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# Procurement Institutions and Essential Drug Supply in Low and Middle-Income Countries

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## Abstract

International procurement institutions play an important role in drug supply. We study price, delivery, and procurement lead time of drug products for major infectious diseases (antiretrovirals, antimalarials, antituberculosis, and antibiotics) in 106 developing countries from 2007-2017 across procurement institution types. We find that pooled procurement lowers prices: pooling internationally is most effective for small buyers and concentrated markets, while pooling within-country is most effective for large buyers and unconcentrated markets. Pooling can reduce delays, but at the cost of longer anticipated procurement lead times. Finally, pooled procurement is more effective for older drugs, compared to patent pooling institutions that target newer drugs. Our findings are robust to alternative fixed effects specifications, instrumental variable estimation, selection-on-unobservables tests, and additional analyses accounting for heterogeneity in demand elasticities across buyers and interactions with major global health initiatives.

JEL Classification: I11; O19; H57
Keywords: global drug diffusion; procurement institutions; price and delay; IP and non-IP barriers

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# 1 Introduction

Global drug diffusion is well-documented to be a slow and inefficient process (Kremer, 2002; Cockburn et al., 2016). Ensuring essential drug supply treating major infectious diseases in low and middle-income countries (LMIC) remains a global challenge, with complicated issues regarding supply chain management, local production capacity, and intellectual property (IP) rights. International procurement institutions have played crucial roles in reducing coordination failures in drug supply by pooling procurement and coordinating delivery within and across regions. Despite wide recognition of the merits of pooled procurement, there is a limited understanding of the tradeoffs involved. Understanding these institutions is increasingly important, as the COVID-19 pandemic has raised major concerns about the resilience of drug supply chains for equitable access in LMIC.

This paper systematically analyzes the efficiency and tradeoffs across procurement institutions that supply essential drug products for leading infectious diseases in LMIC. We study their role in influencing the price, delivery, and procurement lead time, using a rich dataset of drug product purchases covering 106 LMIC during 2007-2017.[1] Our sample includes treatments for four major infectious diseases that disproportionately affect people living in LMIC, including antiretrovirals, antimalarials, antituberculosis, and antibiotics. We distinguish a few major types of procurement institutions by the level of pooling in the drug supply process. Two institutions specialize in pooling procurement across countries, the Global Fund's Pooled Procurement Mechanism (PPM) and the United Nations (UN). In contrast, Central Medical Stores (CMS) pool procurement mainly within a country. Finally, countries can directly purchase drug products from manufacturers.

We build on existing empirical methods to study procurement institutions in transaction and panel regression frameworks, incorporating nuances across procurement institution types and IP licensing institutions. Our baseline analyses include an extensive set of observable controls on demand shifters, demographics, disease profiles, and institutional characteristics on top of high-dimensional drug product-country and year fixed effects. We exploit variation in the utilization of different procurement institutions for the same product in a given country over time, to identify the impact on important outcomes: product prices, procurement lead times, and delivery delays.

We have four key sets of findings. First, drug products procured through pooled procurement institutions are priced lower than those purchased directly from manufacturers. Institutions

[1] We define drug product at the active pharmaceutical ingredient (API)-strength level (e.g., amoxicillin 500mg) and drug at the API level (e.g., amoxicillin). The terms "product" and "drug product" are used interchangeably.

specializing in international pooling (i.e., PPM and UN) lower prices substantially compared to procurement institutions with a domestic or regional focus. Second, the price reductions obtained by procurement institutions are heterogeneous and vary by seller and buyer concentration and drug characteristics. Pooling internationally is most effective at reducing prices for low-volume buyers and for products with more concentrated supply. By contrast, domestic pooling is more effective for high-volume buyers and products with less concentrated supply. Third, we find that pooled procurement institutions and the pooled IP licensing institution (i.e., the Medicines Patent Pool) are effective for different drugs: pooled procurement is most effective in reducing the price of older drugs, while patent pooling largely affects newer drugs. Finally, our analyses of drug delivery conditions reveal that the PPM significantly lowers the probability of delivery delays, but often requires orders to be placed early, resulting in longer procurement lead time between ordering and delivery.

Our baseline identification assumption is that unobservables affecting procurement outcomes are uncorrelated with procurement institution choices, conditional on extensive product-country and year fixed effects and a rich set of observable controls. We use variation over time in outcomes for the same product-country pair. We address potential violations of this assumption using several strategies. First, our results are robust to more demanding fixed effects, including country-year, product-year, country-product, buyer, and manufacturer fixed effects. Second, even conditional on fixed effects, endogeneity may arise if there are unobserved drug-specific demand shocks, or if drug-specific procurement experience affects a country's negotiating ability and procurement institution choice. To address these sources of endogeneity, we use an instrumental variable strategy that exploits correlation in the choices of procurement institutions across drugs or other drug classes for the same country. In addition, we perform the Altonji-Elder-Taber (AET) test (Altonji et al., 2005) generalized by Oster (2019) (i.e., AET-O) to address selection on unobservables. These analyses yield similar results to baseline estimates. Third, we estimate a reduced-form demand function and find the differences across procurement institutions are not explained by heterogeneity in demand elasticities. Finally, we perform additional robustness tests to rule out confounders.

We further examine the interplay between pooled procurement and other institutional factors and management practices in LMIC drug supply for infectious diseases. We account for major institutions, including the U.S. President's Emergency Plan for AIDS Relief (PEPFAR) as a major buyer, and the Clinton Health Access Initiative (CHAI) that negotiates reference prices and organizes a procurement consortium. Our estimates on pooled procurement institutions remain similar,

with little evidence of complementarity with PEPFAR/CHAI. In addition, we account for management practices, including tiered pricing by manufacturers, and the use of advance payment, with the results remaining robust. We also find that international pooled procurement is associated with lower variability in demand faced by manufacturers. Finally, we do not find evidence that these procurement institutions limit the types of products (e.g., patented vs. off-patent) that buyers can procure.

This paper contributes to two strands of the literature. First, we build on the literature on procurement institutions and LMIC drug supply. Institutional procurement reduces uncertainty over quality and uses competitive tendering to spur price competition (Danzon et al., 2015). A study on HIV drugs (before the PPM was formed) finds no significant volume-price relationship (Waning et al., 2009). A case study finds that voluntary pooling via a precursor of the PPM reduces price (Kim and Skordis-Worrall, 2017). A review of 38 studies finds pooling tends to lower drug prices (Seidman and Atun, 2017), but with few results on other outcomes or heterogeneity. Based on drug data from seven LMIC, pooled domestic public procurement reduces prices, but less so when the supply side is highly concentrated (Dubois et al., 2021). Our paper also builds on studies on the theoretical (Chipty and Snyder, 1999; Inderst and Wey, 2007; Inderst and Montez, 2019; Jeon and Menicucci, 2019) and empirical (Baldi and Vannoni, 2017; Chalkidou et al., 2020; Ellison and Snyder, 2010; Clark et al., 2021) consequences of pooled procurement and buyer groups.

We make two main contributions to this literature. First, we provide a richer analysis of the price impact of pooled procurement compared to prior papers, by comparing a variety of procurement mechanisms that differ in the scope of pooling (i.e., international versus domestic), and by analyzing the impact of pooled procurement across a much broader set of LMIC than prior studies. We offer new insights into the institutional nuances in procurement processes across mechanisms (e.g., different ordering processes), and heterogeneity by characteristics (e.g., drug's first approval year and market concentration on both the buyer and seller sides). Second, the policy debate over whether procurement should be pooled emphasizes both price and non-price impacts (e.g., OECD, 2011), but the empirical literature mainly focuses on price, except Clark et al. (2021).[2] Our paper is one of the only studies to empirically analyze non-price outcomes (i.e., delivery delays, procurement lead times) of procurement institutions, and we are the first to do so in the context of essential

[2]Clark et al. (2021) find that pooling procurement of medical devices in Italy reduced prices but increased delivery delays. Gallien et al. (2017) show that unpredictability in fund disbursements and grant monitoring in Global Fund procurement pre-2014 contributed to stockout risks in African countries, but their focus is not on pooled procurement.

drug procurement.

Second, this paper adds to studies on global and domestic drug diffusion by incorporating different types of institutions that can address IP and non-IP barriers. Larger potential market size spurs new drug innovation (Acemoglu and Linn, 2004). Patents are associated with faster global drug diffusion (e.g., more product launches) but higher prices (Cockburn et al., 2016; Duggan et al., 2016; Kyle and Qian, 2017). Studies on IP in health care have focused more on developed countries and find that IP barriers beyond patents (e.g., exclusivity) can deter cumulative innovation or drug entry (Williams, 2013; Sampat and Williams, 2019; Gaessler and Wagner, 2019). Recent papers find biomedical patent pools that facilitate the licensing of patents and know-how, thus supporting essential drug supply in LMIC (Wang, 2022; Galasso and Schankerman, 2022). However, there is a limited understanding of how essential drug procurement by various institutions interacts with patent barriers and institutions that facilitate IP licensing. Our paper evaluates the relative merits of the institutions addressing IP versus non-IP barriers in the diffusion of drugs to LMIC.

Finally, this paper relates to discussions on drug procurement for the COVID-19 pandemic. Despite wide enthusiasm, COVID-19 Vaccines Global Access (COVAX), the global initiative to pool vaccine procurement and distribution to LMIC, fell significantly short of its goal. While there are debates on whether an "IP waiver" can spur vaccine supply, experts agree that non-patent barriers, such as procurement delays and supply chain bottlenecks, significantly prolonged the pandemic in LMIC. Meanwhile, HIV/AIDS, tuberculosis, and malaria remain the top infectious diseases that kill millions of people per year and generate larger disease burdens than COVID in some countries (Bell and Hansen, 2021).[3] Understanding procurement institutions supplying drugs for these diseases is important, as the infrastructure and investments for the AIDS crisis are critical first responders to pandemics in many LMIC.[4] Our study suggests the merits of institutions depend on the urgency of need, which countries may consider in choosing their procurement strategy.

The paper proceeds as follows. Section 2 describes the conceptual considerations and background. Section 3 describes data and the benchmark empirical model. Section 4 reports our main results. Section 5 provides robustness checks and additional analyses. Section 6 concludes.

[3] In 2019, the three diseases caused 2.7 million deaths, and HIV/AIDS accounted for 1.5% of global deaths. Source: ourworldindata.org/hiv-aids

[4] Source: www.unaids.org/sites/default/files/media_asset/20200909_Lessons-HIV-COVID19.pdf

# 2 Background

## 2.1 Conceptual Considerations

Procurement institutions arrange essential drug supply to LMIC through different channels. Procurement can be carried out by large, multilateral agencies that aggregate orders across countries (i.e., PPM and the UN), Central Medical Stores that aggregate orders within a country, and individual health agencies or organizations that directly negotiate terms with manufacturers. Decentralized procurement involves many negotiations between buyers and sellers, where buyers may have limited bargaining power; in contrast, pooled procurement allows buyers to pool orders and simplify the number of transactions involved (Figure 1).

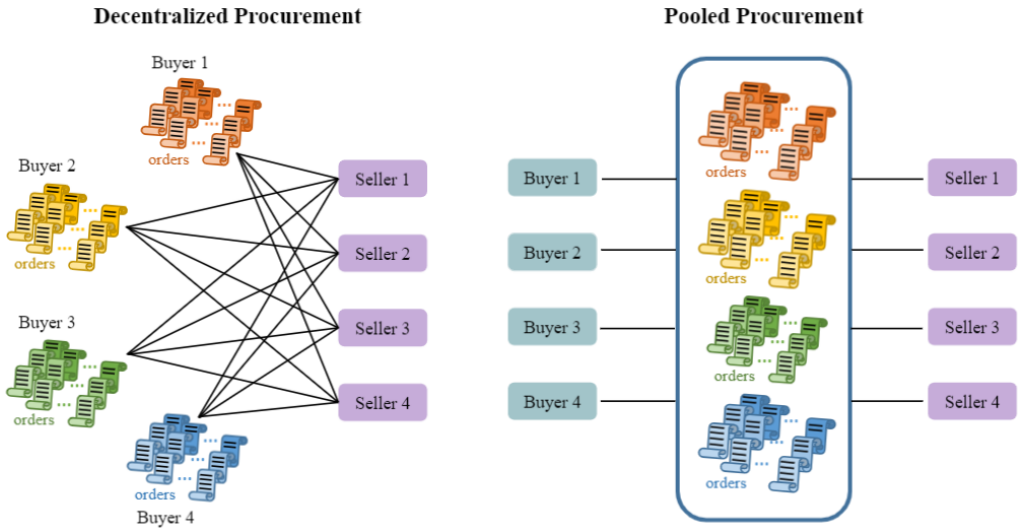


**Figure 1:** Decentralized vs. pooled procurement institutions

A key question is whether pooling procurement can lower prices. A Nash bargaining analysis of negotiations between a seller and multiple buyers reveals that a merger between buyers can reduce negotiated prices as long as the sellers' surplus function is concave (e.g., if costs are convex), but would increase prices otherwise (Chipty and Snyder, 1999). A similar condition holds when considering the role played by large buyers in eroding the value of sellers' outside options (Inderst and Wey, 2007). Alternatively, decentralized buyers may act as price-takers while pooled buyers engage in Nash bargaining with sellers, and pooling reduces prices in this case primarily because pooling allows buyers to negotiate prices rather than take prices as given (Dubois et al., 2021). A related literature examines whether the benefits from pooling are offset by the membership fees that are often charged by group purchasing organizations (GPOs) (Schneller, 2009; Hu and Schwarz,

2011), and how uncertainty about demand and supply affects the benefits of relying on pooled procurement (Hu et al., 2013; Yang and Babich, 2015).

In general, this literature emphasizes that pooled procurement does not unambiguously lower prices. Moreover, it remains an open question how the impact of pooling varies across market features, such as the extent of supply-side concentration, the size of the buyers forming the pool, and the characteristics of the goods being procured. Given the theoretical ambiguity, our empirical analysis looks at whether pooling reduces prices for major infectious drug product procurement in LMIC, how the extent of pooling matters, and under which conditions pooling is most effective.

Procurement institutions can also differ greatly in their non-price impacts. Policy discussions of pooled procurement emphasize that pooling affects not just prices, but also transaction costs, quality, administrative efficiency, and uncertainty surrounding procurement conditions (OECD, 2011; Huff-Rousselle, 2012). This can result in trade-offs that may not be apparent in an analysis purely focused on price. For example, pooled procurement often relies on prior long-term arrangements with suppliers, whereas decentralized purchases are more likely to utilize one-time transactions. The use of long-term arrangements provides greater certainty, but may make the procurement process less flexible and less responsive to ongoing changes in the market (OECD, 2011). These non-price consequences of pooled procurement, however, have been under-studied both theoretically and empirically. Our analysis aims to bridge the gap by empirically evaluating how procurement institutions affect delivery conditions (i.e., delays, procurement lead time).

Finally, procurement institutions can interact with other non-procurement institutions in the supply chain. In drug supply, intellectual property (e.g., patents) delays the global diffusion of new drug products (Cockburn et al., 2016), and IP licensing institutions facilitate LMIC drug diffusion (Wang, 2022; Galasso and Schankerman, 2022). By contrast, for older, off-patent drug products where IP barriers are less of an issue, supply can still be limited due to the low-profit margins and lack of competition (Conti and Berndt, 2020). These drug products are also less likely to be prioritized by IP licensing institutions, and may rely more on procurement institutions. Therefore, we expect heterogeneous effects of procurement institutions by IP barriers and the presence of other institutions. We directly account for IP-related factors and the age of the drug in our analysis.

## 2.2 Procurement Institutions

Our analyses use rich procurement information from Global Fund-supported procurements. The Global Fund is the largest financier of health programs for reducing HIV/AIDS, tuberculosis (TB), and malaria. The Global Fund raises funds in three-year cycles from donor countries and disburses funds to grantees (e.g., a procurement institution or country partner) to implement parts of the program, based on budgeted grant applications. Grant recipients must report data to the Global Fund, which monitors this information, makes it publicly available, and evaluates performance in drug procurement and delivery. The Fund adheres to strict quality assurance policies to ensure medical products procured meet international standards. Four major procurement institutions are utilized beyond decentralized purchases: PPM, UN, Central Medical Stores (CMS), and others (e.g., non-profit organizations, NPOs). These institutions differ in the procurement process: the PPM and UN pool orders across countries, CMS pool orders within a country, and others leverage their respective channels. Table A1 reports more details.

The PPM is a procurement mechanism established by the Global Fund in 2009.[5] The PPM aggregates drug product orders from participating countries and negotiates long-term agreements with manufacturers on prices, delivery conditions, and supply volumes of different products. These agreements include quantity-based price discounts triggered when the order volume exceeds pre-specified volume thresholds. When a Global Fund grantee submits a procurement request through the PPM, the PPM coordinates with the manufacturer to set a delivery date, taking into account that additional orders may need to accumulate to hit these volume thresholds.[6] Prices of goods procured via the PPM generally follow the Global Fund published reference price lists, but the actual price paid may differ depending on how early the order is placed and whether the pooled order meets volume-based thresholds. The PPM also relies on procurement agents who coordinate logistics and delivery, and these agents are paid a fee on the value of each fulfilled order (1.5-5.0% depending on product type).

The UN is the other major institution for drug procurement, with the UNICEF Supply Division the largest among UN entities. All UN divisions have pre-qualification programs for potential suppliers, and procurement is often conducted on the basis of long-term agreements signed with suppliers. These suppliers are selected via formal bidding procedures (i.e., sealed-bid auctions and

[5] www.theglobalfund.org/media/6957/psm_2017-11-arvstrategicmedicineshiv_presentation_en.pdf.

[6] For this reason, the PPM encourages buyers to place orders early. Appendix A.3 describes the process for placing orders with the PPM.

requests for proposals) for large purchase volumes, and informal procedures (i.e., requests for quotations and direct acquisitions) for smaller purchases.[7] Through the UNICEF Supply Division and United Nations Population Fund (UNFPA) Procurement Services, UN entities also act as procurement agents. UN entities maintain physical stockpiles of essential drug products in order to lower stock-out risk and speed up delivery. Each UN entity maintains a catalog of available products, from which partners can make a procurement request (see Appendix A.3 for details). UNICEF charges a 3-8% handling fee and UNFPA charges a 5% administrative fee.[8]

In 12 countries, domestic drug procurement is pooled through the Central Medical Stores (CMS). CMS mainly function to warehouse medical products and are often responsible for drug product procurement and distribution. The operational model of a given CMS is usually decided at the national level: CMS may be fully government-controlled, semi-autonomous, or fully autonomous, and the operational, procurement and funding models are set by the country. Figure A1 depicts a comparison of PPM, UN, and CMS.

We group other procurement agents into an "other" category, mainly comprising non-profit procurement and development organizations (NPOs), foundations, international non-profit organizations (NGOs), and private wholesalers. Examples of NPOs are the Netherlands-based International Dispensary Association (IDA) foundation, the Global Drug Facility (mainly for tuberculosis drugs), and the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ). NPOs use various formal and informal procurement procedures. For example, the German-based GIZ uses informal procedures (such as requests for quotations) for low-value procurements and formal procedures (e.g., invitations to bid and Europe-wide tenders) for larger purchases.[9] NPOs can sign long-term agreements with manufacturers based on requests or bidding outcomes, either for specific projects or in a broader context. Large NGOs (e.g., Medicins Sans Frontieres, i.e., MSF) tend to have in-house supply centers that build long-term relationships with suppliers and through which country offices procure drugs, but these are at a small scale in our sample.[10]

In addition, we control for whether a drug is covered by the Medicines Patent Pool (MPP).

[7] Direct contracting bypassing these procedures is used only in emergencies, or when goods are neither available locally nor from multiple sources.

[8] Fees charged to UN entities are 3-5% for all products and those charged to Gavi are 1.4% for vaccines. While UN entities pool cross-country orders via UNICEF/UNFPA, they also undertake a small share of non-pooled drug procurement outside these channels. Source: https://www.unicef.org/supply/medicines.

