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The Global Direct Inpatient Cost of Antimicrobial Resistance

A MODELLING STUDY

Tim Laurence, Olimpia Lamberti, Robert Smith, Tom Drake, and Anthony McDonnell

Abstract

This study estimates the global direct inpatient healthcare expenditure attributable to antimicrobial resistance (AMR) and projects future expenditures under different scenarios. Using the Institute for Health Metrics and Evaluation's estimates of AMR burden, and a novel epidemiological literature review, new estimates of AMR inpatients admission volumes are produced. Following a literature review of 232 cost studies and statistical modelling, the analysis provides a comprehensive estimate of AMR's financial burden in the healthcare sector for 204 countries. Globally, the study estimates there are 25.4 million hospital admissions with AMR infections annually, representing 3.5 percent of global admissions, with total excess inpatient healthcare expenditure due to AMR estimated at $66.4 billion annually. The study also finds that low- and middle-income countries bear a disproportionate share of these costs relative to their healthcare budgets, with low-income countries spending 2.0 percent and lower-middle-income countries spending 1.5 percent of total healthcare expenditure on AMR-related costs. Future projections indicate that AMR-related healthcare expenditure is likely to increase, potentially reaching $159.4 billion by 2050.

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The Global Direct Inpatient Cost of Antimicrobial Resistance: A Modelling Study

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Executive summary

In 2019 there were an estimated 1.27 million deaths attributable to antimicrobial resistance (AMR), and 4.95 million AMR associated deaths worldwide. While there are studies on the global health burden of AMR, the impact of AMR on healthcare expenditure globally is not well understood.

We estimate direct inpatient healthcare expenditure due to AMR in 204 countries based on a review of 232 AMR-related studies of healthcare costs, Institute for Health Metrics and Evaluation (IHME) estimates of disease burden, and an additional review of 161 epidemiological studies. We use this evidence to estimate the number of inpatient admissions with AMR and the cost per AMR admission disaggregated by 11 infectious syndromes.

We use several different statistical model specifications to estimate costs where our literature review did not identify available estimates. We assess the performance of these models using five tests of the suitability of our estimates: statistical performance, visual inspection, feasibility of cost estimates, conservatism, and overall feasibility of emerging total estimates. We find that regression models can estimate unknown costs relatively effectively, and we quantify the uncertainty this missing cost estimation causes in our final results.

We estimate that the median cost per admission with a resistant infection varies considerably among infectious syndromes. It varies between approximately $100–1,000 in low-income countries, $300–3,000 in lower-middle-income countries, $1,000–10,000 in upper-middle-income countries, and $3,000–30,000 in high-income countries. These costs are approximately double the cost of a comparable admission with a susceptible infection, except for tuberculosis (TB), where resistant cases cost over nine times more than comparable susceptible cases.

We estimate that there are 25.4 million (L: 11.6 million–H: 48.0 million)[1] hospital admissions with an AMR infection globally each year. This is equivalent to 3.5 percent (L: 1.6 percent–H: 6.5 percent) of global admissions. Our estimates of hospital admissions are broadly consistent with two systematic reviews on the rate of hospital acquired infections observed in inpatient settings, but higher than two studies from the US and European Union.

Overall, our estimate of excess global direct inpatient healthcare expenditure due to AMR is $66.4 billion (L: $32.0 billion–H: $156.0 billion). This estimate is lower than the most comparable estimates from the World Health Organization (WHO) and the Organisation for Economic Co-operation and Development (OECD). Our estimates are broadly in line with other previous estimates but notably higher than some key studies, despite our intention to make conservative model assumptions. This divergence is largely explained by these previous cost studies using lower estimates of AMR admission volumes for the US and Europe. However, we estimate overall inpatient

1 L: and H: are short for lower and higher sensitivity respectively. These are not confidence intervals, the approach to uncertainty is explained in sections 2.3 for hospital admissions and 2.4 for overall costs.

expenditure on AMR for 204 geographies, so our methodology for estimating admissions requires comparable data for every geography, which those existing high-income admission estimates would not provide.

Expenditure on AMR admissions is a particular concern for lower- and middle-income countries (LMICs), which spend higher proportions of already tight healthcare budgets treating resistant infections. The median low-income country spends 2.0 percent of total healthcare expenditure on excess resistant costs and the median lower-middle-income country spends 1.5 percent, whereas the median high-income country spends 0.4 percent.

We use our current estimates of healthcare expenditure and prospective scenarios AMR burden (produced by IHME) to estimate how the cost of AMR is likely to change in the future. We find that excess expenditure due to AMR is likely to increase; in our reference prospective scenario it increases from $66.4 billion to $159.4 billion (L: $59.7 billion–H: $229.4 billion). In a scenario where there is an accelerated rise in resistance, there is a possibility that the increase could be even greater. Even in optimistic scenarios, excess expenditure is likely to remain stable over time. Antibiotic development; improvements in access and improved coverage of water, sanitation, and hygiene (WASH); and vaccines have the potential to meaningfully reduce the excess expenditure due to AMR.

