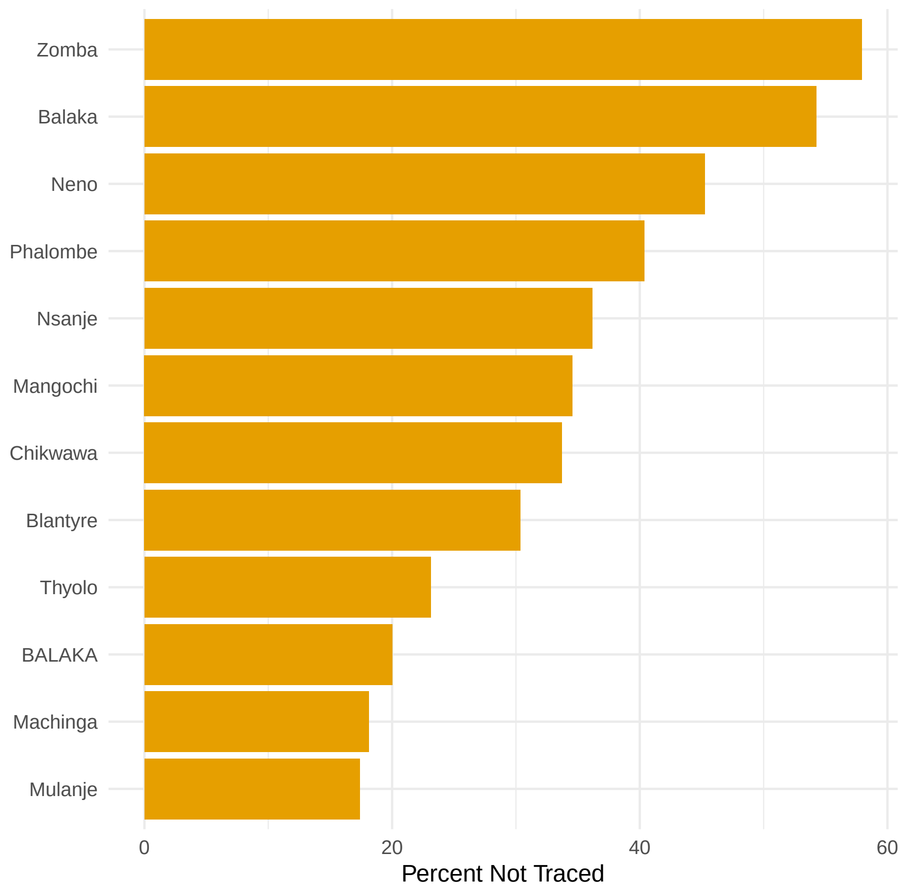


Fig. S25. Monitoring Sticker

9. Challenges

The results presented in the main manuscript require several caveats regarding challenges and acknowledgements of limitations. This section delineates these issues.

Measuring Diversion: Deliberate Malfeasance versus Administrative Weakness. There are several limitations of our measures of diversion. First, and most importantly, they do not perfectly operationalize theft. They partially capture theft and partially capture administrative weaknesses - for example, disorganization, insufficient record-keeping, or inadequate training. Of course, theft and administrative weakness may be correlated. Still, future research could consider how to use the tracking system we developed to more precisely identify theft distinctly from these administrative issues.

Device Manipulation. One important form of non-compliance is tampering. Though we took steps to obfuscate tracking devices, we have anecdotal evidence of at least a few instances where SENTRIES were damaged or simply switched off to stop their tracking capability. Similarly, some SENTINELs were unable to be found after leaving the delivery trucks, even once the logistics company managing the deliveries deployed a team to retrieve them. In the analysis above, we interpret these instances as diversion.

Supplementary Figures

Fig. S26. Monitoring Sticker

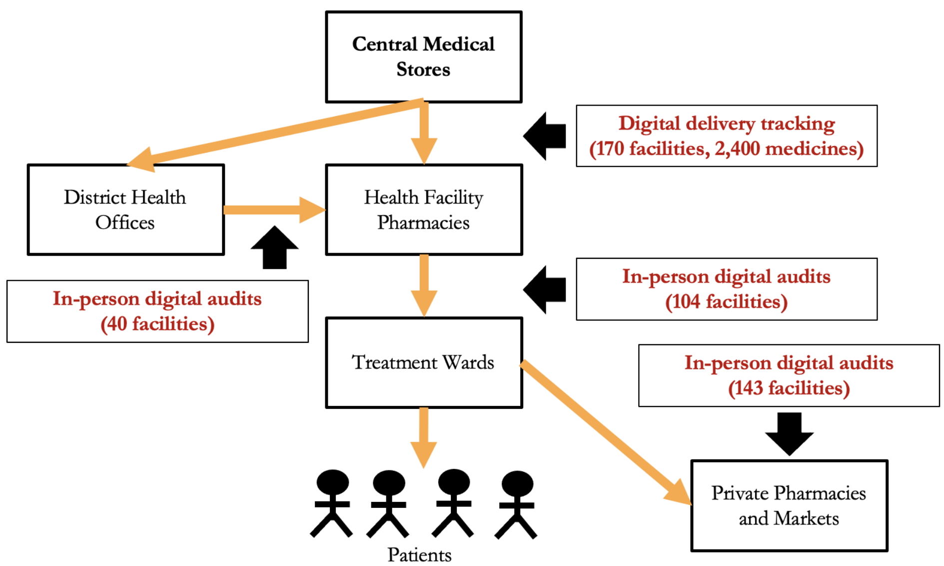
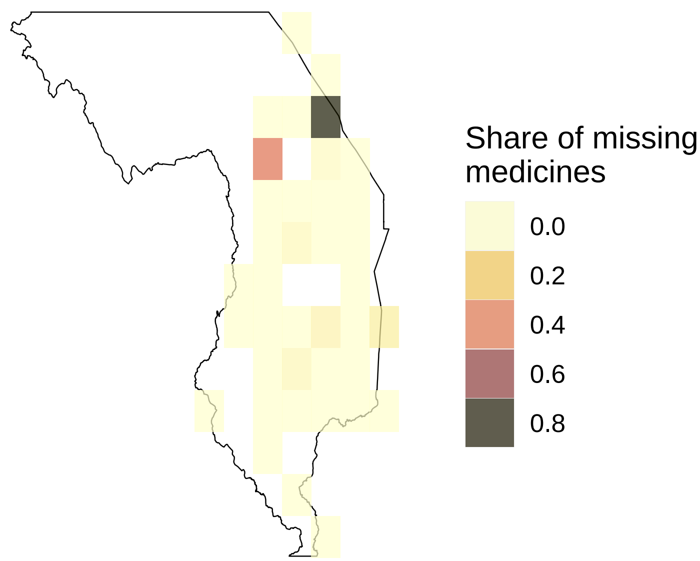


