Queen's Economics Department Working Paper No. 1519

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

Nahim Bin Zahur

Lucy Xiaolu Wang
University of Massachusetts Amherst

Department of Economics
Queen's University
94 University Avenue
Kingston, Ontario, Canada
K7L 3N6

6-2024

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Lucy Xiaolu Wang, Nahim Bin Zahur *

Abstract

International procurement institutions play an important role in drug supply. We study price, delivery, and procurement lead time of drugs 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 lead times. Finally, pooled procurement is more effective for older-generation drugs, compared to patent pooling institutions that target newer drugs.

Keywords: global drug diffusion, procurement institutions, price and delay, IP and non-IP barriers

JEL Codes: I11, O19, H57

*Wang: University of Massachusetts Amherst (xiaoluwang@umass.edu), Max Planck Institute for Innovation and Competition, and Canadian Centre for Health Economics; Zahur: Queen's University (nz17@queensu.ca). For helpful discussions or comments, we thank Carolyn Amole, Charles Becker, Katharina Blankart, Anne Burton, Ying Fan, Sonja Foerster, Radhika Jain, Adriano De Leverano, Deepak Mattur, Roger Mendoza, Andrea Monge, Fiona Scott Morton, Mead Over, Zack Panos, Pavitra Paul, Emma Stewart, Fantaye Teka, Michael Waldman, and participants in the Industry Studies Association meeting 2021, American Society of Health Economists 2021, TIME Colloquium (LMU-MPI-TUM) 2021, IP & Innovation Virtual Seminar, European Policy for Intellectual Property 2021, North East Universities Development Consortium (NEUDC) 2021, iHEA Health System Efficiency Group webinar, cross-disciplinary Knowledge Data Research (xKDR) in India, Canadian Centre for Health Economics, UMass Amherst IO workshop, Essen Health Economics Seminar, Boston University (TPRI) seminar, Shanghai International College of IP seminar, Academy of Management 2022, Intellectual Property Scholars Conference 2022 at Stanford, ZEW-Mannheim workshop on "Economics of Public Procurement", Taiwan Symposium on Innovation Economics, Cornell, International Monetary Fund, Munich Summer Institute, Highland Health Economics Symposium, International Health Economist Association World Congress, and Triangle Health Economics Workshop at Duke Fuqua. Nick Wilson provided helpful research assistance. All errors are ours.

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) is a global challenge, with complicated issues regarding supply chain management, local production capacity, and intellectual property (IP) rights. International procurement institutions have played important 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 led to 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 drugs 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 purchases covering 106 LMIC during 2007-2017. Our sample include treatments for four major infectious diseases that disproportionately affect people living in LMIC, including antiretrovirals, antimalarials, tuberculosis drugs, 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 drugs from manufacturers.

We build on existing empirical methods to study procurement institutions in panel and transaction level regression frameworks, incorporating extra 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-country and year fixed effects. We exploit variation in the utilization of different procurement institutions for the same drug in a given country over time, to identify the impact on outcomes of interest: drug prices, procurement lead times, and delivery delays.

We have four key sets of findings. First, drugs procured through centralized procurement institutions are priced lower than those purchased directly from manufacturers. Institutions 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 drugs with more concentrated supply. By contrast, pooling domestically is more effective for high-volume buyers and for drugs 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 generation 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 anticipated procurement lead times.

Our baseline identification assumption is that unobservables affecting procurement outcomes are uncorrelated with the choice of procurement institutions, conditional on extensive fixed effects at the drug-country and year levels and a rich set of observable controls. We use variation over time in outcomes for the same drug-country pair. We address potential violations of this assumption using several strategies. First, our results are robust to the inclusion of a more demanding set of fixed effects, including country-year, product-year, country-product, 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 as well as their procurement institution choice. To address these sources of endogeneity, we propose an instrumental variable strategy that exploits correlation in the choices of procurement institutions across drugs for the same country. In addition, to test for selection arising from more general forms of endogeneity, we perform the Altonji-Elder-Taber (AET) test (Altonji et al., 2005) for omitted variable bias generalized by Oster (2019) (i.e., AET-O). These additional 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 used in supplying drugs for infectious diseases in LMIC. 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 the use of international pooled procurement is associated with lower variability in demand faced by manufacturers. Finally, we do not find any evidence that these procurement institutions limit the types of drugs (e.g., by drug generation or patent status) that buyers are able to procure.

This paper contributes to two strands of the literature. First, we extend studies on procurement institutions and drug supply in LMIC. Institutional procurement can reduce uncertainty over quality and use competitive tendering to spur price competition (Danzon et al., 2015). A study on HIV drugs before the formation of the PPM 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 (most qualitative) 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 relates to 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.

While most prior papers compare pooled and decentralized procurement, we further distinguish between procurement mechanisms, including the scope of pooling (i.e., international versus domestic). We offer new results on the heterogeneous impact of procurement institutions by drug generation and market concentration on both the buyer and seller sides. Finally, 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 Gallien et al. (2017) and Clark et al. (2021).[1] Ours is one of the first studies to empirically analyze non-price outcomes (i.e., delivery delays, procurement lead times) of procurement institutions for essential drugs.

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

[1] Gallien et al. (2017) show that unpredictability in fund disbursements and grant monitoring in Global Fund procurement prior to 2014 contributed to stockout risks in African countries. Clark et al. (2021) find that pooling procurement of medical devices in Italy reduced prices but increased delivery delays.

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 study biomedical patent pools that facilitate the licensing of patents and know-how and thus essential drug supply in LMIC (Wang, 2022; Galasso and Schankerman, 2022). However, there is a limited understanding of how essential drug procurement by a variety of institutions interacts with patent barriers and institutions that facilitate IP licensing. Our paper evaluates the relative merits of the institutions addressing IP barriers 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, has fallen 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, could make Covid last much longer in LMIC.[2] Moreover, 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 pandemic are critical first responders to COVID-19 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, background, and data. Section 3 reports the benchmark empirical model and results. Section 4 provides robustness checks. Section 5 reports additional analyses. Section 6 concludes.

2 Background and Data

2.1 Conceptual Considerations

Procurement institutions arrange essential drug supply to LMIC through different channels. Drug procurement can be carried out by large, multilateral agencies that aggregate orders across

[2]Sources: https://www.law360.com/internationaltrade/articles/1387141/hiv-drug-ip-waiver-success-should-guide-covid-vax-rollout-; https://law.stanford.edu/2021/05/04/stanfords-lisa-ouellette-on-waiving-covid-19-vaccine-patents/.

[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

countries (i.e., PPM and the UN), by Central Medical Stores that aggregate orders within a country, as well as by 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 also simplify the amount of transactions involved (Figure 1).

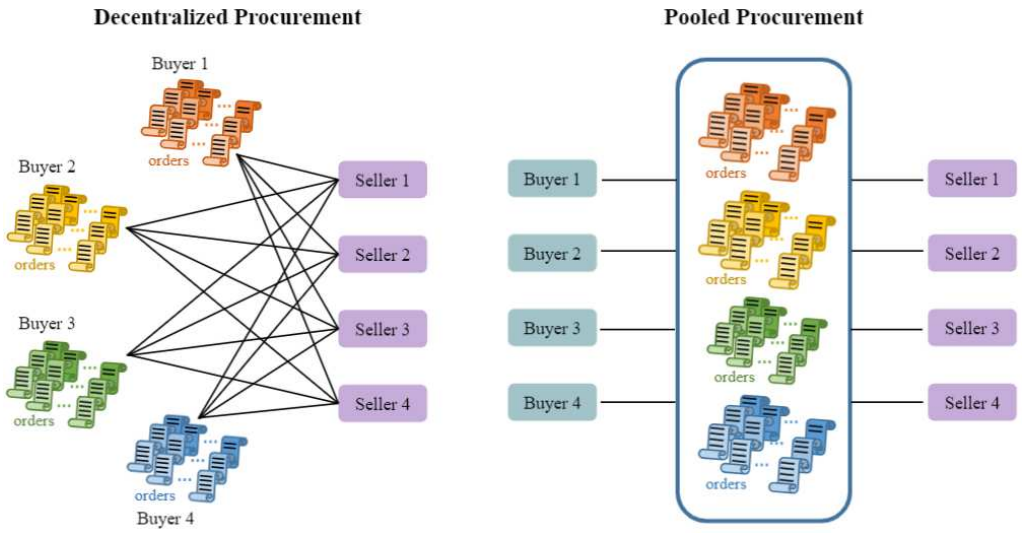

Figure 1: Decentralized vs. pooled procurement institutions

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). This condition would still hold 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 salient mar-

ket features, such as the extent of supply-side concentration, the size of the buyers forming the pool, and characteristics of the goods being procured. Given the theoretical ambiguity, our empirical analysis looks at whether pooling indeed reduces prices for major infectious drug 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 centralization 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 centralized 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 (e.g., 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 drugs (Cockburn et al., 2016), and IP licensing institutions can facilitate LMIC drug diffusion (Wang, 2022; Galasso and Schankerman, 2022). By contrast, for older, off-patent drugs where IP barriers are less of an issue, the supply can still be limited due to the low profit margins and lack of competition (Conti and Berndt, 2020). These drugs 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 depending on 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 its overall program, based on budgeted grant applications. Grant recipients are required to report

data to be monitored by the Global Fund, which also makes such information publicly available and measures and evaluates performance in drug purchases and delivery. The Fund adheres to strict quality assurance policies to ensure medical products procured meet international standards. LMIC utilize four major procurement institutions 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 own channels. Table A1 reports details on the procurement agents under each category.

The PPM is a procurement mechanism established by the Global Fund in 2009 (accounting for about 40% of total spending in our dataset).[5] The PPM aggregates orders on behalf of participating recipient countries and negotiates prices and delivery conditions directly with manufacturers. 68 out of the 106 countries we observe utilized the PPM at least once. The PPM negotiates long-term agreements with manufacturers on prices and supply volumes of different products, and may contract procurement agents to coordinate logistics and delivery. Global Fund grantees can structure procurement orders to place through the PPM. Prices of goods procured via the PPM follow the Global Fund globally negotiated reference price lists, though the actual price paid may differ from the reference price depending on how early the order is placed and whether the pooled order reaches volume thresholds specified in the agreements negotiated by the PPM.[6] Procurement agents issue a quotation to the grantee, file procurement orders with manufacturers, and are paid an agent fee on the value of each fulfilled order (1.5-5.0% depending on product type).[7]

The UN is the other major institution for drug procurement (12% of spending in our sample). Among the UN entities, the UNICEF Supply Division is the largest (10% of transactions). 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. Large orders utilize formal bidding procedures (i.e., sealed-bid auctions and requests for proposals), and smaller orders use informal procedures (i.e., requests for quotations and direct acquisitions). Direct purchase for large orders is used only in emergencies, or when goods are neither available locally nor from multiple sources. Through the UNICEF Supply Division and UNFPA Procurement Services, UN entities

[5] www.theglobalfund.org/media/6957/psm_2017-11-arvstrategicmedicineshiv_presentation_en.pdf.
[6] www.theglobalfund.org/media/5812/ppm_actreferencepricing_table_en.pdf.
[7] Recently, these fees have increased when compared with numbers from archived pages. Source: www.theglobalfund.org/media/8668/ppm_procurementservicesagentfees_list_en.pdf.

also act as procurement agents for their own activities and for country partners (e.g., governments, foundations) and maintain a catalog of available goods, from which partners can request cost estimates. 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) (12% of the transactions in our sample). CMS mainly function to warehouse medical products and are often responsible for drug procurement and distribution. The operational model of a given CMS is 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 the "other" category, which contains mainly non-profit procurement and development organizations (NPOs), as well as 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 a variety of 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 (such as invitations to bid and Europe-wide tenders) for larger purchases.[9] NPOs can sign long term agreements with suppliers based on requests or bidding outcomes in a project-based or general manner. 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). The MPP is an IP licensing institution designed to facilitate generic licensing for drugs typically used in LMIC. The MPP licenses typically cover IP beyond patents, including exemption of exclusivities and transfer of know-how, making licensing more attractive even in countries without effective patents (e.g., patents pending). The MPP also reduces information friction and uncertainty in LMIC patent status, as high-quality international patent data are not always easy to obtain and use (Lerner

[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 orders cross-country via UNICEF/UNFPA, they also undertake a small share of non-pooled drug procurement outside of 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 across public or private entities, as funding sources can affect procurement rules. We abstract away from this aspect as all our transactions are Global Fund-funded. Source for MSF: www.msf.org/msf-medical-product-procurement

and Seru, 2017). The broad MPP territory reduces the risk of unintentional infringement by generic firms, which are the major drug suppliers to many LMIC with no local production capacity.