In this study, we quantify *direct* healthcare expenditure due to AMR. We have not estimated the considerable costs that AMR imposes *indirectly* on healthcare systems in terms of greater need for defensive spending on infection control measures, cancelled procedures due to nosocomial outbreaks, and other changes to general service provision it may necessitate.

Complementary publications by McDonnell et al. (2024) and Countryman et al. (2025) quantify the economic impact on non-health sectors and the macroeconomy more generally.

Acronyms and other abbreviations

Infectious syndromes are abbreviated in visualisations (See Appendix of Antimicrobial Resistance Collaborators (2022) for more information)

Bone	Infections of bones, joints, and related organs
BSI	Bloodstream infections
Cardiac	Endocarditis and other cardiac infections
CNS	Meningitis and other bacterial central nervous system infections
Diarrhoea	Diarrhoea
Gonorrhoea	Gonorrhoea and chlamydia
IAI	Peritoneal and intra-abdominal infections
LRI	Lower respiratory infections and all related infections in the thorax
SSTI	Bacterial infections of the skin and subcutaneous systems
TB	Tuberculosis
Typhoid	Typhoid fever, paratyphoid fever, and invasive non-typhoidal Salmonella
UTI	Urinary tract infections and pyelonephritis

Model specification names (See Appendix 2 for more information)

Linear OLS	Linear regression fit with Ordinary Least Squares (OLS)
Linear ElasticNet	Linear ElasticNet regression
Polynomial ElasticNet	Polynomial ElasticNet regression (polynomial and interaction terms included)
Baseline XGBoost	XGBoost with baseline hyperparameters
Optimised XGBoost	XGBoost with optimised hyperparameters

Organisations

CGD	Center for Global Development
IHME	Institute of Health Metrics and Evaluation
GBD	Global Burden of Disease Study
WHO	World Health Organization
OECD	Organisation for Economic Co-operation and Development
World Bank	World Bank Group

Health system and economic covariates (See Appendix 2 for more information)

CHE	Current healthcare expenditure: total healthcare expenditure for each country estimated by WHO
GDP	Gross Domestic Product: a measure of economic output for a country estimated by the World Bank
PPP	Purchasing Power Parity: relative prices of a country compared to the United States of America
HAQ	Health Care Access and Quality Index: An index approximating healthcare quality and access produced for each country by IHME by analysing amenable mortality
SDI	Sociodemographic Index: An index approximating the level of social and economic development in a country produced by IHME

Epidemiological metrics (See Appendix 3 for more information)

HFR	Hospital fatality rate
IHR	Infection hospitalisation rate
DALY	Disability adjusted life year
YLL	Years of life lost due to premature mortality
YLD	Years of healthy life lost due to disability
PAF	Population attributable fraction

1. Background

The WHO define antimicrobial resistance (AMR) as the occurrence of "*bacteria, viruses, fungi and parasites changing over time and no longer respond to medicines making infections harder to treat and increasing the risk of disease spread, severe illness and death.*" (WHO, 2024b).

As part of the Global Burden of Disease project, Antimicrobial Resistance Collaborators (2022) estimate that there were 1.27 million AMR attributable deaths and 4.95 AMR associated deaths in 2019. While the global health burden of AMR is relatively well understood, the impact of AMR on the global economy is highly uncertain.

Different studies estimate the overall global economic cost of AMR in different ways. The O'Neill Review in collaboration with RAND and KPMG estimate the impact of AMR deaths studies on lost economic output (O'Neill, 2016). The World Bank estimate the macroeconomic impact of AMR using Computable General Equilibrium methods (Ahmed et al., 2017). Complementary publications by McDonnell et al. (2024) and Countryman et al. (2025) quantify the economic impact on non-health sectors and the macroeconomy more generally.

Our contribution is to estimate the direct healthcare costs due to AMR for 204 geographies around the world. The overall research question is: *What are the global direct inpatient healthcare costs due to AMR, now and in the future?* Like many other authors (including the Global Burden of Disease study), we focus only on **bacterial infections** with antibiotic resistance, which is a large subset of AMR.

The OECD and WHO also estimate the global healthcare cost of AMR (WHO, 2024a). OECD (2023) estimate this cost for 34 OECD countries. Other authors also estimate the direct health care costs of AMR at a national level (CDC, 2019; Nelson et al., 2021; Zhen et al., 2021; DHSC, 2018; Wozniak et al., 2022; and Larsson, 2022) or estimate the cost of illness for specific syndromes (Baral et al., 2020; Su et al., 2020). Similarities and difference between our methodologies and results are explored in the discussion section.