[9] www.giz.de/en/downloads/giz2020-en%20report-on-procurement-2019-low-res.pdf

[10] The procurement models of NPOs can vary by funding sources (e.g., public/private) and related rules, but we focus solely on Global Fund-funded transactions. Source for MSF: www.msf.org/msf-medical-product-procurement

The MPP is an IP licensing institution facilitating generic licensing for products supplied to LMIC. These licenses often cover IP beyond patents, including exclusivity exemption and know-how transfer, making licensing more attractive even in countries without effective patents (e.g., patents pending). The MPP also reduces information frictions and uncertainty in LMIC patent status, as high-quality international patent data are not always easy to obtain and use (Lerner and Seru, 2017).

# 3 Data and Methods

## 3.1 Drug Procurement Data

Our primary procurement data source is the Global Fund Price and Quality Reporting database, a publicly accessible database on procurement transactions under Global Fund-supported programs. We focus on essential drug products treating major infectious diseases, including antiretrovirals (ARVs), antimalarials, antituberculosis, and antibiotics.[11] These areas are important, as they are the "big three" infectious diseases in LMIC. In addition, our research question requires procurement data spanning different procurement institutions over a large set of countries (esp. for cross-country pooling). While our data do not capture all transactions, about 40% of spending on ARVs by LMIC is financed by the Global Fund and thus covered in the dataset. Our data cover a high share (85%-100%) of unique compounds available to treat these diseases in LMIC, and the majority of manufacturers of essential drugs that are WHO pre-qualified, as discussed in Appendix A.4.[12]

For each transaction, we observe the quantity of the product purchased, the total cost, the buyer and manufacturer, the date when the order was made, and the scheduled and actual delivery dates. Our raw dataset includes 53,752 transactions from 2007 to 2017; our estimation sample, where we focus on the four major therapeutic areas, includes 39,289 transactions covering 83 unique drugs (APIs, listed in Table A2) and 191 unique products (API-strength).[13] Table A2 lists all the APIs in our sample; note that we treat drug cocktails containing multiple compounds as distinct products

[11] TB is treated with specialized antibiotics; we distinguish other broad-spectrum antibiotics (widely used for non-TB). We exclude transactions of non-essential items (e.g., mosquito nets, condoms, or insecticides) since the procurement process differs substantially. Diagnostic tests and Leprosy drug products are also dropped due to limited information.

[12] All transactions are Global Fund-funded, limiting concerns about funding mixture affecting outcomes. Product prices in our data align with those from the Management Sciences for Health (MSH) International Pricing Guides, which covers a wide range of suppliers, international development organizations, and government agencies.

[13] The estimation sample also excludes transactions with missing values for key variables such as the price. Note that each transaction is for a single product, so we do not directly observe bundling of different products in order placement. To our knowledge, the incentives offered by pooled procurement institutions for buyers to bundle are limited (for example, neither the UN nor the PPM offer discounts for bundling).

from the underlying compounds, consistent with prior work (e.g., Wang (2022)).

We construct two types of outcomes. First, we calculate the purchase price by dividing the total cost by the total standardized quantity (in stock-keeping units, i.e., SKUs), resulting in a measure comparable across transactions of the same drug product. Second, we calculate two delivery-related variables: delay and procurement lead time. Delay is an indicator of whether the actual delivery time is later than the scheduled delivery time, and procurement lead time is the number of days between the order date and the actual delivery date. In some analyses, we aggregate transaction outcomes to a product-country-year panel level, weighting each transaction equally. Our delivery outcomes capture the effective procurement waiting time (for pooling and delivery) and unexpected delays that can increase stockout risks (see Appendix A.2 for details). Overall, our data cover a much broader set of LMIC than prior studies and new outcomes not yet analyzed systematically.[14]

Table 1 shows transactions through different procurement institutions across drug categories. Direct purchases from manufacturers account for 30% of all transactions, with PPM, UN, CMS, and other accounting for 21%, 12%, 13%, and 24% transactions, respectively.[15] The procurement institutions utilized also differ by drug category. PPM and UN are widely used for ARV and antimalaria drug products, but less so for tuberculosis and antibiotics. This is partly due to historical reasons (e.g., antituberculosis procurement being managed mainly by the Global Drug Facility) and because the potential benefits of pooled procurement may be higher for drug categories with a larger LMIC market size (ARV and antimalaria).[16] There is considerable heterogeneity in product prices and the type of procurement mechanism utilized (Panel B). Most of the essential drug products purchased by LMIC are generics, with only 28% patented drug product transactions. About 12% of transactions are covered in the Medicines Patent Pool (MPP). The average procurement lead time is about five months, and almost half of the transactions encountered delays. The average values of main outcomes vary substantially across procurement institutions (Panel C).

Figure 2 shows the geographic distribution of our sample. Figure 3 shows the share of transactions across procurement institutions over time. Overall, direct purchases from manufacturers

[14]Many LMIC, including most sub-Saharan African countries, are not covered in studies using commercial sales data such as IQVIA (Dubois et al., 2021; Galasso and Schankerman, 2022). Our dataset is similar in coverage to the Global Price Reporting Mechanism dataset used in Danzon et al. (2015), but includes information on the procurement institution utilized, procurement lead time and delays that is crucial for comparing procurement mechanisms.

[15]The shares of transactions by low-income, lower-middle income, and upper-middle-income countries are 54%, 30%, and 16% respectively. The median and mean transaction values are $12,600 and $144,000 respectively.

[16]Note that drug product supply is highly concentrated across all categories, with the average product-level HHI equal to 4,973 for ARVs, 5,545 for antimalarials, 6,694 for antibiotics and 7,694 for antituberculosis.

**Table 1:** Descriptive statistics

| Panel A: number of transactions by procurement institution and category | | | | | |
|---|---|---|---|---|---|
| | antibiotics | ARVs | malaria | TB | total |
| Pooled Procurement Mechanism (PPM) | 1 | 6,822 | 1,574 | 30 | 8,427 |
| United Nations (UN) | 2 | 3,952 | 539 | 69 | 4,562 |
| Central Medical Stores (CMS) | 11 | 5,047 | 12 | 19 | 5,089 |
| Others | 1,364 | 1,991 | 249 | 5,770 | 9,374 |
| Direct from manufacturers | 384 | 8,458 | 1,334 | 1,661 | 11,837 |
| Total | 1,762 | 26,270 | 3,708 | 7,549 | 39,289 |
| Panel B: transaction-level summary statistics | # obs. | mean | s.d. | min | max |
| Price (US$/SKU) | 39,289 | 0.38 | 1.15 | 0.0003 | 61 |
| Spending ($1000) | 39,289 | 144 | 608 | 0.001 | 29,700 |
| Procurement lead time (days) | 39,289 | 156.87 | 142.06 | 0 | 1,372 |
| Delayed | 39,289 | 0.48 | 0.50 | 0 | 1 |
| Patented | 39,289 | 0.28 | 0.45 | 0 | 1 |
| Medicines Patent Pool (MPP) | 39,289 | 0.12 | 0.32 | 0 | 1 |
| Panel C: average of main outcomes by procurement institutions | | | | | |
| | price | lead time | delay | | |
| Pooled Procurement Mechanism (PPM) | 0.23 | 237.65 | 0.31 | | |
| United Nations (UN) | 0.26 | 127.67 | 0.62 | | |
| Central Medical Stores (CMS) | 0.15 | 11.46 | 0.15 | | |
| Others | 0.70 | 214.05 | 0.61 | | |
| Direct from manufacturers | 0.37 | 127.84 | 0.59 | | |

*Notes:* "Delayed" is an indicator variable that equals 1 if the transaction was delivered later than the scheduled delivery date and 0 otherwise. "Patented" equals 1 if the drug was under effective patent and 0 otherwise.

declined during the first half of the sample and stabilized afterward. The share of PPM gradually and consistently increased, while the shares of UN and Other procurement institutions (e.g., NPOs and NGOs) have both been relatively stable over time. The increase in the PPM share is largely driven by more countries adopting PPM over time (Figure A2), once countries began using the PPM, the share of their transactions using PPM quickly increased to around 60% within one year of adoption (Figure A3). Countries with lower income are more likely to utilize PPM and UN (the two major international procurement institutions).[17] Finally, the share of CMS rose sharply in

[17] In our sample, 50% of countries that ever used PPM or UN have used both. Countries that rely on both PPM and UN have a lower income ($1,785/capita) compared to countries that only use PPM or UN ($2,886/capita), and countries that never used either PPM or UN ($6,478/capita). About one-third of countries in our sample did not use PPM, with an average income of $5136/capita versus $1696/capita for adopters. Countries with lower income per capita were more likely to adopt PPM in earlier years (Figure A4), possibly because of more limited capacity to negotiate drug prices on their own with manufacturers.

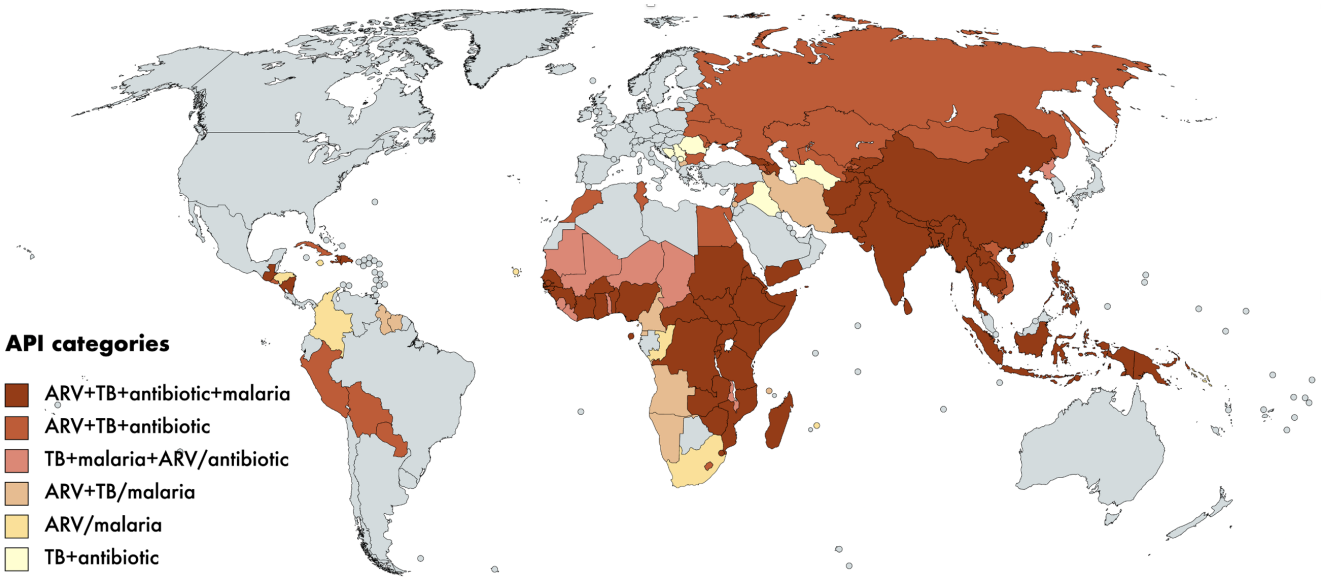


**Figure 2:** Geographical distribution of drug categories in procurement data

2011-2013, but has declined rapidly in recent years, as some countries shifted from CMS to PPM.

## 3.2 Control Variables

We constructed control variables at the product, product-country, and product-country-year levels to capture changes in observables that may affect our outcomes of interest. First, we searched World Health Organization (WHO) and US Food and Drug Administration (FDA) databases and the medical literature to identify the earliest approval years for each drug in our sample; approval dates for newer drugs (mainly ARVs) are from Wang (2022). Many other drugs were introduced earlier and used more widely in LMIC before being approved in the US. To account for differences in approvals across LMIC, we group drugs by broader approval periods, referred to as "age generations" in the heterogeneity analysis (section 4.2). Among the 191 products in our sample, 81 were approved before 1990, 52 between 1991-1996, and 58 from 1997 onward.

Second, we control for country-year level observables on demographics, disease profiles, and institutional factors. Demographic factors include population, GDP per capita, and age structure (i.e., shares of age groups: 0-14, 15-49, 50-64, and 65+). Disease-related controls, drawn from the Global Burden of Disease Study by the Institute for Health Metrics and Evaluation and World Bank, include country-year level measures of disease burden, particularly the prevalence and incidence of HIV, tuberculosis, and malaria. These factors affect drug product demand, thus can influence

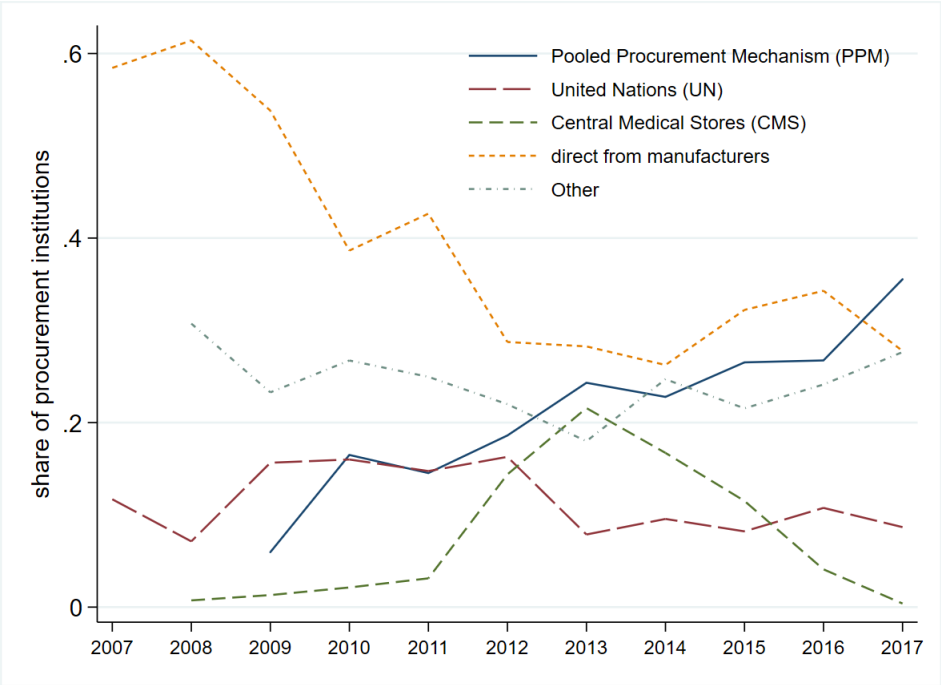


**Figure 3:** Share of transactions by procurement institution over time

the prices. Country-year level institutional factors are the World Bank's World Governance Indicators (WGI), which measure voice and accountability, political stability and absence of violence, government effectiveness, regulatory quality, rule of law, and control of corruption.

Finally, we constructed data on the drug product-country-year level patent status and patent licensing institutions. Patent status is constructed from three sources: (1) the Medicines Patents and Licenses Database (MedsPaL), which sources data from public records on patent status of selected HIV, hepatitis C, tuberculosis, and other products for LMIC; (2) the Patent Information Initiative for Medicines (Pat-INFORMED), hosted by the World Intellectual Property Organization (WIPO) and with additional private data provided by 20 leading biopharmaceutical firms; (3) Drug Patent Watch, a commercial data provider. In addition, we obtained data on whether a patented drug is eligible for pooled licensing from the Medicines Patent Pool (i.e., MPP) from Wang (2022).

## 3.3 Empirical Models

We examine how drug product prices, delivery delays, and procurement lead time vary by procurement institution. Our primary analysis uses the transaction-level data without aggregation. Let $j$ denote a drug product (at the API-strength level), $c$ denote the country buying the drug, and

$t$ denote a year. A country can either purchase a product directly from a manufacturer, or utilize one of $M$ different local or international procurement institutions denoted by $m = 1, ..., M$. Each observation $i$ is a transaction of product $j$ in year $t$ and country $c$ using procurement mechanism $m$.

We consider several outcomes of interest. First, we look at the product purchase price (in logarithms), $log(p_i)$. Second, we construct two outcomes related to product delivery. $T_i$ is the procurement lead time for transaction $i$, calculated as the number of days between the purchase order date and the actual delivery date. $d_i$ is an indicator that equals 1 for transactions where the delivery was delayed and the shipment arrived later than scheduled. We explore the relationship between the outcomes and the choice of procurement institution $m$ using the following specification:[18]

$$Y_i = \sum_m I_i^m \beta^m + X_{jct}\gamma + \delta_{jc} + \delta_t + \varepsilon_i \tag{1}$$

The key regressors are indicators of whether procurement institution $m$ is used for a given transaction ($I_i^m$). We control for fixed effects at the product-country level ($\delta_{jc}$) and year level ($\delta_t$). $X_{jct}$ includes a set of product-country-year and country-year level observable controls. Standard errors are two-way clustered at the country and drug product levels to allow arbitrary autocorrelation of $\varepsilon_i$ within a country and a drug product independently (Cameron et al., 2011).[19] In some specifications, we replace the benchmark product-by-country fixed effects ($\delta_{jc}$) with product-by-buyer fixed effects ($\delta_{jb(c)}$) to absorb within-country cross-buyer variation, if certain buyers are more efficient in procuring some products than others (e.g., health ministry versus and community organizations). We also include transaction volume as a control variable to detect transaction-level volume-price relationships (e.g., due to discounts offered by sellers for buying in bulk).

Our primary interest is in $\beta^m$, the coefficient on procurement institution $m$. For the price outcome $log(p_i)$, $\beta^m$ can be interpreted as the percentage impact of using procurement institution $m$ on the purchase price, relative to the baseline of direct purchase from manufacturers (i.e., when each of the $I_i^m$ variables equals 0). For the delay outcome $d_i$, $\beta^m$ can be interpreted as the increase in the probability of a delivery delay if the country purchases drug products using procurement institution $m$ versus direct purchase from manufacturers. For the procurement lead time outcome $T_i$, $\beta^m$ can be interpreted as the number of additional days it takes to deliver the order if a country

[18] Global Fund began in 2002, made grants to countries before our sample period (2007-2017), and established PPM in 2009. Given our interest in multiple procurement institutions and the lack of sufficient pre-periods before all pooling institutions were established, our setting is unsuitable for event studies and difference-in-differences analyses.

[19] Our results are robust to clustering at the country or country-product levels that often yield smaller standard errors.

uses procurement institution $m$ instead of directly purchasing from the manufacturer.

We conduct our analysis at the transaction level for its greater variation and more interpretable coefficient estimates, and since it aligns more closely with the decision-making processes of buyers (deciding, for each transaction, which institution to utilize). This level allows us to better capture within-country differences and price-volume relationships independent of broader pooling effects. For completeness, we also examine how procurement outcomes vary by procurement institution at the product-country-year level to facilitate comparison to prior work (e.g., Dubois et al., 2021).

$$Y_{jct} = \sum_m S^m_{jct}\beta^m + X_{jct}\gamma + \delta_{jc} + \delta_t + \varepsilon_{jct} \tag{2}$$

Here $Y_{jct}$ denotes outcomes at the product ($j$)-country ($c$)-year ($t$) level: average price $log(p_{jct})$, share of delayed transactions $d_{jct}$, or average procurement lead time $T_{jct}$. $S^m_{jct} \in [0,1]$ denotes the share of transactions of drug $j$ in period $t$ by country $c$ using procurement mechanism $m$. Fixed effects and standard error clustering remain the same as before. See Appendix A.5 for more details.

While our benchmark models include a rich set of fixed effects and extensive controls, there may still be potential endogeneity concerns since procurement institutions are not chosen at random. In section 5, we provide several robustness checks. We first address concerns about potential omitted variable bias by implementing an instrumental variable approach and the Altonji-Elder-Taber (AET)-Oster test. We then estimate demand elasticities across procurement institutions to address the possibility that buyer heterogeneity drives the results. We also consider the role of related institutions, such as PEPFAR and CHAI, in influencing procurement outcomes; and account for management practices, including tiered pricing and pre-payment. Other robustness checks evaluate whether procurement institutions impact drug choices within disease categories and rule out potential confounding factors, such as grantee heterogeneity and the start-up effects of procurement programs. All of these confirm our benchmark results and suggest limited endogeneity.