2.3 Drug Procurement Data

Our primary drug procurement data source is the Global Fund Price and Quality Reporting database, a publicly accessible database that collects data on procurement transactions made under Global Fund-supported programs. We focus on purchases of essential drugs for major infectious diseases, including antiretrovirals (ARVs), anti-malarial, anti-tuberculosis, and antibiotics.[11] These therapeutic areas are particularly important, as they are the "big three" infectious, communicable 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 are financed by the Global Fund and thus covered in the dataset, and the majority of manufacturers of essential drugs that are WHO pre-qualified are included in our dataset, as we document further in Appendix A.3.[12]

For each transaction, we observe the quantity of the drug purchased, the total cost of the purchase, the buyer and manufacturer involved, the date when the order was made, and the scheduled and actual delivery dates for each transaction. We aggregate the raw transaction-level data of 53,752 observations to a product-country-year panel for 2007 to 2017. Here a product is defined as an active pharmaceutical ingredient (API) at a given strength (e.g., abacavir 300 mg), and our final panel has 83 unique APIs and 191 unique products (API-strength combinations).

We construct two types of outcomes. First, we calculate the purchase price by dividing the total cost by the total quantity of the drug purchased, where the quantity is standardized units of API-strength of a given drug. This step results in a standardized measure of the purchase price comparable across different transactions of the same drug product. Second, we calculate two variables related to drug delivery: delay and procurement lead time. Delay is an indicator variable recording whether the actual delivery time is later than the scheduled delivery time for a transaction, and procurement lead time is the number of days between the date of order and the date

[11] TB is treated using specialized antibiotics, and we distinguish other broad-spectrum antibiotics (widely used for non-TB). Our data cover a high share (85%-100%) of unique compounds available to treat these diseases in LMIC (Appendix A.3). We exclude transactions for items that are not essential drugs (e.g., mosquito nets, condoms, or insecticides) since the procurement process for these items differs substantially. We also exclude purchases of drugs for leprosy and tests for HIV, malaria, and TB, due to limited information on these categories.

[12] The fact that all our transactions are Global Fund-funded limits concerns on different funding mixture that may affect purchase outcomes. Source: www.theglobalfund.org/en/sourcing-management/price-quality-reporting/.

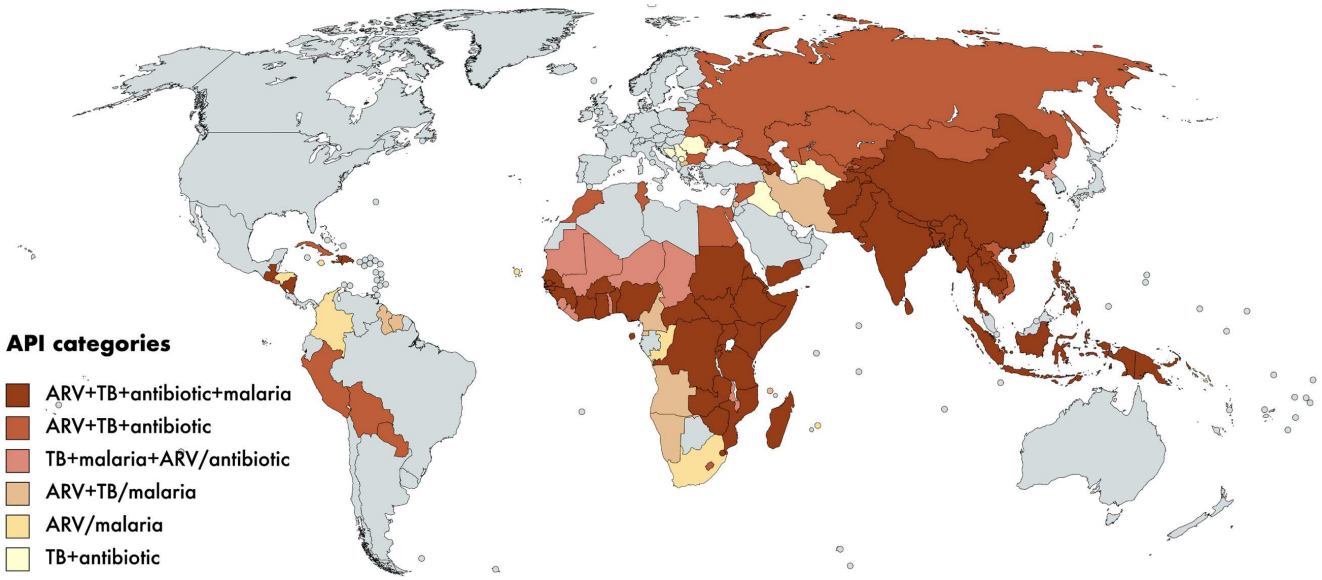

Figure 2: Geographical distribution of drug categories in procurement data

of actual delivery.[13] Our delivery outcomes capture the effective procurement waiting time (for pooling and delivery) as well as unexpected delays that can increase stockout risks (see Appendix A.2 for details). Overall, our drug purchase data cover a much broader set of LMIC compared to existing studies and new outcomes not yet analyzed systematically in the literature.[14]

Table 1 (Panel A) shows transactions made through different procurement institutions across drug categories. Direct purchases from manufacturers account for 31.6% of all transactions, with PPM, UN, CMS, and other accounting for 19.8%, 11.8%, 11.9%, and 24.9% transactions, respectively.[15] The types of procurement institutions utilized also differ by the type of drug purchased. Procurement via the PPM and UN is widely used for ARV and antimalaria drugs, but is less common for tuberculosis and antibiotics. Table A2 lists all the APIs in our sample. Panels B and C show summary statistics for key variables, at the product-country-year level and the transaction level, respectively. There is considerable heterogeneity in both the drug price and the type of procurement mechanism utilized. Most of the essential drugs purchased by LMIC are generics, with only 20%

[13] We then aggregate transaction-level delivery outcomes to the country-drug-year panel level, equally weighting each transaction. Our results are very similar if we instead weigh transactions by the quantity of the product purchased.

[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.

of the observations on patented drugs. About 9% observations are covered in the Medicines Patent Pool (MPP). The average procurement lead time is about five to six months, and around half of the transactions encountered delays (i.e., shipment arrived later than scheduled).

Table 1: Descriptive statistics

Panel A: number of transactions by procurement institution and category					
	antibiotics	ARVs	malaria	TB	total
Pooled Procurement Mechanism (PPM)	0	6830	1575	35	8440
United Nations (UN)	2	4356	577	77	5012
Central Medical Stores (CMS)	13	5047	12	17	5089
Others	1824	2269	266	6266	10625
Direct from manufacturers	425	8852	1426	2753	13456
Total	2264	27354	3856	9148	42622
	# obs.	mean	s.d.	min	max
Panel B: drug prod.-country-year panel summary statistics					
Price (US$/product)	14681	0.49	1.49	0.001	61.13
Spending ($1000)	14681	384	2450	0.002	86300
% PPM	14681	0.28	0.44	0	1
% UN	14681	0.15	0.34	0	1
% CMS	14681	0.02	0.14	0	1
% Direct from manufacturers	14681	0.24	0.42	0	1
% Others	14681	0.32	0.46	0	1
Procurement lead time (days)	14681	171.58	121.13	0	1197
% delayed	14681	0.52	0.45	0	1
Patented	14681	0.2	0.4	0	1
Medicines Patent Pool (MPP)	14681	0.09	0.28	0	1
Panel C: transaction-level summary statistics					
Price (US$/SKU)	39289	0.38	1.15	0.0003	61
Spending ($1000)	39289	144	608	0.001	29,700
% PPM	39289	0.21	0.41	0	1
% UN	39289	0.12	0.32	0	1
% CMS	39289	0.13	0.34	0	1
% Others	39289	0.24	0.43	0	1
% Direct from manufacturers	39289	0.30	0.46	0	1
Procurement lead time (days)	39289	156.87	142.06	0	1,372
% delayed	39289	0.48	0.50	0	1
Patented	39289	0.28	0.45	0	1
MPP	39289	0.12	0.32	0	1

Figure 2 shows the geographic distribution of our sample. Figure 3 shows the share of trans-

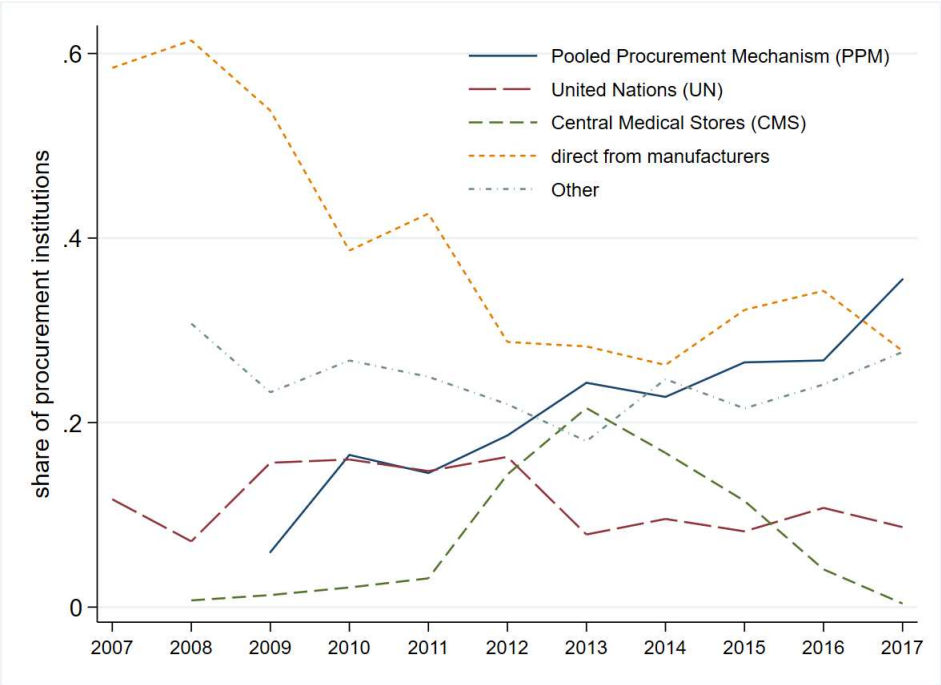

Figure 3: Share of transactions by procurement institution over time

actions across procurement institutions over time. Overall, direct purchases from manufacturers 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 A3), once countries began using the PPM, the share of their transactions using PPM quickly increased to around 60% within one year of adoption.[16] Finally, the share of CMS rose sharply in 2011-2013, but has declined rapidly in recent years, as some countries have shifted from CMS transactions to PPM transactions.

2.4 Control Variables

We collected control variables at the drug, drug-country, and drug-country-year levels to capture changes in observed factors that may affect our outcomes of interest. First, we searched WHO and FDA data and the medical literature to identify generations of drugs that appear in our sample. Drug approval dates for newer drugs, mainly ARVs, are obtained from Wang (2022). Other drug

[16]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. About one-third of countries in our sample did not use PPM, with an average income of 5136 US$/capita versus $1696/capita for adopters.

categories tend to have older generations drugs and often were used widely in LMIC earlier than in the US. Therefore, we group drugs by age generation instead of exact approval years. Among the 191 products in our sample, 81 were approved before 1990, 52 in 1991-1996, and 58 since 1997.

Second, we control for country-year level observables on demographics, disease profiles, and institutional factors. Our demographic factors include population, GDP per capita, and age structure (i.e., population share across age groups: 0-14, 15-49, 50-64, and 65+). Our disease-related controls include country-year level measures of disease burden, particularly the prevalence and incidence of HIV, tuberculosis, and malaria. These affect a country's demand for essential drugs, which can influence the purchase price a country has to pay. We used relevant data from the Global Burden of Disease Study by the Institute for Health Metrics and Evaluation and World Bank. Country-year level institutional factors are the World Bank's World Governance Indicators (WGI), which are six continuous variables on 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-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 drugs 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 Empirical Model and Results: Benchmark

3.1 Empirical Models

We examine how drug prices, delivery delays, and procurement lead time vary by procurement institution at the product-country-year level. Let j denote a drug product (at the active pharmaceutical ingredient (API)-strength level), c denote the country buying the drug, and t denote a year.