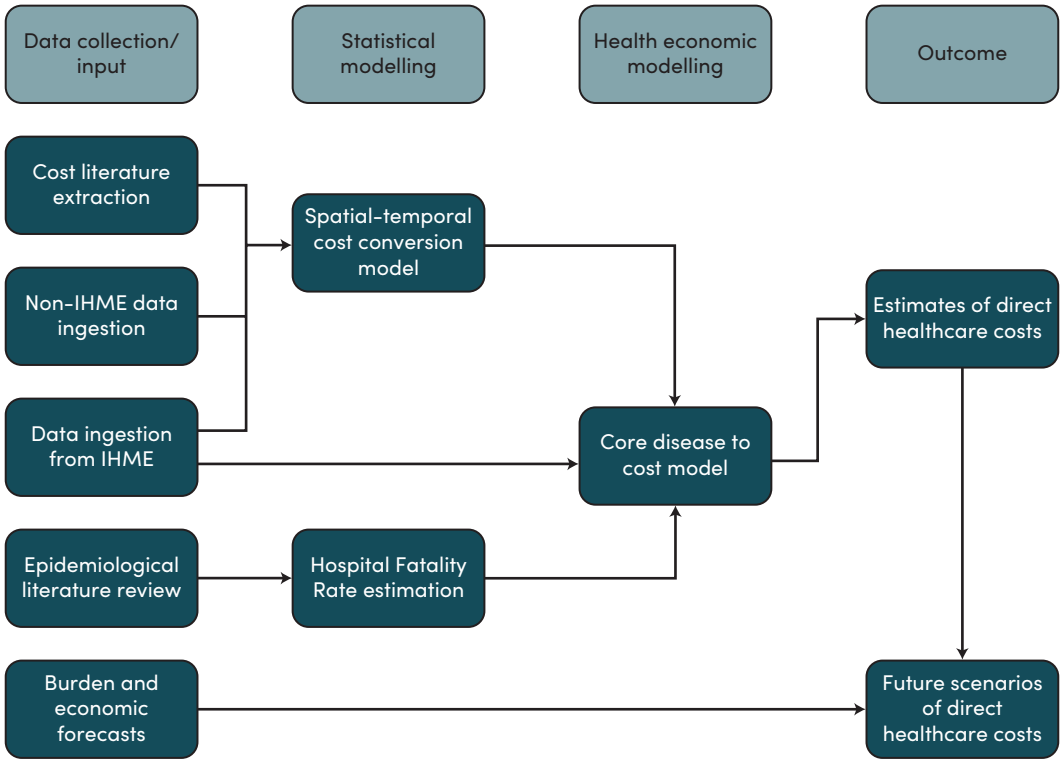
2. Methods

2.1 Overall framework

The general methodology for this study is a cost of illness approach. We estimate the overall cost of AMR inpatient care, from the perspective of the healthcare system, irrespective of which party has financed the care. Figure 1 summarises the overall approach the study. The figure shows that our inputs for the model come from cost literature (see section 2.2.1), data from the Global Burden of Disease (GBD) study provided by IHME, and a review of epidemiological literature (section 2.3). Estimates from the literature are then statistically adjusted to provide estimates for geographies where estimates are not available from the literature (section 2.2.2 and 2.2.3). These data on cost and

quantity of AMR burden are then combined in a health economic framework called the *core disease to cost* model (see section 2.4), where we combine estimates of the cost per AMR inpatient admission and total volume of AMR admissions, to produce overall estimates of healthcare cost. Finally, we describe how we use prospective scenarios of burden from IHME to explore how healthcare expenditure may change in the future (see section 2.5).

FIGURE 1. Overall framework for estimating direct healthcare costs of AMR



IHME groups AMR infections into 12 high-level infectious syndromes (see table of abbreviations on p3) so all other data and evidence is also mapped to these syndromes. One infectious syndrome, *Gonorrhoea*, is excluded from the analysis, because it is almost entirely treated in an outpatient setting. GBD data is disaggregated by 204 countries and territories (referred to as countries henceforth), so our analysis is also performed at this geographic granularity. Any comparisons to total healthcare expenditure are based on WHO estimates (WHO, 2024c) and comparisons to GDP are based on World Bank estimates.

Estimating the cost of global AMR is highly uncertain, as there is no predefined methodology and the inputs to any methodology have considerable limitations. As such, to validate the approach we have undertaken, we set out five tests of suitability of our emerging estimates:

Test 1) Statistical performance of models for unknown costs assessed on holdout data

Test 2) Consistency of estimates with observed data

Test 3) Feasibility of individual cost estimates

Test 4) Conservatism of individual and overall estimates

Test 5) Validity of overall cost of illness per infectious syndrome/per country

2.2 Cost inputs, evidence from the literature and adjustments

2.2.1 Cost extraction

We undertook a literature review of cost per case of (AMR) cases of 12 infectious syndromes, across three settings (inpatient admission cost, outpatient case cost, test cost) and 204 GBD countries. The literature review identified 232 full text papers from which relevant costs were extracted. Some of these papers have multiple countries, or multiple costs (e.g., case costs and test costs) or multiple infectious syndromes, or costs for multiple types of resistance (e.g., resistant cases, susceptible cases and uninfected comparators). Therefore, there are 911 secondary cost estimates (including susceptible or uninfected comparators). See Appendix 1 for the detail on this review. Figure A1.1. depicts a Prisma diagram of how literature was identified and screened for relevancy. Table A1.1. shows the fields extracted from these papers. Table A1.2. shows a descriptive breakdown of these estimates. It shows that only 15 percent of studies focus on outpatient and testing costs, so we decided to focus exclusively on inpatient costs, meaning the *Gonorrhoea* and *Other* infectious syndromes are excluded from the methodology at this stage (excluding 15 cost estimates). It also shows the imbalance in the sample. The following types of studies are underrepresented: studies in low-income countries or countries in the Middle East and North Africa or Central Asia regions, and studies estimating costs of *Cardiac* (endocarditis and other cardiac) and *Bone* (bones, joints, and related organs) infections.