# 4 Results

## 4.1 Main Results

**Centralized Procurement and Prices** We begin by exploring how prices vary across procurement institutions utilized (Table 2, Column (1)). Our baseline specification controls for country-product and year fixed effects, and observables at the country-year and country-year-product level.

Purchasing via either the PPM or the UN significantly reduces the price paid. We find that if a country were to switch from procuring drug products from individual manufacturers to procuring via the PPM, the average transaction price would decrease by 20% (column (1)). Likewise, purchasing via the UN lowers average transaction prices by 13%. In panel-level regressions (Table A8, column (1)), we find that procuring via the PPM and the UN reduces average prices by 30% and 23%, respectively.[20] These results are consistent with the hypothesis that using cross-country pooled procurement institutions can lower average price paid. Pooling orders within a country via Central Medical Stores, by contrast, does not appear to reduce transaction prices, though we find that using CMS is associated with a statistically insignificant 10% reduction in the average price when we analyze at the panel-level (Table A8, column (1)). Other procurement institutions utilized appear to have little effect on the procurement price.

Many observables can affect drug supply efficiency, including factors related to market size, disease conditions, and institutional factors. We include demand-side factors such as the country's population and GDP per capita (in logarithms), the age structure of the population, and measures of incidence and prevalence of HIV, malaria, and tuberculosis.[21] We also control for supply-side factors, including patent status and whether a drug is in the IP licensing institution - the Medicines Patent Pool (MPP) - that facilitates licensing patents, waives data exclusivity, and transfers production know-how for drugs in the pool.[22] Consistent with our hypotheses and prior work (Wang, 2022; Galasso and Schankerman, 2022), the prices are higher for drugs in countries with effective patents, and the MPP substantially reduced the price increase. Regardless of the observable controls, international pooled procurement institutions are always associated with lower prices.

Table A9 in Appendix A.6 presents several robustness checks. We include country-buyer-product fixed effects to account for unobservable differences in buyer characteristics within the same country and find very similar results (column (1)).[23] We then control for transaction vol-

[20] The panel estimates are larger than those estimated from the transaction data, because the transaction-level data is weighted more towards higher-volume buyers, which (as we show later) benefit less from international pooling.

[21] The full set of controls include: (1) income (log GDP per capita) (2) demographics and market size, specifically population (in logarithms) and the share of the population between 0 and 14 years, between 15 and 49 years, between 50 and 64 years and over 65 years (3) disease profiles, including HIV prevalence and incidence (both total and rate), TB prevalence and incidence (total and rate) and malaria prevalence and incidence (total and rate) (4) WGI indicators. We include additional control variables in section 5.5 to address price discrimination via tiered pricing.

[22] Some HIV drugs are included in the MPP during our sample period (2007-2017). The inclusion of a compound into the MPP is found to increase generic drug supply and thus lower prices in relevant countries (Wang, 2022).

[23] Our results are similar if we control for more fixed effects at the country-year, product-year, country-product, and manufacturer levels (Table A10).

**Table 2:** Procurement mechanisms and drug prices, delivery delays and procurement lead time

| | (1) | (2) | (3) |
|---|---|---|---|
| Dep var: | Log(Price) | Delay | Lead time |
| PPM | -0.20*** | -0.28*** | 113.8*** |
| (pool intl.) | (0.052) | (0.049) | (13.3) |
| UN | -0.13*** | 0.059 | 3.86 |
| (pool intl.) | (0.044) | (0.048) | (11.1) |
| CMS | 0.014 | -0.35*** | -38.7*** |
| (pool within) | (0.067) | (0.063) | (12.3) |
| Others | 0.063* | -0.072* | 24.8** |
| | (0.032) | (0.041) | (9.60) |
| Patented | 0.024 | -0.0084 | 3.42*** |
| | (0.053) | (0.041) | (1.17) |
| MPP | -0.23** | 0.067*** | -7.89 |
| | (0.10) | (0.022) | (8.37) |
| ln(population) | 1.09** | -0.58 | 6.63 |
| | (0.53) | (0.71) | (6.98) |
| ln(GDP per capita) | 0.16** | -0.025 | 37.0 |
| | (0.068) | (0.087) | (141.7) |
| Controls | Year FE, ctry-prod FE, controls (ctry-yr and ctry-year-prod) | | |
| N | 39,289 | 39,289 | 39,289 |

*Note:* All columns report transaction-level regressions. The outcome "delay" indicates whether a transaction is delayed (the actual delivery date is after the scheduled date). "Lead time" is the number of days between the order date and actual delivery date. Pooled Procurement Mechanism (PPM), United Nations (UN), Central Medical Stores (CMS), and Medicines Patent Pool (MPP). Standard errors are two-way clustered by country and by product.

ume, as buyers might receive discounts for bulk purchasing (column (2)). Although larger transaction volume is associated with lower prices, the price reductions accruing from using PPM or UN are very similar even after we control for transaction volume (i.e., comparing columns (1) and (2)).[24] Note that contracts with PPM/UN do not impose volume commitments on individual buyers for cross-country pooled procurement, as any commitments apply at the aggregate level. Volume thresholds that trigger price discounts are tied to pooled transactions rather than individual buyer volume. Thus, volume-related endogeneity is minimal.[25] Overall, our results suggest that procure-

[24] Similar to Waning et al. (2009), our finding suggest that increasing *individual* transaction volumes does not meaningfully reduce prices. Volumes are only 8% higher for PPM and 6% for UN compared to direct purchases from manufacturers, with the difference not statistically significant. Instead, the benefits of pooling come mainly from negotiating prices jointly across transactions by pooled procurement institutions.

[25] Section 2.2 discusses the main features of the procurement institutions, and Appendix A.3 elaborates on the context.

ment and IP licensing institutions are key for delivering products to LMIC at lower prices, with pooled procurement (especially cross-country pooling) playing a bigger role in supplying unprofitable off-patent products.

**Centralized Procurement, Delays and Procurement Lead Time** Prior studies have mostly looked at prices, as we did above. We now investigate how drug delivery delays and procurement lead times vary across procurement institutions.[26] We find that if a country were to switch from direct purchases from manufacturers to procuring via the PPM, the probability of delay decreases by 28%, with the estimates statistically significant at the one percent level (Table 2, column (2)). These results are similar in panel-level analysis with the same set of controls (Table A8, column (2)). They are also robust to the inclusion of additional country-buyer-product fixed effects and transaction volume (Table A9, columns (3)-(4)). One possible explanation is that the integrated payment-purchase system built into the PPM reduces the transaction costs of fund transfer and allocation. In addition, early ordering in PPM can reduce delivery delays, as we discuss below.

Among other mechanisms, the transaction-level analyses suggest that CMS transactions are also significantly less likely to be delayed. In our baseline specification, we find a 35% reduction in delays using CMS, or a 25% reduction when we control for country-buyer-product fixed effects and transaction volume. This estimate, however, is insignificant in the panel analysis due to limited statistical power: only a few countries have Central Medical Stores, but some of these (e.g., South Africa) are frequent drug product purchasers. None of the other mechanisms show a statistically significant difference in delays relative to the baseline (buying directly from manufacturers).[27]

We then investigate differences in average procurement lead time across procurement institutions (Table 2, column (3)). Product delivery delays can be reduced through better planning in drug product ordering, such as early ordering when the demand for a drug product is well-anticipated. Alternatively, procurement mechanisms with more efficient shipment schedules or faster turnaround can reduce potential delays. The two mechanisms have different implications for whether certain institutions are more efficient in handling emergencies, such as a surge in demand due to disease outbreaks or pandemics.

[26] Delivery delays or excessively long lead times can increase stock-out risks, a major issue in developing countries (Gallien et al., 2017; Fitzpatrick, 2022).

[27] The coefficient estimate on MPP suggests a small but statistically significant 6.7% increase in delays for patented drugs covered by the MPP (column (2)), but no statistically significant difference in the associated lead time (column (3)). These delays, relative to scheduled delivery date, may arise due to the complexities of the licensing and technology transfer processes when making these drugs available to generic manufacturers for LMIC-focused distribution.

We find an increase in the procurement lead time by 114 days if the purchasing country switches from direct purchases to the PPM. Given that the average lead time for products ordered directly from manufacturers is 132 days, ordering via the PPM is associated with about 86% longer procurement lead time. This finding is quantitatively the same even if we include buyer-country-product fixed effects and control for transaction volume (Table A9, columns (5)-(6)).[28] We find a similar lead time increase (by 105 days) if we perform the analysis at the panel level (Table A8).

Our finding of a longer lead time for PPM likely relates to how PPM pools orders across countries to achieve price reductions. The long-term agreements negotiated by the PPM require reaching certain minimum quantity thresholds to trigger price reductions. Pooling these orders takes time and often requires countries to place orders earlier, resulting in longer lead times. In addition, earlier ordering facilitates the consolidation of shipments and deliveries.[29]

In contrast, switching to CMS reduces procurement lead time by about 39 days in our baseline specification. This drops to 37 days with country-buyer-product fixed effects and 32 days when controlling for transaction volume, and the estimates remain statistically significant. In the panel-level analysis (with limited power), CMS is associated with a 23-day reduction in lead time (but now statistically insignificant). Overall, these results suggest CMS may enable faster delivery, though the evidence is inconclusive. Domestic pooled procurement may be faster than cross-country pooling since the buyer does not need to wait for buyers in other countries to place their orders.

Putting the results of delays and procurement lead time together, we find that pooled international procurement can reduce drug delivery delays, but at the cost of longer lead times. This longer lead time can be less favorable to some buyers due to reduced flexibility for quick orders. In contrast, direct purchases from manufacturers can be a good option for emergencies, allowing faster delivery but at the cost of higher prices and increased risk of unexpected delays.[30]

**Trade-offs and Potential Mechanisms** We find differences in price and non-price impacts across procurement institutions, reflecting different practices and highlighting key trade-offs in designing a procurement strategy. Institutions that systematically pool procurement *across* countries achieve substantial price reductions compared to those with a domestic or regional focus. While both the

[28] The results are similar when we excluded potentially pre-planned orders à la Gallien et al., 2017 (Table A11).

[29] www.theglobalfund.org/media/9332/lfa_trainingpsm-day3psmpoliciesqappmwambopqr_materials_en.pdf.

[30] Our results are similar to Clark et al. (2021), who use a staggered rollout of pooled medical device procurement in Italy, finding a tradeoff between prices and delivery time. Unlike their findings, we find that longer lead time for PPM purchases reduced unexpected delays: although orders took longer, they were more likely to arrive on time.

UN and the PPM engage in cross-country pooling, the PPM generally obtains larger price reductions and lower likelihoods of delivery delays than the UN, but at the cost of a significantly longer procurement lead time. This is likely because the PPM prioritizes early ordering, which helps meet volume thresholds in long-term agreements that trigger price reductions and reduce demand uncertainty faced by manufacturers. Earlier ordering, however, implies a longer lead time, which means buyers faced with a short-term emergency may find it advantageous to rely more on other procurement institutions (e.g., the UN or CMS).[31] Overall, these results suggest international procurement institutions have greater bargaining power and that cross-country pooling helps mitigate market frictions, lower transaction costs, and improve delivery coordination via consolidated shipments.

A natural question is: if cross-country pooling lowers prices, why do not all countries use PPM/UN?[32] First, as discussed above, PPM requires advanced planning that differs by product, often with longer lead time for low-volume products.[33] Second, despite covering a large share of unique compounds for our drug categories (Appendix A.4), not all products are available via cross-country pooling each year (Figure A5). For example, PPM has increased coverage substantially over time, particularly for ARVs (80+% post-2010), but non-ARV coverage has stabled around 30%; UN shows a similar pattern. Third, some countries may avoid relying on international pooling to develop their own domestic procurement institutions and build expertise. National control of the procurement process can reduce concerns over supply security and stability, which are particularly valuable in certain situations (e.g., emergencies or political disruptions).[34]

## 4.2 Heterogeneity: Patent, Drug Age, Volume, and Seller Concentration

We next examine how the price impacts of procurement institutions differ by drug characteristics and market conditions (Table 3) through a set of subsample heterogeneity analyses.

**Purchase volume and seller concentration:** We split the sample into countries with above-median volume purchases of product $j$ in year $t$, and those with below-median volume. For smaller buyers (below median volume), the price reduction from pooled purchasing via the PPM or the UN

[31] In practice, orders placed with the PPM or the UN are more regular (i.e., more evenly spaced over time) than CMS or direct manufacturer orders (Table A3), suggesting buyers rely on international pooling for predictable demand.

[32] Different from Grennan and Swanson (2020), our results are unlikely to be driven by lack of information, given the public procurement data released by Global Fund and many transparency initiatives (see sections 5.4 and 5.6).

[33] See Figure A6 for an illustration of the PPM planning guide published by the Global Fund, which shows that the latest date by which an order has to be placed can differ substantially by product category.

[34] For example, Kenya developed its own drug procurement arrangements and partnerships. Source: https://aidspan.org/kenya-successfully-procures-health-commodities-without-using-global-funds-pooled-procurement/

is larger (Table 3, top panel, columns (2)-(3)). This result suggests that countries making small purchases of a product benefit most from cross-country pooling, as these countries have limited ability to negotiate effectively with suppliers in the absence of pooling.[35] By contrast, the price reduction obtained by using a CMS is higher for countries that are large buyers.

Next, we split the sample by the median level of seller concentration, measured by the Herfindahl-Hirschman Index (HHI) computed using quantities (columns (4)-(5), top panel).[36] Consistent with Dubois et al. (2021), pooling procurement domestically (by CMS) reduces price more when the market is less concentrated, though the estimate is statistically insignificant. By contrast, pooling purchases internationally (via PPM or UM) reduces prices more when the market is more concentrated. This latter finding (new in the literature) likely stems from the buyer power of large buyers like PPM and UN, who can negotiate effectively even with suppliers that control a large market share, in contrast to buyers representing individual countries.

**Patent status and approval year:** Pooled procurement institutions reduce prices similarly by patent status, and the reductions from cross-country pooling institutions are stronger for drugs that are first approved before 1990 (Table 3, bottom panel).[37] Across patent status (columns (1)-(2), bottom panel), the price reductions through PPM and the UN are similar for never-patented drugs and patented drugs. Among other procurement institutions, price reduction estimates are larger in the never-patented sample for CMS (statistically significant at the 10 percent level).

Across approval generations of drugs (columns (3)-(5), bottom panel), the price reductions via PPM and the UN are more substantial for old drugs that were first approved before 1990. The price reductions are smaller (but still meaningful) for drugs first approved in 1997 or later. This pattern might be due to the fact that the market for older drugs is more concentrated on the seller side in our sample than that for newer drugs (conditional on patent status). The majority of essential drugs, particularly non-HIV drugs, were first discovered and used before 1990, with very limited progress in recent decades.[38] Our specifications incorporate product by country fixed effects, addressing

[35] One may be concerned that current purchase volume is endogenous to unobservables affecting the current price: but we find very similar results if we instead classify buyer size using their *lagged* purchase volume (see Table A12).

[36] The HHI is computed using our sample, which covers over 60% of all WHO pre-qualified manufacturers, and 32 other firms vetted for quality via other channels (e.g., originator or US FDA approval). The WHO pre-qualified firms not in our data tend to be small generic firms, thus their exclusion would not significantly affect our HHI calculation.

[37] There is no linear relationship between approval year and patent status, as drug firms often obtain multiple patents on different aspects of an existing drug, e.g., new formulation or improved versions (Hemphill and Sampat, 2012).

[38] There are many cases where decades-old drugs widely used in LMIC are registered as new in the US. An example is malaria drug Coartem (artemether/lumefantrine), developed by Chinese scientists (e.g., 2015 Nobel Laureate Youyou Tu) and used since early 1990. Novartis registered it in the US in 2009 and won a priority review voucher for this

**Table 3:** Procurement mechanism and prices: heterogeneity analysis

| | (1) | (2) | (3) | (4) | (5) |
|---|---|---|---|---|---|
| | baseline | buyer total purchases | | manufacturer HHI | |
| | | high | low | high | low |
| PPM | -0.18*** | -0.12 | -0.23*** | -0.29*** | -0.094 |
| (pool intl.) | (0.058) | (0.088) | (0.062) | (0.088) | (0.067) |
| UN | -0.10** | -0.078 | -0.15*** | -0.19*** | -0.039 |
| (pool intl.) | (0.043) | (0.055) | (0.054) | (0.056) | (0.048) |
| CMS | -0.041 | -0.14** | 0.11*** | 0.013 | -0.055 |
| (pool within) | (0.061) | (0.071) | (0.035) | (0.046) | (0.041) |
| Others | 0.079** | 0.077** | 0.073* | 0.046 | 0.077** |
| | (0.035) | (0.034) | (0.039) | (0.044) | (0.036) |
| N | 39289 | 15145 | 24144 | 19641 | 19648 |
| | country patent status | | approval year | | |
| | ever-patented | never-patented | pre-1990 | 1990s | 1997+ |
| PPM | -0.18*** | -0.17** | -0.19 | -0.16* | -0.12** |
| (pool intl.) | (0.059) | (0.072) | (0.18) | (0.080) | (0.053) |
| UN | -0.100 | -0.10** | -0.29*** | -0.12*** | -0.027 |
| (pool intl.) | (0.071) | (0.045) | (0.11) | (0.042) | (0.044) |
| CMS | 0.069 | -0.13 | -0.13 | 0.016 | 0.017 |
| (pool within) | (0.059) | (0.098) | (0.12) | (0.070) | (0.073) |
| Others | 0.13* | 0.064* | 0.072 | 0.030 | 0.073 |
| | (0.073) | (0.033) | (0.056) | (0.031) | (0.054) |
| N | 11984 | 27305 | 10443 | 12594 | 15958 |
| Controls | Year FE, ctry-prod FE, controls (ctry-yr and ctry-year-prod) | | | | |

*Note:* Standard errors are two-way clustered by country and by product. "Buyer total purchases" refers to the buyer's total purchases of that drug product in that year. Buyer total purchases are high if they are larger than the median for that drug product-year combination, and low otherwise. Manufacturing HHI is high if it exceeds the median HHI observed in the sample (around 5000).

unobserved differences in utilization patterns across countries. While factors such as first-mover advantages and time on the market may influence drug utilization, we acknowledge the limitations of this subsample analysis due to the absence of detailed product approval data for each LMIC.

We perform similar analyses for delays and procurement lead time (Tables A13-A14). We find that the PPM achieves larger delay reductions in more concentrated markets, mirroring our findings on prices and suggesting that the PPM leverages bargaining power to negotiate both lower prices

"new" drug. We abstract from patent issues but use patents and approval years to capture different aspects of value.

and better delivery conditions.

# 5 Robustness Checks

## 5.1 Instrumental Variable Estimation

Despite extensive fixed effects and observable controls showing stable estimates across specifications, potential endogeneity concerns may remain. Drug-specific regional demand shocks (e.g., due to an epidemic) can simultaneously raise overall demand for the drug, leading to higher prices and more participation in pooling. Similarly, simultaneity bias may arise from idiosyncratic product price differences across procurement institutions, and if the pool size is endogenous. For example, if a manufacturer offers a PPM-specific discount on a drug (e.g., amoxicillin), buyers of amoxicillin will be more likely to procure via PPM; but this in turn will increase the total volume of amoxicillin orders placed by the PPM, which may enable the PPM to obtain an even larger price discount.

