CENTER FOR GLOBAL DEVELOPMENT

Costing Antimicrobial Resistance Interventions

Tim Laurence and Anthony McDonnell

Abstract

This study estimates the costs of four key interventions to mitigate antimicrobial resistance globally by 2050. These interventions include improving access to water, sanitation, and hygiene, enhancing childhood vaccination, developing new antibiotics, and increasing access to healthcare and existing antibiotics. Using updated and original costing methods, including a novel Cobb-Douglas production function to cost improved access to healthcare and antibiotics, the total annual costs for these interventions are estimated for 204 countries. The key findings are: it would cost $215.0 billion to scale up household WASH globally, $4.7 billion to achieve 100 percent access to a group of childhood vaccines, and $2.2 billion to develop new antibiotics. Additionally, $59.0 billion would be required to improve access to healthcare and antibiotics. Given that all countries benefit from rolling out these policies, there is a compelling case for high-income countries providing assistance to low- and middle-income countries to help them combat antimicrobial resistance.

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Acronyms and abbreviations

AMR	Antimicrobial resistance
DTP	Diphtheria, Tetanus, Pertussis (vaccine)
GDP	Gross Domestic Product
GLAAS	Global Analysis and Assessment of Sanitation and Drinking-Water
GAVI	Global Alliance for Vaccines and Immunization
HiB	Haemophilus influenzae type B (vaccine)
HIC	High-income country
IHME	Institute for Health Metrics and Evaluation
LIC	Low-income country
LMIC	Low- and middle-income countries
MCV	Meningococcal vaccine
MI4A	Market Information for Access to Vaccines
PCV	Pneumococcal Conjugate Vaccine
Rotavirus	Rotavirus (vaccine)
SDG	Sustainable Development Goals
UHC	Universal Health Coverage
UNICEF	United Nations International Children's Emergency Fund
WASH	Water, sanitation, and hygiene
WHO	World Health Organization

Executive summary

The Institute for Health Metrics and Evaluation (IHME) has modelled several prospective scenarios of the burden of antimicrobial resistance (AMR) to 2050, including interventions seeking to mitigate AMR. These intervention scenarios are:

1. Improving access to water, sanitation and hygiene (WASH) for households
2. Improving access to childhood vaccination
3. Developing new innovative gram-negative antibiotics
4. Improving access to healthcare and existing antibiotics

All these interventions are compared to IHME's reference scenario. This piece of work is the costing companion to those intervention scenarios, estimating approximate country costs to inform financing and resource allocation discussions. We report aggregated costs in this paper and country level estimates are available in the appendix.

WASH: We review relevant literature on the global cost of WASH and update previous estimates by UNICEF and the World Bank on the cost to scale up WASH at a country level for both cost inflation and changes of coverage modelled by IHME. We estimate that the global cost of scaling up WASH to achieve Sustainable Development Goals (SDG) 6.1 and 6.2 is £215.0 billion annually. This estimate is broadly consistent with comparable existing estimates. It is important to note that scaling up WASH has wide ranging benefits past AMR, so the considerable global cost should be viewed against the wide-ranging benefits set out by studies.

Vaccination: We review relevant literature on the global cost of vaccination. We produce novel bottom-up estimates of the cost of closing the vaccination gap at a country level globally. We use data from the MI4A database from the World Health Organization on vaccination costs, and assumptions on the delivery cost of vaccination in order to cost the changing coverage modelled by IHME. We estimate that the cost of scaling up vaccination in line with IHME's modelling is $4.6 billion annually. Our estimates are broadly consistent with existing literature.

Innovation: Developing new antibiotics, particularly targeting gram-negative bacteria, is crucial to mitigating the growing burden of AMR. IHME's model suggests that halving the impact of resistant gram-negative infections would require ten new antibiotics developed per decade, two-thirds of which should be gram-negative focused. Using cost estimates from existing literature we calculate an initial annual cost of $2.2 billion, which, due to rising R&D costs, is expected to increase to $3.7 billion by 2050. We explore five potential funding models to distribute these costs equitably, with particular focus on scenarios where high-income countries bear the majority of the burden, ensuring that low-income countries are not disproportionately impacted.

Access to healthcare: We were unable to identify closely comparable studies estimating the global cost of increasing antibiotic access. IHME model this intervention by estimating the potential

benefits of access *if* it meant countries achieve better bacterial infection outcomes. We develop an original modelling approach, fitting a Cobb-Douglas production function to estimate how resources (antibiotics and other healthcare) are transformed into health outcomes. We use this model to estimate that the additional funding required to close the antibiotic access gap is $59.0 billion annually. This estimate is subject to more limitations than the others because the healthcare resources required to achieve IHME's modelled benefits are highly uncertain.

Water, sanitation, and hygiene cost

In this section we estimate the cost for each country of the Institute for Health Metrics and Evaluation's (IHME) scenario of improving access to water, sanitation, and hygiene (WASH) based on the assumed coverage in their health modelling. This is part of the combined scenario covered by Vollset et al. (2024).

Hutton & Varughese (2016) provided the seminal estimates for the cost of scaling up WASH to achieve SDG 6.1 and 6.2 for 140 countries that still had a considerable gap in coverage. They estimate the annual cost for both global capital requirements ($113.7 billion) and operation and maintenance requirements ($128.8 billion) in 2015 USD. This is based on an original review of unit costs for WASH and data on coverage from the Joint Monitoring Programme; they combine these country specific values to produce bottom-up national estimates combined into regional and global estimates. UNICEF and the World Bank (2020) publish national estimates based on this method.

Strong et al. (2020) and WaterAid (2021) produce related estimates based extensively on Hutton and Varghuese (2016). Strong et al. (2020) only publish the global estimates (alongside national estimates for a small number of countries); they find the annual cost increased to $263.0 billion based on their updates. WaterAid (2021) report the WASH funding gap to be $115.5 billion (where we include a figure they cite for WASH in healthcare settings for comparability). Fox et al. (2019) produce more complete estimates, again based on Hutton and Varghuese but also estimating current cost of existing WASH infrastructure, in addition to funding needed to extend WASH coverage to achieve SDG 6.1 and 6.2. They find that the total cost of WASH infrastructure required is $200.0 billion for capital cost and $305.5 billion for operation and maintenance.

Joseph et al. (2024) estimate WASH spend and need with a different approach. They start their approach with top down estimates of gross capital formation from Fay et al. (2019) and use that to estimate water infrastructure spend, and then combine that with other data to estimate the total expenditure and funding gap in the water sector (including the drinking water and sanitation sub sector). They total annual required spend on WASH for 113 countries to be $210.3 billion.

As well as bottom-up estimates based on micro-costs, there are other country specific estimates collated by international organisations. The United Nations (2022) aggregates 90 estimates of

funding required to achieve national WASH plans, which relate to SDG 6.1 and 6.2 but may not match them completely if countries have plans more modest or extensive than those set out by the SDGs. Aggregating the 90 country estimates for financing requirements suggests that $63.0 billion is needed in those countries. In a separate part of the survey, 63 countries report current expenditure on WASH of $75.0 billion.

In terms of sub-categories within WASH, Ross et al. (2021) only estimates the hygiene portion of WASH for 46 less developed countries. They find extending coverage of hygiene alone is $1.4 billion, which includes activities like hygiene promotion that are often not included in other estimates. Importantly for antimicrobial resistant (AMR) infections, which are often acquired in healthcare settings, Chaitkin et al. (2022) estimate the cost of providing WASH in healthcare settings for the same 46 countries to be $7.9 billion between 2021–2030.

We base our estimates on those reported in the UNICEF and World Bank Tool. We take the estimated cost to achieve SDG 6.1 and 6.2 disaggregated by whether the spending is capital expenditure on new projects, or operation and maintenance costs. We then update these estimated funding gaps for IHME estimates of WASH coverage for 2021 (rather than 2015), this decreases the coverage gap and so the required funding.

We also inflate the costs into 2022 USD, consistent with all other costs in our study. In Table 1, we then compare the current estimated gap to IHME's reference case in 2050, as well as an intervention case where SDG 6.1 and 6.2 is reached. For completeness, we report the total cost to scale, maintain, and operate the WASH infrastructure in these 140 countries. In Table 2, we show the same results disaggregated by World Bank income group in dollar terms; in Table 3 we show them as a percentage of aggregated gross domestic product (GDP). Note that of the 204 geographies we model, only 140 have WASH cost data; the other 64 are either very small or are in high-income (HIC) or upper-middle-income countries, so do not require considerably greater WASH coverage. Therefore, our costs are now lower than those reported by Hutton and Varghuese (2016) or Strong et al. (2020), in spite of considerable inflation over that period in many geographies, because there is a greater level of WASH coverage to build on. Our estimates are higher than WaterAid (2021). Our overall total cost (including ongoing maintenance of the existing capital stock) is broadly comparable to Fox et al. (2019). See Appendix 2 for a table of intervention costs by country.

TABLE 1. Cost of WASH scenarios for 140 countries, by WASH sub-sector (US$ 2022, billion)

	Reference Cost	Intervention Cost	Total Cost
Water	35.6	96.4	230.0
Sanitation	58.2	112.0	288.7
Hygiene	2.0	6.6	23.7
Total	95.8	215.0	542.4

TABLE 2. Cost of WASH scenarios for 140 countries, by World Bank income group (US$ 2022, billion)

	Reference Cost	Intervention Cost	Total Cost
Low-income	8.2	32.4	42.7
Lower-middle-income	41.5	93.7	167.8
Upper-middle-income	45.6	88.0	327.9
High-income	Not included	Not included	Not included

TABLE 3. Cost of WASH scenarios as a percentage of GDP for 140 countries, by World Bank income group (% GDP)

	Reference Cost	Intervention Cost	Total Cost
Low-income	1.40%	5.54%	7.31%
Lower-middle-income	0.54%	1.22%	2.18%
Upper-middle-income	0.15%	0.28%	1.06%
High-income	Not included	Not included	Not included

Vaccine cost

In this section we estimate the cost for each country of IHME's scenario of improving access to vaccinations based on the assumed coverage in their health modelling. This is part of the combined scenario covered by Vollset et al. (2024).