During this extraction, we attempted to isolate and extract the cost of the infection (rather than other healthcare consumed during the admission). However, this was not possible in all studies, as many authors only reported total admission cost (rather than cost after infection diagnosis date, during the course of the infection, or directly attributable to the infection). As such, we present two headline costs. The first is called the *resistant cost*; this is the cost of an admission **with** a resistant infection, where we removed non-infection costs when evidence allowed. We also present a second cost, called *excess resistant cost*, that is derived by subtracting our estimate of the cost of a comparable admission with a susceptible infection from the cost of a *resistant* admission. The resistant cost has a more literal interpretation, as it better reflects actual spend on patients; however, the excess resistant cost is a much more appropriate method for estimating the cost *due* to resistance.[2]

Because almost all *TB* (tuberculosis) studies estimate costs of the total treatment course, rather than a single admission, we also focus on the total cost of treatment.

2 Excess resistant is comparable to the OECD's replacement scenario, and total resistant is comparable to their elimination scenario. See p26, OECD, 2024.

2.2.2 Cost adjustment

The costs extracted from the literature review are inflated and converted to US$ 2022 (Turner et al., 2019). They are also standardised to adjust for research studies disproportionately occurring in higher cost hospitals. All costs are then log transformed (using base 10). See Appendix 1 for more details.

2.2.3 Unknown cost estimation

Once the *Gonorrhoea* and *Other* syndromes are excluded, we estimate the costs of the remaining 11 infectious syndromes for 204 geographies. Therefore, there are 2,244 different geography infectious syndrome pairs. The data extracted from the literature contains 896 estimates, with 71 countries having at least one observation. The sparsity of our data compared to the granularity of our estimates represents a challenge; as such, we compare several different model specifications for estimating unknown costs.

Given the high number of combinations of geographies and infectious syndromes, we do not additionally disaggregate by pathogens and resistance types. This is a limitation, because many studies report differences in costs for different types of pathogens and resistance; see Nelson et al. (2021) for estimates in the United States where different pathogen-resistance pairs lead to admission cost varying by roughly a factor of two. However, it was not possible to estimate this sufficiently rigorously with the cost data collected.

Economic, health system, and study specific covariates are used to model expected log transformed cost. Appendix 2 sets out our exact regression specifications.

Table A2.1. in Appendix 2 sets out the different statistical models used to estimate the unknown cost values. We use the following models:

1. Linear regression fit with Ordinary Least Squares (Linear OLS)
2. Linear ElasticNet regression (Linear ElasticNet)
3. Polynomial ElasticNet regression, which also polynomial and interaction terms included (Polynomial ElasticNet)
4. XGBoost with baseline hyperparameters (Baseline XGBoost)
5. XGBoost with optimised hyperparameters (Optimised XGBoost)

The Linear OLS model is the most widely understood and transparent model used. It is chosen as a specification because of its simplicity and transparency. Also, the linear structure ensures that resistant case costs are higher than susceptible case costs consistently reflecting the weight of evidence. The Linear ElasticNet model may make better out-of-sample predictions than the Linear OLS model because it is a lower variance estimator; it is therefore less subject to overfitting.

The Polynomial ElasticNet specification is a higher variance estimator than the Linear ElasticNet, so may be more prone to overfitting; however, the advantage it offers is the potential to capture meaningful non-linearities in the data (e.g., if certain infectious syndromes or geographies have a higher differential between resistant and susceptible costs).

XGBoost is a type of tree-based method. Tree-based methods are attractive due to their lack of parametric assumptions about the functional form of the relationship between covariates and the outcome variable. We choose XGBoost specifically because researchers have systematically demonstrated its consistent predictive performance on complex datasets; for instance, Bentéjac et al. (2021) find it to be the most effective tree-based method, though do caution the need for hyperparameter tuning. More details on this hyperparameter tuning can be found in Tables A2.1.–A2.3. in Appendix 2, which result in our Optimised XGBoost specification.

2.2.4 Validation of unknown cost estimation

Tests 1–4 all apply to validating the different model specifications used to estimate unknown cost per inpatient case (described in 2.2.3). To assess statistical performance, we hold out validation and test sets that are not used in the estimation of models. We then assess the performance of the models on these data sets to quantify their expected performance on other unknown infectious syndrome geography pairs. Three statistical loss measures are used to assess the models:

1. Symmetric mean absolute percentage error (SMAPE) (Ward & Armstrong, 1981)
2. Root mean square logarithmic error (RMSLE)
3. Root mean square error (RMSE)

