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Using remote tracking technologies to audit and understand medicine theft

Ryan Jablonski,[1] Brigitte Seim,[2] Mariana Carvalho Barbosa,[3] and Clark Gibson[4]

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Abstract: 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, policy-makers 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 policy-makers could also 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.

Key words: corruption, health systems, drug theft, monitoring, Malawi

JEL classification: O10, O38, O55, P00

[1] Department of Government, The London School of Economics and Political Science, London; corresponding author: r.s.jablonski@lse.ac.uk; [2] Department of Public Policy, University of North Carolina at Chapel Hill, Chapel Hill; [3] Department of Political Science, Brown University, Providence; [4] Department of Political Science, University of California, San Diego

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United Nations University World Institute for Development Economics Research provides economic analysis and policy advice with the aim of promoting sustainable and equitable development. The Institute began operations in 1985 in Helsinki, Finland, as the first research and training centre of the United Nations University. Today it is a unique blend of think tank, research institute, and UN agency—providing a range of services from policy advice to governments as well as freely available original research.

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Katajanokanlaituri 6 B, 00160 Helsinki, Finland

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1 Introduction

Medicine theft is a leading cause of preventable disease and is linked with increased mortality in many low-income countries (Mooketsane and Phirinyane 2015; Gaitonde et al. 2016; Onwujekwe et al. 2019). In Malawi, where our study takes place, Ministry of Health officials estimate that nearly 30% of spending on medicines and medical supplies disappears due to theft alone (Mphande 2017). 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 figures in other countries with low-capacity health systems (McPake et al. 1999; Ferrinho and Van Lerberghe 2002; Hsiao 2004; Lewis 2006; Savedoff 2007; Bate et al. 2010; Bouchard et al. 2012; Hope Sr 2015; Hwang et al. 2019; Onwujekwe et al. 2019).

Medicine theft costs governments and donors billions of dollars each year between lost medicine and spending on supplemental supply chain oversight (Ferrinho and Van Lerberghe 2002; Vian 2006; Hanf et al. 2011; Jones and Jing 2011; World Health Organization 2018; Bruckner 2019; García 2019). Medicine theft and other health-sector corruption track with higher infant mortality, maternal mortality, HIV transmission, and poverty (Hanf et al. 2011; Jones and Jing 2011; Muldoon et al. 2011; Fitzpatrick 2022). Further, the burden of this theft falls most heavily on vulnerable individuals, who have fewer resources with which to acquire needed medicines (Hanf et al. 2011).

The persistence of widespread medicine theft is partly due to the difficulty of its detection (Vian 2006; Kohler and Dimancesco 2020). Traditional detection technologies like audits and hotlines struggle to detect theft within the kind of distributed and opaque supply chains typical of 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 policy-makers 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 often vary to the point of being uninformative for policy (García 2019).

Why is detection so challenging? In its reduced form, a 'traditional audit' involves human auditors inspecting government records to identify anomalies and bureaucratic errors and assess which are attributable to corruption. We identify three basic 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 '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 (Brinkerhoff 2004; Barrington et al. 2010; Sant Fruchtman et al. 2021), making theft a low-risk/high-reward option (Mackey and Cuomo 2020; Zuma 2022). For instance, a 2019 audit in Malawi found discrepancies in the stocking records of 96% of audited clinics (The Global Fund 2019).

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 (Vian 2008; Onwujekwe et al. 2019). 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, like when 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) (Vian 2013;

Zamboni and Litschig 2018). As we show below, error is a more common cause of missing medicines than theft. Technologies that rely on end-to-end monitoring—e.g. using scanners and QR codes—can mitigate this problem (Mackey and Cuomo 2020; Swartz et al. 2021). However, end-to-end monitoring is less feasible in many low-income contexts due to lack of necessary capital, skill, and infrastructure required for such solutions to work, and remains prone to error and manipulation, particularly after the point of delivery.