Ozawa et al. (2012) review the evidence on the cost-effectiveness of vaccination in LMICs and conclude that most studies find vaccines are cost-effective and "*are an efficient investment.*"

Various studies have estimated the cost of scaling up vaccine coverage across countries. For instance, Vaughan et al. (2019) systematically review the evidence on the cost of vaccine delivery. They find the incremental delivery (and supply chain) cost per dose, for newly introduced childhood vaccines at health facilities ranged from $0.38 to $2.87 considering economic, financial and fiscal costs, with a mean of $1.27 and a median of $1.14 (in $US 2016). Other settings (e.g., schools) are likely to be higher cost (Vaughan et al., 2019). Portnoy et al. (2020) use 52 estimates of vaccine delivery costs from 29 studies to model estimates of delivery costs for LMICs. By income level, they estimate the cost per dose as $1.41 ($0.52–3.16) for low-income countries (LICs), $1.36 ($0.44–3.32) for lower-middle-income countries, and $2.59 ($0.82–6.38) for upper-middle-income countries. UNICEF (2022) estimate the cost of delivering COVID-19 vaccination across 133 LMICs. They find the unit delivery cost per vaccine is between 0.84–2.64 depending on the exact delivery approach; they are targeting COVID-19 vaccination at adults in this scenario, so it is not fully comparable to the other scenarios focusing on routine vaccination for a given birth cohort.

Several studies model estimates of the cost of vaccine delivery (vaccine costs and delivery costs) compared to estimated financing flows. Ozawa et al. (2016) first estimate the cost of overall vaccination programmes in 94 LMICs (73 then-GAVI-eligible countries and 21 others). They find the

overall cost 2016–2020 to be US$35.7 billion, compared to estimated vaccine financing available of US$28.1 billion, leading to an estimated gap of $7.6 billion ($4.6–$11.8 billion).

Sim et al. (2021) estimate vaccination costs as well as delivery costs. They find that the overall costs of immunisation programmes for 10 vaccines in 94 countries from 2011 to 2030 is $70.8 billion ($56.6–$93.3), which averages approximately $35.8 ($28.6–$47.2) per surviving infant. Sriudomporn et al. (2023) build on both Sim et al. (2021) and Osawa et al. (2016). They base their estimates of financing flows on IHME's Ikilezi et al. (2021) and unit costs on Sim et al. (2021). The total estimated cost of immunisation programmes for16 vaccines in 94 LMICs for the period 2011–2030 is $108.6 billion, resulting in a financing gap 2018–2030 of $30.0 billion.

The range of vaccines we cost follows IHME's modelling. We convert IHME's vaccine coverage assumptions 2022–2050 to estimates of additional infants vaccinated in their reference scenario, and intervention scenario (where uptake is assumed to be 100 percent). In Gavi-eligible countries we consider the incremental cost of moving from DTP-3 to a higher valency vaccine which also protects against HiB. This means there is no additional delivery cost associated with HiB vaccination, only the additional cost for a higher valency of vaccine. In other LMICs and high-income countries (HICs) we assume most infants are already receiving a higher valency (DTPHiB+) vaccine, so model the cost of increasing that vaccine only.

For vaccine dose costs we use the MI4A database from the World Health Organization (WHO). In Gavi-eligible countries and other LMICs, we sense checked the historic costs from MI4A with UNICEF (2024) product menu. We found them broadly consistent. For delivery costs in Gavi-eligible countries and other LMICs, we use illustrative figures that are consistent with available evidence.

For completeness we include approximate costs of vaccination in HICs. Though HICs are not the primary focus of interventions in this study; they are included because benefits derived from interventions are also modelled. Base delivery cost estimates are estimated based on the UK as an illustrative HIC with good data from Crocker-Buque et al. (2019). We also sense checked HIC costs estimates from MI4A by comparing to the British National Formulary, and found them broadly consistent.

In order to inflate the vaccine values from MI4A database, we estimate inflation according to the changes in costs reported in the database (where we control for vaccine type and geography). Our estimate of vaccine-specific cost inflation is 1.7 percent, which we use rather than the World Bank GDP deflator. We prefer this measure of changing costs because we were not sure whether to expect inflation or deflation in the price of vaccines specifically over this time. Table 4 shows our cost input assumptions.

TABLE 4. Per dose vaccine costs by vaccine type and setting (US$ 2022)

Vaccine	Setting	Vaccine Dose (per Dose)	Delivery Cost (per Dose)	Num Doses
DTP	Gavi	0.42	1.50	3
HiB	Gavi	0.57	0.00	3
MCV	Gavi	0.52	1.50	2
PCV	Gavi	3.46	1.50	3
Rotavirus	Gavi	1.64	1.50	*2.5
DTPHiB	Non-Gavi LMIC	5.11	2.50	3
MCV	Non-Gavi LMIC	5.29	2.50	2
PCV	Non-Gavi LMIC	13.11	2.50	3
Rotavirus	Non-Gavi LMIC	3.84	2.50	*2.5
DTPHiB	HIC	30.79	10.00	3
MCV	HIC	51.58	10.00	2
PCV	HIC	75.48	10.00	3
Rotavirus	HIC	49.22	10.00	*2.5

**Note:* Different Rotavirus vaccines are either 2 or 3 doses, so we assume 2.5 for all of them.

Table 5 shows our results. They show that there are considerable costs of increasing vaccination coverage in IHME's reference case, with $2.0 billion annually required to increase coverage. IHME's vaccination intervention scenario increases costs further to $4.6 billion. For completeness, we have also included the total cost of vaccinating the birth cohort with this range of vaccines. This cost appears broadly consistent with previous estimates which focus on a broader range of vaccines, but a more limited range of countries. See Appendix 2 for a table of intervention costs by country.

TABLE 5. Total annual cost per World Bank income group (US$ 2022, million)

	Reference	Intervention	Birth Cohort
Low-income	179	394	959
Lower-middle-income	783	1,464	4,152
Upper-middle-income	367	1,478	3,298
High-income	680	1,340	7,987
Total	2,009	4,676	16,396

The main limitation is that we do not estimate delivery costs for every country separately. This may be a particular limitation if patterns of service utilisation in a country allows for multiple vaccinations within a smaller number of appointments for infants.

Another limitation is that we do not incorporate the increase in patient acquisition costs as the level of vaccine coverage rises. Ozawa et al. (2018) find that delivery cost per dose increases substantially as coverage increases, which may reflect the increasing difficulty of reaching relatively harder-to-reach members of populations who disproportionately remain at higher levels of coverage.

Increased innovation and distribution of gram-negative antibiotics

In this section, we estimate the cost of innovation for new gram-negative antibiotics, that align with the assumptions in IHME's gram-negative drug scenario where the burden of disease from gram-negative resistant infections halves (GBD 2021 Antimicrobial Resistance Collaborators, 2024). IHME's scenario also requires access to these antibiotics to achieve the health benefits outlined in their paper, and the economic benefits that stem from these (GBD 2021 Antimicrobial Resistance Collaborators, 2024).

We assume that the world would follow a patent buyout model, such that the patent for a new innovative antibiotic is shifted into the public domain in return for a one-off payout to the innovator (or held by and international organisation). This model would allow access to be dictated by need and stewardship, at a price closer to marginal manufacturing costs (Anderson, 2014; Renwick et al., 2016). While this assumption would not necessarily be the model adopted in practice, it simplifies the costing, because we have to focus only on the required return for the private sector, rather modelling their launch incentives in different countries and differential pricing strategies they might adopt. We also do not have to cost associated healthcare in this scenario, because we assume patients already accessing generic antibiotics instead receive a more effective innovative one at a similar drug cost.

Innovation costs can be estimated by multiplying the cost for every new drug and by the number of new drugs needed. Unfortunately, however there is no consensus on how many new antibiotics the world needs. The number depends on the quality of the drugs, the breadth of bacteria they can treat, and how quickly bacteria develop resistance both to new drugs and existing drugs. The UK Independent Review on AMR (2016) recommends that 15 new antibiotics should be discovered over the next ten years "of which at least four would be breakthrough products targeting the bacterial species of greatest concern" (O'Neill, 2016). The Infectious Diseases Society of America recommended ten drugs per decade (Boucher et al., 2013). Towse & Bonnifield (2022) suggest that six drugs be developed per decade.

In this study we assume that ten drugs will need to be developed per decade. We also assume that two thirds of these new drugs would need to be gram-negative, this is roughly in line with both IHME's data on the burden of disease (GBD 2021 Antimicrobial Resistance Collaborators, 2024) and WHO's priority pathogen list (WHO, 2024).

Outterson & Rex (2020) estimate that a return of US$ 3.3 billion is needed to fund the development of each drug, or about US$ 2.2 billion per year for an average of 6.7 drugs per decade. We expect these costs to rise more rapidly than inflation, for several reasons. First, research costs tend to rise slightly more rapidly than inflation. This varies by disease area, country, and over time, but in the US for example research costs over the last twenty years have risen 0.5 percent faster than inflation (NIH, 2024). Second, getting a new treatment approved is costly, partly because of higher regulatory

standards and partly because new products must be better than existing ones, which becomes more challenging the better treatments become. The tendency for the cost of drug R&D to rise more quickly than inflation is known as Eroom's law (Scannell et al., 2012). Third, it seems likely that a large portion of natural antibiotic compounds have already been discovered; as the number of new treatments left to discover dwindles, the cost of discovery is likely to rise (Brown & Wright, 2016; McDonnell, Dissanayake, et al., 2024). For these reasons, we assume that research costs will rise at 2 percent above inflation.

Combining these figures gives an annual estimate of US$ 2.2 billion a year in 2024, this is equivariant to 0.0023 percent of the global GDP in 2024. Inflating these costs forward at 2 percent above inflation, would see annual costs in 2050 rise to US$3.7 billion in 2022 dollars, which would be 0.0022 percent of the expected global GDP in 2050. However, these are global estimates and decisions related to how these costs are divided up by different countries, some of them more progressive than others. We explore five different ways that the costs could be distributed—outlined from least to most progressive—in terms of how much countries contribute.