We consider a number of outcomes of interest. First, we look at the average drug purchase price (in logarithms), $log(p_{jct})$. Second, we construct two outcomes related to shipment delivery. T_{jct} is the average procurement lead time across all orders of drug j by country c in period t, where

procurement lead time is calculated as the number of days between the purchase order date and the actual delivery date. d_{jct} is the share of transactions where the delivery was delayed and the shipment arrived later than scheduled. We explore the relationship between the outcomes and the share of purchases using procurement institution m using the following specification:[17]

$$Y_{jct} = \sum_m S^m_{jct}\beta^m + X_{jct}\gamma + \delta_{jc} + \delta_t + \varepsilon_{jct} \tag{1}$$

Here Y_{jct} denotes one of three outcomes: price $log(p_{jct})$, delays d_{jct}, or procurement lead time T_{jct}. A country can either purchase a product directly from a manufacturer, or utilize one of the M different local or international procurement institutions denoted by $m = 1, ..., M$. $S^m_{jct} \in [0,1]$ denotes the share of transactions of drug j in period t by country c using procurement mechanism m.[18] We control for fixed effects at the country-product level δ_{jc} and the year level δ_t. X_{jct} includes a set of drug-country-year and country-year level observable controls. Standard errors are two-way clustered at the country and drug product levels to allow for arbitrary autocorrelation of ε_{jct} within a country and a drug product independently (Cameron et al., 2011).[19]

Our primary interest is in β^m, the coefficient on the share of transactions by procurement institution m. For the price outcome $log(p_{jct})$, β^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}, β^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}, β^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. We also use 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 remain broadly similar.

We also conduct our analysis using the transaction-level data without any aggregation, where we directly use variation across product-country-year-mechanism and can further control order-

[17] 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.

[18] The results are very similar when using quantity-weighted share of drug j in year t by country c using mechanism m.

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

level volume. We estimate the following equation, where each observation i is a separate transaction of drug product j in year t and country c using procurement mechanism m:

$$Y_i = \sum_m I_i^m \beta^m + X_{jct}\gamma + \delta_{jb(c)} + \delta_t + \varepsilon_i \tag{2}$$

The key regressors of interest are now indicator variables representing whether procurement institution m is used for a given transaction (i.e., I_i^m). In addition to the benchmark product-by-country fixed effects (δ_{jc}), here we use $\delta_{jb(c)}$ to denote product-by-buyer fixed effects and absorb within-country cross-buyer variation if certain buyers are more efficient in procurement than others (e.g., health ministry and community organizations may have advantages in buying different products). In some specifications, we also included transaction volume as a control variable to detect order-level volume-price relationship (e.g., due to discounts offered by sellers for buying in bulk).

While our benchmark models include a rich set of fixed effects and extensive controls, there can still be potential endogeneity concerns since procurement institutions are not chosen at random. In section 4, we provide several robustness checks to address these concerns. 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 our results. All of these confirm our benchmark results and suggest limited endogeneity.

3.2 Results: Centralized Procurement and Prices

We begin by exploring how drug prices vary across procurement institutions utilized (Table 2). Across specifications, we increase the level of fixed effects to demonstrate coefficient stability, and we report panel-level (columns (1)-(2)) and transaction-level results (columns (3)-(6)). Column (1) 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 average price paid. The estimates imply that if the share of orders using PPM were to increase from 0 to 1 (i.e., if a country were to switch from procuring drugs solely from individual manufacturers to procuring solely via the PPM), the average price would decrease by 30%. Similarly, UN procurement reduces prices by 23%. These results are consistent with the hypothesis that using cross-country pooled procurement institutions is associated with a lower average price paid.

In addition, pooling orders within a country via Central Medical Stores is associated with a 10% reduction in the average price, though the estimate is statistically insignificant.

Table 2: Procurement mechanisms and drug prices

Dep var: ln(price)	(1)	(2)	(3)	(4)	(5)	(6)
	Panel-level		Transaction-level			
% PPM	-0.30***	-0.38***	-0.20***	-0.18***	-0.19***	-0.17***
(pool intl.)	(0.058)	(0.073)	(0.052)	(0.058)	(0.053)	(0.059)
% UN	-0.23***	-0.23***	-0.13***	-0.10**	-0.13***	-0.10**
(pool intl.)	(0.053)	(0.061)	(0.044)	(0.043)	(0.045)	(0.044)
% CMS	-0.10	-0.041	0.014	-0.041	-0.062	-0.083
(pool within)	(0.073)	(0.14)	(0.067)	(0.061)	(0.056)	(0.056)
% Others	0.027	-0.040	0.063*	0.079**	0.055*	0.073**
	(0.039)	(0.054)	(0.032)	(0.035)	(0.032)	(0.036)
ln(Transaction volume)					-0.028***	-0.025***
					(0.0074)	(0.0076)
Patented	0.023	-0.0023	0.024	0.00020	0.021	-0.0019
	(0.051)	(0.051)	(0.053)	(0.050)	(0.053)	(0.049)
MPP	-0.31***	-0.27***	-0.23**	-0.20**	-0.23**	-0.19**
	(0.10)	(0.089)	(0.10)	(0.087)	(0.10)	(0.087)
ln(population)	0.67		1.09**	0.68	1.19**	0.84
	(0.53)		(0.53)	(0.74)	(0.54)	(0.74)
ln(GDP per capita)	0.13**		0.16**	0.19***	0.16**	0.19***
	(0.055)		(0.068)	(0.068)	(0.067)	(0.068)
Controls	Year FE, ctry-prod FE, controls (ctry-yr and ctry-year-prod)					
Country-year FE		Y				
Country-buyer-product FE				Y		Y
N	14,681	14,681	39,289	39,289	39,289	39,289

Note: Columns (1)-(2) report panel-level regressions; columns (3)-(6) report transaction-level regression results. Columns (4)-(6) include country-buyer-product FE, where the buyer is the organization within the country making the purchase (e.g., health ministry). 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.

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 logarithm of each country's population and GDP per capita, the age structure of the population, and measures of incidence and prevalence of HIV, malaria, and tuberculosis.[20] We also control for supply-side

[20]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

factors, including patent status and whether a drug is in the IP licensing institution - the Medicines Patent Pool (MPP) - that can facilitate licensing patents, waive data exclusivity, and transfer production know-how for drugs included in the pool.[21] 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, pooled procurement institutions are always associated with lower prices. The price reduction from pooled procurement tends to be larger in size collectively in our sample than the reduction benefited from the MPP, as the majority of drugs in our sample are off-patents.

We provide evidence that our results are robust to the inclusion of a more demanding set of country-product and country-year fixed effects (column (2)). These account for unobserved differences at the country-year level that cannot be captured by our observed factors. The results are very similar to those in column (1). Notably, the estimated impact of PPM is the largest (38% price reduction) in the most demanding specification with both country-product and country-year level fixed effects, compared to the other specifications. We keep the panel specification in column (1) as the preferred specification with observable controls in line with the literature.

We also report our analyses at the transaction level. We find that purchasing via the PPM and the UN lowers transaction prices by 20% and 13% respectively (column (3)). These estimates are smaller in magnitude than those from the panel data, because the transaction-level data is weighted more towards larger countries, which (as we show later) benefit less from international pooled procurement institutions. Additionally, we include country-buyer-product fixed effects to account for unobservable differences in buyer characteristics within the same country (column (4)) and find very similar results.[22] We then control for transaction volume, as buyers might receive discounts for purchasing in bulk (columns (5)-(6)). Although larger transaction volume is associated with lower prices, the price reductions accruing from the use of PPM or UN are very similar even after we control for the effect of volume (i.e., comparing columns (4) and (6)).[23] Overall, our results

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 5.2 to address price discrimination via tiered pricing.

[21] 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).

[22] Our results are similar if we control for more fixed effects at the country-year, product-year, country-product, and manufacturer levels (see Table A7).

[23] Thus, similar to Waning et al. (2009), our findings suggest that increasing the volume of drugs purchased in *individual* transactions is unlikely to play a big role in reducing prices. Indeed, we find that individual transaction volumes are only 8% higher for PPM and 6% for UN compared to direct purchases from manufacturers, with the difference not

suggest that both procurement institutions and IP licensing institutions are important in delivering essential drugs to LMIC at lower prices, and pooled procurement institutions (particularly when pooling across countries) play a bigger role in supplying non-profitable off-patent drugs.

3.3 Results: Centralized Procurement, Delays and Procurement Lead Time

Prior studies have mostly looked at prices, as we did in the previous section. We now investigate how drug delivery delays and procurement lead times vary across procurement institutions.[24]

The outcome for delays is the share of transactions of drug j purchased by country c in period t that arrived later than scheduled. When the share of transactions using PPM rises from 0% to 100%, the share of delayed orders decreases by 26%, and the estimates are statistically significant at the one percent level (Table 3, column (1)). These results are similar in transaction-level analysis with the same set of controls (column (2)) and with additional country-buyer-product fixed effects (column (3)). One possible explanation is that the integrated payment-purchase system built into the design of the PPM reduces the transaction costs of fund transfer and allocation. In addition, the use of early ordering in PPM can reduce delivery delays, as we discuss below.

Among the other mechanisms, the transaction-level analyses suggest that CMS transactions are 26-35% less likely to be delayed. This effect is insignificant in the panel analysis, due to limited power: only a few countries have Central Medical Stores but some of these (e.g., South Africa) are frequent purchasers of essential drugs. None of the other mechanisms involve a statistically significant difference in delays relative to the baseline (buying directly from manufacturer).

We then investigate differences in average procurement lead time across procurement institutions (Table 3, right panel). Mechanically, drug delivery delays can be reduced by better planning in drug ordering, for example through more early ordering for drugs with certainty in anticipated demand. Alternatively, procurement mechanisms with more efficient shipment schedules or faster turnaround can reduce potential delays. The two mechanisms have different implications regarding whether certain institutions can be more efficient in handling emergency situations, including a surge in demand due to disease outbreaks or pandemic situations.

We find an increase in the procurement lead time by 105 days if the share of transactions

statistically significant. Instead, the benefits of pooling are mainly accrued by ensuring that the prices across separate transactions are negotiated jointly by pooled procurement institutions.

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

Table 3: Procurement mechanisms: delivery delay and procurement lead time

	(1)	(2)	(3)	(4)	(5)	(6)
	delay			procurement lead time		
	panel	transact.	transac.	panel	transact.	transac.
% PPM	-0.26***	-0.28***	-0.25***	105.4***	113.8***	114.0***
(pool intl.)	(0.050)	(0.049)	(0.053)	(10.5)	(13.3)	(15.9)
% UN	0.084	0.059	0.0095	1.45	3.86	11.9
(pool intl.)	(0.056)	(0.048)	(0.051)	(11.8)	(11.1)	(9.12)
% CMS	-0.080	-0.35***	-0.26***	-23.6	-38.7***	-32.5***
(pool within)	(0.083)	(0.063)	(0.054)	(23.5)	(12.3)	(12.3)
% Others	-0.044	-0.072*	-0.077*	12.8	24.8**	27.8***
	(0.040)	(0.041)	(0.043)	(7.77)	(9.60)	(9.82)
Patented	0.019	-0.0084	-0.0015	-1.53	3.42***	2.82**
	(0.046)	(0.041)	(0.042)	(11.1)	(1.17)	(1.23)
MPP	0.011	0.067***	0.083***	1.81	-7.89	-9.88
	(0.027)	(0.022)	(0.026)	(5.67)	(8.37)	(8.85)
ln(pop.)	-0.47	-0.58	-0.34	-34.0	6.63	7.58
	(0.81)	(0.71)	(0.59)	(118.5)	(6.98)	(6.44)
ln(GDP p.c.)	0.069	-0.025	-0.072	30.0	37.0	111.0
	(0.081)	(0.087)	(0.088)	(22.8)	(141.7)	(182.4)
Controls	Year FE, ctry-prod FE, controls (ctry-yr and ctry-year-prod)					
Ctry-buyer-prod FE			Y			Y
N	14,681	39,289	39,289	14,681	39,289	39,289

Note: The outcome "delay" indicates whether purchases of drug *j* by country *c* in year *t* are delayed on average; "procurement lead time" is the average number of days between the order date and actual delivery date. For the lead time analysis, we drop any transactions where the order was likely to be pre-planned. "Panel" refers to regressions using panel data, while "transact." refers to regressions using transaction-level data. In columns (3) and (6), we include country-buyer-product FE, where the buyer is the organization within the country making the purchase (e.g., health ministry). Acronyms: 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.

using PPM rises from 0 to 1 (column (4)). Given that the average shipping time for drugs ordered directly from manufacturers is 132 days, ordering via the PPM is associated with about 80% longer procurement lead time. This likely relates to how the PPM uses pooling across countries to achieve price reductions. The long-term agreements negotiated by the PPM specify that prices are reduced after a minimum quantity threshold is reached. Pooling orders to hit these thresholds takes time and countries often have to place their orders earlier, which results in a longer lead time. In addition,

earlier ordering facilitates consolidation of shipments and deliveries.[25]