Third, traditional audits rarely provide data at scale and never 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 small proportion of health facilities. Low-scale audits mean that perpetrators can often avoid detection by shifting theft to places more difficult to audit. Lack of timely data undermines a government's ability to address irregularities as they occur or to close supply chain loopholes before significant losses accumulate (Leung et al. 2016).

In this study, we propose and evaluate a corruption detection approach that addresses all three of these traditional audit weaknesses. Our approach allows us to 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 Malawi's medicine supply chain. We then perform a multi-stage 'remote tracking audit' to detect the scale and points of diversion,[1] as well as the ultimate destination for the diverted medicines. This approach is more scalable, timely, and cost effective than traditional audits.[2] 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.[3] We cross-validate the remote tracking audit data with survey data and 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.[4]

We use data from these remote tracking audits to shed new light on the 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 the majority of the diversion that would be picked up by a traditional audit, implying that existing studies overestimate and misidentify patterns of corruption.

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[1] 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.

[2] See the supporting information (SI) document for cost details.

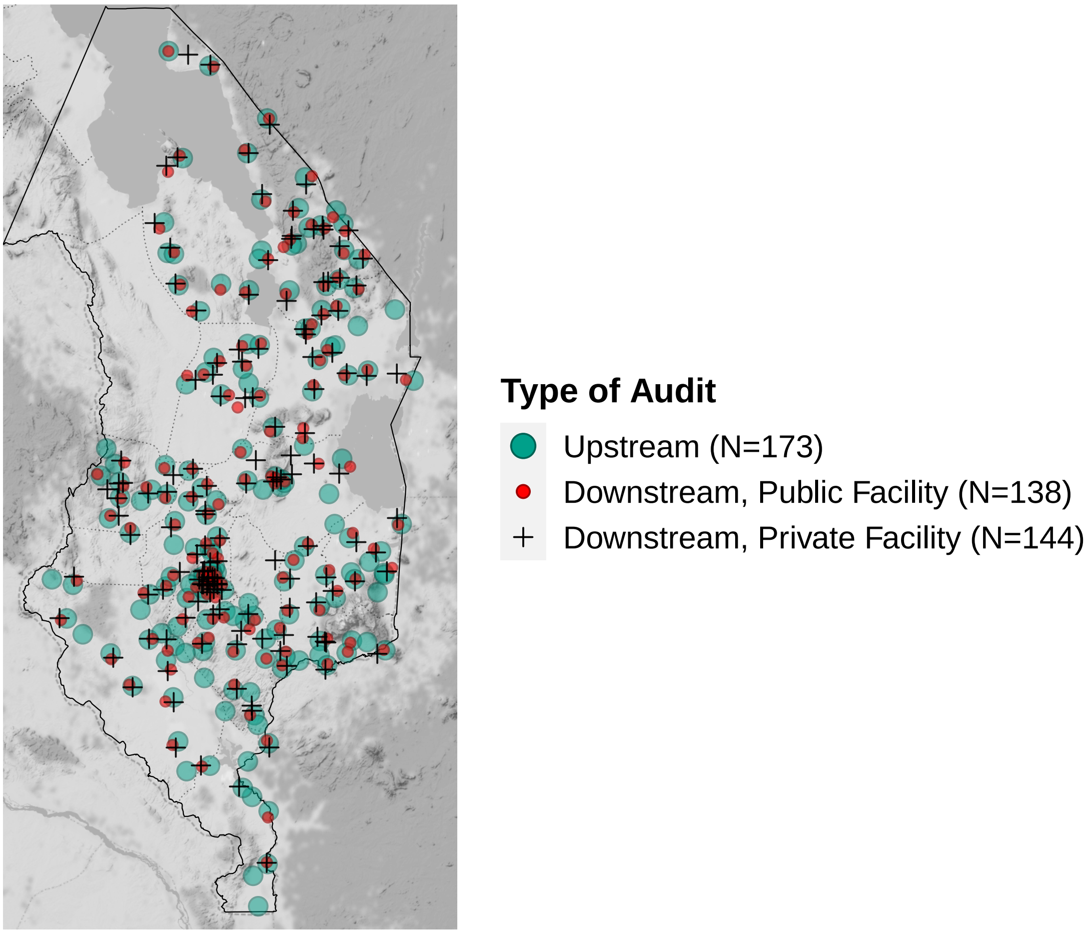
[3] See the SI for a discussion of the health system and the institutional challenges in the Malawian context.