1. Weighted on share of antibiotic resistance
2. Weighted on population
3. Weighted on GDP
4. Only high-income countries pay, weighted on GDP
5. Weighted on a countries GDP over the World Bank's high-income country threshold (so that only high-income countries would pay and within this group wealthier countries pay a larger portion of their GDP)

As shown in Table 6, the different distributions lead to the financial burden falling on very different countries. Assigning cost based on need, either as measured by the burden of resistance, or population, leads to costs falling on low- and lower-middle-income countries which may be unsustainable given their more modest healthcare budgets. Also a very low share of the cost burden falls on HICs. Low-income countries would spend 220 times more as a share of GDP in the AMR weighting, and 43 times more in the population weighting scenarios. Sharing costs based on a share of GDP leads to countries spend 0.0023 percent of their GDP on an AMR solution, with HICs funding almost 60 percent of the cost. This scenario is still not equitable, as low-income countries still lag behind higher-income settings on the provision of some basic healthcare services, so the opportunity cost of this funding is still higher for poorer countries. The last two scenarios limit costs only to HICs, with the wealthiest countries within the high-income group spending far more when the amount over the HIC threshold is used to weight the burden, however the cost to HICs as a whole does not change.

We categorise countries based on the income bands they are in in 2022. However, many middle-income countries are expected to be considered high income by 2050, and a few to have done so by 2025; and as a consequence, would be expected to contribute a settlement in which only HICs pay.

TABLE 6. Share of cost by different income groups under different cost sharing assumptions, in 2024 and 2050. In million 2022 USD, cost as a share of GDP in parenthesis

Weighted By	Low-Income in 2022		Lower-Middle-Income in 2022		Upper-Middle-Income in 2022		High-Income in 2022	
Year	2024	2050	2024	2050	2024	2050	2024	2050
AMR burden	$434 (0.054%)	$710 (0.023%)	$1,193 (0.014%)	$1,960 (0.0082%)	$475 (0.0015%)	$767 (0.0013%)	$142 (0.0002%)	$245 (0.0003%)
Population	$205 (0.025%)	$512 (0.017%)	$892 (0.011%)	$1,550 (0.0064%)	$802 (0.0025%)	$1,117 (0.0019%)	$344 (0.0006%)	$503 (0.0006%)
GDP	$18 (0.0023%)	$66 (0.0022%)	$187 (0.0023%)	$523 (0.0022%)	$719 (0.0023%)	$1,275 (0.0022%)	$1,319 (0.0023%)	$1,817 (0.0022%)
High-income only GDP	$0(0%)	$0(0%)	$0(0%)	$0(0%)	$56 (0.0001%)	$1,404 (0.0024%)	$2,188 (0.0038%)	$2,278 (0.0027%)
GDP over high-income threshold	$0(0%)	$0(0%)	$0(0%)	$0(0%)	$3 (0.0001%)	$912 (0.0016%)	$2,241 (0.0039%)	$2,769 (0.0033%)

As dividing costs as a share of GDP only within HICs is an idea already widely put forward, and used by the UK government in the UK subscription model, to calculate what they see as their fair share of R&D costs (the UK originally weighted on GDP per capita our weighting 3, before moving to GDP per capita within HICs)(Berdud et al., 2022; NHS England, 2024). Given that HICs are likely to pay the majority of cost under any equitable scenario, politically it might also be sensible for them to fund R&D on their own, given that it requires coordination of a much smaller number of countries.

The biggest limitation in this study is that we do not know how many new antibiotics the world will need to keep gram-negative resistance in check. It is also difficult to know what level of investment is needed to generate each new drug and there are very real political questions about how these costs need to be shared across countries that it is difficult to know ex-anti.

Access to healthcare

Introduction

This scenario relates to the better care scenario estimated by IHME and published in GBD 2021 Antimicrobial Resistance Collaborators (2024) and Vollset et al. (2024).

There is considerable evidence on appropriate use of antibiotics at a patient level—for example the WHO AWaRe Book (Zanichelli et al., 2023). However, it is challenging to define appropriate use of antibiotics from aggregate data programmatically across countries. Analysis of access could focus on comparing volumes of drugs consumed by countries; however, different countries have different epidemiological and health system structures, that may mean the same course of action is more or less appropriate in a given setting. For instance, in a resource-constrained healthcare setting where infection control is particularly challenging, it will be necessary to treat the higher volumes of infections that result.

Conversely, in a HIC with considerable resources for diagnostics, testing before providing antibiotics may be totally appropriate, when infeasible given current resource allocation in a LIC.

IHME have modelled the health impacts of antibiotic access through a *what if* scenario, assessing *what if* health systems changed to improve outcomes for bacterial infection to those of the 85th percentile country in terms of outcomes. This scenario is valuable to demonstrate the potential benefits of greater access; however, it does not provide a clear view of what resources (and so costs) would be required to achieve it.

There are five important dimensions of access that will inform the health economic approach to costing:

1. **Divergent appropriate demand for antibiotics.** If there is a lack of basic infrastructure (like WASH) or prevention (like vaccination) or other epidemiological drivers (like climate, or demographics) then the appropriate use of antibiotics will vary considerably between different countries.
2. **A general lack of antibiotics.** Some people may completely forgo necessary treatment with antibiotics because they are unable to procure them.
3. **The wrong antibiotics.** Some people may purchase (or be prescribed) antibiotics that are not the most appropriate given their pathogen (and potential resistance).
4. **The *efficiency* of antibiotics distribution.** Some countries may use lots of antibiotics, but a lack of stewardship means that they are given to the wrong people, who receive little or no benefit from them.
5. **A lack of access to healthcare.** People may receive a sub-optimal level of related healthcare (e.g., testing, other medications, clinical oversight, inpatient-care). Someone who purchases the correct antibiotics over the counter may still have sub-optimal clinical management because they do not receive other aspects of healthcare.

Methods

The introduction sets out the many challenges in trying to cost antibiotic access appropriately. They suggest any effective costing needs to adjust for risk, allow for varying efficiency of transforming healthcare resources, and consider a lack of access in terms of antibiotics and other healthcare services. We use the best available data to estimate a Cobb-Douglas *production* function to model the transformation of healthcare resources into healthcare outcomes (Cobb & Douglas, 1928).

We use data from Browne et al. (2021), who estimate defined daily doses of antibiotics by GBD country. We use data from Moses et al. (2019) on health service provision, who estimate per capita outpatient and inpatient appointments by GBD country. We normalise all input indicators by dividing them by the maximum rate observed and multiplying by 100. We combine inpatient and outpatient healthcare indicators into a single variable healthcare.

For outcomes, we use GBD risk-adjusted estimates of amenable mortality for 6 GBD causes that include bacterial infections. These causes were originally collated in Haakenstad et al. (2022) to estimate the Health Access Quality Index. We use the absolute difference in risk-adjusted deaths for each outcomes measure. We also normalise this measure so the minimum lives lost becomes 100, and the maximum lives lost is 0. Therefore, our output has the interpretation of lives saved compared to a theoretical minimum level based on the lowest survival rate observed globally. We weighted each cause of death equally, because some of the causes of death (e.g., lower respiratory) are not bacterial only, so it would not be appropriate to weight by cause-specific numbers of deaths. We estimate New Zealand has the highest score of 99 and Somalia has the lowest score of 14.

We exclude countries with incomplete data leading to 195 out of 204 countries being represented.

We use estimates from (Laurence et al., 2025) for the average cost of susceptible bacterial infection costs in inpatient settings from using their headline model specification. We illustratively assume that 10 percent of the inpatient admission is antibiotic cost, based on Allel et al. (2024) and supported by a targeted review of other studies where the cost of antibiotics range from 0.5–30.0 percent of the admission cost (MacVane et al. (2014); Leistner et al. (2014); Iskandar et al. (2021); Cheah et al. (2013); Huang et al. (2018); Le et al. (2014)). We use outpatient cost estimates from the WHO-Choice Model (Bertram & Edejer, 2021). Finally, we include illustrative antibiotic prescription costs shown in Table 7 (Meena & Jayanthi (2021); Srivastava & Kantharia (2019); Zhu et al. (2021); Joint Formulary Committee (2024)[1]). It is important to note that while many antibiotics like doxycycline or amoxicillin may be available at low cost, a small number of less commonly used antibiotics are far more expensive. Also, in many countries around the world originator antibiotics are widely used despite being considerably more expensive than generics.

TABLE 7. Assumed mean cost per outpatient antibiotic prescription (2022 $US)

World Bank Income Group	Antibiotic Cost
Low-income	0.50
Lower-middle-income	1.50
Upper-middle-income	5.00
High-income	10.00

Using the following functional form, we estimate a Cobb Douglas production function:

$$Y = AH^{\alpha}M^{\beta} \quad (1)$$

Where:

- Y is health outcome
- A is our total factor productivity

1 We extract oral tablet costs of: Phenoxymethylpenicillin, Amoxicillin, Ciprofloxacin, Doxycycline, Cefalexin, and Linezolid to represent a range of antibiotic prices from BNF.

- H is overall healthcare
- M is medicine (antibiotic doses)
- α and β are parameters to be estimated showing how inputs lead to outputs

We log transform both sides of (1) yielding (2) to enable estimation using a linear regression model.

$$ln(Y) = ln(A) + \alpha\, ln(H) + \beta\, ln(M) \quad (2)$$

We estimate (2) with a linear regression model for the *average* productivity of transforming healthcare inputs into healthcare outputs estimates based on the regression across countries. We then keep estimates of α and β constant and use them to estimate A at a country level, and so estimate *country* specific total factor productivity.

We have to make some other assumptions and adjustments. We assume that:

1. The resources in countries with 85 percent percentile outcomes or above are left unchanged.
2. Countries will improve outcomes by increasing either input (H or M) depending on which has a higher marginal product of a 1-unit increase (where a unit is 1 percent of the maximum observed). We do not optimise based on cost, as that would likely lead to overuse of antibiotics.
3. Countries will not reduce current levels of antibiotic use or decrease admissions or outpatient appointments below current levels in order to increase access.
4. We do not observe bacterial inpatient admissions or outpatient appointments directly. Therefore, we estimate them by assuming that there are 30 doses of antibiotics associated with a relevant inpatient admission and 10 doses associated with a relevant outpatient admission. We assume at full access 10 percent of doses are delivered in inpatient settings when the access gap is closed. The other 90 percent are delivered in outpatient settings, as that is observed in Europe (ECDC, 2023). Countries that have a higher ratio of inpatient services to outpatient services in Moses et al. (2019) are assumed to currently deliver a higher proportion of doses in those settings, but this discrepancy is assumed to close somewhat as access increases. We assume that no antibiotics are currently distributed without appointments (to be consistent with our optimal scenario). Finally, we assume that all antibiotics are given for treatment (rather than prophylaxis). Patel et al. (2022), Moore et al. (2024) and Xavier et al. (2023) find 80 percent, 84 percent and 84 percent of antibiotics are given as treatment in hospitals in Japan, South Africa, and Mozambique, respectively.