Putting the results of delays and procurement lead time together, our results suggest that pooled international procurement can reduce drug delivery delays, but at the cost of longer procurement lead times. In contrast, direct purchases from manufacturers can be a good option for emergency situations, which allow for faster delivery, but at the cost of paying higher prices and a higher risk of unexpected delivery delays.[26]

We further investigate the effect of procurement institutions on lead time at the transaction level. The transaction-level analyses allow us to include country-buyer-product fixed effects to account for within-country heterogeneity in buyer characteristics. We continue to find longer lead times (by 114 days) when the PPM is used; by contrast, CMS lead times are shorter by about 32-39 days compared to purchases made directly from the manufacturer (columns (5)-(6)).[27]

3.4 Heterogeneity: Patent, Drug Age, Volume, and Seller Concentration

Purchase volume and seller concentration: We split the sample into countries that have above-median volume purchases of drug j in year t, and those that have below-median volume (Table 4, top panel, columns (2)-(3)). For larger buyers, the price reduction from pooled purchasing through the PPM or the UN is significantly smaller. This result suggests that countries with small purchases of a drug are best able to benefit via cross-country pooling, as these countries are the least likely to be able to negotiate effectively with drug suppliers in the absence of pooling. By contrast, the price reduction obtained by using a CMS is larger for countries that are large buyers. Next, we split sample by the median level of seller concentration, measured by the Herfindahl-Hirschman Index (HHI) computed using quantities (columns (4)-(5), top panel).[28] Consistent with Dubois et al. (2021), pooling procurement domestically (by CMS) reduces price more when the market is less concentrated. By contrast, pooling purchases internationally (via PPM or UM) reduces price more when market is more concentrated. This latter finding likely stems from the buyer power of

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

[26] Our results share similarities to Clark et al. (2021) that use the staggered rollout of pooled procurement for medical devices within Italy as a natural experiment. They also find evidence of a tradeoff between prices and delays (waiting time). However, our findings differ in that the longer procurement lead time of PPM purchases was accompanied by a reduction in unexpected delays: although orders took longer to deliver, they were more likely to arrive on time.

[27] We have also repeated this analysis after excluding orders that may be pre-planned (a la Gallien et al., 2017). The results are similar, with lead times about 94-95 days longer with PPM and 39-43 days shorter with CMS (Table A8).

[28] 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 the exclusion would not significantly affect our HHI calculation.

large buyers like PPM and UN that can negotiate effectively even with suppliers that control a large share of the market, in contrast to buyers representing individual countries. This is a new finding, as prior studies have not examined international procurement institutions by seller concentration.

Table 4: Procurement mechanism and prices: heterogeneity analysis

	(1)	(2)	(3)	(4)	(5)
	baseline	buyer total purchases		manufacturer HHI	
		high	low	high	low
% PPM	-0.30***	-0.22***	-0.43***	-0.37***	-0.20***
(pool intl.)	(0.058)	(0.054)	(0.085)	(0.066)	(0.051)
% UN	-0.23***	-0.17***	-0.32***	-0.29***	-0.15***
(pool intl.)	(0.053)	(0.043)	(0.071)	(0.065)	(0.050)
% CMS	-0.10	-0.23**	-0.017	0.069	-0.15**
(pool within)	(0.073)	(0.10)	(0.081)	(0.13)	(0.061)
% Others	0.027	0.043	0.0038	-0.036	0.040
	(0.039)	(0.039)	(0.054)	(0.050)	(0.032)
N	14681	7483	7198	7236	7445
	country patent status		approval year		
	ever-patented	never-patented	pre-1990	1990s	1997+
% PPM	-0.25***	-0.31***	-0.36**	-0.26***	-0.15***
(pool intl.)	(0.063)	(0.067)	(0.17)	(0.074)	(0.050)
% UN	-0.24**	-0.22***	-0.29***	-0.20***	-0.13**
(pool intl.)	(0.092)	(0.051)	(0.10)	(0.059)	(0.050)
% CMS	-0.0029	-0.12*	-0.23	0.040	-0.096
(pool within)	(0.082)	(0.069)	(0.14)	(0.076)	(0.064)
% Others	0.020	0.028	0.024	0.014	-0.0067
	(0.046)	(0.043)	(0.051)	(0.034)	(0.060)
N	3389	11292	4937	4169	5575
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.

Patent status and approval year: Pooled procurement institutions reduce prices similarly by patent status, and the price reductions from cross-country pooled procurement institutions are stronger for drugs that are first approved before 1990 (Table 4, bottom panel).[29] Across patent status (columns (1)-(2), bottom panel), the price reductions obtained through PPM are slightly larger for

[29]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).

never-patented drugs, while price reductions through the UN are slightly larger for patented drugs, but the magnitudes of the differences are neither economically nor statistically significant. Among other procurement institutions, price reduction estimate appears to be larger in the never-patented sample for CMS (but only statistically significant at the 10 percent level).[30] Across generations of drugs (columns (3)-(5), bottom panel), the price reductions for PPM and the UN are more substantial for old drugs that were first approved before 1990. The price reductions are smaller (though still meaningful) for drugs that were first approved in 1997 or later. This pattern might be due to the fact that the market for older drugs are 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.[31] We perform similar analyses for delays and procurement lead time (Tables A5-A6).

3.5 Discussion of Trade-offs and Potential Mechanisms

Our results shed light on both the price and non-price impacts of a variety of procurement institutions (both international and domestic) used for the supply of essential drugs for major infectious diseases. First, we find the two institutions that systematically pool procurement *across* countries (the UN and the PPM) are able to achieve substantial price reductions, relative to institutions with a domestic or regional focus. These institutions are especially effective at obtaining lower prices when individual LMIC are small buyers, or when LMIC purchase drugs with more concentrated supply. These findings are consistent with international procurement institutions having greater bargaining ability when negotiating with drug manufacturers. In addition, the pooling of procurement across countries may also mitigate market frictions and reduce transaction costs in decentralized drug supply. For example, one of the benefits of using the PPM is that it allows consolidating multiple orders into single shipments, improving coordination in delivery.

Second, we find heterogeneity in both price and non-price impacts across international procurement institutions, which reflects different practices in procurement and highlights key trade-

[30] Note that the MPP coefficient is much larger in the sample of countries where a drug is ever patented, and is smaller in the never-patented sample, consistent with prior studies (Wang, 2022; Galasso and Schankerman, 2022).

[31] There are quite a few cases where decades-old drugs widely used in LMIC are registered as new drugs in the US. An example is malaria drug Coartem (artemether/lumefantrine), where both compounds were developed by Chinese scientists (e.g., the 2015 Nobel prize to Youyou Tu) and used in combination since early 1990. Novartis registered it in the US in 2009 and won a priority review voucher for bringing "new" drugs to the US. We abstract away from direct patent issues but use this set of tests on patents and age generations to capture different aspects of drug value.

offs involved in designing a procurement strategy. While both the UN and the PPM engage in cross-country pooling, the PPM is generally able to obtain larger price reductions and lower likelihoods of delivery delays than the UN, but at the cost of a significantly longer *anticipated* procurement lead time. This is likely because the PPM's procurement prioritizes early ordering, which helps reach the volume thresholds in long-term agreements that trigger price reductions, and lowers the uncertainty in demand faced by manufacturers; both of these channels result in price reductions, and the latter channel lowers the likelihood of delays. Earlier ordering, however, necessarily implies a longer procurement lead time, which may mean that buyers faced with a short-term emergency may have to rely more on other procurement institutions (such as the UN, or Central Medical Stores).[32]

A natural question is: if cross-country pooling leads to lower prices, why do not all countries use PPM/UN?[33] First, as discussed above, PPM requires advanced planning that differs by product, with the lead time often longer for low-volume products.[34] Second, despite covering a large share of unique compounds for our disease categories (Appendix A.3), 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 the non-ARV product coverage stabled around 30%; UN shares a similar product coverage pattern. Third, some countries may avoid relying on international pooling entirely so as to develop their own domestic procurement institutions and enhance their expertise in procurement. Having 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).[35]

[32] Note that CMS price estimates are negative and CMS can reduce both chance of delay and procurement lead time, but the estimates lack statistical precision.

[33] 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 in drug procurement (see sections 5.1 and 5.3 for details).

[34] 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.

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

4 Robustness Checks

4.1 Instrumental Variable Estimation

Despite extensive fixed effects and observable controls showing stable estimates across specifications, there may remain some potential endogeneity concerns. Drug-specific regional demand shocks (e.g., due to an epidemic) can raise overall demand for the drug, leading to higher prices, but also increase participation in pooling. In addition, there may be learning effects: more experience purchasing a drug may cause countries to improve in their ability to negotiate lower prices, and simultaneously affect procurement institution choices. Countries with greater drug-specific experience may opt to use international pooling institutions more as they learn how to work with them more effectively, or use them less as they prioritize domestic pooling institutions; the net effect of learning is ambiguous. If learning is uniform across drugs, 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 drug-country pair, then endogeneity may not be fully accounted for by our fixed effects. Overall, the direction of potential OLS bias is unclear.[36]

To address the potential endogeneity of procurement institutions utilized, we instrument the procurement share of institution m, S^m_{jct} using the share of transactions of *other* APIs in the *same* country by procurement institution m in year t, to capture the idea that procurement institution choices are likely to be positively correlated within a country. For example, a health ministry that already procures most of its other drugs 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 drug j as well. These instruments are valid if unobservables ε_{jct} affecting the price of drug 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 observable controls. These instruments help alleviate the endogeneity concerns mentioned above: a regional demand shock for a specific drug j, or drug-specific experience accumulation (either of which may affect the price paid for drug j), could influence the country's choice of procurement institution for that particular drug, but is unlikely to

[36] If regional demand shocks result in some 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 some endogeneity, the direction of bias is unclear: e.g., if learning effects are concentrated on a particular procurement institution, then OLS estimates of the price reduction from pooling may be upward biased.

immediately affect its choice of procurement institutions for other drugs.[37]

Table 5: Instrumental variable estimation

	(1)	(2)	(3)	(4)	(5)
	OLS	2SLS	2SLS	2SLS	2SLS
% PPM	-0.30***	-0.22***	-0.29***	-0.20***	-0.21***
(pool intl.)	(0.060)	(0.053)	(0.061)	(0.054)	(0.054)
% UN	-0.23***	-0.18***	-0.21***	-0.15***	-0.16***
(pool intl.)	(0.053)	(0.052)	(0.056)	(0.054)	(0.056)
% CMS	-0.10	-0.068	-0.097	-0.062	-0.058
(pool within)	(0.075)	(0.076)	(0.073)	(0.076)	(0.098)
% Others	0.027	0.050	0.033	0.058	0.052
	(0.040)	(0.040)	(0.041)	(0.043)	(0.055)
Instrument for		%PPM	%UN	%PPM, %UN	All
Controls	Year FE, ctry-prod FE, controls (ctry-yr and ctry-yr-prod)				
N	14,681	13,645	13,645	13,645	13,645
Cragg-Donald F-stat		8667.9	4137.2	2060.5	818.6
Kleibergen-Paap F-stat		176.9	119.0	61.8	26.2

Note: Column (1) repeats the baseline estimates from column (3) of Table 2. In columns (2)-(5), we instrument for procurement share of institution *m* using the procurement share of institution *m* in the same countries for other drugs. In column (2), we only instrument for %PPM. In column (3), we only instrument for %UN. In column (4), we instrument for both %PPM and %UN. Finally, in column (5), we instrument for %PPM, %UN, %CMS and %Others. Standard errors are two-way clustered by country and by product.

The results further strengthen our main conclusions (Table 5). In column (2), we instrument for the transaction share of PPM, and treat the other procurement mechanisms as exogenous regressors. In column (3), we instrument for the transaction share of UN. In column (4), we instrument for both the PPM and UN transaction shares. Finally, in column (5), which is the most demanding specification, we instrument for the shares of all 4 procurement institutions. The results remain similar after instrumenting for the procurement shares. We find a 21% reduction in prices from the PPM and a 16% reduction in prices from the UN (column (5)), qualitatively similar to corresponding 30% and 23% estimates in our baseline OLS results (column (1)). The first-stage F-statistics indicate that weak identification is unlikely to be a concern in this setting. Table A19 repeats IV

[37] One might be concerned that countries with greater experience purchasing drugs might be able to improve their ability to negotiate prices for *all* drugs that they purchase. However, this is unlikely to drive our results, since we include country-by-drug fixed effects and a rich set of country-by-year controls (e.g., rich measures of governance) that are likely to control for country-level time-varying differences in bargaining ability. Our baseline results are robust to including country-by-year fixed effects that would directly capture time-varying country-specific bargaining ability.

regressions for our other outcomes of interest (delays and procurement lead time), again finding similar results to our baseline OLS results. The results from instrumental variable regressions are also similar to our baseline estimates if we use transaction-level analysis instead (Table A20).