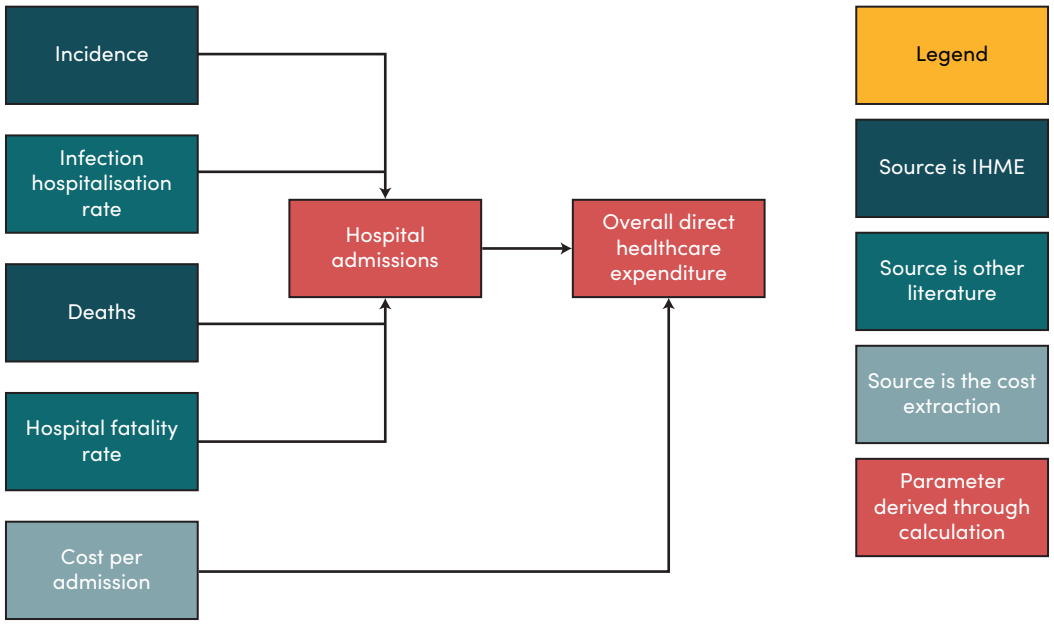
SMAPE and RMSLE are particularly useful for this task because the estimates vary by orders of magnitude and these measures are not skewed by the absolute size of the estimate. RMSE is included for completeness, as a widely used metric, but may be insensitive to poor model performance in low-income settings. Appendix 2 sets out in more detail how we apply tests 2, 3, and 4 to validate our unknown cost estimation, by comparing data to observations and expected ranges identified by the authors and ensuring estimates are sufficiently conservative.

2.3 Quantity inputs, evidence from the literature, and adjustments

Antimicrobial Resistance Collaborators (2022) sets out the approach of the Institute for Health Metrics and Evaluation (IHME) and their AMR Collaborator Network for estimating the deaths and incidence due to AMR as part of their Global Burden of Disease (GBD) study. Our study follows their definitions of infectious syndromes, as well as different pathogens and resistance types. Unfortunately, GBD does not include estimates of the number of hospital inpatient admissions due to AMR, which would be the ideal input to our cost of illness model. As such, we use IHME's estimates of incidence and deaths to estimate hospital admissions using the framework set out in Figure 2.

These adjustments include multiplying incident infections by infection hospitalisation rates (IHR) from the literature and dividing deaths by hospital fatality rates (HFR) from the literature.

FIGURE 2. Overall framework for estimating direct healthcare costs of antimicrobial resistance



We undertook a literature review of relevant epidemiological parameters in order to estimate hospital fatality rates and infection hospitalisation rates for the relevant infectious syndromes in different geographies. We identified 450 estimates of HFR, which was considerably more than the eight estimates for IHR. The approach to the literature search is set out in Appendix 3, including Figure A3.1. for the Prisma Diagram and Table A3.4. for a summary of the inputs used.

Many infectious syndromes and geographies did not have HFR estimates. As such, we estimate these unknown values using a mixed effects hierarchical model. The specification of this model is set out in Appendix 3.

The limited number of IHR results identified from the literature, meant we had to assume IHRs from some syndromes may apply to others and make assumptions for how this evidence may apply to missing geographies; these assumptions are uncertain and set out in Table A3.5. in Appendix 3. The evidence for HFR is considerably stronger and more complete than for IHR. The evidence supporting the estimation of deaths from AMR by IHME are also stronger than the evidence supporting the estimation of incidence. Therefore, the estimates of hospital admissions resulting from the deaths and HFR combination have a considerably stronger evidence base than those resulting from incidence and IHR. When aggregating the estimates of hospital admissions we use a geometric average between the estimates produced by the two methods.

For our central estimate, we weight our geometric average towards the estimates that are higher quality (derived from death and HFR), which happens to lead to lower overall estimates, so is also a conservative decision.

We also estimate the lower bound of admissions by using the minimum of either method, and a higher set of estimates where we use an unweighted geometric average between the methods. The lower estimates and higher estimates also use IHME's lower and higher estimates of deaths and incidence accordingly. These uncertainty intervals are denoted by (L: – H:) in the relevant sections.

We again approach *TB* differently to the other infectious syndromes, where we estimate the overall fatality rate for a cohort starting treatment, rather than those admitted to hospital. This allows us to estimate quantities of patient treated (not just admissions) that are consistent with our cost estimates (which are per treated patient, rather than per admission).