We explore the implications of these assumptions in the limitations section.

Results

To demonstrate the challenge of estimating the increase in resources required, we first show observed data on the variability of the efficiency of the health production function with respect to antibiotics and other healthcare into patient outcomes. Figure 1 shows healthcare usage and antibiotic consumption, where dots are coloured by outcome quartiles. As the chart shows, some countries that have outcomes in the top quartile use relatively few antibiotics and have low healthcare utilisation (e.g., Costa Rica). Conversely, some countries are estimated to use above average levels of antibiotics, but achieve in the bottom quartile of outcomes (e.g., United Republic of Tanzania).

The results of our regression model are shown in Table 8. We estimate that total factor productivity is 32.74. We estimate both α and β to be below 1 and significant. Our estimate for α and β are very similar suggesting increasing healthcare and antibiotics are both essential to improve outcomes.

TABLE 8. Estimated parameters of the Cobb-Douglas health production function

Parameters	Estimate	Std_Error
A	32.74	1.11
α	0.13	0.03
β	0.15	0.03

Figure 2 shows isoquants of the different combinations of antibiotics and other healthcare required to achieve health outcomes at the 12.5th, 37.5th, 62.5th and 87.5th percentiles, respectively.

FIGURE 1. Antibiotic and healthcare service usage coloured by outcome quartiles

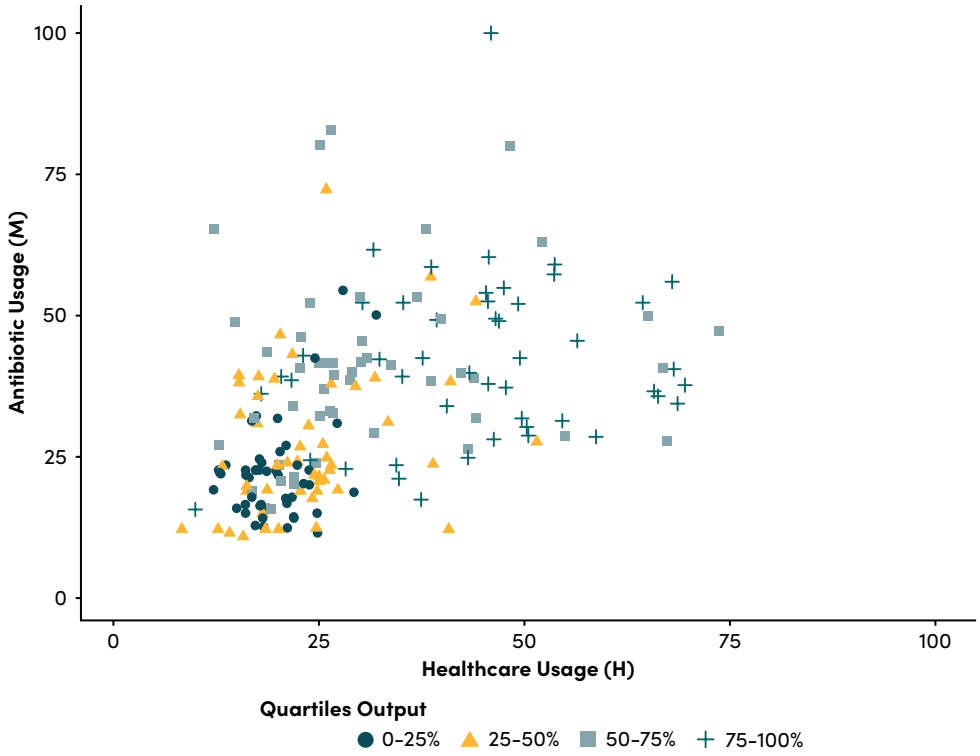


FIGURE 2. Isoquants of a Cobb-Douglas Production Function (for outcomes of bacterial infections due to inputs of antibiotics and other healthcare services)

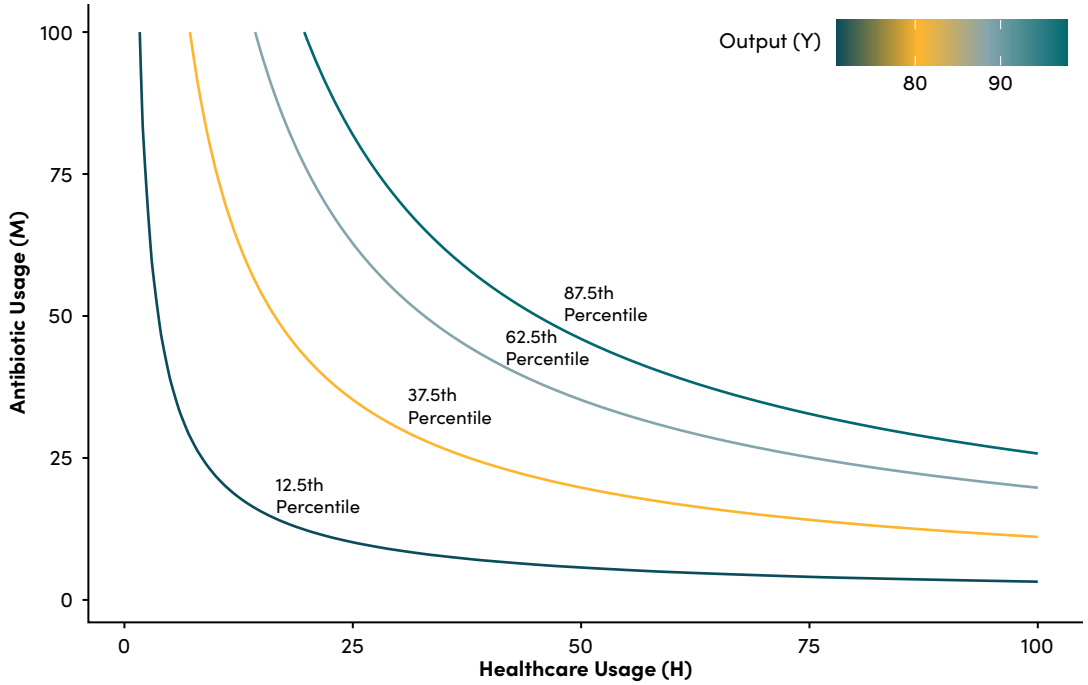


Figure 2 demonstrates that a country with half the maximum observed healthcare/antibiotics usage (a score of 50 on each axis) and average productivity is expected to achieve the 87.5th percentile of health outcomes. IHME model the potential gain from access as the 85th percentile in outcomes. The chart also demonstrates the low degree of substitutability estimated between these two inputs. At average productivity, low values of either variable cannot be compensated for with higher values of the other.

We can also estimate A (total factor productivity) for each of the countries with data. These estimates are subject to considerable uncertainty because all of our data come with considerable measurement error at a country level. We use both *average* and *country(-specific)* estimates of total factor productivity to estimate the requirement for additional resources to mitigate the access gap. Table 9 shows the results for average productivity and Table 10 for country productivity. The overall global cost is broadly similar between these two scenarios between $59.0 billion and $77.5 billion globally. In spite of low-income countries having the lowest gap in access to make up, lower health care costs mean it is less expensive than in lower-middle-income countries. The considerable divergence in cost for lower-middle-income countries between Table 9 and Table 10 is because LICs are estimated to have below average total factor productivity—with Somalia estimated to be a large outlier in this regard. The uncertainty in estimating total factor productivity at a country level means results based on the average are our preferred estimates. See Appendix 2 for a table of intervention costs by country.

TABLE 9. Average productivity: Absolute cost of the access intervention by World Bank group and cost type (2022 $US millions)

World Bank Income Group	Scenario	Antibiotics Inpatient	Antibiotics Outpatient	Healthcare Inpatient	Healthcare Outpatient	Total
Low-income	Average	294	242	2,488	1,100	4,125
Lower-middle-income	Average	1,183	1,414	22,428	10,378	35,403
Upper-middle-income	Average	4,539	1,243	5,120	3,591	14,493
High-income	Average	333	126	1,923	2,555	4,936
Total	Average	6,349	3,025	31,959	17,624	58,957

TABLE 10. Country productivity: Absolute cost of the access intervention by World Bank group and cost type (2022 $US millions)

World Bank Income Group	Scenario	Antibiotics Inpatient	Antibiotics Outpatient	Healthcare Inpatient	Healthcare Outpatient	Total
Low-income	Country	1,534	2,326	8,865	5,137	17,861
Lower-middle-income	Country	1,427	1,851	25,456	11,894	40,629
Upper-middle-income	Country	4,485	1,137	4,894	3,487	14,004
High-income	Country	354	135	1,941	2,553	4,983
Total	Country	7,800	5,449	41,156	23,071	77,477

Limitations

This analysis is subject to considerable uncertainty:

1. Data limitations in all of the underlying sources.
2. Simplifications in terms of treating antibiotics, inpatient, and outpatient care as substitutable when there is considerable heterogeneity within these categories. These distinctions matter, because an access gap could exist where the wrong antibiotics are available, and this may not be captured effectively in our framework.
3. We treat health as a linear outcome, where factors of production can be combined to save lives. However, our outcome is a somewhat arbitrary weighting of a selection of relevant causes. The minimum and maximum of our outcome are based on current observed data, rather than true minimum or maximum risk. This theoretical minimum or maximum is near impossible to motivate globally because it is likely to be highly variable based on non-healthcare interventions like nutrition and WASH (Armstrong et al., 1999). These minimum and maximum values inform the resulting values of total factor productivity across countries, and so different reasonable starting values could be the difference between saying low-income settings are marginally more or less productive than average. In the Appendix, we demonstrate the results of another outcome measure based on ranking rather than absolute values of outcome variables.