[4] For a review of other ways mobile technologies have been adapted to prevent corruption in the health sector, see Mackey and Cuomo (2020).

2 Remote tracking audits

We collaborated with the Malawi Ministry of Health, the Malawi Drug Theft Investigations Unit, and a technology company, OnAsset Technologies (USA), to develop our theft detection approach. We designed the approach to audit the medicine supply chain from the Central Medical Stores Trust (CMST) warehouse to health facilities in Malawi's Southern Region. In the 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).[5] 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 scheduled to receive re-deliveries 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.

Figure 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.
Source: authors' elaboration using spatial data from GADM (n.d.) and Kahle and Wickham (2013).

The audit protocol involved two types of OnAsset tracking devices:[6] (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

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

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

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.

2.1 Upstream remote tracking audits

We conducted upstream tracking audits of October and November 2021 to identify medicines diverted during the delivery process. 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 diverted (Table 1). At most facilities, we tracked all orders of these medicines.[7]

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. These medicines were intended for delivery to 170 facilities, ranging from large district hospitals to small local health centres. Team members attached the devices to pill bottles or placed them in boxes for non-bottled medicines.[8] We created and placed stickers on each SENTINEL to discourage officials from removing the devices. The stickers declared the SENTINEL was a 'shipping temperature and humidity monitoring device', property of the Ministry of Health and should not be removed from packaging.[9] 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

Source: authors' elaboration.

2.2 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 remained at the correct facility in the following weeks. To audit each of these public

[7] 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.

[8] 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.

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

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.[10] The goal of these audits was to identify instances of theft: where government medicines were being sold for a profit in private facilities. During these audits, the research staff 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.[11] 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.

We monitored the data captured by SENTRY devices in real time to ensure sample and protocol compliance.

3 Health facility surveys

Before initiating these audits, from January to March 2019, we conducted face-to-face surveys with Malawians living in the catchment area of a random sample of 97 health facilities in Southern Malawi. Trained Malawian enumerators carried out these surveys in either English or Chichewa, as per the subjects' preference. 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. With a special focus on their observations of theft, the survey also included a list experiment to measure the prevalence of public medicine resale. 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. As discussed below, we use these baseline data to validate our remote tracking audit data and to compare citizen perceptions of stock-outs and theft to our audit data.

These survey data confirm that theft is a significant problem in Malawi. An estimated 50% ($\pm$ 5%) of respondents across 79% of facilities reported observing the illegal sale of medicines that should have been provided for free.

4 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 tracked to and dropped off at the health facility that ordered

[10] 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.

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

the medicine. It equals one if a medicine was tracked elsewhere. 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 supporting information [SI] document[12]).

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 the set of facilities experiencing 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 (Jablonski and Seim 2023).