In addition, there may be learning effects: more experience purchasing a product may cause countries to improve their ability to negotiate lower prices, and simultaneously affect procurement institution choices. Countries with greater drug-specific experience may use international pooling institutions more as they learn how to participate in cross-country pools more effectively, or use these pools less as countries prioritize domestic pooling; the net effect of learning is ambiguous. If learning is uniform across drug products, then endogeneity is not a concern as our results are robust to the inclusion of country-year fixed effects; but if learning over time is specific to a particular product-country pair, then endogeneity may not be fully accounted for by our fixed effects. Overall, the direction of potential OLS bias is unclear.[39]

To address potential endogeneity of procurement institution choices, we instrument for $I_i^m$ (an indicator for whether procurement institution $m$ is utilized for transaction $i$) with the share of transactions of *other* drugs (APIs) in the same country by procurement institution $m$ in year $t$. These instruments are valid if unobservables $\varepsilon_i$ affecting the price of drug product $j$ paid by country $c$ are uncorrelated with the procurement institution choices of other drugs for the same country, after controlling for fixed effects and other observables. These instruments help alleviate

[39] If regional demand shocks result in endogeneity, then OLS estimates of the price reduction from pooling may be downward biased (since countries join pools more during periods with higher demand and higher prices). If learning yields endogeneity, the direction of bias is unclear: e.g., if learning effects are concentrated on a particular pooled procurement institution, then OLS estimates of the price reduction from pooling may be upward biased.

the endogeneity concerns mentioned above. A regional demand shock for a specific drug, or drug-specific experience accumulation (either of which may affect the price paid), could influence the country's choice of procurement institution for that drug, but is unlikely to immediately affect the institution chosen for other drugs.[40] Simultaneity bias also does not arise with these IVs since idiosyncratic price differences across procurement institutions for a specific drug may influence buyers' choices for that drug, but not the choice of procurement institutions for other drugs.

These instruments are relevant because procurement institution choices are likely to be positively correlated within a country. For example, a health ministry that already procures most of its other products through institution $m$ will have staff that are already familiar with that institution's procurement rules and may have existing relationships with that institution, all of which increases the likelihood that it will use institution $m$ for product $j$ as well.

A potential remaining concern is that there may be correlated demand shocks across multiple related drugs. For example, if there is a malaria outbreak in a country, this outbreak may raise the demand simultaneously for multiple antimalarial drugs. Therefore, we also consider an alternative approach where the IV is the share of transactions in *other drug classes* for that same country using procurement institution $m$.[41] Because these IVs use a country's procurement share in other drug classes, correlated demand shocks do not pose a threat to identification: if there is a demand shock specific to a drug class (e.g., a malaria outbreak), that is unlikely to directly affect the country's demand for drugs in other drug classes (e.g., the country's demand for anti-tuberculosis drugs).

The results further strengthen our main conclusions (Table 4). For each outcome (price, delay, lead time), we compare the OLS results with 2SLS results, where we instrument the shares of each of the four types of procurement institutions. Panel A shows results when the IV is the procurement share of the same country in other APIs, and Panel B shows results when the IV is the procurement share of the same country in other drug classes. The results remain similar, regardless of which IVs

[40] One may worry that as countries gain more experience in purchasing a drug, they might improve their ability to negotiate prices for *all* drugs. This is unlikely to drive our results, as we include country-by-drug product fixed effects and country-by-year controls that account for country-level time-varying differences in bargaining ability, and our results are robust to including country-by-year fixed effects that directly capture time-varying country-specific bargaining ability.

[41] For example, the IV for the PPM procurement share of an anti-malarial drug product (e.g., artesunate 100mg) would be the same country's PPM procurement share for all drug products that are *not* antimalarials. Drug classes are defined based on drugs' mechanism of action. There are 10 drug classes: antibiotic, malaria, tuberculosis, and seven classes within HIV drugs (entry inhibitors (EIs), fusion inhibitors (FIs), integrase inhibitors (IIs), non-nucleoside reverse transcriptase inhibitors (NNRTIs), nucleoside reverse transcriptase inhibitors (NRTIs), NNRTI+NRTIs, and protease inhibitors (PIs)).

**Table 4:** Instrumental variable estimation

| Dep var: | (1) OLS ln(price) | (2) 2SLS ln(price) | (3) OLS delay | (4) 2SLS delay | (5) OLS lead time | (6) 2SLS lead time |
|---|---|---|---|---|---|---|
| Panel A: instrument using procurement share of other drugs (APIs) | | | | | | |
| PPM | -0.20*** | -0.20*** | -0.28*** | -0.22*** | 114.1*** | 110.4*** |
| (pool intl.) | (0.052) | (0.056) | (0.049) | (0.081) | (13.6) | (20.9) |
| UN | -0.13*** | -0.17*** | 0.059 | 0.21 | 4.06 | -14.9 |
| (pool intl.) | (0.044) | (0.060) | (0.048) | (0.14) | (11.1) | (30.6) |
| CMS | 0.014 | -0.11* | -0.35*** | -0.19** | -48.0*** | -57.8*** |
| (pool within) | (0.067) | (0.061) | (0.063) | (0.083) | (12.6) | (18.1) |
| Others | 0.063* | 0.037 | -0.072* | -0.14 | 23.9** | 48.0* |
| | (0.032) | (0.069) | (0.041) | (0.11) | (9.67) | (25.8) |
| Cragg-Donald F-stat | | 1233.5 | | 1233.5 | | 1233.5 |
| Kleibergen-Paap F-stat | | 10.8 | | 10.8 | | 10.8 |
| Panel B: instrument using procurement share of other drug classes | | | | | | |
| PPM | -0.20*** | -0.20*** | -0.28*** | -0.26*** | 114.1*** | 92.2*** |
| (pool intl.) | (0.052) | (0.045) | (0.049) | (0.085) | (13.6) | (15.4) |
| UN | -0.13*** | -0.20*** | 0.059 | 0.21 | 4.06 | -24.6 |
| (pool intl.) | (0.044) | (0.060) | (0.048) | (0.14) | (11.1) | (24.3) |
| CMS | 0.014 | -0.0034 | -0.35*** | -0.19*** | -48.0*** | -61.7*** |
| (pool within) | (0.067) | (0.057) | (0.063) | (0.063) | (12.6) | (15.0) |
| Others | 0.063* | 0.041 | -0.072* | -0.19 | 23.9** | 22.0 |
| | (0.032) | (0.066) | (0.041) | (0.16) | (9.67) | (29.3) |
| Cragg-Donald F-stat | | 913.7 | | 913.7 | | 913.7 |
| Kleibergen-Paap F-stat | | 13.0 | | 13.0 | | 13.0 |

*Note:* Odd-numbered columns repeats the baseline estimates from Table 2. In even-numbered columns, we instrument for the procurement share of institution *m*. In Panel A, the instrument is the procurement share of institution *m* in the same country for other APIs; in Panel B, the instrument is the procurement share of institution *m* in the same country for products that are not in the same drug class. All specifications include year fixed effects, country-by-product fixed effects, and country-by-year and patent controls. Standard errors are two-way clustered by country and by product.

we use. We find a 20% reduction in prices from the PPM and a 17-20% reduction in prices from the UN (column (2)), qualitatively similar to corresponding 20% and 13% estimates in our baseline OLS results (column (1)). Similarly, we continue to find that the PPM lowers the likelihood of delays but with a longer lead time, and that CMS transactions lower both the likelihood of delays and lead times. The first-stage F-statistics indicate that weak identification is unlikely to be a concern here. Overall, our IV analyses suggest limited endogeneity concerns.

## 5.2 Altonji-Elder-Taber(AET)-Oster Method

To further address concerns that omitted variables not captured by our model could bias our estimates, we estimate parameter bounds accounting for omitted variable bias based on the Altonji-Elder-Taber method (Altonji et al., 2005) generalized by Oster (2019). This method assumes that selection on observables is likely informative about selection on unobservables. Thus, the stability of coefficients and $R^2$ movement as we add controls can be used to infer how much the coefficients would change due to selection on unobservables. Oster (2019) formalizes this by performing both a controlled regression (all observed controls included) and an uncontrolled regression (no additional controls or fixed effects). The coefficients and $R^2$ from these two sets of regressions can then be used to calculate bounds under the assumption that selection on unobservables is proportional to selection on observables. Appendix A.7 details the AET-O method and our implementation. Table A26 reports a set of *bounding values* for the main coefficient estimates reported in Table 2. Even under the most conservative parametrization à la Oster (2019), the set of AET-O adjusted bounds for estimates of procurement institutions are very similar to the benchmark estimates. Therefore, the AET-O method implies tight bounds for each main estimate, suggesting that selection on unobservables is unlikely to significantly bias our estimates.

## 5.3 Reduced-form Demand Estimation

A potential confounding explanation for why prices differ by procurement institution is that demand elasticities differ for buyers who purchase using different procurement institutions. If buyers with more elastic demand are more likely to use pooled procurement, the lower prices received may reflect buyer heterogeneity rather than the procurement institution used. To examine whether the demand elasticities are higher for buyers using a higher share of pooled procurement institutions than the elasticities for buyers that primarily purchase directly from manufacturers, we perform a reduced-form demand regression (similar to Dubois et al., 2021) using the following equation:

$$log(q_{jct}) = \alpha^{p} log(p_{jct}) + \sum_{m} \alpha^{pm} S^{m}_{jct} log(p_{jct}) + X_{jct}\gamma + \delta_{cj} + \delta_{t} + \nu_{jct} \tag{3}$$

$q_{jct}$ is the total quantity of drug product $j$ purchased by country $c$ in year $t$. The coefficient $\alpha^{p}$ is the demand elasticity when all of the drugs are purchased directly from manufacturers. The coefficient $\alpha^{pm}$ on the interaction term $S^{m}_{jct} log(p_{jct})$ captures how the demand elasticity changes

as the share of transactions carried out using procurement mechanism $m$ increases. To address potential endogeneity of prices due to simultaneity, we use a standard approach in the literature and instrument for the price by using the average price of the same drug product in other countries in the same year (following Hausman, 1996), the idea being that prices in other markets reflect unobserved cost shocks and hence serve as supply shifters. These instruments are valid if demand shocks are uncorrelated across markets after controlling for the set of fixed effects (at the product-by-country and year levels) and other observables (same as those used in our main specification).[42]

Table 5 column (1) presents the results of an OLS regression of the reduced-form demand function with no interactions. Column (2) instruments for price. Column (3) includes interaction terms of price and the shares of each procurement institution. Across specifications, the baseline price coefficients are not statistically significantly different from each other given the wide standard errors. The demand elasticity is lower for purchases made through the PPM (-0.19), compared to direct purchases from manufacturers (-0.30). For other categories, there is no statistically significant difference in the demand elasticity. If differences in demand elasticities were the primary reason behind price differences across procurement channels, we would have expected to see higher prices charged for PPM purchases, given that these buyers appear to be less demand elastic. Thus, our findings are unlikely to be driven by differences in demand elasticities across buyers.

## 5.4 Related Institutions: PEPFAR and CHAI

Some other institutions also contribute to essential drug supply to LMIC directly or indirectly. Notable examples are the United States President's Emergency Plan for AIDS Relief (PEPFAR) and the Clinton Health Access Initiative (CHAI). We discuss their roles and examine their effects.

PEPFAR is a US government initiative launched in 2003 to tackle the HIV/AIDS epidemic. The US government, through PEPFAR, is a major purchaser of ARVs on behalf of LMIC. The funding was primarily allocated to 15 focus countries with high prevalence of HIV/AIDS in its initial phase (2003-2008) and was expanded to cover a wider range of countries from 2008 onward. We collected data on (1) the list of drug products approved by the FDA for PEPFAR and the approval years, (2) the 15 focus countries targeted during PEPFAR's first phase, and (3) the countries that were supported by PEPFAR in its subsequent phases. We created a time-varying indicator for

[42] We compare the same product within the same country and year, procured through different institutions. Any simultaneity stemming from the joint determination of price and quantity in the market should not differ meaningfully across procurement institutions, as they are affected by the same underlying market conditions (e.g., cost shocks).

**Table 5:** Reduced-form demand estimates

| | (1) OLS | (2) 2SLS | (3) 2SLS |
|---|---|---|---|
| ln(price) | -0.41*** | -0.31 | -0.30 |
| | (0.078) | (0.19) | (0.19) |
| ln(price)*% PPM | | | 0.11** |
| (pool intl.) | | | (0.047) |
| ln(price)*% UN | | | 0.015 |
| (pool intl.) | | | (0.083) |
| ln(price)*% CMS | | | 0.19 |
| (pool within) | | | (0.23) |
| ln(price)*% Others | | | -0.031 |
| | | | (0.050) |
| % PPM | -0.13 | -0.099 | 0.17 |
| (pool intl.) | (0.091) | (0.10) | (0.15) |
| % UN | -0.21* | -0.18 | -0.15 |
| (pool intl.) | (0.11) | (0.12) | (0.24) |
| % CMS | 0.0052 | 0.016 | 0.43 |
| (pool within) | (0.37) | (0.37) | (0.70) |
| % Others | -0.048 | -0.052 | -0.12 |
| | (0.10) | (0.100) | (0.15) |
| Controls: Year & ctry-prod FEs, controls (ctry-yr-prod) | | | |
| N | 13,312 | 13,312 | 13,312 |
| Cragg-Donald F-stat | | 3053 | 594 |
| Kleibergen-Paap F-stat | | 57.18 | 12.34 |

*Note:* In columns (2) and (3), we instrument for the price using the average price of the same drug in other countries during the same year. In column (3), we allow the coefficient on the price to depend on the share of drugs purchased using different procurement mechanisms. Standard errors are two-way clustered by country and by product.

whether a purchase was made by a PEPFAR-supported country for an eligible product, which we include in our regressions. We also control for purchases of PEPFAR-eligible products by PEPFAR focus countries, in case the effects of PEPFAR are different for these countries.

Our estimates on procurement institutions remain similar (Table A15). Prices are not significantly different for PEPFAR-eligible purchases. When interacting procurement institution shares with the PEPFAR indicator, we find little evidence of complementarity between international pooled procurement institutions (PPM and UN) and PEPFAR. We do find that CMS (pooling within-country) are able to obtain a significantly lower price for PEPFAR-eligible products, suggesting

that countries using CMS can benefit from the presence of a large buyer that purchases the same product. The results are similar if we control separately for PEPFAR focus countries.[43]

CHAI has built a procurement consortium and offers reference prices. Until 2014, CHAI negotiated ceiling prices for selected products with generic manufacturers (Waning et al., 2009), which CHAI consortium countries were eligible for. In 2015, CHAI changed to provide "reference" prices to manufacturers, who made a non-binding commitment to offer these prices to CHAI consortium countries. We included two indicators for CHAI eligibility: (1) a transaction is ceiling-price-eligible if the importing country is in the consortium and the product-manufacturer pair is subject to a CHAI ceiling price (pre-2014); (2) a transaction is reference-price-eligible if the importing country is in the consortium and the product-manufacturer pair is subject to a CHAI reference price (2015 onwards).[44] After accounting for CHAI, our estimates on procurement institutions remain similar (Table A16). Prices are 8% lower for purchases eligible for CHAI reference prices but do not significantly differ by ceiling price eligibility.[45]

## 5.5 Management Practices: Tiered Pricing, Pre-payment, Order Frequency

Tiered pricing is used by drug firms to price differentially based on per-capita income of importing countries. Our baseline positive estimate on GDP per capita is consistent with tiered pricing. In practice, manufacturers may group countries to receive different pricing terms, so the income effect may be non-linear. Thus, we classify LMIC into Category 1 countries (eligible for the largest discounts) and others.[46] We interact GDP per capita with patent status and an indicator for non-Category 1 countries (Table A17). Non-Category 1 countries negotiate prices case-by-case with manufacturers, which may lead to a stronger price-income relationship. The estimate of GDP per capita is larger for non-Category 1 countries but not statistically significant. We then allow the effect of procurement institutions to vary by Category 1 status and find evidence that the PPM

[43] PEPFAR eligibility can be especially important for pediatric ARV formulations, where purchase decisions may be coordinated across buyers. Nevertheless, we find similar results when allowing the interaction between PEPFAR and share of procurement institutions to differ for adult and pediatric formulations. Results are available upon request.

[44] Application to join the CHAI consortium is fairly simple. About 80 countries are in the consortium during our sample period. We thank Carolyn Amole and Zack Panos at CHAI for sharing information on prices and the consortium.

[45] This result is different from Waning et al. (2009), which found sizeable effects of CHAI ceiling prices on transaction prices during 2002-2007 (when CHAI was more active in procurement). The lack of impact from ceiling price is likely because CHAI moved away from direct involvement in procurement post-2007, when our sample begins.

[46] We use Boehringer Ingelheim's definition of Category 1 countries, which includes all least-developed countries, all low-income countries and all of Africa (MSF, 2013). Our results are robust to other definitions, e.g., by using AbbVie's definition (where all African countries and all least-developed countries are considered Category 1).

lowers prices more for non-Category 1 countries, who may face higher prices in direct negotiations.

Advance payment is another management practice often used in drug procurement. Advance payment can potentially reduce upfront costs as manufacturers are paid partially or fully in advance by buyers (38% of the transactions in our sample). When we control for whether or not the transaction was pre-paid (Table A18), we find the coefficient on prepayment is negative but small in magnitude and statistically indistinguishable from zero, strengthening the results that our estimates on procurement institutions are not capturing effects from this management practice.

We then study how order frequency and variability vary by procurement institutions, which can potentially improve planning by manufacturers and buyers. We calculate order frequency at the manufacturer-product-year level as the number of distinct orders of a product received by a manufacturer in a year. We measure order variability as the coefficient of variation (CV) of the total quantity ordered for a manufacturer for each product within a year. We assess how order frequency and CV vary by the share of orders a manufacturer receives from procurement institutions by product-year (Table A19). The results suggest that pooled procurement institutions make fewer orders and reduce variability in demand faced by manufacturers, thus reducing the need to hold large inventories or respond to sudden demand swings.[47] However, this comes at the cost of flexibility for buyers, who have fewer opportunities to place urgent, last-minute orders.

## 5.6 Other Results

One possible concern with international procurement institutions is that they may limit the drug product choices for recipient countries. For instance, UNICEF Supply Division procurement generally requires the recipient country to select from an existing catalog. Pooled procurement may not align with each country's preferences, which may be limited by the subset of available drug products (Figure A5). To evaluate whether lack of availability systematically hinders procurement outcomes, we examine whether the types of drugs purchased within a therapeutic category vary substantially by procurement institution. We focus on two main attributes, patent status and drug age generation, and we estimate a drug category-country-year level regression testing whether the share of drugs with these attributes differs by procurement institution. We find no statistically significant differences in the share of patented drug products or different generations of products

[47] In addition, we repeat our baseline regressions while controlling for both order frequency and CV, finding very similar estimates on procurement institutions and little impact of reduced variability on price, delay, and lead time.

across procurement institutions purchased (Table A20). Appendix A.8 provides more details.

We perform additional analyses to support the mechanism and rule out other potential confounding factors. First, we test the complementarity between procurement institutions and IP licensing institutions by adding interaction terms, and find no statistically significant evidence of substitution or complementarity. Second, we add covariates on the share of Global Fund allocated grants awarded to governments, multilateral, or other sectors to capture potential grantee-based preferences in procurement institutions. Our results are robust to the inclusion of these controls. Third, we compare our in-sample prices with median prices for the same product reported in the MSH International Pricing Guide and test if these price differences vary systematically by procurement institution (Table A21). We continue to find cross-country pooling lowers prices.

Fourth, we examine the start-up effect of the PPM, established in 2009. We find little evidence that PPM effectiveness differs between initial (2009-11) and subsequent years (Table A22). Fifth, we run a diagnostic test with fixed effects for how shipping costs are reported (Table A23). Shipping cost is excluded from total cost in most transactions and is unknown or included in the total cost for some transactions. The results remain similar. Sixth, we examine the effect of procurement institutions by drug category, interacting each institution with therapeutic area (Table A24). Cross-country pooling has the largest effect for antiretroviral and antituberculosis, though the statistical power is limited for antituberculosis. Finally, our results are robust to alternative, more nuanced definitions of "Other" procurement institutions (Table A25), finding similar results.