2.4 Overall estimation of direct inpatient expenditure

We estimate overall cost by multiplying the cost and quantity of inpatient admissions for each infectious syndrome and geography. Appendix 4 sets out the algebra for the estimation of hospital admissions and resulting estimation of overall cost. We estimate both the cost of admissions with a resistant infection, and the excess resistant cost due to the patient having a resistant rather than susceptible infection.

We incorporate uncertainty in the cost per admission, as well as number of admissions in order to produce lower and higher estimates of overall inpatient expenditure, denoted by (L: – H:) in the relevant sections. This time lower estimates denote the minimum estimate out of our five model specifications, and higher represents the maximum. Statistical confidence intervals are undefined for several of our model specifications, and bootstrapping approximate confidence intervals for such a diverse range of models was deemed out of scope for this study.

As discussed in section 2.1, the estimates produced by this methodology will be subject to considerable uncertainty. Tests 4 and 5 (conservatism and feasibility of overall estimates) will be used to assess the overall estimates (and each of the component parts).

2.5 Future scenarios

2.5.1 Burden scenarios

Separate from Antimicrobial Resistance Collaborators (2022), IHME have produced prospective scenarios of the burden of AMR out to 2050 (Vollset et al., 2024). They estimate deaths, disability adjusted life years (DALYs), years of life lost (YLLs), and years lived with disability (YLDs). Unfortunately, these estimates do not map exactly to infectious syndromes which are used in the

2019 estimates. However, they are broadly comparable estimates available to support the quantity side of a prospective cost of future illness study. As such, we run multiple different approaches where future cost increases proportionately to each of IHME's different burden metrics in turn. Death data is generally the strongest data and is the most related to hospital admissions, so is our preferred burden metric to use in this extrapolation.

Table 1 sets out IHME's 3 baseline scenarios exploring how burden may change without interventions (reference, accelerated rise in resistance).

TABLE 1. Baseline scenarios

Scenario Name	Scenario Description
Reference case	IHME project resistance forward using historical trends. Changing burden also reflects expected changes in demographics and risk factors.
Accelerated rise in resistance case	Rather than presume that all countries follow the trajectory of the average country between 1990 and 2021, in this scenario IHME look at what would happen if resistance followed the trend of a country in the 15th percentile over this period.

IHME also estimate scenarios where there are global public health interventions to tackle AMR. These scenarios are set out in Table 2.

TABLE 2. Intervention scenarios

Scenario Name	Scenario Description
Access (to antibiotics)	The reference case is adapted to reflect a world where everyone has access to antibiotics. IHME modelled this by assuming that the case fatality rate for bacterial infections would fall to the same as a country in the 85th percentile of health quality.
Innovation (of gram-negative antibiotics)	The reference case is adapted to reflect a world where there is a healthy pipeline of gram-negative antibiotics. IHME model this by presuming that the fatality rate for gram-negative infections fall by X percent
Access and **innovation**	IHME combine the impact of their scenario on access to antibiotics and their scenario on innovation of gram-negative antibiotics
Combined scenario	IHME supplement the Access and innovation scenarios to project what would happen if there was also access to key vaccines, and water, sanitation and hygiene.

2.5.2 Cost per death (or DALY) scenarios

Cost per admission may also be different in the future, and this is subject to considerable uncertainty. Appendix 5 sets out the relevant evidence which motivates our choice of scenarios. We estimate the impact of this uncertainty by modelling four scenarios overall, per measure of burden:

Scenario 1) Cost per death (or DALY) stays constant

Scenario 2) Cost per death (or DALY) increases with GDP based on current observed relationship

Scenario 3) Cost per death (or DALY) outpaces GDP growth

Scenario 4) Cost per death (or DALY) increases with GDP, but falls due to innovation decreasing treatment intensity

The GDP estimates used to inform these scenarios come from the Shared Socioeconomic Pathways (Riahi et al., 2017).