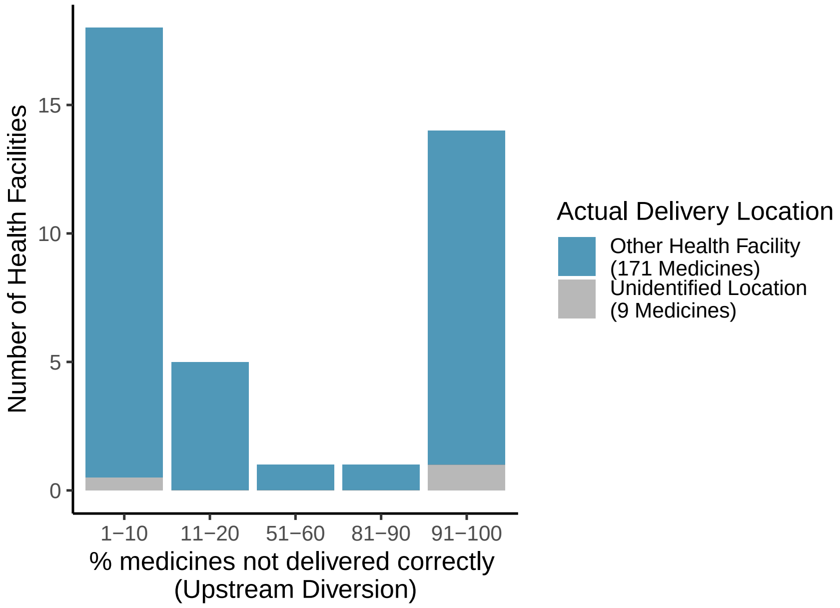
In order to differentiate between theft and error, we classify upstream diversion into cases where a medicine was plausibly delivered at a public health facility versus cases where a medicine was most likely delivered to a location that was not a public health facility (Figure 2a). Nearly all (95%) instances 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.[13]

[12] Available under 'Supplementary material' at: https://doi.org/10.35188/UNU-WIDER/2023/434-2.

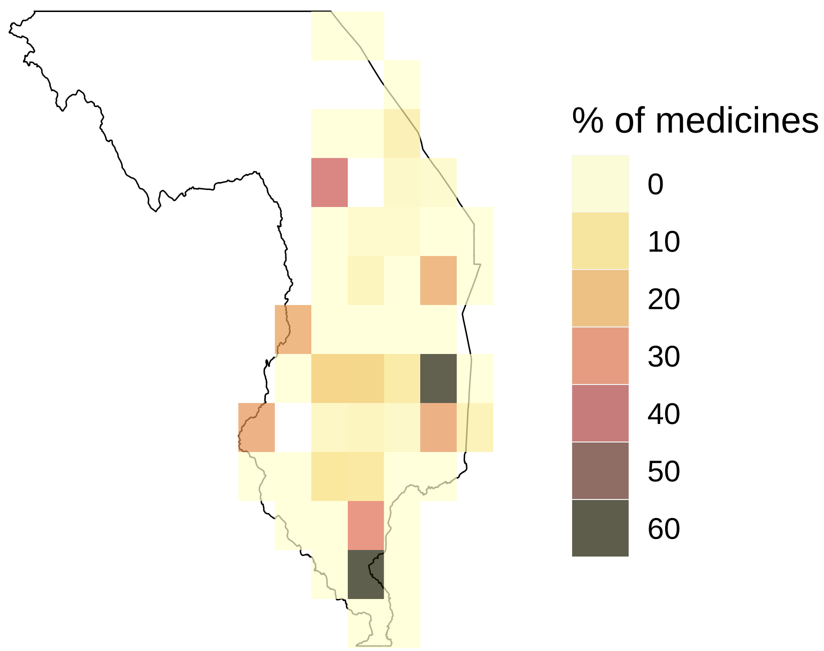
[13] We code a medicine as delivered to a health facility if there was a health facility within the confidence interval of the final delivery coordinates. Since this is an estimate, we expect a small amount of classification error. Thus, these data are also consistent with *all* deliveries occurring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

Figure 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.

Source: authors' analysis; shape files are from GADM (n.d.).