4. We assume that no antibiotics are distributed without appointments, this means there may be larger outpatient appointment gaps than we currently model. This effect is likely to be surprisingly small because many countries with high volumes of self-procured antibiotics also have large access gaps compared to outpatient appointment volumes.
5. We have to make somewhat arbitrary assumptions about dosing and steady state mix of inpatient and outpatient services that will not hold for every country around the world.
6. We do not consider scenarios where more effective stewardship or distribution of healthcare resources generally lead to better outcomes with fewer resources. The high variability of total factor productivity suggests a key role for infection control, stewardship, and policy interventions like regulatory approvals of a wider range of antibiotics or health technology assessment to allocate healthcare resources more effectively between patients.
7. We only adjust for epidemiology of bacterial infections at baseline to the extent Haakenstad et al. (2022) can adjust for it in their amenable mortality estimates. This risk adjustment is highly uncertain.
8. We implicitly assume highly elastic supply of healthcare resources because we use fixed unit costs when resources are being scaled up considerably. In practice, trying to achieve access scenarios over the short run would likely lead to considerable inflation in these unit costs.

Conclusion

This report provides country-level estimates for the cost of scaling up four interventions to combat antimicrobial resistance. These are the cost of access to WASH, vaccinations, improved innovation of gram-negative drugs, and access to quality healthcare. We are not aware of another AMR study that seeks to cost four interventions against AMR in this way. Heterogeneity between countries and different choices that might be made to rollout interventions mean that these results will not perfectly represent the true costs, but serve as a useful guide to the high-level cost of rolling out policies to combat resistance.

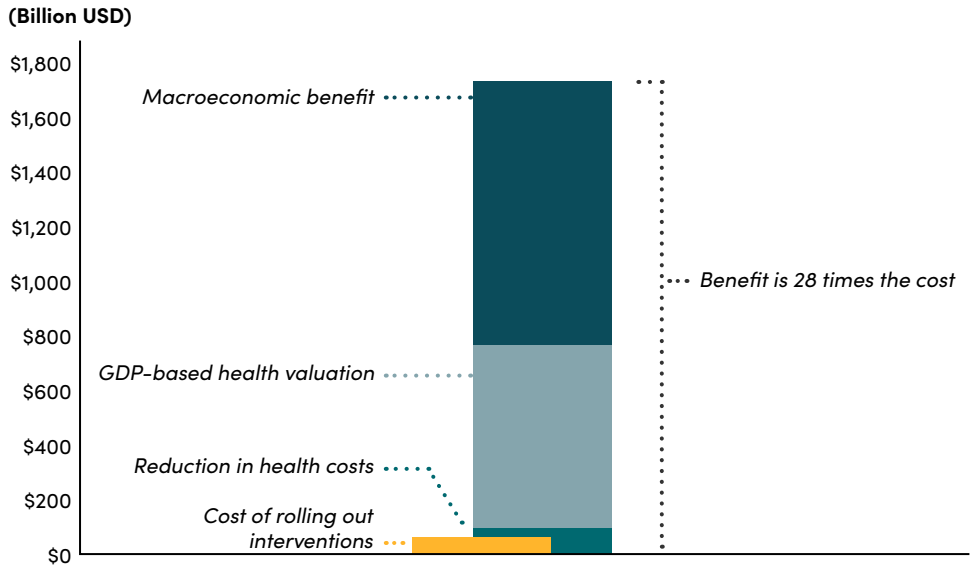
As highlighted in Table 11, the cost of rolling out improved water, sanitation, and hygiene (WASH) are far greater than the other three interventions. However this should not be seen as a reason not to invest in WASH. WASH will have huge benefits that will accrue far beyond the scope of AMR. In more holistic evaluations WASH has been shown to improve, education, nutrition, growth in children, and reduces many infectious diseases (Arnold et al., 2013; Pickering et al., 2019). It is not possible to make the economic case for universal WASH coverage based on AMR alone. Some more specific WASH interventions, such as providing clean water to health clinics, are likely to be better targeted at reducing AMR (McDonnell & Klemperer, 2022). Improved WASH coverage in healthcare settings would yield large benefits to other patient groups (WaterAid, 2021).

TABLE 11. Cost of rolling out different interventions by World Bank income group in million USD 2022

World Bank Income Group	Additional Wash	Vaccination	Innovation	Better Access
Low-income	32,400	394	0	4125
Lower-middle-income	93,700	1,464	0	35,403
Upper-middle-income	88,000	1,478	56	14,493
High-income	Not included	1,340	2,188	4,936
Total	215,000	4,676	2,244	58,957

Other work done as part of the EcoAMR series has looked at the wider return on investment from rolling out these interventions and show that for rolling out new-gram-negative antibiotics and improved access to health treatment would generate 28 times more in benefits than the cost of these policies as is shown in Figure 3 (McDonnell et al., 2024). This shows that in the long-term investing in new antibiotics and quality treatment for bacterial infections will save health systems money. They will also cause large macro-economic benefits and health benefits that are very valuable for their own sake.

FIGURE 3. Estimated annual costs (in US$) and benefits in 2050 of better treatment for bacterial infections and innovative new gram-negative drugs



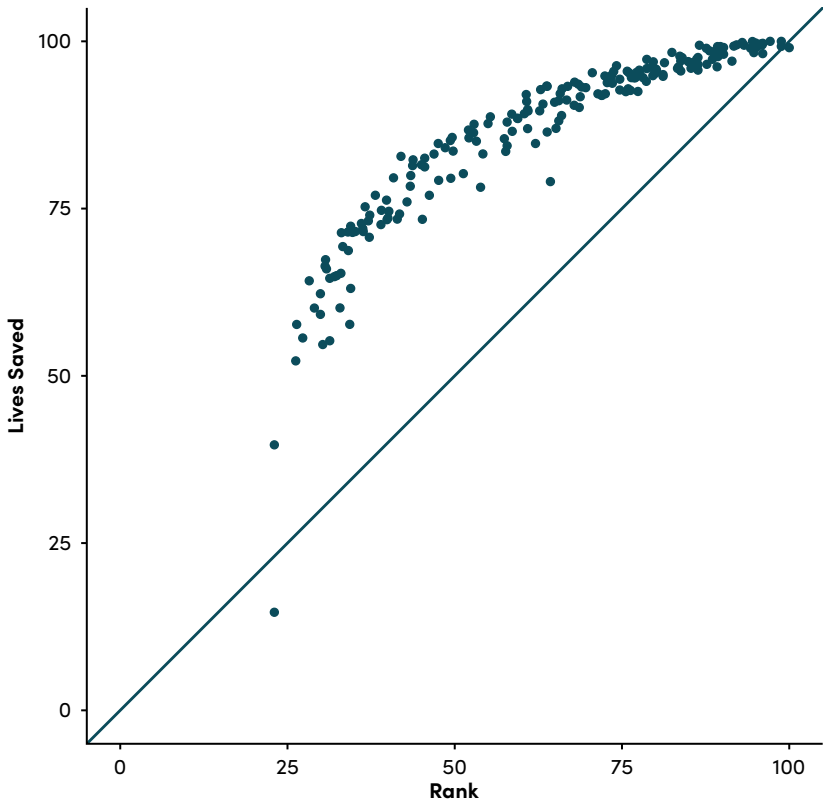
Finally, it is worth noting that the costs of all of these interventions tend to fall on low- and middle income countries more so than on HICs. This is because access to good healthcare treatment, vaccination, and WASH are much more likely to exist in the wealthiest countries. Given that all countries benefit from rolling out these policies, there is a compelling case for high-income countries providing assistance to LMICs to help them combat resistance.

Appendix 1: Sensitivity with ranked outcomes rather than lives saved

The Cobb-Douglas function we utilise is generally employed when considering production of physical goods. However, we are interested in health outcomes, which are considerably less tangible. One of the most subjective modelling choices we make is in the calculation of our outcome variable and which is then used to estimate the resources required to increase outcomes.

In this appendix, we instead normalise health outcomes such that the best performing country gets a score of 100 for that outcome. All other countries get a score out of 100 relative to them based on their rank on this outcome. We then average these ranks so the country with the best outcomes, Ireland, gets 93, whereas Somalia has the lowest mean rank of 12. Figure A1.1 shows a comparison between this rank outcome to our original lives saved outcome. They have a non-linear relationship because rank is inherently linear, but absolute health outcomes are diminishing, with relatively small differences for bacterial infection outcomes between countries with the highest outcomes.

FIGURE A1.1. Comparison between the lives saved and rank approach



This non-linear relationship is replicated in the Cobb-Douglas function where parameter values for α and β are now considerably higher, representing smaller diminishing returns of more healthcare or antibiotics on these newly linear health outcomes.

TABLE A1.1. Estimates of the Cobb-Douglas parameters for an alternative specification of the outcome

Parameters	Estimate	Std_Error
A	2.71	1.24
α	0.50	0.07
β	0.37	0.07

As Tables A1.1 and A1.2 demonstrate, the total costs estimated are now considerably higher than those reported in Tables 8 and 9. These costs are likely to be higher because there are many countries with outcomes relatively close to the highest performing countries in absolute terms, who are now ranked considerably below them. This leads to a larger general estimate of the access gap between countries. The difference between costs required for LICs between *average* and *country* productivity scenarios is much lower, suggesting that estimation of total factor productivity is highly sensitive to the choice of outcome measure.