# 6 Conclusion

We analyze drug supply in 106 countries during 2007-2017 for major infectious diseases (antiretrovirals, antimalarials, antituberculosis, and antibiotics), finding pooled procurement institutions lower prices. The price reductions are larger for cross-country pooling, particularly for low-volume buyers and products with more concentrated supply. Pooling domestically is more effective for high-volume buyers and products with less concentrated supply. The price reductions are not driven by more elastic demand associated with pooled procurement, or selection in unobserved factors, and are robust to alternative estimation strategies and robustness tests. One major pooled procurement institution (PPM) also reduces delivery delays but relies mainly on earlier ordering, increasing lead times. We find no evidence that pooled procurement institutions limit drug attributes buyers can procure within a drug category. Finally, the Medicines Patent Pool and pooled

procurement institutions reduce prices and increase access to different drug products.

Our results have several implications. First, pooled procurement reduces product prices, but the effectiveness varies by drug attributes and market features, such as buyer size and seller concentration. This suggests countries may want to choose a mix of procurement institutions, depending on the demand and disease profiles. Second, while PPM can reduce delays, early ordering results in longer procurement lead time despite more reliable deliveries. This suggests pooling may not work well for emergencies, when direct purchases may be faster. Third, pooled procurement institutions supplement IP licensing institutions (i.e., MPP) in LMIC drug supply, as the former has experience acquiring higher shares of older drug products while the latter focuses on patented drugs.

There are a few limitations. We focus on drug products treating the pre-Covid "big three" infectious diseases most fatal to people living in LMIC, thus our results may not generalize to non-communicable diseases or procurement in high-income countries. Although we obtained the best datasets available, we could not analyze the universe of the data nor capture all cross- and within-country unobservables in the supply chain. As COVID-19 further damaged the progress in reducing the disease burdens of "the big three" in LMIC, future research is greatly needed.

Our findings offer insights into LMIC drug supply challenges that persist beyond specific crises. As in the HIV/AIDS pandemic, drug supply in LMIC often lags globally, causing lingering impacts long after the peak of a crisis. While our analysis focuses on the period before the Covid-19 pandemic (with our data ending in 2017), challenges such as limited local production capacity, supply chain inefficiencies, and IP barriers remain important considerations for procurement strategies. The COVID-19 pandemic introduced additional complexities, including heightened demand surges, trade restrictions, and shifts in procurement behavior (e.g., stockpiling and supplier diversification), which our data do not capture. Given these factors, our findings should be interpreted within the context of pre-COVID institutional dynamics. Nonetheless, our analysis highlights crucial trade-offs in procurement institution design, emphasizing the need for adaptable strategies to ensure efficient and reliable drug supply to LMIC in both regular and emergency situations.

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# Online Appendix for "Procurement Institutions and Essential Drug Supply in Low and Middle-Income Countries"

**Contents**

# A Appendix

## A.1 Institutional Details and Descriptive Statistics

**Table A1:** Procurement institutions

| Category | Description |
|---|---|
| PPM | Global Fund's Pooled Procurement Mechanism, implemented mostly by the Partnership for Supply Chain Management Inc (PFSCM), with minor shares from IDA Foundation |
| UN | United Nations Children's Fund (UNICEF), United Nations Population Fund (UNFPA), World Health Organization (WHO) |
| CMS | Central Medical Stores |
| Others | (1) non-profit development agencies, such as Crown Agents, and Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ); (2) non-profit procurement organizations, such as Global Drug Facility (GDF), IDA Foundation (IDA), Population Services International (PSI), and i+ Solutions; (3) foundations, international NGOs (Medicins Sans Frontieres, Population Services International), private wholesalers. |

*Note:* In our sample, PFSCM only shows up as a procurement agent acting on behalf of PPM.

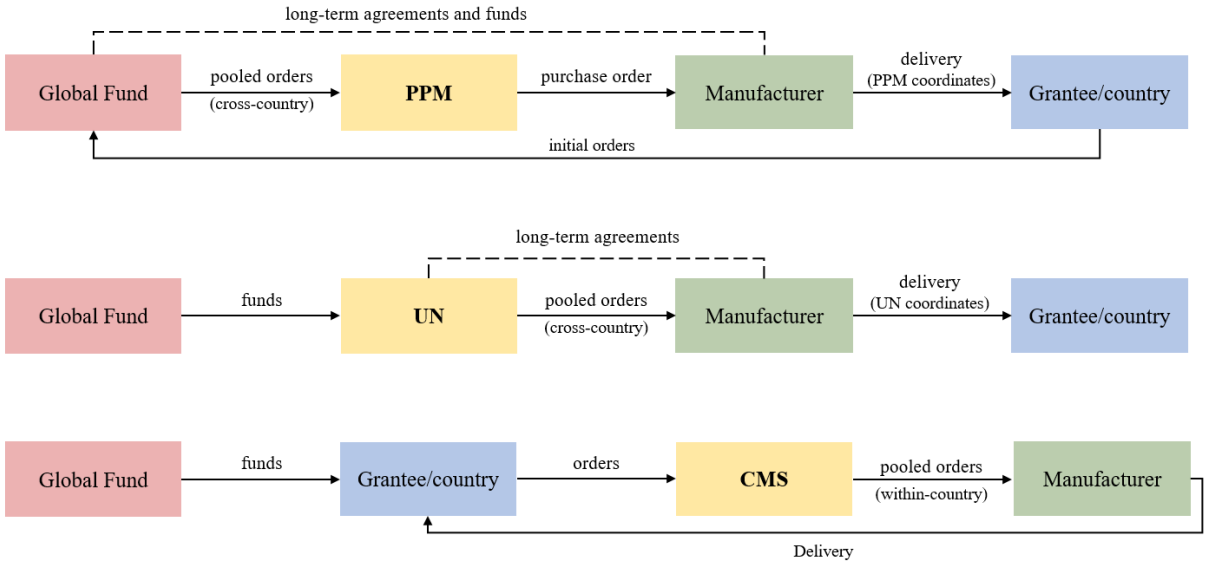



**Figure A1:** Procurement institutions comparison

**Table A2:** Major drugs in the sample

| Drug category | API | |
|---|---|---|
| antibiotic | amoxicillin+clavulanate | meropenem |
| | clarithromycin | moxifloxacin |
| | imipenem+cilastatin | ofloxacin |
| | levofloxacin | |
| antiretroviral | abacavir | lamivudine |
| | abacavir+lamivudine | lamivudine+nevirapine+stavudine |
| | abacavir+lamivudine+zidovudine | lamivudine+nevirapine+zidovudine |
| | atazanavir | lamivudine+stavudine |
| | atazanavir+ritonavir | lamivudine+tenofovir |
| | darunavir | lamivudine+tenofovir+nevirapine |
| | didanosine | lamivudine+zidovudine |
| | dolutegravir | lopinavir+ritonavir |
| | efavirenz | maraviroc |
| | efavirenz+emtricitabine+tenofovir | nelfinavir |
| | efavirenz+lamivudine+tenofovir | nevirapine |
| | efavirenz+lamivudine+zidovudine | tenofovir |
| | emtricitabine | tipranavir |
| | emtricitabine+tenofovir | zidovudine |
| | enfuvirtide | raltegravir |
| | etravirine | ritonavir |
| | fosamprenavir | saquinavir |
| | indinavir | stavudine |
| malaria | amodiaquine+sulfadoxine+pyrimethamine | artesunate+sulfadoxine+pyrimethamine |
| | arteether | chloroquine |
| | artemether | dihydroartemisinin+piperaquine |
| | artemether+lumefantrine | mefloquine |
| | artemotil | primaquine |
| | artesunate | quinine |
| | artesunate+amodiaquine | quinine+resorcine |
| | artesunate+mefloquine | sulfadoxine+pyrimethamine |
| tuberculosis | amikacin | isoniazid+rifampicin |
| | bedaquiline | kanamycin |
| | capreomycin | linezolid |
| | cycloserine | pas sodium |
| | delamanid | protionamide |
| | ethambutol | pyrazinamide |
| | ethambutol+isoniazid | pyridoxine |
| | ethambutol+isoniazid+pyrazinamide+rifampicin | rifabutin |
| | ethambutol+isoniazid+rifampicin | rifampicin |
| | ethionamide | rifapentine |
| | isoniazid | streptomycin |
| | isoniazid+pyrazinamide+rifampicin | terizidone |

*Note:* The table lists all the 83 APIs in our estimation sample.

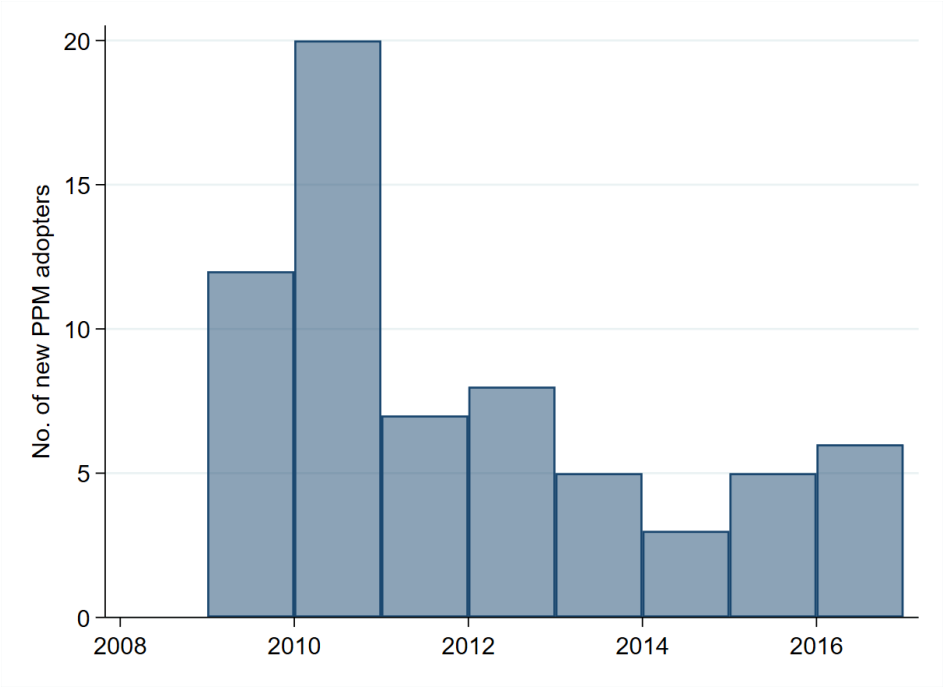



**Figure A2:** Number of new PPM adopters in our sample by year

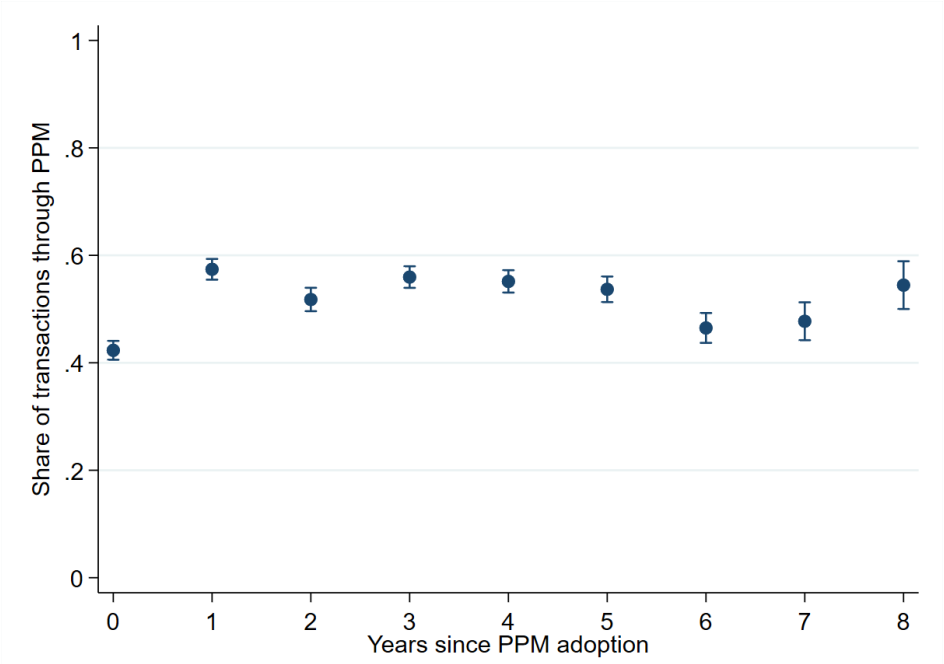



**Figure A3:** Binscatter plot of PPM transaction share by years since countries first used PPM

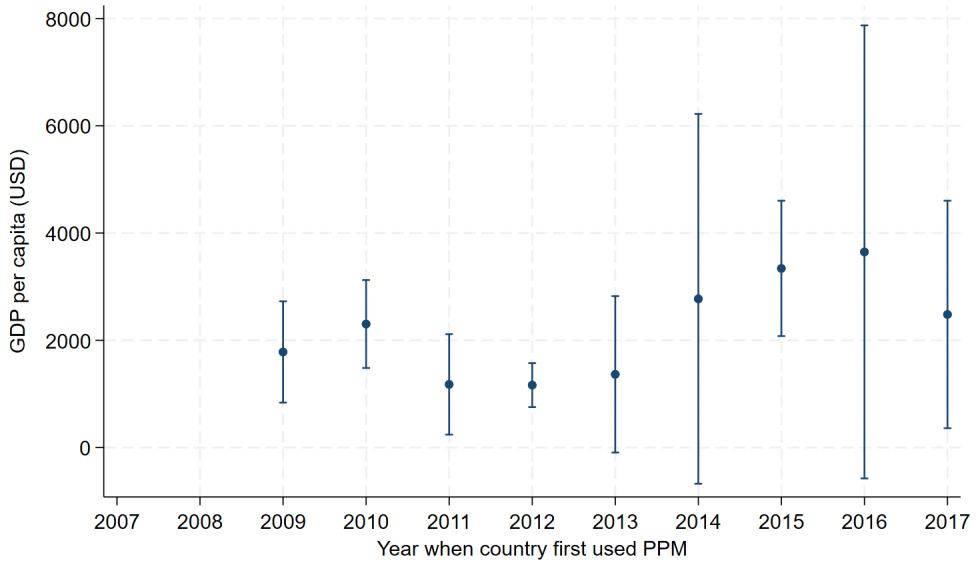



**Figure A4:** Binscatter plot of GDP per capita and first year when countries used PPM

*Note:* The vertical axis is each country's GDP per capita (averaged across 2007–2017). This only includes countries that used the Global Fund for drug purchases by 2008 (to avoid confounding PPM adoption with Global Fund entry).

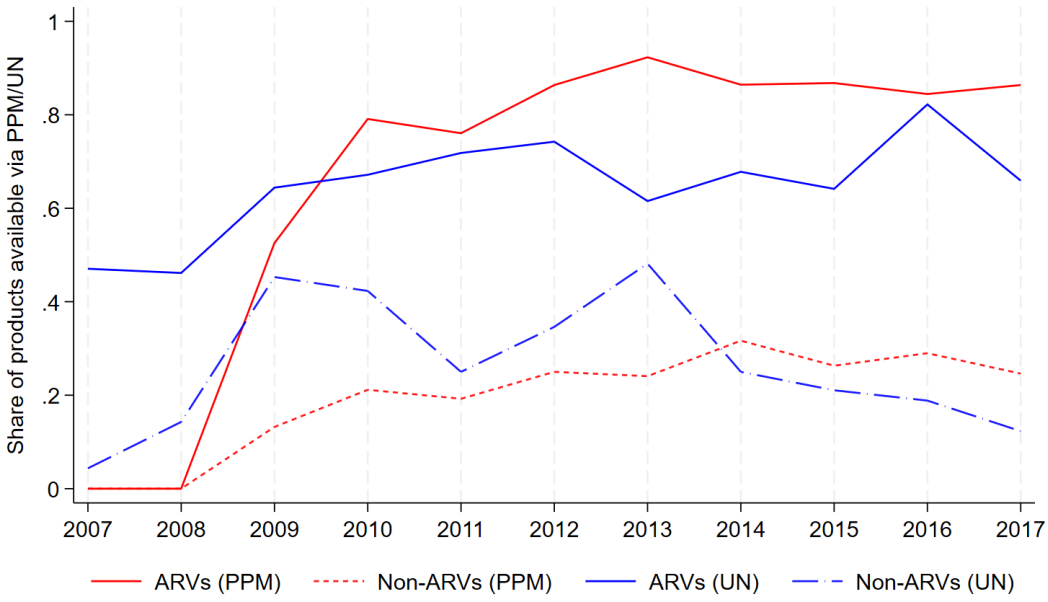



**Figure A5:** Share of products available via international pooled procurement institutions

*Note:* For each year, we calculate and plot the share of products (API-strength) that are available via PPM and UN.

**Table A3:** Regularity of orders placed with different procurement institutions

| | Average Coefficient of Variation | |
|---|---|---|
| | Time Between Transactions | Quantity |
| PPM | 1.31 | 0.99 |
| UN | 1.47 | 1.16 |
| CMS | 2.61 | 0.73 |
| Others | 1.29 | 0.94 |
| Direct | 2.57 | 1.05 |

*Note:* We calculate how regularly countries place orders with different procurement mechanisms using two measures. For each country-product-procurement mechanism, we first calculate (i) the time interval between consecutive transactions and (ii) the total monthly quantity purchased. We then compute the coefficient of variation (CV) for each country-product-procurement mechanism. This table reports the average CVs across country-products by each procurement mechanism, based on these two measures.

## A.2 Procurement Lead Time and Delivery Delays: More Details

Two important outcome variables we study are procurement lead time and delivery delays. In this section, we further elaborate on how these two outcomes are measured.

There are three crucial pieces of information we observe in the raw data. First, we observe the purchase order date, which is defined as the date when a price was first secured (but not necessarily the final price) from a manufacturer or intermediary (Global Fund, 2021). This date is commonly regarded as the order placement date: see, for instance, Gallien et al. (2017).[1] Second, we observe the scheduled delivery date, which is the planned delivery date specified in the purchase order. This is the date by which the supplier has agreed to deliver the order. Finally, we observe the actual delivery date or the date when a product is delivered (recorded in Global Fund's Price and Quality Reporting database after the final delivery).

Based on the three pieces of information, we defined our key non-price outcomes accordingly. We define the "procurement lead time" as the number of days from the purchase order date to the actual delivery date. This outcome captures the whole time period between when an order is placed and when the delivery actually materializes, and is the best proxy we have for the *effective* time taken for a purchase. A long procurement lead time can result from advanced planning or delays in delivery. We then define a "delivery delay" occurring whenever the actual delivery date is after the

[1] It is worth noting that the prices we observe are the final price after the delivery has been made, not the initial price quoted in the purchase order.

scheduled delivery date. An unexpected delay can result in higher stockout risk.