5 Findings of downstream remote tracking audits

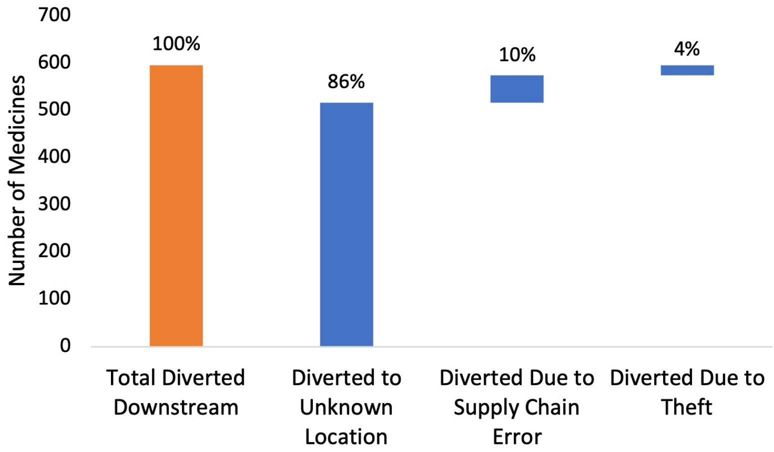
Using the data from the downstream remote tracking audits, we create the variable *Downstream Diversion*. This variable equals one if a medicine was correctly delivered to its intended public health facility (i.e. not diverted upstream) but then was *not* subsequently found at that facility during the 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. Eighty of the 133 health facilities—60%—audited during the downstream remote tracking audit experienced some downstream diversion. As with Upstream Diversion, we find some geographical clustering of Downstream Diversion, particularly around facilities in border and remote areas (Figure 3b).

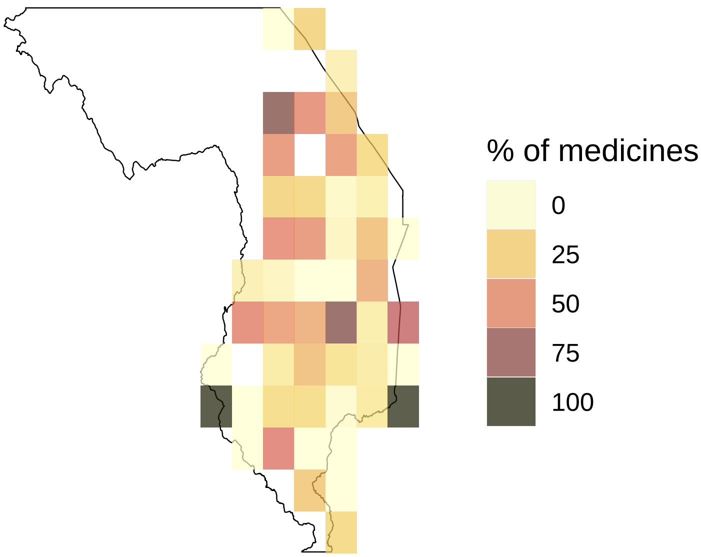
Based on the downstream remote tracking audits, we can glean some information about the destinations of these diverted medicines. Figure 3a disaggregates the set of medicines diverted downstream into three categories: those not found in the downstream remote tracking audit and are therefore in unknown locations; those found at other (incorrect) public health facilities and whose diversion is most likely due to supply chain error; and those 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 4% of the downstream diverted medicines overall—were found at a private facility and therefore were likely stolen. We provide a more complete summary of the final location of all tracked medicines in the Sankey diagram in Figure 5.

Figure 3: Patterns in *Downstream Diversion* (medicines missing during downstream remote tracking audit)