3. Results

3.1 Performance of models at estimating cost per admission

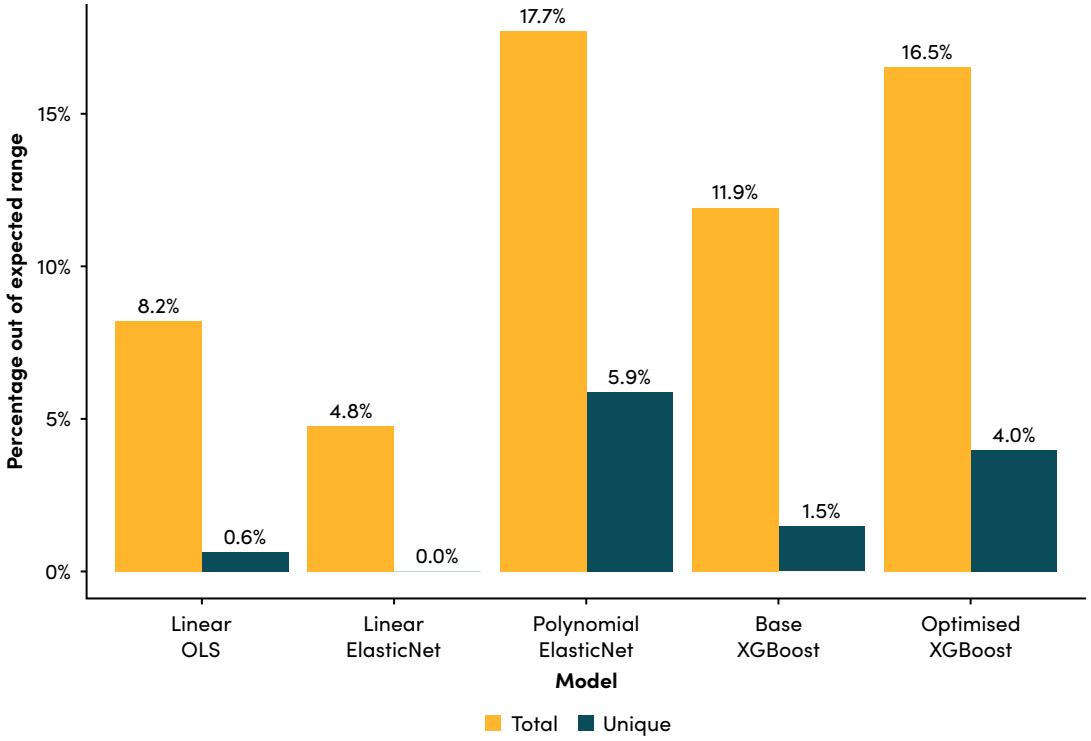
We set out detailed assessment of model explainability and performance in Appendix 6. The key conclusion is that the covariates that appear to be driving model results are in line with theory. The best performing model statistically is the Optimised XGBoost model, which has the smallest statistical loss as measured by RMSLE, reported in Table 3. Despite this, the highest performing statistical models Polynomial ElasticNet and Optimised XGBoost perform less well on other tests. They often predict infeasible estimates, as summarised in Figure 3, and do not appear conservative for many geographies. The Linear ElasticNet performs marginally less well statistically. However, it appears to predict feasible estimates, rarely falling outside the authors' defined range of expectations. The Linear ElasticNet model also gives relatively conservative results, and feasible overall estimates result (as discussed in section 3.4). Therefore, our headline specification is the Linear ElasticNet model.

TABLE 3. Statistical performance metrics for different model specifications, performance on the *validation* set

Model	SMAPE	RMSE	RMSLE
Baseline data variability	0.48*	32,876	0.29
Linear OLS	0.76	11,600	0.49
Linear ElasticNet	0.73	9,902	0.49
Poly ElasticNet	**0.63**	9,726	0.47
Baseline XGBoost	0.68	**9,666**	0.50
Optimised XGBoost	0.65	10,855	**0.45**

Notes: *Baseline SMAPE is approximated by the SMAPE of group-mean on a log scale.

FIGURE 3. Percentage of cost per admission predictions out of expected range for each model



Note: ***Total*** indicates that model and other models predicted out of expectations for that syndrome geography pair whereas ***unique*** indicates that only that model predicted out of expected range for that pair.

TABLE 4. Summary of the rankings of different cost estimation model specifications for different tests

Model	Statistical Performance	Visual Inspection	Outlier Detection	Conservative	Feasibility
Linear OLS	5	3	2	**1**	2
Linear ElasticNet	4	2	**1**	2	**1**
Poly ElasticNet	2	**1**	5	3	5
Baseline XGBoost	3	5	3	4	3
Optimised XGBoost	**1**	4	4	5	4

The performance on the held-out test set is also reported in Table 5. This test set was not used for any setting of hyperparameters used to tune the model, so represents the most valid estimate of the expected statistical performance of the headline model specification at out of sample prediction. The performance of the other models is reported for completeness. On this test set the Linear ElasticNet performs similarly to performance on the validation set, suggesting we did not overfit to the validation set in our hyperparameter optimisation. The Linear ElasticNet performs competitively with other models on the test set, but marginally less well than the Polynomial ElasticNet or Optimised XGBoost (which are both more flexible models).

TABLE 5. Statistical performance metrics for different model specifications, performance on the *test* set

Model	SMAPE	RMSE	RMSLE
Baseline data variability	0.48*	32,876	0.29
Linear OLS	0.73	21,325	0.45
Linear ElasticNet	0.73	23,006	0.46
Poly ElasticNet	0.66	19,069	**0.41**
Baseline XGBoost	0.72	22,454	0.47
Optimised XGBoost	**0.65**	**18,670**	0.44