## A.3 Process for Placing Orders under PPM and UN

### Process for Placing Orders under Pooled Procurement Mechanism (PPM)

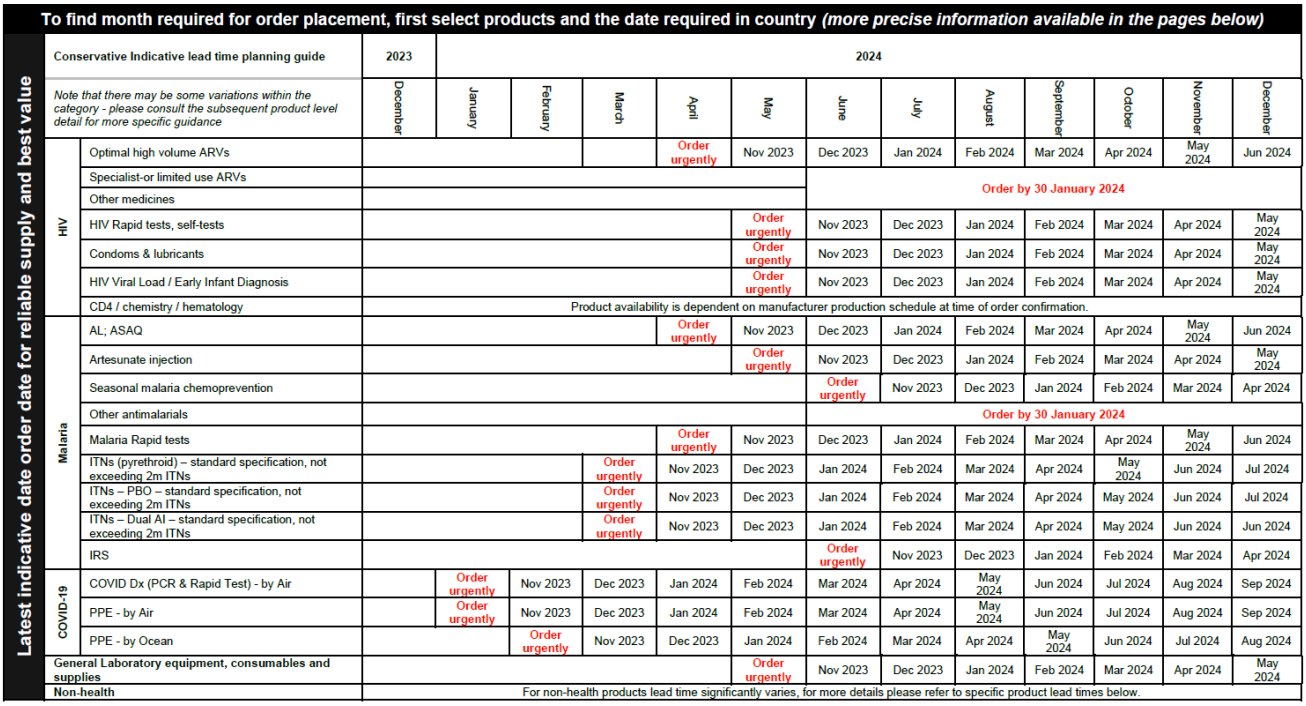
The procurement involves a few steps when using the Global Fund's PPM. The PPM uses volume thresholds specified in long-term agreements with manufacturers to obtain additional price discounts. To increase the likelihood of hitting these volume thresholds, buyers are encouraged to place orders early (Global Fund, 2022). The sequence of events for a purchase made through the PPM can be described as follows:[2]

1. Country places procurement request with the PPM.
2. PPM places a purchase order (the date is captured by the purchase order date) and agrees with a manufacturer on a scheduled delivery date (as specified on the purchase order).
3. PPM waits for other orders to reach the volume thresholds pre-specified in the long-term agreements with manufacturers. Depending on which volume threshold is reached, the actual price is finalized accordingly.
4. The manufacturer delivers. Actual delivery date is realized, which can be either earlier or later than the scheduled delivery date.

In our dataset, we only observe the order placement date, but not the date when the country places the procurement request with the PPM. Despite this challenge, we find credible evidence that a purchase order is issued shortly after a country places a procurement request. To confirm this, we consulted a delivery planning guide for the PPM published by the Global Fund with information on "indicative lead times" for a set of products: this is defined by the Global Fund as the time from making a procurement request to the delivery. We obtained 2017 data on the indicative lead time from the delivery planning guide, Global Fund (2017).[3] We compared the indicative lead time with our data-defined measure of procurement lead time and found they are similar. Specifically, the average "indicative lead time" is 174 days in the Global Fund report, while the average time between purchase order date and scheduled delivery date is 196 days in our sample for the same set

[2] This information was collected from the Global Fund's reports and its procurement platform interface, as well as from practitioners working in drug procurement in developing countries.

[3] See Figure A6 for an example planning guide.



To find month required for order placement, first select products and the date required in country *(more precise information available in the pages below)*

Latest indicative date order date for reliable supply and best value

| | Conservative Indicative lead time planning guide | 2023 | 2024 | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *Note that there may be some variations within the category - please consult the subsequent product level detail for more specific guidance* | December | January | February | March | April | May | June | July | August | September | October | November | December |
| HIV | Optimal high volume ARVs | | | | | Order urgently | Nov 2023 | Dec 2023 | Jan 2024 | Feb 2024 | Mar 2024 | Apr 2024 | May 2024 | Jun 2024 |
| HIV | Specialist-or limited use ARVs | | | | | | | Order by 30 January 2024 | | | | | | |
| HIV | Other medicines | | | | | | | | | | | | | |
| HIV | HIV Rapid tests, self-tests | | | | | | Order urgently | Nov 2023 | Dec 2023 | Jan 2024 | Feb 2024 | Mar 2024 | Apr 2024 | May 2024 |
| HIV | Condoms & lubricants | | | | | | Order urgently | Nov 2023 | Dec 2023 | Jan 2024 | Feb 2024 | Mar 2024 | Apr 2024 | May 2024 |
| HIV | HIV Viral Load / Early Infant Diagnosis | | | | | | Order urgently | Nov 2023 | Dec 2023 | Jan 2024 | Feb 2024 | Mar 2024 | Apr 2024 | May 2024 |
| HIV | CD4 / chemistry / hematology | Product availability is dependent on manufacturer production schedule at time of order confirmation. | | | | | | | | | | | | |
| Malaria | AL; ASAQ | | | | | Order urgently | Nov 2023 | Dec 2023 | Jan 2024 | Feb 2024 | Mar 2024 | Apr 2024 | May 2024 | Jun 2024 |
| Malaria | Artesunate injection | | | | | | Order urgently | Nov 2023 | Dec 2023 | Jan 2024 | Feb 2024 | Mar 2024 | Apr 2024 | May 2024 |
| Malaria | Seasonal malaria chemoprevention | | | | | | | Order urgently | Nov 2023 | Dec 2023 | Jan 2024 | Feb 2024 | Mar 2024 | Apr 2024 |
| Malaria | Other antimalarials | | | | | | | Order by 30 January 2024 | | | | | | |
| Malaria | Malaria Rapid tests | | | | | Order urgently | Nov 2023 | Dec 2023 | Jan 2024 | Feb 2024 | Mar 2024 | Apr 2024 | May 2024 | Jun 2024 |
| Malaria | ITNs (pyrethroid) – standard specification, not exceeding 2m ITNs | | | | Order urgently | Nov 2023 | Dec 2023 | Jan 2024 | Feb 2024 | Mar 2024 | Apr 2024 | May 2024 | Jun 2024 | Jul 2024 |
| Malaria | ITNs – PBO – standard specification, not exceeding 2m ITNs | | | | Order urgently | Nov 2023 | Dec 2023 | Jan 2024 | Feb 2024 | Mar 2024 | Apr 2024 | May 2024 | Jun 2024 | Jul 2024 |
| Malaria | ITNs – Dual AI – standard specification, not exceeding 2m ITNs | | | | Order urgently | Nov 2023 | Dec 2023 | Jan 2024 | Feb 2024 | Mar 2024 | Apr 2024 | May 2024 | Jun 2024 | Jun 2024 |
| Malaria | IRS | | | | | | | Order urgently | Nov 2023 | Dec 2023 | Jan 2024 | Feb 2024 | Mar 2024 | Apr 2024 |
| COVID-19 | COVID Dx (PCR & Rapid Test) - by Air | | Order urgently | Nov 2023 | Dec 2023 | Jan 2024 | Feb 2024 | Mar 2024 | Apr 2024 | May 2024 | Jun 2024 | Jul 2024 | Aug 2024 | Sep 2024 |
| COVID-19 | PPE - by Air | | Order urgently | Nov 2023 | Dec 2023 | Jan 2024 | Feb 2024 | Mar 2024 | Apr 2024 | May 2024 | Jun 2024 | Jul 2024 | Aug 2024 | Sep 2024 |
| COVID-19 | PPE - by Ocean | | | Order urgently | Nov 2023 | Dec 2023 | Jan 2024 | Feb 2024 | Mar 2024 | Apr 2024 | May 2024 | Jun 2024 | Jul 2024 | Aug 2024 |
| | General Laboratory equipment, consumables and supplies | | | | | | Order urgently | Nov 2023 | Dec 2023 | Jan 2024 | Feb 2024 | Mar 2024 | Apr 2024 | May 2024 |
| | Non-health | For non-health products lead time significantly varies, for more details please refer to specific product lead times below. | | | | | | | | | | | | |

**Figure A6:** Global Fund's planning guide for procurement orders via the PPM

*Note:* This figure shows the PPM planning guide for October 2023 published by Global Fund. Source: https://www.theglobalfund.org/media/10755/psm_categoryproductlevelprocurementdeliveryplanning_guide_en.pdf.

of products during 2017. Our measure of procurement lead time (the time between the purchase order date and the delivery date) is therefore a close proxy for the unobserved performance variable of interest (the time between when buyers made their procurement request and the delivery date).

### Process for Placing Orders Through the UN

Each UN entity maintains a catalog of available products, allowing UN partners (e.g., countries) to submit procurement requests. The process for placing orders via the UNICEF Supply Division, which accounts for the majority of UN transactions in our dataset, is as follows:[4]

1. The country selects the product to be supplied from the UNICEF Supply Catalogue, and submits a procurement request (including a request for a cost estimate).

2. The UNICEF issues a cost estimate, and the country signs a Memorandum of Understanding (MOU) and makes advance payment.

[4]See https://www.unicef.org/supply/faq-procurement-services.

3. Following this, UNICEF procures the drug product and arranges for delivery. The products are in many cases sourced from the UN's Global Supply and Logistics Hub in Copenhagen, which maintains a stockpile of essential drug products.

The procedure is similar for other UN entities: for example, the UNFPA also maintains its own supply catalog, from which its partners can issue a procurement request.

## A.4 Importance and Representativeness of Our Sample

**Spending on drugs for "the big three" in LMIC:** Our sample of LMIC includes 106 countries with a total population of around 5.5 billion people as of 2015. There are a few studies that estimate total health spending by LMIC for the "big three" infectious diseases. A study published by the Global Burden of Disease Health Financing Collaborator Network estimates that in 2015, total health spending by LMIC on HIV/AIDS equaled $26.95bn (Dieleman et al., 2018), broken down into $8.03 bn (for low-income countries), $9.40 bn (for lower-middle income countries) and $9.52 bn (for upper-middle income countries). Micah et al. (2020) find that in 2017, health spending by LMIC equaled $20.2 bn for HIV/AIDS, $10.9bn on tuberculosis, and $5.1bn on malaria. Based on these studies, it is evident that health spending on these infectious diseases continues to impose a substantial burden on LMIC (in addition to the direct health impacts).

Comprehensive data on LMIC spending on drugs for these diseases is very limited, as many LMIC do not collect systematic data on how healthcare spending for different diseases is allocated to drug purchases. For the three major diseases we study (HIV/AIDS, TB, malaria), drug spending is likely to account for a sizeable share of overall health spending: for HIV/AIDS, 25% of all spending by LMIC in 2020 was accounted for by spending on HIV drugs.[5] Therefore, LMIC invest substantial amounts into the purchases of drugs for these infectious diseases.

**Representativeness of sample:** Our data include transactions reported in Global Fund's Price and Quality Reporting database. While this is not the universe of all procurement of essential drugs (in our therapeutic categories) by LMIC, it accounts for a sizeable share. In particular, the Global Fund financed around 40% of purchases of ARVs by LMIC (Global Fund, 2016).

[5] See https://www.aidsmap.com/news/aug-2022/second-line-treatment-nearly-nine-times-more-expensive-first-line-upper-middle-income.

Our data cover a high share of the drugs that are used by LMIC to treat these diseases. For ARVs used to treat HIV/AIDs, our sample covers 23 compounds out of the total 27 unique ARV compounds approved by 2017, among which four compounds were approved late in our sample period (during 2012-2017).[6] Thus, our data includes 85% compounds available to treat HIV. For malaria and tuberculosis drugs, it is harder to collect the pool of all available drugs, so we consulted the WHO Essential Medicine Lists (EML), which contains the drugs considered to be most effective and safe to meet the most important needs in a health system.[7] Our sample covers 13 out of 15 unique malaria compounds and all 18 unique tuberculosis compounds in the WHO EML.[8]

In addition, our data cover a large share of the manufacturers of essential drugs (for the four therapeutic categories we study). Global Fund grantees can purchase quality-assured generic drugs that have been either: 1) pre-qualified by the WHO pre-qualification program, 2) authorized for use by a stringent drug regulatory authority (e.g., the US FDA), or 3) recommended for use by an expert review panel.[9] There are a total of 99 manufacturers in our database, among which 67 are WHO pre-qualified and 32 are not included in WHO pre-qualification data. 44 manufacturers in WHO pre-qualification data are not captured by our sample. This means that our dataset includes 60.4% (=67/(67+44)) of the WHO pre-qualified manufacturers, and additionally includes 32 manufacturers that qualify through criteria (2) and (3). It is worth noting that some leading manufacturers (e.g., Gilead and Bayer) in our sample qualify under criterion 2. In contrast, most of the 44 firms that are WHO pre-qualified but outside our sample are small generic manufacturers. Thus, our sample covers most manufacturers in the market, particularly major ones.

Table A4 illustrates the number of APIs purchased using different procurement institutions, both for the full set of APIs in our sample, as well as broken down by different therapeutic areas. A substantial share of the drugs (particularly ARVs) are purchased using PPM or UN. Nearly all APIs are also purchased directly from manufacturers, and we also confirmed that there are no drugs

[6] Source: https://hivinfo.nih.gov/understanding-hiv/fact-sheets/fda-approved-hiv-medicines. Some APIs are cocktails with multiple compounds, which is why we have 36 APIs for ARVs with 23 unique compounds.

[7] Source: https://www.who.int/groups/expert-committee-on-selection-and-use-of-essential-medicines/essential-medicines-lists. The WHO EML is frequently used by countries to help develop their own local lists of essential medicines. The lists are updated every two years, and we consulted all editions between 2007-2017. Note that antibiotics are not reported in EML before 2017 (the end of our sample period).

[8] Our sample also includes three other malaria drugs and one more TB drug outside the list that are widely used globally.

[9] see https://www.theglobalfund.org/en/sourcing-management/quality-assurance/medicines/ and https://www.theglobalfund.org/media/10377/psm_2021-09-27_invitation-to-manufacturers_en.pdf. It is worth noting that Gilead Sciences (i.e., the market leader for HIV drugs) did not join the WHO pre-qualification program during our sample period but is an important manufacturer in our sample, with products qualified under criterion 2).

in our sample that are only purchased through PPM or UN. As we include product-country fixed effects, we use *within*-country-product variation in the utilization rate of procurement institutions, instead of cross-country or cross-product variation in the utilization to identify the effects.

**Table A4:** Number of APIs purchased using different procurement institutions

| No. of APIs purchased using procurement institution | | | | | |
|---|---|---|---|---|---|
| | Direct from manufacturer | PPM | UN | CMS | Others |
| All | 80 | 57 | 58 | 33 | 73 |
| HIV/AIDS | 36 | 33 | 31 | 22 | 34 |
| Tuberculosis | 22 | 10 | 12 | 5 | 23 |
| Malaria | 16 | 13 | 13 | 5 | 9 |
| Antibiotics | 6 | 1 | 2 | 1 | 7 |

Table A5 compares the prices paid by buyers in our data with prices for the same products reported in the widely used International Medical Products Price Guide published by Management Sciences for Health (MSH). These guides, available annually from 1996 to 2015, report median prices for a set of products from pharmaceutical suppliers, development organizations, and government agencies.[10] Importantly, the prices reported by MSH reflect not just purchases subsidized by the Global Fund, but also other types of procurement (e.g., purchases under the PEPFAR program, or those that are not subsidized by international organizations). As Table A5 illustrates, prices in the Global Fund dataset are, on average, quite similar to the prices of the same products in the MSH guide. The correlation coefficient between the Global Fund prices and MSH prices is 0.94.

**Table A5:** Comparison of Sample Prices with Benchmark Prices in MSH Guides

| | | | Percentiles | | | | |
|---|---|---|---|---|---|---|---|
| | N | Mean | 5th | 25th | Median | 75th | 95th |
| Price in Global Fund data | 324 | 0.321 | 0.016 | 0.047 | 0.105 | 0.280 | 0.728 |
| Price in MSH Guide | 324 | 0.408 | 0.019 | 0.062 | 0.133 | 0.323 | 1.370 |

*Note:* Each observation is a median price for a product-year calculated only when data are available from both Global Fund and MSH, with a minimum of 20 transactions per product-year in raw data to ensure reliability. To ensure comparability, we calculate the median price per product-year from Global Fund transaction data, since the MSH reports only report the median price by product-year. Unit: $/SKU.

[10] Source: https://msh.org/resources/international-medical-products-price-guide-2/.

Table A6 further reports the countries covered in our sample and main analyses by income group as of 2007 (the beginning of our sample period). Our sample includes 49 low-income countries (L), 45 lower-middle income countries (LM), 11 upper-middle-income countries (UM), and one high-income country (H). All countries are resource-limited to different extents.[11]

**Table A6:** Country coverage in our sample

| inc. | countries |
|---|---|
| L | Afghanistan, Bangladesh, Benin, Burkina Faso, Burundi, Cambodia, Central African Republic, Chad, Comoros, Congo (Democratic Republic), Ivory Coast, Eritrea, Ethiopia, Gambia, Ghana, Guinea, Guinea-Bissau, Haiti, Kenya, Korea (Democratic Peoples Republic), Kyrgyzstan, Lao, Liberia, Madagascar, Malawi, Mali, Mauritania, Mozambique, Myanmar, Nepal, Niger, Nigeria, Pakistan, Papua New Guinea, Rwanda, Sao Tome & Principe, Senegal, Sierra Leone, Solomon Islands, Somalia, Tajikistan, Tanzania, Togo, Uganda, Uzbekistan, Vietnam, Yemen, Zambia, Zimbabwe |
| LM | Angola, Armenia, Azerbaijan, Bhutan, Bolivia, Bosnia and Herzegovina, Cameroon, Cape Verde, China, Colombia, Congo, Djibouti, Dominican Republic, Egypt, El Salvador, Georgia, Guatemala, Guyana, Honduras, India, Indonesia, Iran, Iraq, Kosovo, Lesotho, North Macedonia, Moldova, Mongolia, Morocco, Namibia, Nicaragua, Palestine, Paraguay, Peru, Philippines, South Sudan, Sri Lanka, Sudan, Swaziland, Syrian Arab Republic, Thailand, Timor-Leste, Tunisia, Turkmenistan, Ukraine |
| UM | Belarus, Bulgaria, Cuba, Jamaica, Kazakhstan, Mauritius, Romania, Russia, Serbia, South Africa, Suriname |
| H | Equatorial Guinea |

*Note:* The table lists all 106 countries in our sample. "Inc." refers to World Bank income categories: low-income (L), lower-middle income (LM), upper-middle income (UM), and high-income (H). For our analysis using observable controls, the sample includes 99 countries, with the above excluding 7 countries: North Korea, Kosovo, Moldova, Palestine, Somalia, Swaziland, and Syria. The attrition is due to missing controls: GDP/capita data are unavailable for North Korea/Somalia, population data are unavailable for Kosovo, and no governance measures for Palestine etc.

[11] Note that even though Equatorial Guinea is classified as a high-income country, it is still resource-limited and needs international help in drug procurement.

## A.5 Panel-level Analysis and Results

To facilitate comparison to earlier literature, we also performed a full set of panel-level analyses, following equation (2) whose specification is briefly discussed in section 3.3. Here we elaborate more before reporting the results.

For the price outcome $log(p_{jct})$, the coefficient on the share of transactions by procurement institution $m$ ($\beta^m$) can be interpreted as the percentage impact of using procurement institution $m$ on the purchase price, relative to the baseline of direct purchase from manufacturers (i.e., when each of the $S^m_{jct}$ variables equals 0). For the outcome of delays $d_{jct}$, $\beta^m$ can be interpreted as the additional share of transactions delayed if the country purchases drugs using procurement institution $m$ versus direct purchase from manufacturers. For the procurement lead time outcome $T_{jct}$, $\beta^m$ can be interpreted as the number of additional days it takes to deliver the order if a country uses procurement institution $m$ relative to direct purchase from the manufacturer.

Table A7 shows summary statistics for the product-country-year panel, while Table A8 shows the estimation results. We have also used a more demanding specification that includes country-year fixed effects and country-product fixed effects. In those analyses, $X_{jct}$ only includes controls that vary across drugs purchased by a given country in a given year (e.g., the drug patent status). The results (available upon request) remain broadly similar.