TABLE A1.2. Ranked outcome sensitivity average productivity: Absolute cost of the access intervention by World Bank group and cost type (2022 $US millions)

World Bank Income Group	Scenario	Antibiotics Inpatient	Antibiotics Outpatient	Healthcare Inpatient	Healthcare Outpatient	Total
Low-income	Average	188	131	3,555	1,495	5,369
Lower-middle-income	Average	927	808	40,018	17,237	58,990
Upper-middle-income	Average	7,518	2,582	19,948	9,069	39,117
High-income	Average	41	30	4,413	7,118	11,602
Total	Average	8,674	3,551	67,934	34,919	115,078

TABLE A1.3. Ranked outcome sensitivity country productivity: Absolute cost of the access intervention by World Bank group and cost type (2022 $US millions)

World Bank Income Group	Scenario	Antibiotics Inpatient	Antibiotics Outpatient	Healthcare Inpatient	Healthcare Outpatient	Total
Low-income	Country	304	227	5,168	2,048	7,748
Lower-middle-income	Country	1,186	1,278	45,261	19,933	67,658
Upper-middle-income	Country	9,749	2,127	17,913	7,817	37,605
High-income	Country	211	26	4,420	6,072	10,729
Total	Country	11,450	3,658	72,762	35,870	123,740

Appendix 2: Country level estimates

This appendix contains only reference estimates of the cost of interventions at a country level. These estimates are based on uncertain modelling, and so are subject to considerable uncertainty, which has not been quantified here. National estimates based on local data may be more likely to represent the true cost of these interventions. If national estimates are unavailable, these estimates may offer an indication based on globally available evidence. The cost of innovation is not included in this table, as this is ultimately a global cost, and how it is divided between countries will have to be a political decision.

TABLE A2.1. Estimated country intervention costing results (2022 $US million)

GBD Country	WASH	Vaccination	Healthcare Access
Afghanistan	692.2	30.7	270.6
Albania	62.2	0.2	37.8
Algeria	1,672.4	36.3	734.1
American Samoa	NA	0.1	0.4
Andorra	NA	0.0	0.0
Angola	3,125.4	81.6	355.4
Antigua and Barbuda	NA	0.4	0.5
Argentina	1,313.7	14.5	472.2
Armenia	58.3	0.2	6.1
Australia	NA	12.1	0.0
Austria	NA	9.0	0.0
Azerbaijan	584.9	5.4	142.0
Bahamas	NA	0.6	12.5
Bahrain	NA	0.6	32.3
Bangladesh	3,749.1	20.8	1,903.9
Barbados	NA	0.6	3.9
Belarus	213.9	5.0	14.4
Belgium	NA	8.7	0.0
Belize	28.7	0.5	2.7
Benin	359.2	4.4	100.5
Bermuda	NA	0.0	0.0
Bhutan	24.8	0.2	16.5
Bolivia (Plurinational State of)	275.0	7.7	430.9
Bosnia and Herzegovina	58.0	1.8	6.0
Botswana	221.8	1.7	69.6
Brazil	7,821.8	67.9	1,147.9
Brunei Darussalam	NA	2.6	7.1
Bulgaria	62.7	0.7	27.0
Burkina Faso	827.1	5.4	336.5
Burundi	349.5	1.4	19.4
Cabo Verde	29.2	0.5	5.0
Cambodia	321.8	3.8	67.4

TABLE A2.1. (Continued)

GBD Country	WASH	Vaccination	Healthcare Access
Cameroon	1,281.8	10.0	217.9
Canada	NA	47.3	0.0
Central African Republic	127.7	2.3	38.0
Chad	1,425.6	35.6	123.3
Chile	NA	52.0	52.7
China	27,770.3	640.3	3,883.2
Colombia	1,692.6	10.6	40.0
Comoros	54.4	0.4	3.3
Congo	360.8	1.7	43.3
Cook Islands	0.7	NA	NA
Costa Rica	424.3	0.6	5.5
Cote d'Ivoire	1,832.0	10.4	247.7
Croatia	NA	6.9	0.0
Cuba	270.8	5.9	16.2
Cyprus	NA	2.4	0.0
Czechia	NA	38.0	16.7
Democratic People's Republic of Korea	136.2	8.2	18.4
Democratic Republic of the Congo	4,248.7	64.4	253.6
Denmark	NA	11.0	0.0
Djibouti	77.7	0.4	16.7
Dominica	3.0	0.0	0.9
Dominican Republic	896.7	7.1	50.7
Ecuador	627.2	10.1	398.6
Egypt	2,401.9	150.6	712.4
El Salvador	381.4	1.3	48.0
Equatorial Guinea	150.7	3.1	31.9
Eritrea	562.1	0.2	23.2
Estonia	NA	3.8	3.5
Eswatini	79.6	0.4	33.8
Ethiopia	7,611.3	56.7	536.2
Fiji	25.3	0.3	6.4
Finland	NA	4.7	0.0
France	NA	139.6	0.0
Gabon	305.9	3.0	22.5
Gambia	63.7	0.5	7.3
Georgia	66.5	1.1	14.9
Germany	NA	51.1	0.0
Ghana	1,687.4	3.1	203.0
Greece	NA	13.2	74.3
Greenland	NA	0.1	0.3
Grenada	3.0	0.1	0.3
Guam	NA	0.8	5.6
Guatemala	785.7	9.9	99.2

TABLE A2.1. (Continued)

GBD Country	WASH	Vaccination	Healthcare Access
Guinea	734.3	13.9	163.4
Guinea-Bissau	82.3	0.7	9.5
Guyana	14.9	0.2	8.5
Haiti	461.1	4.9	100.7
Honduras	625.9	4.4	28.6
Hungary	NA	11.2	0.0
Iceland	NA	1.0	0.0
India	30,072.4	608.0	13,624.5
Indonesia	7,630.6	273.9	1,104.8
Iran (Islamic Republic of)	6,311.5	67.7	1,023.7
Iraq	3,897.6	45.7	421.9
Ireland	NA	4.9	0.0
Israel	NA	13.2	0.0
Italy	NA	26.5	0.0
Jamaica	169.1	1.9	7.6
Japan	NA	39.8	0.0
Jordan	270.5	14.7	37.3
Kazakhstan	863.9	7.9	49.1
Kenya	2,687.3	6.5	560.3
Kiribati	2.0	0.2	0.8
Kuwait	NA	3.4	0.0
Kyrgyzstan	108.9	0.9	14.5
Lao People's Democratic Republic	158.2	2.7	67.8
Latvia	NA	1.0	4.1
Lebanon	112.7	7.6	57.0
Lesotho	145.5	0.2	37.3
Liberia	152.6	1.8	10.7
Libya	344.6	0.7	99.4
Lithuania	NA	3.4	11.7
Luxembourg	NA	0.4	0.0
Madagascar	1,838.0	22.4	66.0
Malawi	738.8	3.6	137.9
Malaysia	1,797.2	14.4	347.2
Maldives	16.2	0.4	10.6
Mali	850.5	13.6	205.5
Malta	NA	0.7	0.0
Marshall Islands	2.4	0.1	0.5
Mauritania	426.6	1.8	22.0
Mauritius	51.5	0.4	11.7
Mexico	5,139.7	74.3	260.0
Micronesia (Federated States of)	3.3	0.1	0.9
Monaco	NA	NA	NA
Mongolia	136.3	2.7	53.4

TABLE A2.1. (Continued)

GBD Country	WASH	Vaccination	Healthcare Access
Montenegro	9.1	0.5	6.4
Morocco	1,419.2	4.4	566.1
Mozambique	2,276.1	3.7	203.2
Myanmar	1,726.3	13.4	406.5
Namibia	263.9	0.9	55.9
Nauru	0.3	NA	NA
Nepal	598.5	2.9	464.0
Netherlands	NA	34.5	0.0
New Zealand	NA	5.3	0.0
Nicaragua	381.7	0.0	4.5
Niger	1,071.7	15.3	115.0
Nigeria	16,799.2	199.3	6,084.1
Niue	NA	NA	NA
North Macedonia	38.0	0.9	22.9
Northern Mariana Islands	NA	0.1	1.4
Norway	NA	2.0	0.0
Oman	NA	13.5	140.2
Pakistan	4,299.8	27.5	3,087.0
Palau	1.2	NA	NA
Palestine	NA	1.4	32.0
Panama	183.7	8.5	9.4
Papua New Guinea	518.2	9.9	70.0
Paraguay	224.0	4.9	164.6
Peru	819.9	20.2	219.7
Philippines	2,586.6	87.1	324.0
Poland	NA	57.7	77.2
Portugal	NA	11.2	16.1
Puerto Rico	NA	4.7	63.9
Qatar	NA	0.5	17.7
Republic of Korea	NA	63.7	63.7
Republic of Moldova	67.7	0.6	4.2
Romania	659.4	34.3	196.7
Russian Federation	5,794.7	30.5	265.3
Rwanda	457.0	0.5	121.8
Saint Kitts and Nevis	NA	NA	NA
Saint Lucia	10.3	0.1	0.5
Saint Vincent and the Grenadines	5.7	0.1	0.3
Samoa	2.9	0.6	1.2
San Marino	NA	NA	NA
Sao Tome and Principe	14.0	0.0	3.0
Saudi Arabia	NA	14.0	1,030.4
Senegal	737.8	1.5	85.1
Serbia	109.4	1.9	33.0

TABLE A2.1. (Continued)

GBD Country	WASH	Vaccination	Healthcare Access
Seychelles	9.5	0.0	6.1
Sierra Leone	281.7	1.7	25.7
Singapore	NA	14.1	9.0
Slovakia	NA	7.0	22.7
Slovenia	NA	4.3	0.0
Solomon Islands	11.3	0.1	3.8
Somalia	359.8	31.0	230.6
South Africa	3,469.5	14.7	1,539.6
South Sudan	794.4	17.9	55.5
Spain	NA	60.3	0.0
Sri Lanka	490.7	17.3	203.6
Sudan	2,132.4	12.7	129.8
Suriname	31.5	0.7	6.1
Sweden	NA	5.5	0.0
Switzerland	NA	16.5	0.0
Syrian Arab Republic	869.7	7.8	135.6
Taiwan (Province of China)	NA	30.1	0.0
Tajikistan	143.4	5.0	175.1
Thailand	2,597.4	28.6	556.1
Timor-Leste	97.9	2.2	12.5
Togo	313.2	1.6	37.0
Tokelau	NA	NA	NA
Tonga	2.9	0.1	0.7
Trinidad and Tobago	NA	3.8	21.3
Tunisia	299.8	3.3	139.1
Turkey	2,079.3	32.9	1,317.9
Turkmenistan	208.8	0.3	40.7
Tuvalu	0.1	NA	NA
Uganda	1,956.2	18.3	272.0
Ukraine	923.5	24.4	68.6
United Arab Emirates	NA	5.0	1,134.3
United Kingdom	NA	53.6	0.0
United Republic of Tanzania	4,132.3	12.3	1,378.3
United States Virgin Islands	NA	0.3	1.9
United States of America	NA	369.5	1,865.8
Uruguay	NA	7.8	22.8
Uzbekistan	477.9	3.0	80.2
Vanuatu	7.1	0.6	2.5
Venezuela (Bolivarian Republic of)	2,273.2	40.4	337.8
Viet Nam	2,741.7	84.1	2,264.4
Yemen	839.2	12.3	294.3
Zambia	1,970.4	5.3	252.3
Zimbabwe	1,321.4	2.3	347.6

References

Allel, K., Hernández-Leal, M. J., Naylor, N. R., Undurraga, E. A., Abou Jaoude, G. J., Bhandari, P., Flanagan, E., Haghparast-Bidgoli, H., Pouwels, K. B., & Yakob, L. (2024). Costs-effectiveness and cost components of pharmaceutical and non-pharmaceutical interventions affecting antibiotic resistance outcomes in hospital patients: a systematic literature review. *BMJ Glob. Health*, *9*(2), e013205.