A potential remaining concern with the IVs 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. To alleviate this concern, we reconstruct the IVs using a country's procurement share in *other* drug classes. The idea is that if there is a demand shock specific to a drug class, that is unlikely to directly affect the country's demand for drugs in other drug classes. Our results remain robust with this set of instruments (Table A21). Overall, our IV analyses suggest limited endogeneity concerns.

4.2 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). The idea behind this method is that selection on observables is potentially 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 idea by carrying out both a controlled regression (where all observed controls are included) and an uncontrolled regression (with no additional controls or fixed effects included). The coefficients and R^2 from these two sets of regressions can then be used to calculate bounds on the estimated effects, under the assumption that selection on unobservables is proportional to selection on observables. Appendix A.5 details the AET-O method and our implementation following the literature.

Appendix Table A22 reports a set of bounding values for the main coefficient estimates. Under our most conservative parametrization of the Oster (2019) approach, the bounds on the coefficients of PPM, UN, and CMS procurement shares in the price regression (Table 2) are estimated to be (-0.303,-0.299), (-0.227,-0.226) and (-0.105,-0.101) respectively. In the delay regression (Table 3 column (1)), the estimated bounds on the PPM coefficient are (-0.262,-0.257). Finally, in the procurement lead time regression (Table 3 column (3)), the estimated bounds on the PPM coefficient are (105.05,105.40). Therefore, the AET-O method implies tight bounds for each of the main estimates, suggesting that selection on unobservables is unlikely to significantly bias our estimates.

4.3 Reduced-form Demand Estimation

A potential confounding explanation for why prices differ by procurement institution is that demand elasticities differ for buyers that purchase using different procurement institutions. If buyers with more elastic demand are more likely to utilize centralized procurement, then the lower prices received by those buyers may reflect their demand elasticity rather than the procurement institution utilized. To examine whether the demand elasticities for buyers using a higher share of multilateral procurement institutions are higher 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 j purchased by country c in year t. The coefficient α_p is the demand elasticity when all of the drugs are purchased directly from manufacturers. The coefficient α_{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 endogeneity of prices, we use a standard approach in the literature and instrument for the price by using the average price of the same drug 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 and other observables.

Column (1) of Table 6 presents the results of a simple OLS regression of the reduced-form demand function, with no interactions. Column (2) instruments for price. Finally, 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.

Table 6: 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.

5 Additional Analysis

5.1 Related Institutions: PEPFAR and CHAI

In addition to the procurement institutions we study, some other institutions also contribute to supply of essential drugs to LMIC directly or indirectly. Two 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 the corresponding effects below.

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

Our estimates on procurement institutions remain unchanged (Table A9). The price estimates are lower for PEPFAR-eligible purchases, but not statistically significant. When interacting the share of procurement institutions with the PEPFAR indicator, we find little evidence of complementarity between international pooled procurement institutions (PPM and UN) and PEPFAR. We do find that Central Medical Stores (pooling within-country) are able to obtain a significantly lower price for PEPFAR-eligible drugs, suggesting that countries using CMS can benefit from the presence of a large buyer that purchases the same drugs (i.e., PEPFAR). The results are similar if we control separately for PEPFAR focus countries, or in transaction-level analysis.[38]

CHAI has built a procurement consortium and offers reference prices. Until 2014, CHAI negotiated ceiling prices for selected drugs with generic manufacturers (Waning et al., 2009). CHAI consortium member countries were eligible for these ceiling prices when buying from manufacturers subject to the agreements. 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 separate indicators for CHAI eligibility: (1) a transaction is CHAI ceiling-price-eligible if the importing country is part of the CHAI consortium, and the drug-manufacturer pair being purchased is subject to a CHAI ceiling price (pre-2014); (2) a transaction is CHAI reference-price-eligible if the importing country is part of the CHAI consortium, and the drug-manufacturer pair being purchased is subject to a CHAI reference price (2015 onwards).[39] After accounting for CHAI, our estimates on procurement institutions remain very similar (Table A10). Prices are 10% lower for purchases eligible for CHAI reference prices but do not significantly differ by ceiling

[38] 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.

[39] 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.

price eligibility (column (2)); the effect is similar with transaction-level data (column (5)).[40]

5.2 Management Practices: Tiered Pricing, Pre-payment, Order Frequency

Tiered pricing is a practice that drug firms may use to price differentially by per-capita income group of the importing countries. Our baseline positive estimate on GDP per capita is consistent with tiered pricing. In practice, manufacturers may group importing countries, which then receive different pricing terms, so the relationship with income may be non-linear. We examine this by classifying LMIC into Category 1 countries (eligible for the largest price discounts) and all others.[41] We interact GDP per capita with patent status and an indicator for non-Category 1 countries (Table A11). Non-Category 1 countries ineligible for tiered price discounts negotiate prices on a case-to-case basis with manufacturers, which may lead to a stronger price-income relationship. The estimate on GDP per capita is larger for non-Category 1 countries (but not statistically significant, columns (2) & (5)). We then allow the effect of procurement institutions to vary by whether a country is in Category 1 (columns (3) & (6)). We find evidence that the PPM leads to larger price reductions for non-Category 1 countries, who might be subject to higher prices in direct negotiations. But this interaction term is only statistically significant in the transaction-level analysis.

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). We control for this management practice explicitly at both panel and transaction-level (Table A12). The estimate on prepayment is negative but statistically indistinguishable from zero and small in magnitude, strengthening the results that our estimates on procurement institutions are not capturing effects from this management practice.

We then study how much price and delivery effects may be driven by changes in order frequency and variability made by procurement institutions, potentially allowing for better planning by manufacturers and buyers. We calculate order frequency at the manufacturer-product year level as the number of distinct purchase orders of that product received by the manufacturer in a year. We measure order variability by the coefficient of variation (CV) of the total quantity ordered for

[40] 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 effect from ceiling price is likely because CHAI moved away from direct involvement in procurement post-2007, when our sample begins

[41] 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).

that manufacturer for each product within a year. We examine how order frequency and CV vary by the share of orders that a manufacturer receives from procurement institutions by product-year (Table A14). The results suggest that pooled procurement institutions make less frequent orders but reduce variability in demand faced by manufacturers (as measured by the CV), thus reducing the need to hold large inventories or respond to large swings in demand.[42]

5.3 Other Results

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. 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, which are a subset of drugs available (Figure A5). To evaluate whether lack of availability significantly hinders procurement outcomes systematically, we examine whether the types of drugs purchased within a therapeutic category vary substantially by the procurement institution utilized. 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 across procurement institutions regarding the share of patented drugs or different generation of drugs purchased (Table A23). Appendix A.6 provides more details of this analysis.

We also perform a few additional analyses to support the mechanism and to 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 drug reported in the MSH International Pricing Guide and test if these price differences vary systematically by procurement institution (Table A13). We continue to find cross-country pooling lowers prices.

[42] 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.

Fourth, we examine the start-up effect of establishing a new procurement institution, given that the PPM only began operating in 2009. We find little evidence that the PPM's effectiveness differs between its initial (2009-11) and subsequent years (Table A16). Fifth, we run a diagnostic test that includes fixed effects for how shipping costs are reported (Table A17). 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, by interacting each institution with therapeutic area (Table A18). The effect of cross-country pooling is the largest for antiretroviral and tuberculosis drugs. However, the statistical power is more limited for TB drugs, where cross-country pooling is not widely used, and countries often purchase through the Global Drug Facility. Finally, our results are robust to alternative definitions of "Other" procurement institutions (Table A15). 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 – IDA foundation, Global Drug Facility – and other NPOs. Our results remain robust.

6 Conclusion

We analyze drug supply in 106 countries during 2007-2017 for major infectious diseases (antiretrovirals, antimalarials, antituberculosis, and antibiotics) and find that pooled procurement institutions lower prices compared to decentralized purchases. The price reductions are larger for institutions pooling across countries, particularly for low-volume buyers and drugs with more concentrated supply. In contrast, pooling domestically is more effective for high-volume buyers and for drugs 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 delays in drug delivery, but relies mainly on earlier ordering, leading to increased lead times. We find no evidence that pooled procurement institutions limit the drug attributes buyers are able to procure within a disease category. Finally, the Medicines Patent Pool (an IP licensing institution) and pooled procurement institutions reduce prices for and increase access to different classes of drugs.

Our results have several implications. First, pooled procurement institutions play an important

role in reducing drug prices, but the effectiveness is heterogeneous and depends on drug attributes and features of the markets, such as buyer size and seller concentration. Countries with different demand and disease profiles may want to choose a mixture of procurement institutions to optimize the outcomes. Second, while certain pooled procurement institutions (i.e., PPM) can reduce delays, buyers typically order early, leading to a longer procurement lead time despite more reliable deliveries. This suggests pooling may not work out as well for emergency situations, when direct purchase from manufacturers may be faster. This is reflected in the supply shortage of COVID vaccines to LMIC, where the COVAX initiative (i.e., pooled procurement of vaccines) accounted for only 4% of the vaccines administered worldwide as of June 2021.[43] Third, pooled procurement institutions supplement IP licensing institutions (i.e., MPP) in facilitating LMIC drug supply, as the former has experience acquiring higher shares of older drugs while the latter is more relevant for patented drugs where voluntary licensing and technology transfer are of higher importance.

There are a few limitations. We focus on drugs 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 data sources 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.[44]

Our findings are relevant to LMIC drug supply in the context of the COVID-19 pandemic. As in the case of the HIV/AIDS pandemic, the supply of drugs in LMIC lags behind the rest of the world, and this may cause lingering impacts on LMIC long after the peak of a pandemic. Despite very different settings, one common theme is that there are multiple market frictions for LMIC drug supply, including lack of local drug production capacity, supply chain issues, and IP barriers. There is unlikely to be a single policy or institution that can address all the frictions. The development of procurement institutions that rely on international funds or government subsidies can complement market-based IP licensing institutions that can reduce IP barriers. Our analysis highlights crucial trade-offs involved in using different types of procurement institutions in both regular and emergency contexts, contributing to the understanding of the design of institutions to maintain efficient and reliable drug supply to LMIC.

[43] Source: www.scientificamerican.com/article/covax-effort-to-vaccinate-the-world-is-faltering/.

[44] Source: www.theglobalfund.org/en/news/2021/2021-09-08-global-fund-results-report-reveals-covid-19-devastating-impact-on-hiv-tb-and-malaria-programs/.

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

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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.

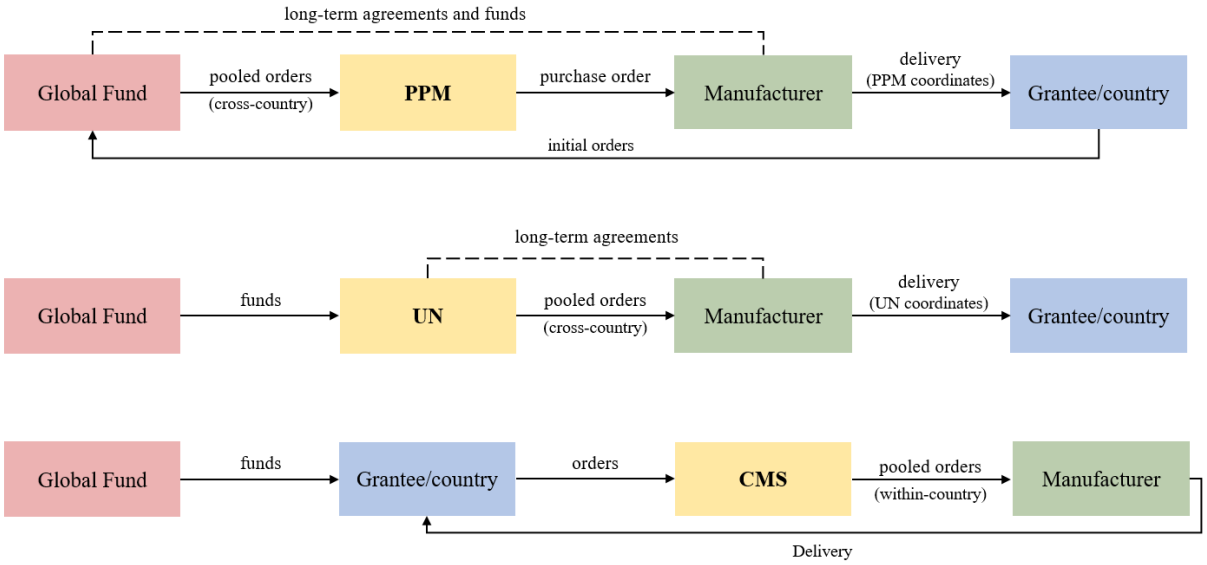


Figure A1: Procurement institutions comparison

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 sample.