**Table A7:** Summary statistics for the drug product-country-year panel

| Drug prod.-country-year panel summary statistics | | | | | |
|---|---|---|---|---|---|
| Price (US$/product) | 14,681 | 0.49 | 1.49 | 0.001 | 61.13 |
| Spending ($1000) | 14,681 | 384 | 2450 | 0.002 | 86,300 |
| % PPM | 14,681 | 0.28 | 0.44 | 0 | 1 |
| % UN | 14,681 | 0.15 | 0.34 | 0 | 1 |
| % CMS | 14,681 | 0.02 | 0.14 | 0 | 1 |
| % Direct from manufacturers | 14,681 | 0.24 | 0.42 | 0 | 1 |
| % Others | 14,681 | 0.32 | 0.46 | 0 | 1 |
| Procurement lead time (days) | 14,681 | 171.58 | 121.13 | 0 | 1,197 |
| % delayed | 14,681 | 0.52 | 0.45 | 0 | 1 |
| Patented | 14,681 | 0.2 | 0.4 | 0 | 1 |
| Medicines Patent Pool (MPP) | 14,681 | 0.09 | 0.28 | 0 | 1 |

*Note:* Summary statistics for the data aggregated to a product-country-year panel. Pooled Procurement Mechanism (PPM), United Nations (UN), Central Medical Stores (CMS), and Medicines Patent Pool (MPP). Standard errors are two-way clustered by country and by product.

**Table A8:** Procurement mechanisms and prices, delays and lead time: panel-level analysis

| Dep var: | ln(price) | delay | lead time |
|---|---|---|---|
| % PPM | -0.30*** | -0.26*** | 105.4*** |
| (pool intl.) | (0.058) | (0.050) | (10.5) |
| % UN | -0.23*** | 0.084 | 1.45 |
| (pool intl.) | (0.053) | (0.056) | (11.8) |
| % CMS | -0.10 | -0.080 | -23.6 |
| (pool within) | (0.073) | (0.083) | (23.5) |
| % Others | 0.027 | -0.044 | 12.8 |
| | (0.039) | (0.040) | (7.77) |
| Patented | 0.023 | 0.019 | -1.53 |
| | (0.051) | (0.046) | (11.1) |
| MPP | -0.31*** | 0.011 | 1.81 |
| | (0.10) | (0.027) | (5.67) |
| ln(population) | 0.67 | -0.47 | -34.0 |
| | (0.53) | (0.81) | (118.5) |
| ln(GDP per capita) | 0.13** | 0.069 | 30.0 |
| | (0.055) | (0.081) | (22.8) |
| Controls | Year FE, ctry-prod FE, controls (ctry-yr and ctry-year-prod) | | |
| N | 14,681 | 14,681 | 14,681 |

*Note:* These regressions are carried out with the data aggregated to a product-country-year panel. %PPM refers to the share of transactions carried out using PPM; %UN, %CMS, %Others are defined similarly. Pooled Procurement Mechanism (PPM), United Nations (UN), Central Medical Stores (CMS), and Medicines Patent Pool (MPP). Standard errors are two-way clustered by country and by product.

## A.6 Additional Results

**Table A9:** Procurement mechanisms and prices: robustness checks

| | (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|---|
| Dep var: | ln(price) | | delay | | lead time | |
| PPM | -0.18*** | -0.17*** | -0.25*** | -0.25*** | 114.2*** | 114.0*** |
| (pool intl.) | (0.058) | (0.059) | (0.053) | (0.053) | (16.2) | (15.9) |
| UN | -0.10** | -0.10** | 0.0095 | 0.0095 | 12.0 | 11.9 |
| (pool intl.) | (0.043) | (0.044) | (0.051) | (0.051) | (9.20) | (9.12) |
| CMS | -0.041 | -0.083 | -0.26*** | -0.25*** | -37.4*** | -32.5*** |
| (pool within) | (0.061) | (0.056) | (0.054) | (0.054) | (12.0) | (12.3) |
| Others | 0.079** | 0.073** | -0.077* | -0.076* | 27.1*** | 27.8*** |
| | (0.035) | (0.036) | (0.043) | (0.044) | (9.89) | (9.82) |
| ln(Transaction volume) | | -0.025*** | | 0.0025 | | 2.82** |
| | | (0.0076) | | (0.0039) | | (1.23) |
| Patented | 0.00020 | -0.0019 | -0.0015 | -0.0013 | -10.1 | -9.88 |
| | (0.050) | (0.049) | (0.042) | (0.042) | (8.77) | (8.85) |
| MPP | -0.20** | -0.19** | 0.083*** | 0.082*** | 8.26 | 7.58 |
| | (0.087) | (0.087) | (0.026) | (0.027) | (6.56) | (6.44) |
| ln(population) | 0.68 | 0.84 | -0.34 | -0.36 | 128.8 | 111.0 |
| | (0.74) | (0.74) | (0.59) | (0.59) | (183.5) | (182.4) |
| ln(GDP per capita) | 0.19*** | 0.19*** | -0.072 | -0.071 | 37.2 | 37.6 |
| | (0.068) | (0.068) | (0.088) | (0.088) | (23.5) | (23.7) |
| Controls | Year FE, ctry-buyer-prod FE, controls (ctry-yr and ctry-year-prod) | | | | | |
| N | 39,289 | 39,289 | 39,289 | 39,289 | 39,289 | 39,289 |

*Note:* In all columns, we include country-buyer-product FE, where the buyer is the organization within the country making the purchase (e.g., health ministry). In even-numbered columns, we also control for ln(transaction volume). Pooled Procurement Mechanism (PPM), United Nations (UN), Central Medical Stores (CMS), and Medicines Patent Pool (MPP). Standard errors are two-way clustered by country and by product.

**Table A10:** Transaction-level analysis: effect of procurement institutions on prices, with alternative choices of fixed effects

| | (1) | (2) | (3) | (4) | (5) |
|---|---|---|---|---|---|
| PPM | -0.20*** | -0.19*** | -0.14*** | -0.13*** | -0.13*** |
| (pool intl.) | (0.052) | (0.058) | (0.043) | (0.038) | (0.045) |
| UN | -0.13*** | -0.12*** | -0.12*** | -0.11*** | -0.099*** |
| (pool intl.) | (0.044) | (0.045) | (0.036) | (0.032) | (0.032) |
| CMS | 0.014 | 0.11*** | 0.11*** | 0.11*** | 0.026 |
| (pool within) | (0.067) | (0.036) | (0.033) | (0.025) | (0.022) |
| Others | 0.063* | 0.037 | 0.035 | 0.046** | 0.047** |
| | (0.032) | (0.029) | (0.024) | (0.018) | (0.020) |
| Patented | 0.024 | -0.032 | 0.0059 | 0.00013 | -0.015 |
| | (0.053) | (0.057) | (0.040) | (0.033) | (0.025) |
| MPP | -0.23** | -0.22*** | -0.044 | -0.10*** | -0.085** |
| | (0.10) | (0.081) | (0.046) | (0.038) | (0.042) |
| ln(population) | 1.09** | | | | |
| | (0.53) | | | | |
| ln(GDP per capita) | 0.16** | | | | |
| | (0.068) | | | | |
| Year FE | Y | Y | Y | Y | Y |
| Country-product FE | Y | Y | Y | Y | Y |
| Country-year FE | | Y | Y | Y | Y |
| Product-year FE | | | Y | Y | Y |
| Manufacturer FE | | | | Y | Y |
| Country-buyer-product FE | | | | | Y |
| N | 39,289 | 39,289 | 39,289 | 39,289 | 39,289 |
| $R^2$ | 0.95 | 0.96 | 0.97 | 0.97 | 0.98 |

*Note:* Transaction-level data is used for this analysis. Column (1) has the baseline specification with product-country and year fixed effects, as well as other controls. In each remaining column we progressively add fixed effects. Column (2) adds country-year fixed effects; column (3) further adds product-year fixed effects; column (4) adds manufacturer fixed effects, and finally column (5) also includes country-buyer-product FE, where the buyer is the organization within the country making the purchase (e.g., health ministry). Standard errors are two-way clustered by country and by product.

We perform the heterogeneity analysis for shipment delays (Table A13) and procurement lead time (Table A14). Overall, we do not find much evidence of significant heterogeneity in the impact of procurement mechanisms on delays or lead times.

**Table A11:** Transaction-level analysis: procurement lead time after dropping pre-planned orders

| | (1) | (2) |
|---|---|---|
| PPM | 94.7*** | 94.8*** |
| (pool intl.) | (6.53) | (7.98) |
| UN | -1.43 | 1.44 |
| (pool intl.) | (7.98) | (7.66) |
| CMS | -43.2*** | -39.4*** |
| (pool within) | (10.3) | (10.2) |
| Others | 14.0** | 14.2** |
| | (6.41) | (6.81) |
| Patented | 2.67*** | 2.25** |
| | (0.93) | (0.93) |
| MPP | -4.42 | -5.52 |
| | (7.48) | (7.25) |
| Year FE | Y | Y |
| Ctry-prod FE | Y | Y |
| $X_{ctry-year}$ | Y | Y |
| $X_{ctry-year-prod}$ | Y | Y |
| Ctry-buyer-prod FE | | Y |
| N | 32,855 | 32,855 |

*Note:* Transaction-level data is used for this analysis. We drop pre-planned orders using the following procedure. We first identify all orders made on a given date with the same manufacturer-buyer-drug combination. Within this set of orders, some orders have a later scheduled delivery date than the earliest delivery date, which are very likely to be pre-planned orders, so we drop them. We also drop any orders that have a scheduled lead time longer than 365 days. In column (2), we include country-buyer-product FE, where the buyer is the organization within the country making the purchase (e.g., health ministry). Standard errors are two-way clustered by country and by product.

**Table A12:** Procurement mechanism and prices: effect of buyer purchase volume

| | (1) | (2) | (3) | (4) | (5) |
|---|---|---|---|---|---|
| | baseline | buyer total purchases | | buyer lagged total purchases | |
| | | high | low | high | low |
| PPM | -0.18*** | -0.12 | -0.23*** | -0.11 | -0.20*** |
| (pool intl.) | (0.058) | (0.088) | (0.062) | (0.082) | (0.062) |
| UN | -0.10** | -0.078 | -0.15*** | -0.059 | -0.12** |
| (pool intl.) | (0.043) | (0.055) | (0.054) | (0.061) | (0.044) |
| CMS | -0.041 | -0.14** | 0.11*** | -0.077 | -0.014 |
| (pool within) | (0.061) | (0.071) | (0.035) | (0.081) | (0.072) |
| Others | 0.079** | 0.077** | 0.073* | 0.0092 | 0.066* |
| | (0.035) | (0.034) | (0.039) | (0.036) | (0.035) |
| N | 39289 | 15145 | 24144 | 13338 | 25951 |
| Controls | Year FE, ctry-prod FE, controls (ctry-yr and ctry-year-prod) | | | | |

*Note:* In Columns (2) - (3), we classify buyers based on their total purchases of product $j$ in the current year $t$ (with "high" referring to observations for buyers with purchase volume larger than the median). In Columns (4) - (5), we carry out the classification using the buyer's total purchases of the product in the *previous* period (with "high" referring to observations for buyers with past or lagged purchase volume larger than the median). Standard errors are two-way clustered by country and by product.

**Table A13:** Procurement mechanism and delays: heterogeneity analysis

| | (1) | (2) | (3) | (4) | (5) |
|---|---|---|---|---|---|
| | baseline | buyer total purchases | | manufacturer HHI | |
| | | high | low | high | low |
| PPM | -0.25*** | -0.24*** | -0.25*** | -0.33*** | -0.24*** |
| (pool intl.) | (0.053) | (0.081) | (0.066) | (0.065) | (0.053) |
| UN | 0.0095 | -0.027 | -0.0076 | -0.022 | 0.027 |
| (pool intl.) | (0.051) | (0.073) | (0.060) | (0.060) | (0.065) |
| CMS | -0.26*** | -0.19** | -0.32*** | -0.31*** | -0.25*** |
| (pool within) | (0.054) | (0.075) | (0.058) | (0.052) | (0.058) |
| Others | -0.077* | -0.10 | -0.084** | -0.062 | -0.064 |
| | (0.043) | (0.069) | (0.034) | (0.053) | (0.063) |
| N | 39289 | 13338 | 25951 | 19641 | 19648 |
| | country patent status | | approval year | | |
| | ever-patented | never-patented | pre-1990 | 1990s | 1997+ |
| PPM | -0.25*** | -0.24*** | -0.24** | -0.27*** | -0.23*** |
| (pool intl.) | (0.084) | (0.054) | (0.094) | (0.061) | (0.064) |
| UN | -0.035 | 0.015 | 0.023 | -0.022 | 0.041 |
| (pool intl.) | (0.086) | (0.053) | (0.069) | (0.068) | (0.061) |
| CMS | -0.27*** | -0.087 | 0.0037 | -0.25*** | -0.27*** |
| (pool within) | (0.065) | (0.069) | (0.066) | (0.048) | (0.067) |
| Others | -0.095 | -0.071* | -0.021 | -0.087 | -0.080 |
| | (0.092) | (0.038) | (0.047) | (0.067) | (0.054) |
| N | 11984 | 27305 | 10443 | 12594 | 15958 |
| Controls | Year FE, ctry-prod FE, controls (ctry-yr and ctry-year-prod) | | | | |

*Note:* The outcome "delay" indicates whether purchases of drug $j$ by country $c$ in year $t$ are delayed on average. Standard errors are two-way clustered by country and by product.

**Table A14:** Procurement mechanism and lead time: heterogeneity analysis

| | (1) | (2) | (3) | (4) | (5) |
|---|---|---|---|---|---|
| | baseline | buyer total purchases | | manufacturer HHI | |
| | | high | low | high | low |
| PPM | 114.2*** | 128.9*** | 102.4*** | 116.4*** | 112.6*** |
| (pool intl.) | (16.2) | (14.8) | (13.7) | (12.6) | (14.2) |
| UN | 12.0 | 5.36 | 20.4* | 4.70 | 2.42 |
| (pool intl.) | (9.20) | (10.3) | (11.3) | (9.82) | (9.37) |
| CMS | -37.4*** | -24.9 | -45.7*** | -44.7*** | -28.6** |
| (pool within) | (12.0) | (19.7) | (12.9) | (14.8) | (12.0) |
| Others | 27.1*** | 27.4** | 29.9** | 17.3 | 25.3** |
| | (9.89) | (10.9) | (12.4) | (11.5) | (12.2) |
| N | 39289 | 13338 | 25951 | 19641 | 19648 |
| | country patent status | | approval year | | |
| | ever-patented | never-patented | pre-1990 | 1990s | 1997+ |
| PPM | 113.1*** | 114.3*** | 79.8*** | 124.2*** | 115.4*** |
| (pool intl.) | (14.0) | (13.3) | (16.9) | (17.6) | (14.0) |
| UN | -16.7 | 17.3* | 3.07 | 19.6 | 6.29 |
| (pool intl.) | (16.5) | (9.86) | (14.5) | (12.1) | (8.23) |
| CMS | -43.5*** | -2.58 | -9.36 | -34.1** | -39.0*** |
| (pool within) | (7.57) | (14.5) | (22.0) | (14.6) | (9.71) |
| Others | 11.1 | 30.3*** | 5.54 | 39.5*** | 20.7 |
| | (20.4) | (8.39) | (12.3) | (13.3) | (13.8) |
| N | 11984 | 27305 | 10443 | 12594 | 15958 |
| N | 3389 | 11292 | 4937 | 4169 | 5575 |
| Controls | Year FE, ctry-prod FE, controls (ctry-yr and ctry-year-prod) | | | | |

*Note:* The outcome "procurement lead time" is the average number of days between the order date and actual delivery date. Standard errors are two-way clustered by country and by product.

**Table A15:** PEPFAR and drug prices

| | (1) | (2) | (3) |
|---|---|---|---|
| PPM | -0.20*** | -0.16* | -0.16** |
| (pool intl.) | (0.052) | (0.081) | (0.081) |
| UN | -0.13*** | -0.16*** | -0.16*** |
| (pool intl.) | (0.044) | (0.054) | (0.056) |
| CMS | 0.014 | 0.15** | 0.19*** |
| (pool within) | (0.067) | (0.066) | (0.068) |
| Others | 0.063* | 0.063 | 0.061 |
| | (0.032) | (0.046) | (0.045) |
| PEPFAR | | 0.036 | -0.20 |
| | | (0.19) | (0.12) |
| PEPFAR*% PPM | | -0.072 | -0.073 |
| | | (0.098) | (0.10) |
| PEPFAR*% UN | | 0.041 | 0.055 |
| | | (0.072) | (0.075) |
| PEPFAR*% CMS | | -0.17*** | -0.38*** |
| | | (0.053) | (0.085) |
| PEPFAR*% Others | | -0.0032 | 0.010 |
| | | (0.052) | (0.054) |
| PEPFAR focus | | | 0.51*** |
| | | | (0.14) |
| PEPFAR focus*% PPM | | | 0.028 |
| | | | (0.069) |
| PEPFAR focus*%UN | | | -0.030 |
| | | | (0.083) |
| PEPFAR focus*% CMS | | | 0.19*** |
| | | | (0.059) |
| PEPFAR focus*% Others | | | -0.057 |
| | | | (0.069) |
| N | 39289 | 39289 | 39289 |

*Note:* Acronyms: Pooled Procurement Mechanism (PPM), United Nations (UN), Central Medical Stores (CMS), President's Emergency Plan for AIDS Relief (PEPFAR). Standard errors are two-way clustered by country and by product. All regressions include year fixed effects, country-by-product fixed effects and the same set of controls as in Table 2. "PEPFAR" refers to purchases of eligible drugs by all countries supported by PEPFAR. "PEPFAR focus" refers to purchases of eligible drugs by the 15 focus countries targeted in PEPFAR's first phase. Information on PEPFAR was obtained from https://data.pepfar.gov/.

**Table A16:** CHAI eligibility and price

| | (1) | (2) | (3) |
|---|---|---|---|
| % PPM | -0.20*** | -0.20*** | -0.19*** |
| (pool intl.) | (0.052) | (0.052) | (0.056) |
| % UN | -0.13*** | -0.13*** | -0.12*** |
| (pool intl.) | (0.044) | (0.044) | (0.042) |
| % CMS | 0.014 | 0.010 | 0.036 |
| (pool within) | (0.067) | (0.065) | (0.057) |
| % Others | 0.063* | 0.063** | 0.072* |
| | (0.032) | (0.031) | (0.037) |
| CHAI ceiling-eligible | | -0.0026 | 0.046 |
| | | (0.031) | (0.044) |
| CHAI reference-eligible | | -0.081*** | -0.093** |
| | | (0.028) | (0.035) |
| CHAI ceiling-eligible*PPM | | | -0.068 |
| | | | (0.047) |
| CHAI ceiling-eligible*UN | | | -0.089* |
| | | | (0.050) |
| CHAI ceiling-eligible*CMS | | | -0.13** |
| | | | (0.056) |
| CHAI ceiling-eligible*Others | | | -0.036 |
| | | | (0.051) |
| CHAI reference-eligible*PPM | | | 0.033 |
| | | | (0.044) |
| CHAI reference-eligible*UN | | | -0.053 |
| | | | (0.067) |
| CHAI reference-eligible*CMS | | | 0.051 |
| | | | (0.042) |
| CHAI reference-eligible*Others | | | -0.067 |
| | | | (0.047) |
| N | 39289 | 39289 | 39289 |

*Note:* Standard errors are two-way clustered by country and by product. All regressions include year fixed effects, country-by-product fixed effects and the same set of controls as in Table 2. "CHAI ceiling-eligible" equals 1 if the transaction is eligible for ceiling prices negotiated by the Clinton Health Access Initiative (CHAI), in the years 2014 and before. "CHAI reference-eligible" equals 1 if the transaction is eligible for reference prices negotiated by the Clinton Health Access Initiative (CHAI), in the years 2015 and after.