(a) Final destinations of downstream diverted medicines



(b) Map of *Downstream Diversion*

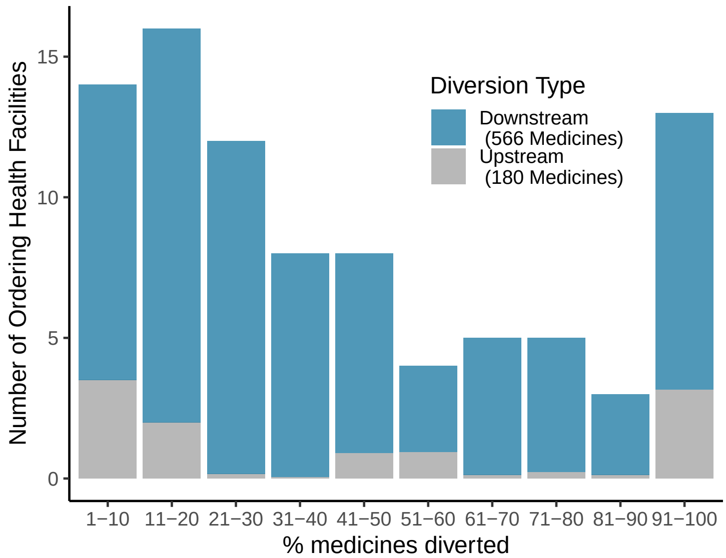


Note: the top panel shows a breakdown in final destinations of the medicines diverted downstream. The orange bar represents the total set of medicines diverted downstream and the blue bars show the subset of diverted medicines for each of three destinations: unknown locations; other public health facilities;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

Source: authors' analysis; shape files are from GADM (n.d.).

We find more evidence of downstream than upstream diversion. In Figure 4, we plot the per cent 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 of total diversion ($R^2 = 0.20$). However we emphasize that some public health facilities are experiencing upstream diversion of almost all of their medicines (the far right bar in Figure 4).

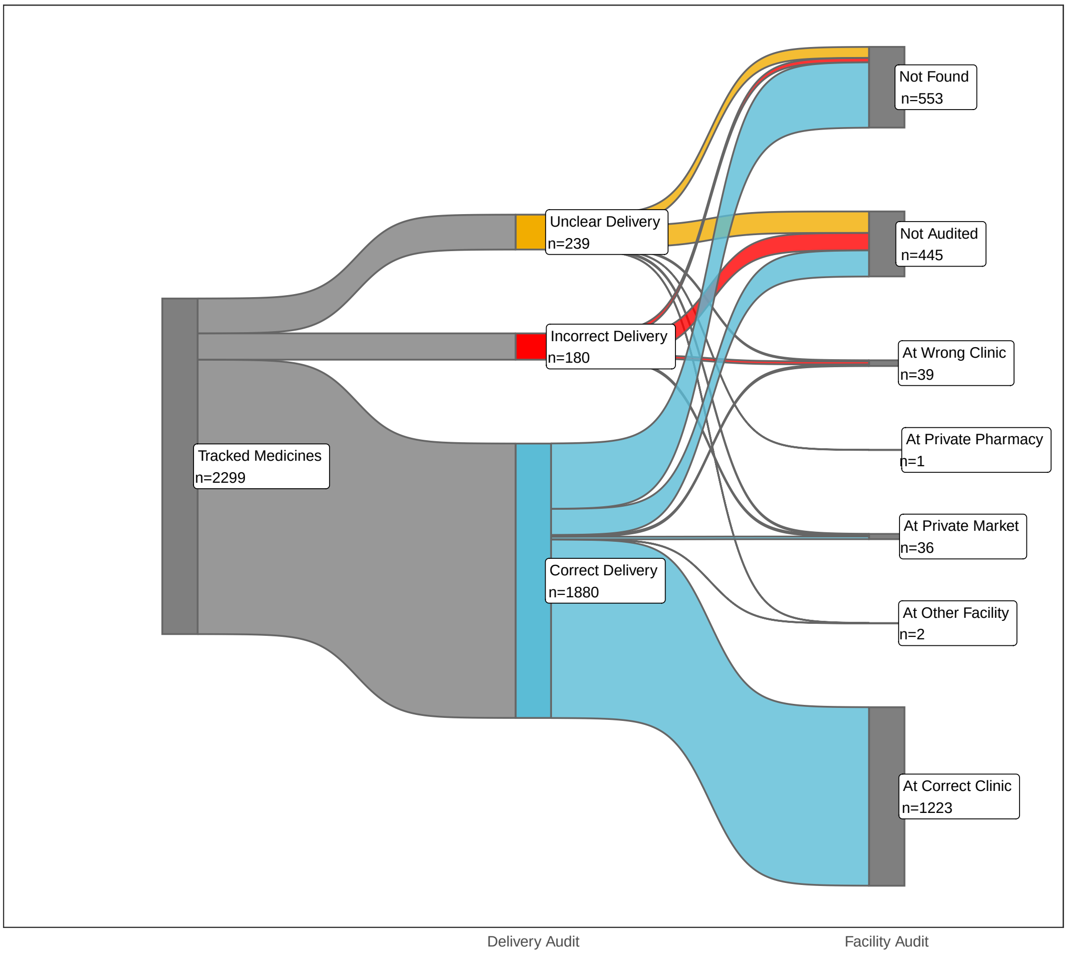
Figure 4: Histogram of diversion: downstream vs. upstream



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.