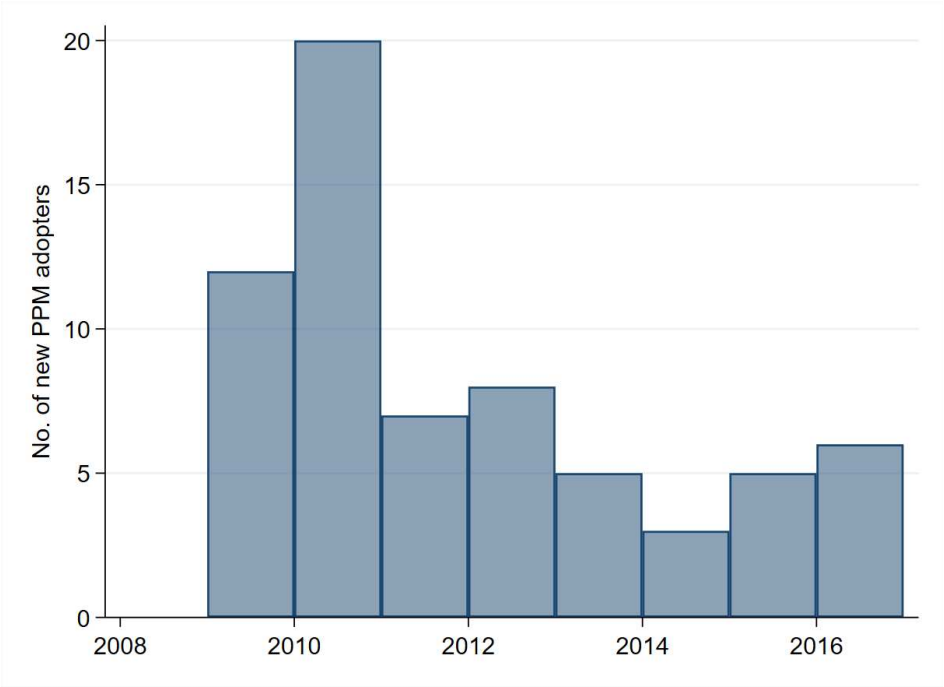


Figure A2: Number of new PPM adopters in our sample by year

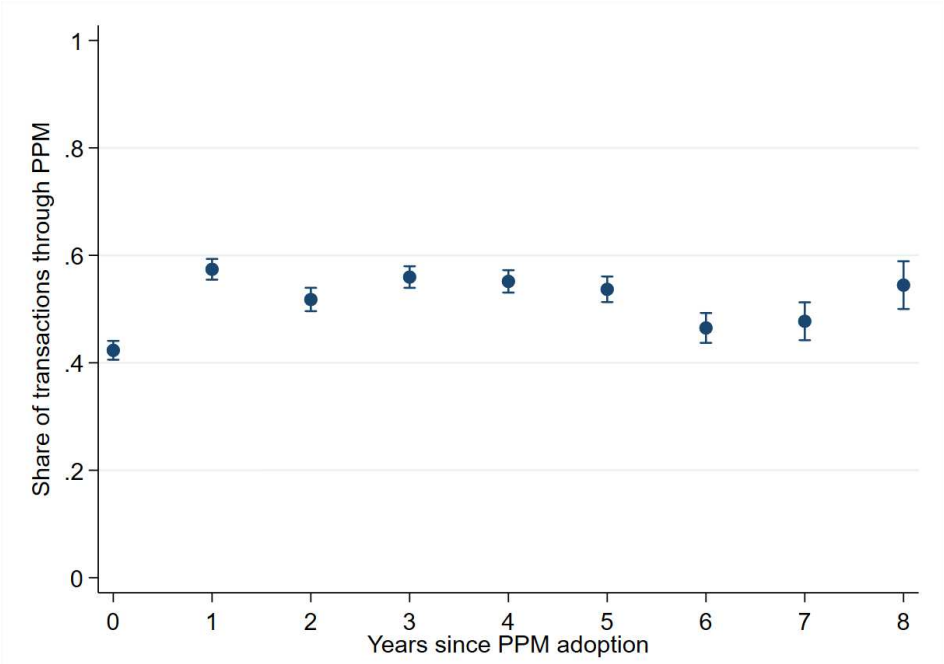


Figure A3: Binscatter plot of PPM transaction share by years since countries first used PPM

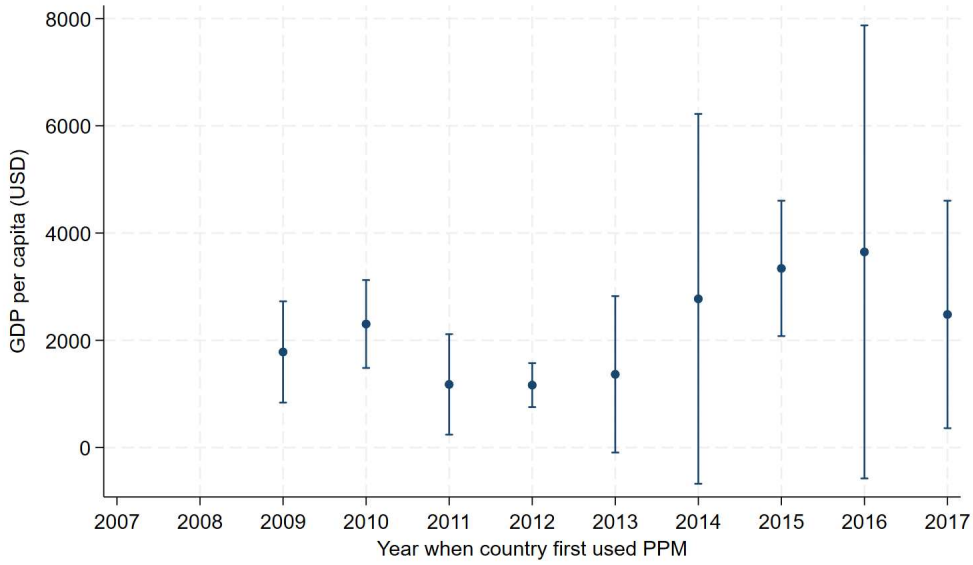


Figure A4: Binscatter plot of GDP per capita and first year when countries used PPM

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).

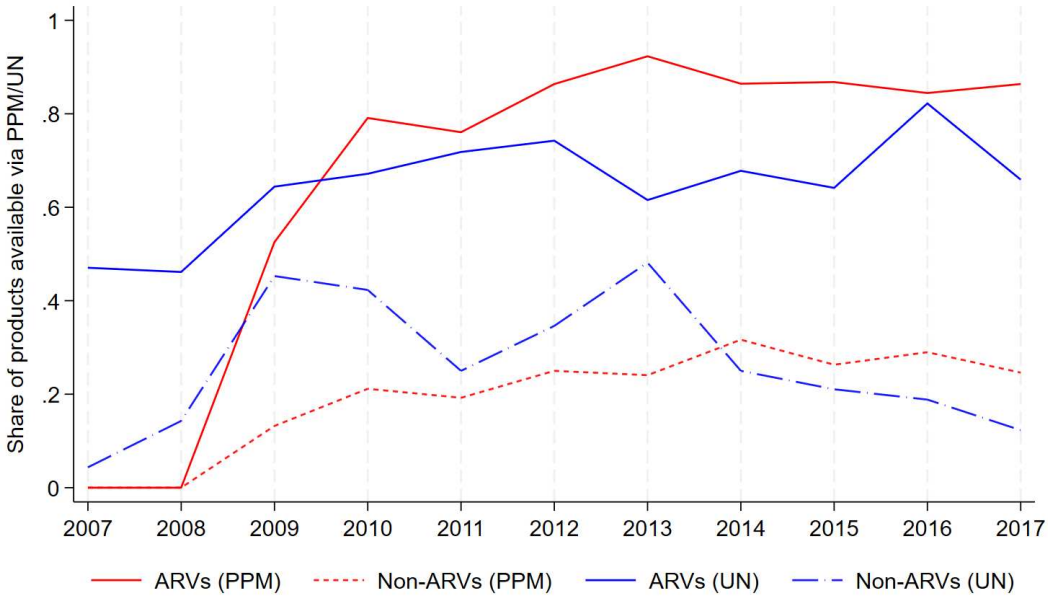
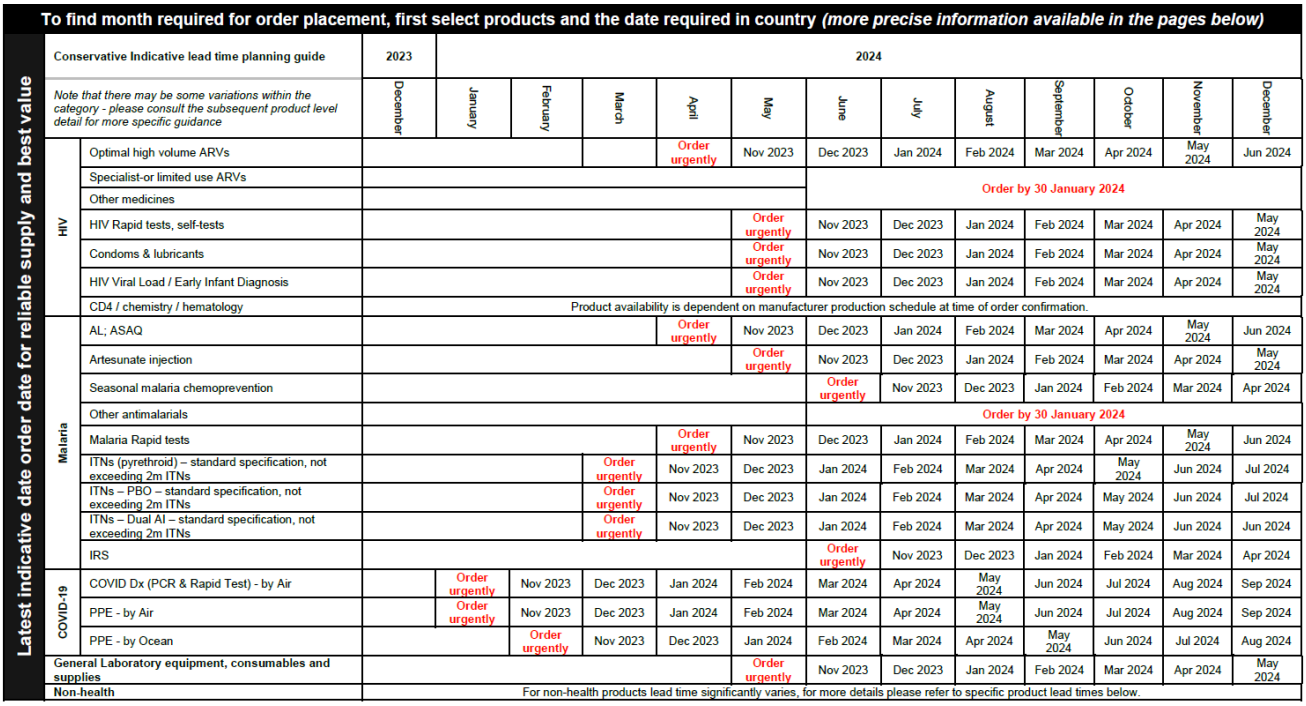


Figure A5: Share of products available via international pooled procurement institutions

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



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 Pooled Procurement Mechanism (PPM)

Note: This illustrates the PPM planning guide for October 2023 published on Global Fund's website. Source: https://www.theglobalfund.org/media/10755/psm_categoryproductlevelprocurementdeliveryplanning_guide_en.pdf.

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 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).

[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.

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

The procurement involves a few steps when using the Global Fund’s Pooled Procurement Mechanism (PPM). The PPM uses volume thresholds specified in long-term agreements with manufacturers as a way 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). We compared the indicative lead time

[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.

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 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).

A.3 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.[3] 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) carried out 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).

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).[4] 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

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

[4] 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.

and safe to meet the most important needs in a health system.[5] Our sample covers 13 out of 15 unique malaria compounds and all 18 unique tuberculosis compounds in the WHO EML.[6]

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.[7] 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.