**Table A17:** Tiered pricing

| | (1) | (2) | (3) |
|---|---|---|---|
| PPM | -0.20*** | -0.20*** | -0.15*** |
| (pool intl.) | (0.052) | (0.053) | (0.048) |
| UN | -0.13*** | -0.13*** | -0.11** |
| (pool intl.) | (0.044) | (0.046) | (0.044) |
| CMS | 0.014 | 0.018 | 0.016 |
| (pool within) | (0.067) | (0.066) | (0.067) |
| Others | 0.063* | 0.063* | 0.055** |
| | (0.032) | (0.033) | (0.023) |
| Patented | 0.024 | -0.20 | -0.13 |
| | (0.053) | (0.44) | (0.47) |
| ln(GDP per capita) | 0.16** | 0.10 | 0.081 |
| | (0.068) | (0.068) | (0.069) |
| Patented*ln(GDP per capita) | | 0.030 | 0.019 |
| | | (0.060) | (0.065) |
| Not category 1*ln(GDP per capita) | | 0.15 | 0.21** |
| | | (0.092) | (0.094) |
| Not category 1*PPM | | | -0.25** |
| | | | (0.100) |
| Not category 1*UN | | | -0.10 |
| | | | (0.10) |
| Not category 1*CMS | | | 0.093 |
| | | | (0.13) |
| Not category 1*Others | | | 0.012 |
| | | | (0.084) |
| N | 39289 | 39289 | 39289 |

*Note:* Acronyms: Pooled Procurement Mechanism (PPM), United Nations (UN), and Central Medical Stores (CMS). Standard errors are two-way clustered by country and by product. All regressions include year fixed effects, country-by-product fixed effects and the same set of controls as in Table 2. Category 1 countries are those eligible for the most discounted prices offered by companies engaging in tiered pricing: this includes all least-developed countries, all low-income countries and all of Africa. "Not category 1" refers to all other countries.

**Table A18:** Procurement mechanism and price: control for pre-paid orders

| | (1) | (2) |
|---|---|---|
| % PPM | -0.20*** | -0.19*** |
| (pool intl.) | (0.053) | (0.058) |
| % UN | -0.12*** | -0.083* |
| (pool intl.) | (0.043) | (0.043) |
| % CMS | 0.014 | -0.041 |
| (pool within) | (0.067) | (0.062) |
| % Others | 0.066** | 0.080** |
| | (0.031) | (0.035) |
| Prepaid | -0.035 | -0.041 |
| | (0.025) | (0.025) |
| Ctry-buyer-prod FE | | Y |
| N | 39,289 | 39,289 |

*Note:* Both columns additionally include country-product and year fixed effects, as well as all the country-year and country-product-year controls included in Table 2. Acronyms: Pooled Procurement Mechanism (PPM), United Nations (UN), and Central Medical Stores (CMS). Standard errors are two-way clustered by country and by product. "Pre-paid" refers to transactions where the manufacturer is paid in advance, either fully or partially.

**Table A19:** Procurement institutions and variation in manufacturer orders

| | (1) | (2) |
|---|---|---|
| Dependent variable | Order Frequency | Coefficient of variation |
| % PPM | -5.27** | -0.24*** |
| (pool intl.) | (2.43) | (0.047) |
| % UN | -3.02 | -0.27** |
| (pool intl.) | (3.31) | (0.12) |
| % CMS | 1.99 | -0.60*** |
| (pool within) | (3.12) | (0.091) |
| % Others | -2.95** | -0.23*** |
| | (1.40) | (0.078) |
| Controls: manu-year & manu-prod FE, controls (manu-yr-prod) | | |
| N | 2296 | 2296 |

*Note:* Acronyms: Pooled Procurement Mechanism (PPM), United Nations (UN), and Central Medical Stores (CMS). Standard errors are two-way clustered by manufacturer and by product. The data is organized as a manufacturer-product-year panel, and all regressions include manufacturer-year and manufacturer-product fixed effects, as well as controls for patent and IP licensing status. The dependent variable in column (1) is the number of distinct purchase orders of the product from the manufacturer in the selected year. The dependent variable in column (2) is the coefficient of variation in the total quantity of the product ordered from the manufacturer in the selected year.

**Table A20:** Procurement institutions and types of drugs purchased

| | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| | Ctry-year-drug class panel | | Ctry-year-category panel | |
| Dependent variable: | % patented | % pre-1990s | % patented | % pre-1990s |
| % PPM | 0.0083 | 0.034 | 0.0040 | 0.053 |
| (pool intl.) | (0.022) | (0.051) | (0.021) | (0.041) |
| % UN | 0.044 | 0.018 | 0.031 | 0.021 |
| (pool intl.) | (0.027) | (0.016) | (0.026) | (0.030) |
| % CMS | 0.022 | 0.050 | 0.0042 | 0.10 |
| (pool within) | (0.021) | (0.074) | (0.023) | (0.11) |
| % Others | 0.015 | 0.026 | 0.000098 | 0.047 |
| | (0.015) | (0.031) | (0.0093) | (0.032) |
| Year FE | Y | Y | Y | Y |
| Country-category FE | Y | Y | Y | Y |
| Controls (ctry-year) | Y | Y | Y | Y |
| N | 3890 | 3,890 | 2225 | 2225 |
| $R^2$ | 0.54 | 0.80 | 0.60 | 0.77 |

*Note:* "% patented" is the share of transactions that are for patented drugs; "% pre-1990" is the share of transactions for drugs that were approved pre-1990. Columns (1) and (2) use data at the country-year-drug class level with 10 drug classes: antibiotic, malaria, tuberculosis, and seven classes within HIV drugs (entry inhibitors (EIs), fusion inhibitors (FIs), integrase inhibitors (IIs), non-nucleoside reverse transcriptase inhibitors (NNRTIs), nucleoside reverse transcriptase inhibitors (NRTIs), NNRTI+NRTIs, and protease inhibitors (PIs)). Columns (3) and (4) use a country-year-drug category panel with 4 categories: antibiotics, malaria, tuberculosis and antiretrovirals. Standard errors are two-way clustered by country and by product.

**Table A21:** Prices relative to benchmark prices

| | (1) | (2) |
|---|---|---|
| PPM | -0.16*** | -0.12** |
| (pool intl.) | (0.052) | (0.054) |
| UN | -0.14*** | -0.11* |
| (pool intl.) | (0.045) | (0.056) |
| CMS | 0.057 | -0.033 |
| (pool within) | (0.086) | (0.088) |
| Others | 0.029 | 0.042 |
| | (0.034) | (0.028) |
| Ctry-buyer-prod FE | | Y |
| N | 27,415 | 27,415 |

*Note:* Acronyms: Pooled Procurement Mechanism (PPM), United Nations (UN), and Central Medical Stores (CMS). Standard errors two-way clustered by country and by product. All regressions include year fixed effects, country-by-product fixed effects and the same set of controls as in Table 2. The dependent variable is the difference between the logarithm of the price in our dataset and logarithm of the median price for the same product-year reported in the MSH International Pricing Guide. Thus, the coefficient on PPM can be interpreted as the % reduction in the price *relative* to the median price reported in the MSH, when the PPM is used.

**Table A22:** Pooled Procurement Mechanism: start-up effects

| | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| % PPM | -0.18*** | -0.18*** | -0.16** | -0.16** |
| (pool intl.) | (0.060) | (0.059) | (0.067) | (0.066) |
| % UN | -0.13*** | -0.13*** | -0.11** | -0.11** |
| (pool intl.) | (0.044) | (0.043) | (0.043) | (0.043) |
| % CMS | 0.017 | 0.016 | -0.035 | -0.035 |
| (pool within) | (0.069) | (0.070) | (0.063) | (0.064) |
| % Others | 0.062** | 0.062** | 0.077** | 0.077** |
| | (0.031) | (0.031) | (0.035) | (0.035) |
| % PPM*(2009-2011) | -0.049 | | -0.061 | |
| | (0.059) | | (0.063) | |
| % PPM*2009 | | -0.026 | | -0.039 |
| | | (0.076) | | (0.070) |
| % PPM*2010 | | -0.027 | | -0.057 |
| | | (0.059) | | (0.058) |
| % PPM*2011 | | -0.070 | | -0.067 |
| | | (0.097) | | (0.098) |
| Ctry-buyer-prod FE | | | Y | Y |
| N | 39,289 | 39,289 | 39,289 | 39,289 |

*Note:* Acronyms: Pooled Procurement Mechanism (PPM), United Nations (UN), and Central Medical Stores (CMS). Standard errors are two-way clustered by country and by product. All regressions additionally include year fixed effects, country-by-product fixed effects and the same set of controls as in Table 2. Note that the PPM started in the year 2009.

**Table A23:** Procurement mechanism and price: control for how shipping cost is reported

| | (1) | (2) |
|---|---|---|
| % PPM | -0.19*** | -0.17*** |
| (pool intl.) | (0.054) | (0.060) |
| % UN | -0.13*** | -0.10** |
| (pool intl.) | (0.044) | (0.043) |
| % CMS | 0.010 | -0.045 |
| (pool within) | (0.066) | (0.060) |
| % Others | 0.063* | 0.079** |
| | (0.033) | (0.036) |
| Ctry-buyer-prod FE | | Y |
| N | 39,289 | 39,289 |

*Note:* Acronyms: Pooled Procurement Mechanism (PPM), United Nations (UN), and Central Medical Stores (CMS). Standard errors are two-way clustered by country and by product. In comparison to Table 2, we also include dummy variables for how the shipping cost is reported: specifically, a dummy variable for whether or not it is included in the final price, and a dummy variable for transactions where the reporting of shipping costs is unknown.

**Table A24:** Procurement mechanism and price, for different drug categories

| | (1) | (2) |
|---|---|---|
| % PPM * ARV | -0.27*** | -0.26*** |
| (pool intl.) | (0.055) | (0.055) |
| % PPM *TB | -0.17 | -0.17 |
| | (0.19) | (0.20) |
| % PPM * Malaria | 0.091* | 0.18*** |
| | (0.048) | (0.060) |
| % UN * ARV | -0.16*** | -0.11** |
| (pool intl.) | (0.054) | (0.052) |
| % UN * TB | -0.20** | -0.18* |
| | (0.093) | (0.096) |
| % UN * Malaria | -0.067 | -0.097 |
| | (0.056) | (0.073) |
| % CMS * ARV | 0.0049 | -0.055 |
| (pool within) | (0.073) | (0.065) |
| % Others * ARV | 0.067* | 0.080** |
| | (0.035) | (0.039) |
| % Others * TB | 0.046 | 0.045 |
| | (0.054) | (0.062) |
| % Others * Antibiotic | 0.16 | 0.24 |
| | (0.32) | (0.36) |
| % Others * Malaria | -0.016 | -0.0032 |
| | (0.11) | (0.071) |
| Ctry-buyer-prod FE | | Y |
| N | 39,289 | 39,289 |

*Note:* Acronyms: Pooled Procurement Mechanism (PPM), United Nations (UN), and Central Medical Stores (CMS). Standard errors are two-way clustered by country and by product. We include interaction effects between different drug categories and procurement institutions, but drop interaction effects for which there are fewer than 20 observations, since these are absorbed by our fixed effects. The interactions for which there are insufficiently many observations are PPM*Antibiotics, UN*Antibiotics, CMS*Antibiotic, CMS*TB and CMS*Malaria. All regressions additionally include year fixed effects, country-by-product fixed effects and the same set of controls as in Table 2.

**Table A25:** Alternative definitions of other procurement institutions

| | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| % PPM | -0.20*** | -0.19*** | -0.18*** | -0.18*** |
| (pool intl.) | (0.052) | (0.052) | (0.058) | (0.058) |
| % UN | -0.13*** | -0.13*** | -0.11** | -0.10** |
| (pool intl.) | (0.045) | (0.044) | (0.044) | (0.042) |
| % CMS | 0.014 | 0.013 | -0.041 | -0.043 |
| (pool within) | (0.067) | (0.066) | (0.061) | (0.060) |
| % NPO | 0.055 | | 0.076* | |
| | (0.038) | | (0.046) | |
| % IDA | | 0.069 | | 0.096* |
| | | (0.044) | | (0.052) |
| % GDF | | 0.12** | | 0.16** |
| | | (0.050) | | (0.061) |
| % Other NPO | | -0.072 | | -0.068 |
| | | (0.050) | | (0.054) |
| % Others (not NPO) | 0.084** | 0.086** | 0.084*** | 0.086*** |
| | (0.035) | (0.036) | (0.029) | (0.031) |
| Ctry-buyer-prod FE | | | Y | Y |
| N | 39,289 | 39,289 | 39,289 | 39,289 |

*Note:* We decompose the "Other" category into NPOs and others (e.g., private wholesalers) and further decompose NPOs into the two largest NPOs in our sample (i.e., IDA foundation, Global Drug Facility) and other NPOs. Acronyms: Pooled Procurement Mechanism (PPM), United Nations (UN), and Central Medical Stores (CMS). Standard errors are two-way clustered by country and by product. All regressions additionally include year fixed effects, country-by-product fixed effects and the same set of country-year and country-product-year controls as in Table 2. NPO refers to non-profit procurement organizations.

## A.7 AET-O Method Description

In section 5.2, we demonstrated that our estimates are robust to accounting for selection on unobservables using the approach by Oster (2019), building on the AET method developed by (Altonji et al., 2005). Here we describe in more detail how we implement this approach.

To implement the method, we repeat our baseline regressions without any additional controls or fixed effects (so that the only regressors are the procurement share variables). We then calculate the bounding values of $\beta$ as:

$$\beta^* = \widetilde{\beta} - \delta(\mathring{\beta} - \widetilde{\beta})\frac{R^2_{max} - \widetilde{R^2}}{\widetilde{R^2} - \mathring{R^2}}$$

Here $\mathring{\beta}$ and $\mathring{R}^2$ are the coefficient estimates and R-squared values from the regression with no controls, while $\widetilde{\beta}$ and $\widetilde{R^2}$ are the coefficient estimates and R-squared values from the regression with the full set of controls and fixed effects. $\delta$ is the relative degree of selection on observable and unobservable factors, while $R^2_{max}$ is the R-squared from a hypothetical regression of the outcome on the treatment variables when we are able to include both observed and unobserved controls.

Following Oster (2019) and several recent papers implementing the method (Squicciarini, 2020; Tabellini, 2020; Verner and Gyöngyösi, 2020), we assume equal selection on observables and unobservables, implying $\delta = 1$. We set the maximum possible R-squared to $\min(1, \Pi * \widetilde{R})$ with a benchmark rule of thumb of $\Pi = 1.3$, and we also report results from a more demanding assumption with $\Pi = 2$. As shown in Table A26, the set of AET-O adjusted boundary estimates for each of the procurement institutions are very similar to the benchmark estimates (both with panel-level and transaction-level analysis), meaning that the estimated effects of procurement institutions are unlikely to be explained away by unobservables. The bounds on the coefficients of PPM, UN, and CMS in the price regression are estimated to be (-0.195, -0.190), (-0.133, -0.130) and (0.014, 0.035) respectively.[12] In the delay regression, the estimated bounds on the PPM coefficient are (-0.281, -0.280). Finally, in the procurement lead time regression, the estimated bounds on the PPM coefficient are (114.10, 119.70).

[12] One bound is the baseline estimate of the coefficient when we include all observed controls. The other bound is the hypothetical value of the coefficient assuming equal selection on unobservables and observables, calculated using the AET-O method.

**Table A26:** Parameter bounds robust to selection on observables, based on Oster (2019)

| *Transaction-level* | No controls | | All controls | | $R^2_{max}$ | | Bounding values | |
|---|---|---|---|---|---|---|---|---|
| Specification | $\mathring{\beta}$ | $\mathring{R}^2$ | $\tilde{\beta}$ | $\tilde{R}^2$ | $\Pi = 1.3$ | $\Pi = 2$ | $\beta^*_{\Pi=1.3}$ | $\beta^*_{\Pi=2}$ |
| **Price** | | | | | | | | |
| PPM | -0.283 | 0.027 | -0.195 | 0.952 | 1 | 1 | -0.190 | -0.190 |
| UN | -0.200 | 0.027 | -0.133 | 0.952 | 1 | 1 | -0.130 | -0.130 |
| CMS | -0.397 | 0.027 | 0.014 | 0.952 | 1 | 1 | 0.035 | 0.035 |
| **Delay** | | | | | | | | |
| PPM | -0.279 | 0.123 | -0.280 | 0.377 | 0.490 | 0.754 | -0.280 | -0.281 |
| **Procurement Lead Time** | | | | | | | | |
| PPM | 109.80 | 0.261 | 114.10 | 0.582 | 0.757 | 1 | 116.44 | 119.70 |

| *Panel-level* | No controls | | All controls | | $R^2_{max}$ | | Bounding values | |
|---|---|---|---|---|---|---|---|---|
| Specification | $\mathring{\beta}$ | $\mathring{R}^2$ | $\widetilde{\beta}$ | $\widetilde{R}^2$ | $\Pi = 1.3$ | $\Pi = 2$ | $\beta^*_{\Pi=1.3}$ | $\beta^*_{\Pi=2}$ |
| **Price** | | | | | | | | |
| PPM | -0.190 | 0.014 | -0.299 | 0.967 | 1 | 1 | -0.303 | -0.303 |
| UN | -0.188 | 0.014 | -0.226 | 0.967 | 1 | 1 | -0.227 | -0.227 |
| CMS | 0.019 | 0.014 | -0.101 | 0.967 | 1 | 1 | -0.105 | -0.105 |
| **Delay** | | | | | | | | |
| PPM | -0.242 | 0.072 | -0.257 | 0.482 | 0.627 | 0.964 | -0.262 | -0.275 |
| **Procurement lead Time** | | | | | | | | |
| PPM | 106.30 | 0.142 | 105.40 | 0.600 | 0.780 | 1 | 105.05 | 104.61 |

## A.8 Do Procurement Institutions Limit Drug Choices within a Category?

One possible concern with relying on international procurement institutions is that they may limit the drug choices of the recipient country. For instance, procurement through the UNICEF Supply Division generally requires the recipient country to select from an existing catalog of products.[13] As international pooled procurement institutions pool orders across countries, the preferences of individual countries for specific drugs may not necessarily be reflected in the set of drugs obtained in the process. To evaluate whether the lack of availability of certain drugs significantly hinders procurement outcomes, we examine whether the attributes of drugs purchased within a therapeutic category substantially differ by the procurement institution utilized. We consider two main attributes: (1) patent status, which equals 1 if a drug is patented in a country in a given year; (2) drug age generation, which equals 1 if a drug was approved prior to 1990. Specifically, let $a(j)$ denote the category to which drug $j$ belongs. Let $z_{jct}$ denote a binary drug-level attribute. We estimate the following equation at the drug category-country-year level:

$$Y^z_{act} = \sum_m S^m_{act}\beta^m + X_{ct}\gamma + \delta_{ac} + \delta_t + \varepsilon_{act} \tag{A1}$$

Here $Y^z_{act}$ is the share of drugs with attribute $z$ (e.g., share of patented drugs) within a therapeutic category. $S^m_{act}$ denotes the share of transactions carried out by procurement institution $m$. $X_{ct}$ includes country-year observables. $\delta_{ac}$ denotes fixed effects at the drug category by country level to account for unobserved differences between drug categories in each country (e.g., different unobserved disease conditions). $\delta_t$ denotes fixed effects at the year level to account for differences across time. We use two definitions of therapeutic category: a broad category with antibiotics, antimalarials, TB, and antiretroviral drugs, and a detailed category that distinguishes different classes of antiretroviral drugs. Standard errors are two-way clustered by country and by product.

The results suggest that pooled procurement institutions do not limit the types of drugs LMIC are able to procure (Table A20). Specifically, column (1) and column (3) shows that the share of drugs patented does not substantially differ by procurement institution. Columns (2) and (4) illustrate that using PPM and UN is associated with an increase in the share of drugs approved prior to 1990, but the effect is small in magnitude (less than 5%) and not statistically significant.

[13] Details are available at https://www.unicef.org/supply/faq-procurement-services.

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