Fig. S27. Diagram of Digital Tracking and Auditing Activities

Fig. S28. Photos taken during In-Person Digital Audits

Fig. S29. Where Do Missing Medicines Go?



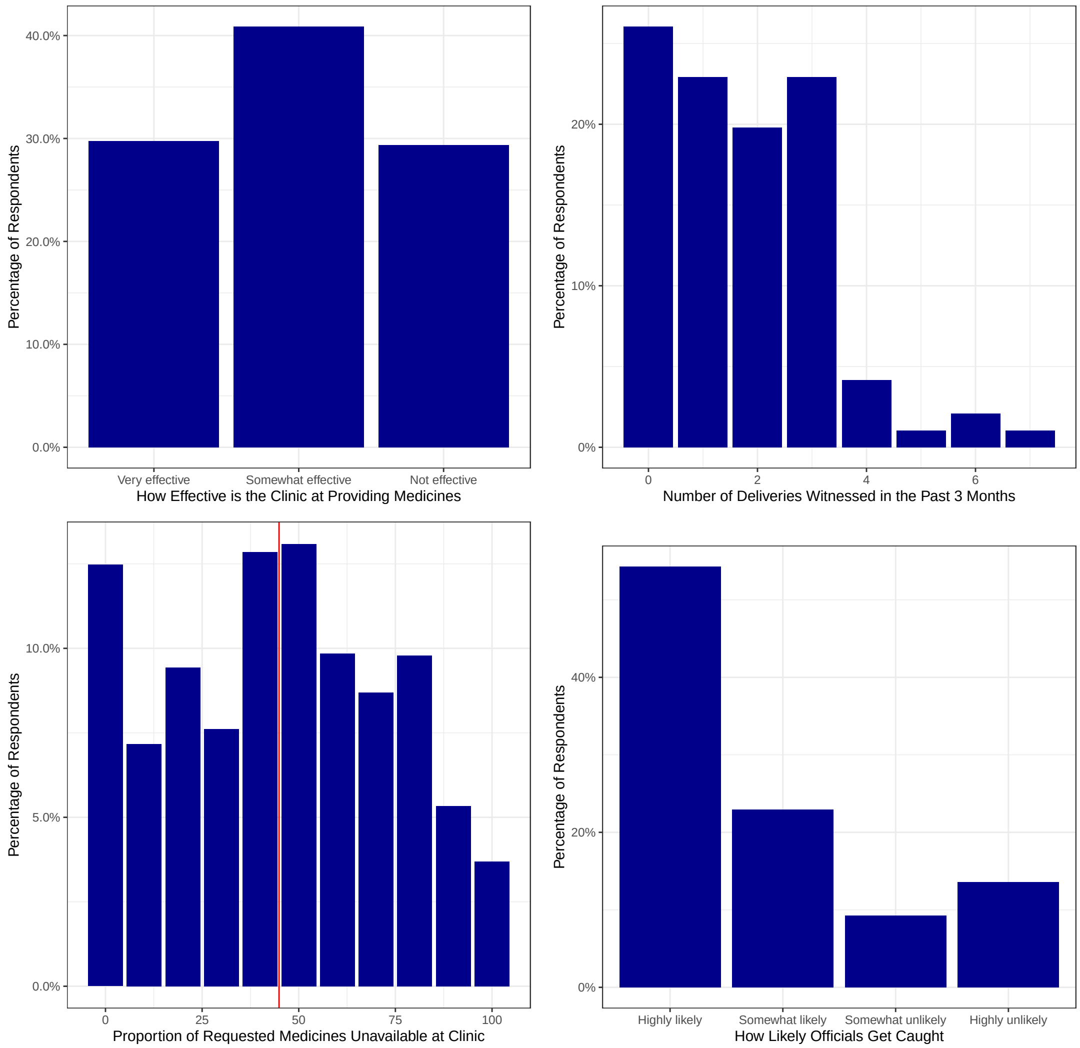


Fig. S30. Baseline Results

10. References

References

1. Oxfam, Missing medicines in malawi campaigning against ‘stock-outs’ of essential drugs, (Oxfam), Technical report (2012).
2. TG Fund, Audit report: Global fund grants in malawi, (The Global Fund), Technical report (2016).
3. E Lodenstein, et al., “we come as friends”: approaches to social accountability by health committees in northern malawi. *BMC health services research* **19**, 1–14 (2019).
4. N Meinshausen, G Ridgeway, Quantile regression forests. *J. machine learning research* **7** (2006).