Finally, Table A3 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 in our sample that are only purchased through PPM or UN. As we include drug-country fixed effects, we use *within*-country-drug variation in the utilization rate of procurement institutions, instead of cross-country or cross-drug variation in the utilization to identify the effects.

Table A4 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.[8]

[5] 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).

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

[7] 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).

[8] Note that even though Equatorial Guinea is classified as a high-income country, it is still resource-limited and needs

Table A3: 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 A4: 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.

international help in drug procurement.

A.4 Additional Results

We perform the heterogeneity analysis for shipment delays (Table A5) and procurement lead time (Table A6). Overall, we do not find much evidence of significant heterogeneity in the impact of procurement mechanisms on delays or lead times.

Table A5: Procurement mechanism and delays: panel-level heterogeneity analysis

	(1)	(2)	(3)	(4)	(5)
	baseline	buyer total purchases		manufacturer HHI	
		high	low	high	low
% PPM	-0.26***	-0.27***	-0.26***	-0.32***	-0.24***
(pool intl.)	(0.050)	(0.054)	(0.074)	(0.069)	(0.054)
% UN	0.084	0.068	0.10	0.073	0.11*
(pool intl.)	(0.056)	(0.059)	(0.081)	(0.069)	(0.059)
% CMS	-0.080	0.021	-0.17*	-0.11	-0.079
(pool within)	(0.083)	(0.098)	(0.092)	(0.17)	(0.094)
% Others	-0.044	-0.0043	-0.11*	-0.059	-0.017
	(0.040)	(0.040)	(0.054)	(0.042)	(0.047)
N	14681	7483	7198	7236	7445
	country patent status		approval year		
	ever-patented	never-patented	pre-1990	1990s	1997+
% PPM	-0.20**	-0.27***	-0.27***	-0.30***	-0.23***
(pool intl.)	(0.082)	(0.049)	(0.066)	(0.048)	(0.061)
% UN	0.12	0.072	0.031	0.043	0.14**
(pool intl.)	(0.083)	(0.055)	(0.070)	(0.063)	(0.061)
% CMS	-0.16*	0.016	0.19*	-0.22***	-0.034
(pool within)	(0.084)	(0.091)	(0.11)	(0.054)	(0.12)
% Others	-0.041	-0.045	-0.036	-0.079	0.021
	(0.070)	(0.036)	(0.040)	(0.048)	(0.054)
N	3389	11292	4937	4169	5575
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 A6: Procurement mechanism and procurement lead time: panel-level heterogeneity

	(1)	(2)	(3)	(4)	(5)
	baseline	buyer total purchases		manufacturer HHI	
		high	low	high	low
% PPM	105.4***	114.8***	92.7***	116.9***	102.4***
(pool intl.)	(11.0)	(12.2)	(11.9)	(14.1)	(10.9)
% UN	1.45	-1.26	-0.62	12.0	-11.1
(pool intl.)	(11.8)	(14.3)	(11.9)	(14.7)	(12.8)
% CMS	-23.6	-27.6	-14.5	-16.1	-26.5
(pool within)	(23.7)	(22.7)	(24.0)	(40.3)	(18.1)
% Others	12.8	19.6*	5.11	16.2	15.6
	(7.84)	(10.1)	(9.36)	(10.4)	(9.91)
N	14681	7483	7198	7236	7445
	country patent status			approval year	
	ever-patented	never-patented	pre-1990	1990s	1997+
% PPM	107.1***	103.0***	83.3***	110.4***	108.5***
(pool intl.)	(13.4)	(11.8)	(14.3)	(14.8)	(12.0)
% UN	-37.9***	10.4	12.2	0.47	-4.90
(pool intl.)	(13.7)	(11.7)	(14.7)	(15.4)	(11.2)
% CMS	-35.4	-3.49	4.98	-29.7	-23.4
(pool within)	(27.7)	(22.4)	(35.1)	(25.8)	(29.5)
% Others	-3.54	14.3	14.1	18.1	6.27
	(13.0)	(8.91)	(12.1)	(11.3)	(10.3)
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 A7: 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
Drug-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 drug-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 drug-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.

Table A8: 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 A9: PEPFAR and drug prices

	(1)	(2)	(3)	(4)	(5)	(6)
		Panel-level			Transaction-level	
% PPM	-0.30***	-0.30***	-0.30***	-0.20***	-0.16*	-0.16**
(pool intl.)	(0.060)	(0.078)	(0.078)	(0.052)	(0.081)	(0.081)
% UN	-0.23***	-0.22***	-0.23***	-0.13***	-0.16***	-0.16***
(pool intl.)	(0.053)	(0.057)	(0.057)	(0.044)	(0.054)	(0.056)
% CMS	-0.10	0.027	0.019	0.014	0.15**	0.19***
(pool within)	(0.075)	(0.093)	(0.10)	(0.067)	(0.066)	(0.068)
% Others	0.027	0.027	0.026	0.063*	0.063	0.061
	(0.040)	(0.046)	(0.046)	(0.032)	(0.046)	(0.045)
PEPFAR		-0.15	-0.16		0.036	-0.20
		(0.12)	(0.11)		(0.19)	(0.12)
PEPFAR*% PPM		0.0034	-0.0044		-0.072	-0.073
		(0.085)	(0.091)		(0.098)	(0.10)
PEPFAR*% UN		-0.0020	-0.015		0.041	0.055
		(0.085)	(0.099)		(0.072)	(0.075)
PEPFAR*% CMS		-0.21**	-0.096		-0.17***	-0.38***
		(0.088)	(0.11)		(0.053)	(0.085)
PEPFAR*% Others		0.0028	0.0013		-0.0032	0.010
		(0.071)	(0.078)		(0.052)	(0.054)
PEPFAR focus			0.087			0.51***
			(0.17)			(0.14)
PEPFAR focus*% PPM			0.057			0.028
			(0.066)			(0.069)
PEPFAR focus*%UN			0.074			-0.030
			(0.10)			(0.083)
PEPFAR focus*% CMS			-0.18*			0.19***
			(0.092)			(0.059)
PEPFAR focus*% Others			0.023			-0.057
			(0.085)			(0.069)
Controls: Year FE, country-product FE, controls (country-year and country-year-product)						
N	14681	14681	14681	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 A10: CHAI eligibility and price

	(1)	(2)	(3)	(4)	(5)	(6)
	Panel-level			Transaction-level		
% PPM	-0.30***	-0.30***	-0.30***	-0.20***	-0.20***	-0.19***
(pool intl.)	(0.060)	(0.060)	(0.063)	(0.052)	(0.052)	(0.056)
% UN	-0.23***	-0.23***	-0.21***	-0.13***	-0.13***	-0.12***
(pool intl.)	(0.053)	(0.053)	(0.050)	(0.044)	(0.044)	(0.042)
% CMS	-0.10	-0.11	-0.13	0.014	0.010	0.036
(pool within)	(0.075)	(0.076)	(0.083)	(0.067)	(0.065)	(0.057)
% Others	0.027	0.025	0.024	0.063*	0.063**	0.072*
	(0.040)	(0.040)	(0.046)	(0.032)	(0.031)	(0.037)
CHAI ceiling-eligible		0.0040	0.016		-0.0026	0.046
		(0.035)	(0.056)		(0.031)	(0.044)
CHAI reference-eligible		-0.096**	-0.094*		-0.081***	-0.093**
		(0.043)	(0.050)		(0.028)	(0.035)
CHAI ceiling-eligible*PPM			-0.032			-0.068
			(0.058)			(0.047)
CHAI ceiling-eligible*UN			-0.063			-0.089*
			(0.078)			(0.050)
CHAI ceiling-eligible*CMS			0.083			-0.13**
			(0.090)			(0.056)
CHAI ceiling-eligible*Others			0.014			-0.036
			(0.056)			(0.051)
CHAI reference-eligible*PPM			0.053			0.033
			(0.047)			(0.044)
CHAI reference-eligible*UN			-0.14**			-0.053
			(0.068)			(0.067)
CHAI reference-eligible*CMS			-0.014			0.051
			(0.12)			(0.042)
CHAI reference-eligible*Others			-0.17			-0.067
			(0.12)			(0.047)
Controls: Year FE, country-product FE, controls (country-year and country-year-product)						
N	14681	14681	14681	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 A11: Tiered pricing

	(1)	(2)	(3)	(4)	(5)	(6)
		Panel-level			Transaction-level	
% PPM	-0.30***	-0.30***	-0.27***	-0.20***	-0.20***	-0.15***
(pool intl.)	(0.060)	(0.061)	(0.064)	(0.052)	(0.053)	(0.048)
% UN	-0.23***	-0.22***	-0.22***	-0.13***	-0.13***	-0.11**
(pool intl.)	(0.053)	(0.053)	(0.064)	(0.044)	(0.046)	(0.044)
% CMS	-0.10	-0.090	-0.12	0.014	0.018	0.016
(pool within)	(0.075)	(0.076)	(0.086)	(0.067)	(0.066)	(0.067)
% Others	0.027	0.029	0.035	0.063*	0.063*	0.055**
	(0.040)	(0.041)	(0.041)	(0.032)	(0.033)	(0.023)
Patented	0.023	-0.049	-0.049	0.024	-0.20	-0.13
	(0.052)	(0.41)	(0.41)	(0.053)	(0.44)	(0.47)
ln(GDP per capita)	0.13**	0.072	0.065	0.16**	0.10	0.081
	(0.055)	(0.056)	(0.057)	(0.068)	(0.068)	(0.069)
Patented*ln(GDP per capita)		0.010	0.0091		0.030	0.019
		(0.055)	(0.055)		(0.060)	(0.065)
Not category 1*ln(GDP per capita)		0.15	0.18*		0.15	0.21**
		(0.10)	(0.11)		(0.092)	(0.094)
Not category 1*PPM			-0.13			-0.25**
			(0.096)			(0.100)
Not category 1*UN			-0.013			-0.10
			(0.11)			(0.10)
Not category 1*CMS			0.24*			0.093
			(0.12)			(0.13)
Not category 1*Others			-0.018			0.012
			(0.090)			(0.084)
Controls: Year FE, ctry-prod FE, controls (ctry-yr and ctry-year-prod)						
N	14681	14681	14681	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 A12: Procurement mechanism and price: control for pre-paid orders

	(1)	(2)	(3)
	Panel-level	Transaction-level	
% PPM	-0.30***	-0.20***	-0.19***
(pool intl.)	(0.061)	(0.053)	(0.058)
% UN	-0.22***	-0.12***	-0.083*
(pool intl.)	(0.053)	(0.043)	(0.043)
% CMS	-0.10	0.014	-0.041
(pool within)	(0.075)	(0.067)	(0.062)
% Others	0.029	0.066**	0.080**
	(0.039)	(0.031)	(0.035)
% Prepaid	-0.018	-0.035	-0.041
	(0.027)	(0.025)	(0.025)
Controls: Year & ctry-prod FE, controls (ctry-yr-prod)			
Ctry-buyer-prod FE			Y
N	14,681	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. “Pre-paid" refers to transactions where the manufacturer is paid in advance, either fully or partially.

Table A13: Prices relative to benchmark prices

	(1)	(2)	(3)
Dep var: ln price diff. MSH	Panel-level	Transaction-level	
% PPM	-0.22***	-0.16***	-0.12**
(pool intl.)	(0.059)	(0.052)	(0.054)
% UN	-0.17***	-0.14***	-0.11*
(pool intl.)	(0.055)	(0.045)	(0.056)
% CMS	-0.056	0.057	-0.033
(pool within)	(0.096)	(0.086)	(0.088)
% Others	-0.011	0.029	0.042
	(0.034)	(0.034)	(0.028)
Controls: Year & ctry-prod FE, controls (ctry-yr-prod)			
Ctry-buyer-prod FE			Y
N	9,745	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 drug-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 A14: 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 A15: Other procurement institutions

	(1)	(2)	(3)	(4)	(5)	(6)
	Panel-level		Transaction-level			
% PPM	-0.30***	-0.30***	-0.20***	-0.19***	-0.18***	-0.18***
(pool intl.)	(0.060)	(0.060)	(0.052)	(0.052)	(0.058)	(0.058)
% UN	-0.23***	-0.23***	-0.13***	-0.13***	-0.11**	-0.10**
(pool intl.)	(0.053)	(0.053)	(0.045)	(0.044)	(0.044)	(0.042)
% CMS	-0.10	-0.100	0.014	0.013	-0.041	-0.043
(pool within)	(0.075)	(0.075)	(0.067)	(0.066)	(0.061)	(0.060)
% NPO	0.039		0.055		0.076*	
	(0.045)		(0.038)		(0.046)	
% IDA		0.064		0.069		0.096*
		(0.051)		(0.044)		(0.052)
% GDF		0.11*		0.12**		0.16**
		(0.059)		(0.050)		(0.061)
% Other NPO		-0.099		-0.072		-0.068
		(0.061)		(0.050)		(0.054)
% Others (not NPO)	-0.018	-0.013	0.084**	0.086**	0.084***	0.086***
	(0.058)	(0.058)	(0.035)	(0.036)	(0.029)	(0.031)
Controls	Year FE, ctry-prod FE, controls (ctry-yr and ctry-year-prod)					
Ctry-buyer-prod FE					Y	Y
N	14681	14681	14681	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. NPO refers to non-profit procurement organizations.