Anderson, J. (2014). Developing and Conserving Innovative Antibiotics – De-Linking Volumes from Sales. *Proposed Models for Antibiotic Innovation and Conservation: Technical Consultation on Antibiotic Innovation*. https://cdn.who.int/media/docs/default-source/antimicrobial-resistance/amr-gcp-irc-website/proposedmodels-technicalconsultationantibioticinnovation-2014-05-13.pdf?sfvrsn=d4629130_4

Armstrong, G. L., Conn, L. A., & Pinner, R. W. (1999). Trends in infectious disease mortality in the United States during the 20th century. *JAMA*, *281*(1), 61–66.

Arnold, B. F., Null, C., Luby, S. P., Unicomb, L., Stewart, C. P., Dewey Kathryn G and Ahmed, T., Ashraf, S., Christensen, G., Clasen, T., Dentz, H. N., Fernald, L. C. H., Haque, R., Hubbard, A. E., Kariger, P., Leontsini, E., Lin, A., Njenga, S. M., Pickering, A. J., Ram, P. K., … Colford Jr, J. M. (2013). Cluster-randomised controlled trials of individual and combined water, sanitation, hygiene and nutritional interventions in rural Bangladesh and Kenya: the WASH Benefits study design and rationale. *BMJ Open*, *3*(8), e003476.

Berdud, M., Kourouklis, D., Brassel, S., Towse, A., Steuten, L., & Firth, I. (2022). *The Economics of Antibiotics – Part 3: Creating a Healthy Global Market for New Antibiotics*. https://www.ohe.org

Bertram, M. Y., & Edejer, T. T. T. (2021). Introduction to the special issue on "the World Health Organization CHOosing Interventions that are cost-Effective (WHO-CHOICE) update". *Int. J. Health Policy Manag.*, *10*(11), 670–672.

Boucher, H. W., Talbot, G. H., Benjamin Jr, D. K. and B. J., Guidos, R. J., Jones, R. N., Murray, B. E., Bonomo, R. A., Gilbert, D., & Infectious Diseases Society of America. (2013). 10 x '20 Progress–development of new drugs active against gram-negative bacilli: an update from the Infectious Diseases Society of America. *Clin. Infect. Dis.*, *56*(12), 1685–1694.

Brown, E. D., & Wright, G. D. (2016). Antibacterial drug discovery in the resistance era. *Nature*, *529*(7586), 336–343.

Browne, A. J., Chipeta, M. G., Haines-Woodhouse, G., Kumaran, E. P. A., Hamadani, B. H. K., Zaraa, S., Henry, N. J., Deshpande, A., Reiner Jr, R. C., Day, N. P. J., Lopez, A. D., Dunachie, S., Moore, C. E., Stergachis, A., Hay, S. I., & Dolecek, C. (2021). Global antibiotic consumption and usage in humans, 2000–18: a spatial modelling study. *Lancet Planet. Health*, *5*(12), e893–e904.

Chaitkin, M., McCormick, S., Alvarez-Sala Torreano, J., Amongin, I., Gaya, S., Hanssen, O. N., Johnston, R., Slaymaker, T., Chase, C., Hutton, G., & Montgomery, M. (2022). Estimating the cost of achieving basic water, sanitation, hygiene, and waste management services in public health-care facilities in the 46 UN designated least-developed countries: a modelling study. *The Lancet Global Health*, *10*(6), e840–e849. https://doi.org/10.1016/S2214-109X(22)00099-7

Cheah, A. L. Y., Spelman, T., Liew, D., Peel, T., Howden, B. P., Spelman, D., Grayson, M. L., Nation, R. L., & Kong, D. C. M. (2013). Enterococcal bacteraemia: factors influencing mortality, length of stay and costs of hospitalization. *Clin. Microbiol. Infect.*, *19*(4), E181–9.

Cobb, C. W., & Douglas, P. H. (1928). A Theory of Production. *The American Economic Review*, *18*(1), 139–165.

Crocker-Buque, T., Mohan, K., Ramsay, M., Edelstein, M., & Mounier-Jack, S. (2019). What is the cost of delivering routine vaccinations at GP practices in England? A comparative time-driven activity-based costing analysis. *Hum. Vaccin. Immunother.*, *15*(12), 3016–3023.

ECDC. (2023). *Antimicrobial consumption in the EU/EEA (ESAC-Net) - Annual Epidemiological Report for 2022*. https://www.ecdc.europa.eu/en/publications-data/surveillance-antimicrobial-consumption-europe-2022

Fay, M., Lee, H. Il, Mastruzzi, M., Han, S., & Cho, M. (2019). *Hitting the Trillion Mark A Look at How Much Countries Are Spending on Infrastructure*. https://openknowledge.worldbank.org/server/api/core/bitstreams/36b3f2e0-f27f-5f81-a858-84167e75767b/content

Fox, Charles J. E., Lopez-Alascio, B., Fay, M., Nicolas, C., & Rozenberg, J. (2019). *Beyond the Gap: Chapter 2 Water, Sanitation, and Irrigation*. https://documents1.worldbank.org/curated/en/189471550755819133/pdf/134795-vol-1-33256cmp-eProof-rev.pdf

GBD 2021 Antimicrobial Resistance Collaborators. (2024). Global burden of bacterial antimicrobial resistance 1990–2021: a systematic analysis with forecasts to 2050. *Lancet*, *404*(10459), 1199–1226.

Haakenstad, A., & GBD 2019 Healthcare Access Quality Collaborators. (2022). Assessing performance of the Healthcare Access and Quality Index, overall and by select age groups, for 204 countries and territories, 1990–2019: a systematic analysis from the Global Burden of Disease Study 2019. *Lancet Glob. Health*, *10*(12), e1715–e1743.

Huang, W., Qiao, F., Zhang, Y., Huang Jing and Deng, Y., Li, J., & Zong, Z. (2018). In-hospital medical costs of infections caused by carbapenem-resistant Klebsiella pneumoniae. *Clin. Infect. Dis.*, *67*(suppl_2), S225–S230.

Hutton, G., & Varughese, M. (2016). *The Costs of Meeting the 2030 Sustainable Development Goal Targets on Drinking Water, Sanitation, and Hygiene*. https://openknowledge.worldbank.org/entities/publication/cfbfaf80-3930-5ffd-a5bf-6ded12a1340e

Ikilezi, G., Micah, A. E., Bachmeier, S. D., Cogswell, I. E., Maddison, E. R., Stutzman Hayley N and Tsakalos, G., Brenzel, L., & Dieleman, J. L. (2021). Estimating total spending by source of funding on routine and supplementary immunisation activities in low-income and middle-income countries, 2000–17: a financial modelling study. *Lancet*, *398*(10314), 1875–1893.

Iskandar, K., Roques, C., Hallit, S., Husni-Samaha, R., Dirani, N., Rizk, R., Abdo, R., Yared, Y., Matta, M., Mostafa, I., Matta, R., Salameh, P., & Molinier, L. (2021). The healthcare costs of antimicrobial resistance in Lebanon: a multi-centre prospective cohort study from the payer perspective. *BMC Infect. Dis.*, *21*(1), 404.

Joint Formulary Committee. (2024). *British National Formulary*. https://bnf.nice.org.uk/

Joseph, G., Hoo, Y. R., Wang, Q., Bahuguna, A., & Andres, L. (2024). *FUNDING A WATER-SECURE FUTURE An Assessment of Global Public Spending*. https://documents.worldbank.org/en/publication/documents-reports/documentdetail/099050624154572979/p172944100adb1042188ab1d289e7f2f00b

Laurence, T., Lamberti, O., Smith, R., Drake, T., & McDonnell, A. (2025). The Global Direct Inpatient Cost of Antimicrobial Resistance: A Modelling Study. https://www.cgdev.org/publication/global-direct-inpatient-cost-antimicrobial-resistance-modelling-study

Le, P., Griffiths, U. K., Anh, D. D., Franzini, L., Chan, W., Pham, H., & Swint, J. M. (2014). The economic burden of pneumonia and meningitis among children less than five years old in Hanoi, Vietnam. *Trop. Med. Int. Health*, *19*(11), 1321–1327.

Leistner, R., Bloch, A., Sakellariou, C., Gastmeier, P., & Schwab, F. (2014). Costs and length of stay associated with extended-spectrum β-lactamase production in cases of Escherichia coli bloodstream infection. *J. Glob. Antimicrob. Resist.*, *2*(2), 107–109.

MacVane, S. H., Tuttle, L. O., & Nicolau, D. P. (2014). Impact of extended-spectrum β-lactamase-producing organisms on clinical and economic outcomes in patients with urinary tract infection. *J. Hosp. Med.*, *9*(4), 232–238.