Source: authors' analysis.

Figure 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.

Source: authors' analysis.

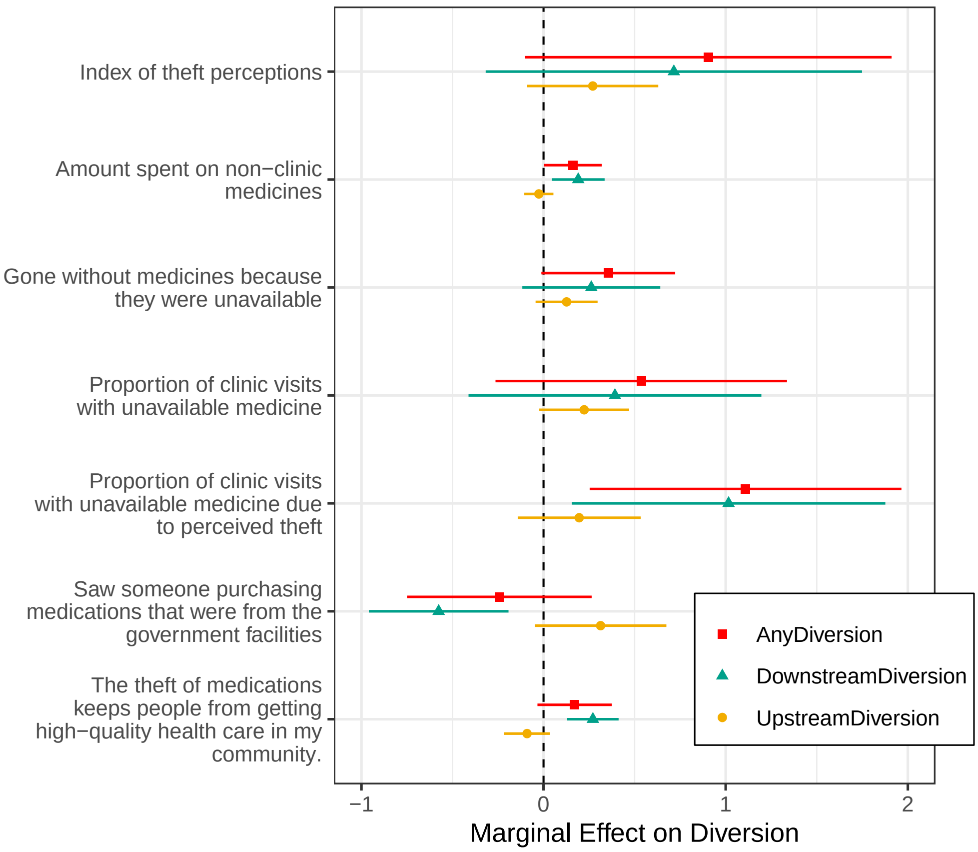
5.1 Medicine diversion during or after redelivery

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 districts in which we audited redeliveries, we identified 39 tracked medicines which were eligible to be redelivered.[14] Yet, we were only able to locate seven of these (18%) at the correct receiving facility (see the SI).

[14] 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.

6 Validation of remote tracking measures

Figure 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 on facility and include district and facility type fixed effects.

Source: authors' analysis.