Table A16: Pooled Procurement Mechanism: start-up effects

	(1)	(2)	(3)	(4)	(5)	(6)
	Panel-level		Transaction-level			
% PPM	-0.30***	-0.30***	-0.18***	-0.18***	-0.16**	-0.16**
(pool intl.)	(0.063)	(0.063)	(0.060)	(0.059)	(0.067)	(0.066)
% UN	-0.23***	-0.23***	-0.13***	-0.13***	-0.11**	-0.11**
(pool intl.)	(0.053)	(0.053)	(0.044)	(0.043)	(0.043)	(0.043)
% CMS	-0.10	-0.099	0.017	0.016	-0.035	-0.035
(pool within)	(0.076)	(0.077)	(0.069)	(0.070)	(0.063)	(0.064)
% Others	0.027	0.027	0.062**	0.062**	0.077**	0.077**
	(0.040)	(0.040)	(0.031)	(0.031)	(0.035)	(0.035)
% PPM*(2009-2011)	0.0050		-0.049		-0.061	
	(0.046)		(0.059)		(0.063)	
% PPM*2009		0.027		-0.026		-0.039
		(0.070)		(0.076)		(0.070)
% PPM*2010		-0.015		-0.027		-0.057
		(0.059)		(0.059)		(0.058)
% PPM*2011		0.017		-0.070		-0.067
		(0.048)		(0.097)		(0.098)
Controls	Year FE, ctry-prod FE, controls (ctry-yr and ctry-year-prod)					
Ctry-buyer-prod FE					Y	Y
N	14681	14681	14681	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. Note that the PPM started in the year 2009.

Table A17: Procurement mechanism and price: control for how shipping cost is reported

	(1)	(2)	(3)
	Panel-level	Transaction-level	
% PPM	-0.29***	-0.19***	-0.17***
(pool intl.)	(0.064)	(0.054)	(0.060)
% UN	-0.22***	-0.13***	-0.10**
(pool intl.)	(0.054)	(0.044)	(0.043)
% CMS	-0.10	0.010	-0.045
(pool within)	(0.072)	(0.066)	(0.060)
% Others	0.029	0.063*	0.079**
	(0.041)	(0.033)	(0.036)
Controls: Year & ctry-prod FE, controls (ctry-yr-prod)			
Ctry-buyer-prod FE			Y
N	14,681	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: whether it is included in the final price, or not.

Table A18: Procurement mechanism and price, for different drug categories

	(1) Panel-level	(2) Transaction-level	(3)
% PPM * ARV	-0.34***	-0.27***	-0.26***
(pool intl.)	(0.061)	(0.055)	(0.055)
% PPM * TB	-0.48	-0.17	-0.17
	(0.33)	(0.19)	(0.20)
% PPM * Malaria	0.14	0.091*	0.18***
	(0.11)	(0.048)	(0.060)
% UN * ARV	-0.25***	-0.16***	-0.11**
(pool intl.)	(0.062)	(0.054)	(0.052)
% UN * TB	-0.21**	-0.20**	-0.18*
	(0.10)	(0.093)	(0.096)
% UN * Malaria	-0.084	-0.067	-0.097
	(0.11)	(0.056)	(0.073)
% CMS * ARV	-0.12*	0.0049	-0.055
(pool within)	(0.069)	(0.073)	(0.065)
% Others * ARV	0.040	0.067*	0.080**
	(0.044)	(0.035)	(0.039)
% Others * TB	0.047	0.046	0.045
	(0.062)	(0.054)	(0.062)
% Others * Antibiotic	-0.010	0.16	0.24
	(0.20)	(0.32)	(0.36)
% Others * Malaria	-0.34	-0.016	-0.0032
	(0.24)	(0.11)	(0.071)
Controls: Year & ctry-prod FE, controls (ctry-yr-prod)			
Ctry-buyer-prod FE			Y
N	14,681	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.

Table A19: Instrumental variable estimation: delay and lead time (panel-level)

	(1)	(2)	(3)	(4)	(5)
Panel A: Delay	OLS	2SLS	2SLS	2SLS	2SLS
% PPM	-0.26***	-0.28***	-0.21***	-0.23***	-0.27***
(pool intl.)	(0.050)	(0.079)	(0.065)	(0.085)	(0.073)
% UN	0.084	0.072	0.19	0.18	0.12
(pool intl.)	(0.056)	(0.066)	(0.13)	(0.13)	(0.11)
% CMS	-0.080	-0.090	-0.061	-0.069	-0.036
(pool within)	(0.083)	(0.084)	(0.086)	(0.085)	(0.097)
% Others	-0.044	-0.049	-0.013	-0.019	-0.17
	(0.040)	(0.041)	(0.050)	(0.050)	(0.10)
Panel B: Lead time	OLS	2SLS	2SLS	2SLS	2SLS
% PPM	105.4***	112.6***	94.2***	101.3***	105.7***
(pool intl.)	(11.0)	(20.0)	(17.1)	(22.8)	(19.5)
% UN	1.45	5.57	-24.2	-19.8	-12.5
(pool intl.)	(11.8)	(13.8)	(29.9)	(29.4)	(26.0)
% CMS	-23.6	-20.8	-28.7	-25.8	-31.1
(pool within)	(23.7)	(24.4)	(23.6)	(24.3)	(28.3)
% Others	12.8	15.1*	5.61	7.72	27.8
	(7.84)	(8.63)	(11.5)	(11.7)	(21.5)
Instrument for		PPM	UN	PPM, UN	All
Controls	Year FE, ctry-prod FE, controls (ctry-yr and ctry-yr-prod)				
N	39,289	38,994	38,994	38,994	38,994
Cragg-Donald F-stat		8667.9	4137.2	2060.5	818.6
Kleibergen-Paap F-stat		176.9	119.0	61.8	26.2

Note: Column (1) repeats the baseline estimates for delay from column (1) of Table 3, and for procurement lead time from column (4). In columns (2)-(5), we instrument for procurement share of institution *m* using the procurement share of institution *m* in the same country for other drugs. In column (2), we only instrument for %PPM. In column (3), we only instrument for %UN. In column (4), we instrument for both %PPM and %UN. Finally, in column (5), we instrument for %PPM, %UN, %CMS and %Others. Acronyms: Pooled Procurement Mechanism (PPM), United Nations (UN), and Central Medical Stores (CMS). Standard errors are two-way clustered by country and by product.

Table A20: Instrumental variable estimation: all outcomes (transaction-level)

	(1)	(2)	(3)	(4)	(5)
Panel A: Price	OLS	2SLS	2SLS	2SLS	2SLS
PPM	-0.20***	-0.16***	-0.21***	-0.18***	-0.20***
(pool intl.)	(0.052)	(0.057)	(0.058)	(0.062)	(0.056)
UN	-0.13***	-0.12***	-0.17**	-0.15**	-0.17***
(pool intl.)	(0.044)	(0.041)	(0.068)	(0.065)	(0.060)
CMS	0.014	0.019	0.011	0.016	-0.11*
(pool within)	(0.067)	(0.058)	(0.059)	(0.058)	(0.061)
Others	0.063*	0.070**	0.054	0.062*	0.037
	(0.032)	(0.030)	(0.035)	(0.035)	(0.069)
Panel B: Delay	OLS	2SLS	2SLS	2SLS	2SLS
PPM	-0.28***	-0.29***	-0.21***	-0.22**	-0.22***
(pool intl.)	(0.049)	(0.067)	(0.077)	(0.091)	(0.081)
UN	0.059	0.053	0.23	0.23	0.21
(pool intl.)	(0.048)	(0.057)	(0.15)	(0.15)	(0.14)
CMS	-0.35***	-0.36***	-0.34***	-0.34***	-0.19**
(pool within)	(0.063)	(0.057)	(0.065)	(0.063)	(0.083)
Others	-0.072*	-0.075*	-0.031	-0.034	-0.14
	(0.041)	(0.043)	(0.055)	(0.058)	(0.11)
Panel C: Lead time	OLS	2SLS	2SLS	2SLS	2SLS
PPM	114.1***	117.5***	102.5***	105.4***	110.4***
(pool intl.)	(13.6)	(18.9)	(15.4)	(21.6)	(20.9)
UN	4.06	5.64	-26.6	-24.9	-14.9
(pool intl.)	(11.1)	(11.3)	(32.5)	(31.4)	(30.6)
CMS	-48.0***	-47.5***	-50.4***	-49.9***	-57.8***
(pool within)	(12.6)	(13.1)	(12.2)	(12.7)	(18.1)
Others	23.9**	24.7***	16.9	17.6	48.0*
	(9.67)	(8.91)	(12.3)	(12.2)	(25.8)
Instrument for		PPM	UN	PPM, UN	All
Controls	Year FE, ctry-prod FE, controls (ctry-yr and ctry-yr-prod)				
N	39,289	38,994	38,994	38,994	38,994
Cragg-Donald F-stat		16736.1	5984.8	2964.3	1233.5
Kleibergen-Paap F-stat		136.3	29.9	11.6	10.8

Note: Column (1) repeats the baseline estimates for price from column (3) of Table 2, delay from column (2) of Table 3, and for procurement lead time from column (5) of Table 3. In columns (2)-(5), we instrument for procurement of institution *m* using the procurement share of institution *m* in the same country for other drugs. In column (2), we only instrument for PPM. In column (3), we only instrument for UN. In column (4), we instrument for both PPM and UN. Finally, in column (5), we instrument for PPM, UN, CMS and Others. Acronyms: Pooled Procurement Mechanism (PPM), United Nations (UN), and Central Medical Stores (CMS). Standard errors are two-way clustered by country and by product.

Table A21: Instrumental variable estimation: construct IVs excluding drugs from same drug class

	(1)	(2)	(3)	(4)	(5)
	OLS	2SLS	2SLS	2SLS	2SLS
% PPM	-0.30***	-0.19***	-0.23***	-0.19***	-0.20***
(pool intl.)	(0.060)	(0.045)	(0.052)	(0.046)	(0.046)
% UN	-0.23***	-0.16***	-0.18***	-0.15**	-0.16***
(pool intl.)	(0.053)	(0.047)	(0.058)	(0.057)	(0.056)
% CMS	-0.10	-0.017	-0.031	-0.015	-0.0046
(pool within)	(0.075)	(0.056)	(0.052)	(0.057)	(0.070)
% Others	0.027	0.034	0.021	0.036	0.0062
	(0.040)	(0.040)	(0.039)	(0.041)	(0.050)
Instrument for		%PPM	%UN	%PPM, %UN	All
Cragg-Donald F-stat		9239.4	3327.5	1691.1	624.4
Kleibergen-Paap F-stat		369.1	113.5	59.6	20.3

Note: In columns (2)-(5), we instrument for procurement share of institution *m* using the procurement share of institution *m* in the same country for other drugs that are not in the same drug class. The columns are organized similarly to Table 5. 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.

A.5 AET-O Method Description

In section 4.2, 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.

In order 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 β^* as $\beta^* = \widetilde{\beta} - \delta(\mathring{\beta} - \widetilde{\beta})\frac{R^2_{max} - \widetilde{R^2}}{\widetilde{R^2} - \mathring{R^2}}$, where $\mathring{\beta}$ 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. δ 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 A22, 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.

Table A22: Parameter bounds robust to selection on observables, based on Oster (2019)

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

Transaction-level	No controls		All controls		R^2_{max}		Bounds	
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

A.6 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.[9] 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. δ_{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). δ_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 A23). Specifically, column (1) and column (3) shows that the share of drugs patented does not substantially differ by procurement institution. Columns (2) and (4) illustrates that using PPM and UN is associated with a increase in the share of drugs approved prior to 1990, but the effect is small in magnitude (less than 5%) and not statistically significant.

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

Table A23: 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.

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