McDonnell, A., Countryman, A., Laurence, T., Gulliver, S., Drake, T., Edwards, S., Kenny, C., Lamberti, O., Morton, A., Shafira, A., Smith, R., & Guzman, J. (2024). *Forecasting the Fallout from AMR: Averting the Health and Economic Impacts through One Health Policy and Investment*. https://doi.org/10.20506/ecoAMR.3544

McDonnell, A., Dissanayake, R., Klemperer, K., Toxvaerd, F., & Sharland, M. (2024). *The Economics of Antibiotic Resistance* (Issue 682). https://www.cgdev.org/publication/economics-antibiotic-resistance

McDonnell, A., & Klemperer, K. (2022). *WASHing Away Resistance: Why the UK Should Invest in Water, Sanitation, and Hygiene to Tackle Anti-Microbial Resistance*. https://www.cgdev.org/sites/default/files/washing-away-resistance-why-uk-should-invest-water-sanitation-and-hygiene-tackle-AMR.pdf

Meena, D. K., & Jayanthi, M. (2021). Cost analysis of different antibiotic brands available in Indian market with reference to National List of Essential Medicines. *Indian J. Community Med.*, *46*(1), 93–96.

Moore, D. P., Chetty, T., Pillay, A., Karsas, M., Cloete, J., Balakrishna Yusentha and Reddy, T., Archary, M., van Kwawegen, A., Thomas, R., Nakwa, F. L., Waggie Zainab and Magrath, S., Goga, A., & Jeena, P. (2024). Antibiotic and antifungal use in paediatric departments at three academic hospitals in South Africa. *IJID Reg.*, *10*, 151–158.

Moses, M. W., Pedroza, P., Baral, R., Bloom, S., Brown, J., Chapin, A., Compton Kelly and Eldrenkamp, E., Fullman, N., Mumford, J. E., Nandakumar, V., Rosettie, K., Sadat, N., Shonka, T., Flaxman, A., Vos Theo and Murray, C. J. L., & Weaver, M. R. (2019). Funding and services needed to achieve universal health coverage: applications of global, regional, and national estimates of utilisation of outpatient visits and inpatient admissions from 1990 to 2016, and unit costs from 1995 to 2016. *Lancet Public Health*, *4*(1), e49–e73.

National Institutes of Health (NIH). (2024). *Biomedical Research and Development Price Index: Fiscal Year 2023 Update and Projections for FY 2024–FY 2029*.

NHS England. (2024). *Antimicrobial Products Subscription Model: Guidance on Commercial Arrangements*. https://www.england.nhs.uk/long-read/antimicrobial-products-subscription-model-guidance-on-commercial-arrangements/

O'Neill, J. (2016). *Tackling Drug-Resistant Infections Globally: Final Report and Recommendations (O'Neill Review)*. https://amr-review.org/sites/default/files/160518_Final%20paper_with%20cover.pdf

Outterson, K., & Rex, J. H. (2020). Evaluating for-profit public benefit corporations as an additional structure for antibiotic development and commercialization. *Transl. Res.*, *220*, 182–190.

Ozawa, S., Grewal, S., Portnoy, A., Sinha, A., Arilotta, R., Stack, M. L., & Brenzel, L. (2016). Funding gap for immunization across 94 low- and middle-income countries. *Vaccine*, *34*(50), 6408–6416.

Ozawa, S., Mirelman, A., Stack, M. L., Walker, D. G., & Levine, O. S. (2012). Cost-effectiveness and economic benefits of vaccines in low- and middle-income countries: a systematic review. *Vaccine*, *31*(1), 96–108.

Ozawa, S., Yemeke, T. T., & Thompson, K. M. (2018). Systematic review of the incremental costs of interventions that increase immunization coverage. *Vaccine*, *36*(25), 3641–3649.

Patel, P. K., Satoh, N., Narita, M., Cho, Y., Oshiro, Y., Suzuki, T., Fowler, K. E., Greene, M. T., Tokuda, Y., & Kaye, K. S. (2022). Inpatient antibiotic prescribing patterns using the World Health Organization (WHO) Access Watch and Reserve (AWaRe) classification in Okinawa, Japan: A point-prevalence survey. *Antimicrob. Steward. Healthc. Epidemiol.*, *2*(1), e155.

Pickering, A. J., Null, C., Winch, P. J., Mangwadu, G., Arnold, B. F., Prendergast, A. J., Njenga, S. M., Rahman, M., Ntozini, R., Benjamin-Chung, J., Stewart, C. P., Huda, T. M. N., Moulton, L. H., Colford Jr, J. M., Luby, S. P., & Humphrey, J. H. (2019). The WASH Benefits and SHINE trials: interpretation of WASH intervention effects on linear growth and diarrhoea. *Lancet Glob. Health*, *7*(8), e1139–e1146.

Portnoy, A., Vaughan, K., Clarke-Deelder Emma and Suharlim, C., Resch, S. C., & Brenzel Logan and Menzies, N. A. (2020). Producing standardized country-level immunization delivery unit cost estimates. *Pharmacoeconomics*, *38*(9), 995–1005.

Renwick, M. J., Brogan, D. M., & Mossialos, E. (2016). A systematic review and critical assessment of incentive strategies for discovery and development of novel antibiotics. *J. Antibiot. (Tokyo)*, *69*(2), 73–88.

Ross, I., Esteves Mills, J., Slaymaker, T., Johnston, R., Hutton, G., Dreibelbis, R., & Montgomery, M. (2021). Costs of hand hygiene for all in household settings: Estimating the price tag for the 46 least developed countries. *BMJ Global Health*, *6*(12). https://doi.org/10.1136/bmjgh-2021-007361

Scannell, J. W., Blanckley, A., Boldon, H., & Warrington, B. (2012). Diagnosing the decline in pharmaceutical R&D efficiency. *Nat. Rev. Drug Discov.*, *11*(3), 191–200.

Sim, S. Y., Watts, E., Constenla, D., Huang, S., Brenzel, L., & Patenaude, B. N. (2021). Costs of immunization programs for 10 vaccines in 94 low- and middle-income countries from 2011 to 2030. *Value Health*, *24*(1), 70–77.

Sriudomporn, S., Sim, S. Y., Mak, J., Brenzel, L., & Patenaude, B. N. (2023). Financing and funding gap for 16 vaccines across 94 low- and middle-income countries, 2011-30. *Health Aff. (Millwood)*, *42*(1), 94–104.

Srivastava, R., & Kantharia, N. D. (2019). Analysis of price variation of some commonly used antibacterial agents. *Int. J. Basic Clin. Pharmacol.*, *8*(7), 1567.

Strong, C., Kuzma, S., Vionnet, S., & Reig, P. (2020). *Achieving Abundance: Understanding The Cost of a Sustainable Water Future*. https://files.wri.org/d8/s3fs-public/achieving-abundance.pdf

Towse, A., & Bonnifield, R. S. (2022). *An Ambitious USG Advanced Commitment for Subscription-Based Purchasing of Novel Antimicrobials and Its Expected Return on Investment* (Issue 277). https://www.cgdev.org/publication/ambitious-usg-advanced-commitment-subscription-based-purchasing-novel-antimicrobials

UN. (2022). *Strong Systems and Sound Investments Evidence on and Key Insights Into Accelerating Progress on Sanitation, Drinking-Water And Hygiene Un-Water Global Analysis and Assessment of Sanitation and Drinking-Water GLAAS 2022 Report*. https://glaas.who.int/docs/librariesprovider2/default-document-library/glaas_2022_report_final-13dec.pdf?sfvrsn=f6b6f522_15

UNICEF. (2020). *UNICEF WASH SDG Costing Tool*. https://www.sanitationandwaterforall.org/sites/default/files/2020-09/WASH_SDG_Costing_Tool_En2020.pdf

UNICEF. (2022). *Costs and predicted financing gap to deliver COVID-19 vaccines in 133 low- and middle-income countries*. https://www.unicef.org/media/114216/file/Costs-and-Predicted-Financing-Gap-to-Deliver-COVID-19-Vaccines-in-133-Low-and-Middle-Income-Countries.pdf

UNICEF. (2024). *Product Menu for all Vaccines Supplied by UNICEF*. https://www.unicef.org/supply/pricing-data

Vaughan, K., Ozaltin, A., Mallow, M., Moi, F., Wilkason, C., Stone, J., & Brenzel, L. (2019). The costs of delivering vaccines in low- and middle-income countries: Findings from a systematic review. *Vaccine X*, *2*(100034), 100034.

Vollset, S. E., Altay, U., Bhattacharjee, N. V., Chalek, J., Giannakis, K., Gray, A., Han, C., Lindstedt, P. A., Naghavi, M., Raggi, C., Smith, A. E., Smith, G., Swetschinski, L., Wool, E., Yuan, C. W., & Murray, C. J. L. (2024). *Forecasting the Fallout from AMR: Human Health Impacts of Antimicrobial Resistance*. World Organisation for Animal Health and World Bank. https://doi.org/10.20506/ecoAMR.3540

WaterAid. (2021). *Mission-critical: Invest in water, sanitation and hygiene for a healthy and green economic recovery WaterAid*. https://washmatters.wateraid.org/sites/g/files/jkxoof256/files/mission-critical-invest-in-water-sanitation-and-hygiene-for-a-healthy-and-green-economic-recovery_2.pdf

WHO. (2024). *WHO Bacterial Priority Pathogens List, 2024: Bacterial Pathogens of Public Health Importance to Guide Research, Development and Strategies to Prevent and Control Antimicrobial Resistance*. https://www.who.int/publications/i/item/9789240093461

Xavier, S. P., Silva, A. M. C. Da, & Victor, A. (2023). Antibiotic prescribing patterns in pediatric patients using the WHO AWaRe framework in a Quaternary hospital in Nampula, Mozambique. In *Research Square*.

Zanichelli, V., Sharland, M., Cappello, B., Moja, L., Getahun, H., Pessoa-Silva, C., Sati, H., van Weezenbeek, C., Balkhy, H., Simão, M., Gandra, S., & Huttner, B. (2023). The WHO AWaRe (Access, Watch, Reserve) antibiotic book and prevention of antimicrobial resistance. *Bull. World Health Organ.*, *101*(4), 290–296.

Zhu, Y., Xu, X., Fang, W., Wang, Y., Dai, H., & Li, X. (2021). Availability, cost and affordability of selected antibiotics and antiviral medicines against infectious diseases from 2013 to 2019 in Nanjing, China. *Trop. Med. Int. Health*, *26*(5), 518–529.