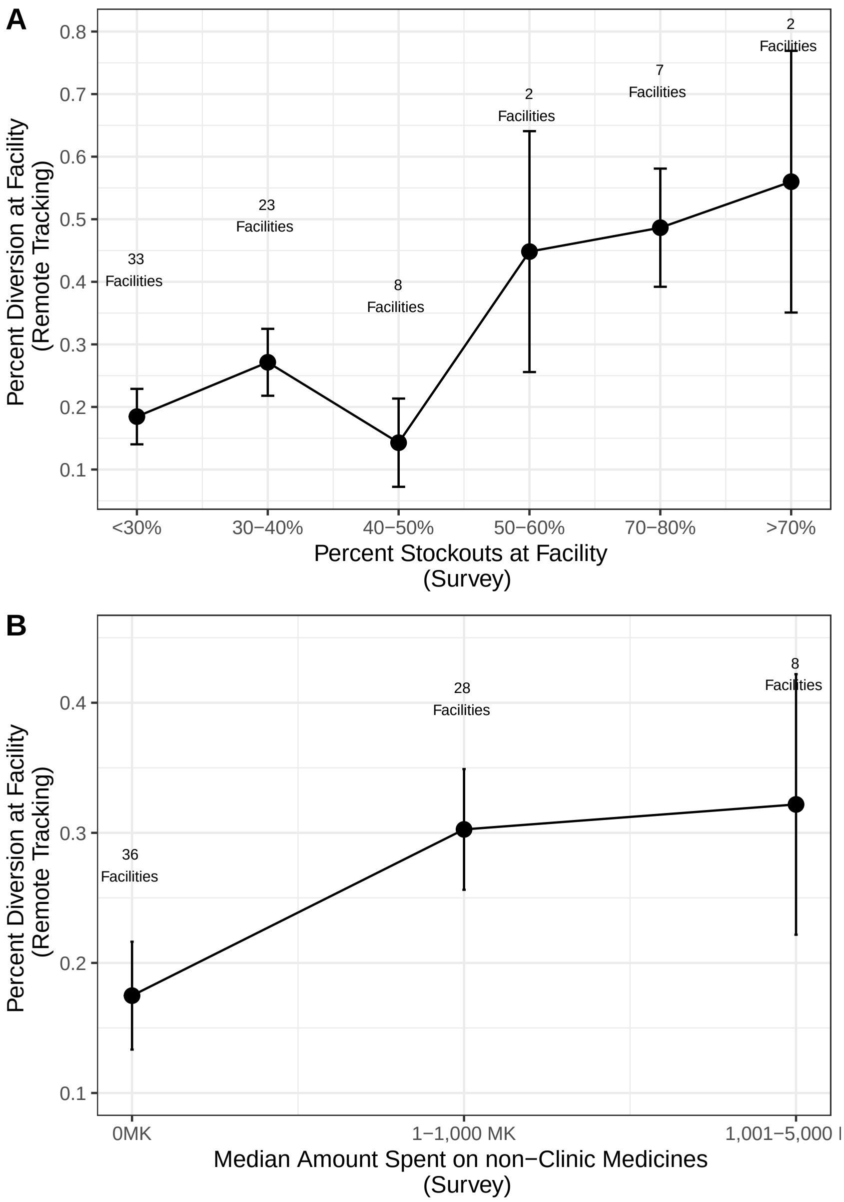
7 Diversion and public health

Our survey data also suggest that medicine diversion has negative consequences on health care. Respondents report that 26% of needed medicines were unavailable at their health facilities. Respondents attribute about a third of these stock-outs to theft.[15] 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.

[15] Respondents claim 38% of unavailable medicines are missing because they believe "someone stole the medicine."

Figure 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 respondent median level of expenditure on medicine (the x-axis) to the observed rate of diversion (the y-axis) at the facility level with 95% confidence intervals.

Source: authors' analysis.

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

Additionally, our results imply that existing anti-corruption interventions focused on theft during delivery are likely to be less consequential in improving the overall accuracy of intended deliveries. 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 including remote tracking audits in the arsenal of approaches designed to improve medicine delivery. 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 can be also efficient in a crisis environment when physical audits are impossible (this study was indeed 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.

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