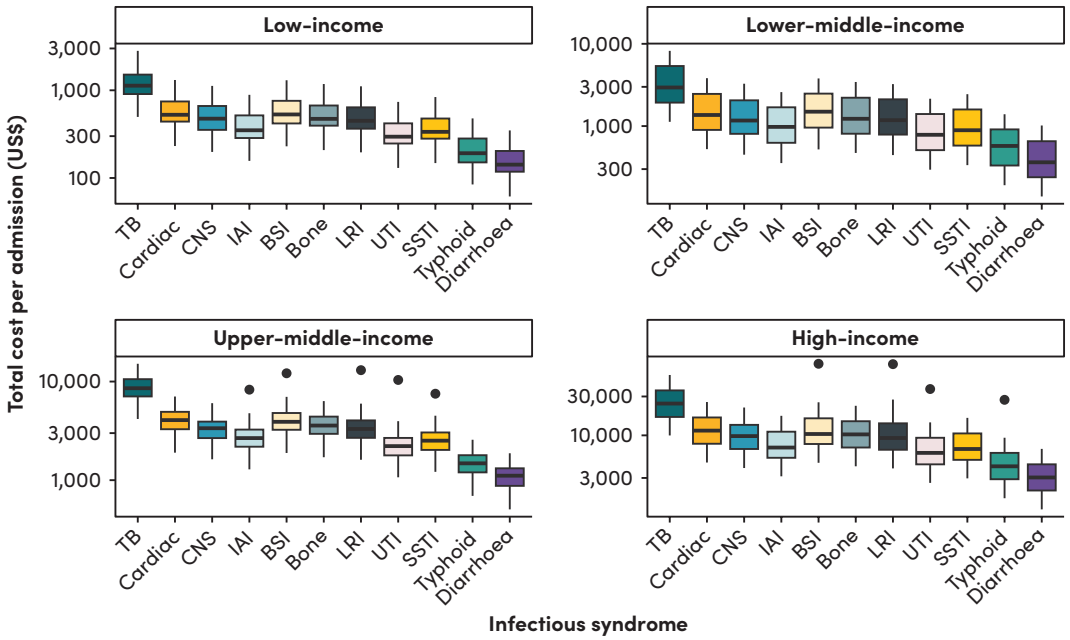
Note: *Baseline SMAPE is approximated by the SMAPE of group-mean on a log scale.

3.2 Cost per admission

Having demonstrated that the Linear ElasticNet is the best performing model, we show the estimates it produces. Figure 4 shows the range of cost per admission estimates disaggregated by infectious syndrome, grouped by World Bank income group. *TB* is consistently estimated to be the most expensive infectious syndrome to treat, where this cost represents the whole treatment course for a *TB* case rather than a single admission. *Diarrhoea* is the least expensive admission type, but also a syndrome with relatively poor-quality cost data, so this finding is tentative.

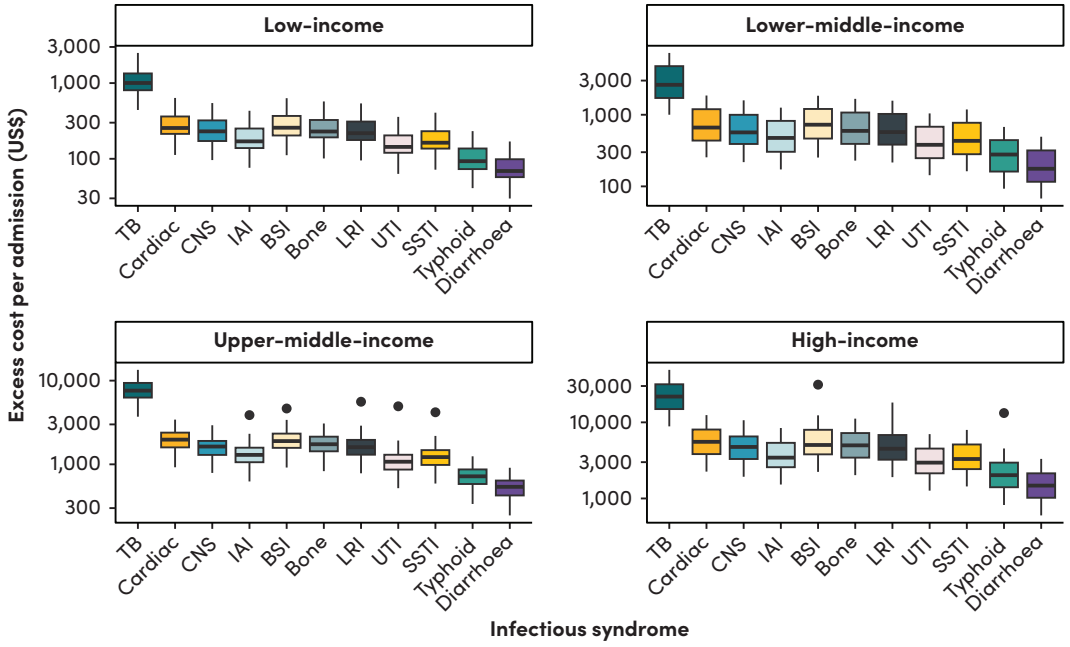
We find that the median cost per admission with a resistant infection for each infectious syndrome varies between approximately $100–1,000 in low-income countries, $300–3,000 in lower-middle-income countries, $1,000–10,000 in upper-middle-income countries and $3,000–30,000 in high-income countries. Figure 5 shows the excess cost per resistant admission, which are harder to interpret but a more representative estimate of the additional cost due to resistance. These excess costs are smaller but still increase with income level as expected.

FIGURE 4. Cost per resistant admission for different syndromes and countries



Note: Costs estimated by the headline Linear ElasticNet specification.

FIGURE 5. Excess cost per resistant admission for different syndromes and countries

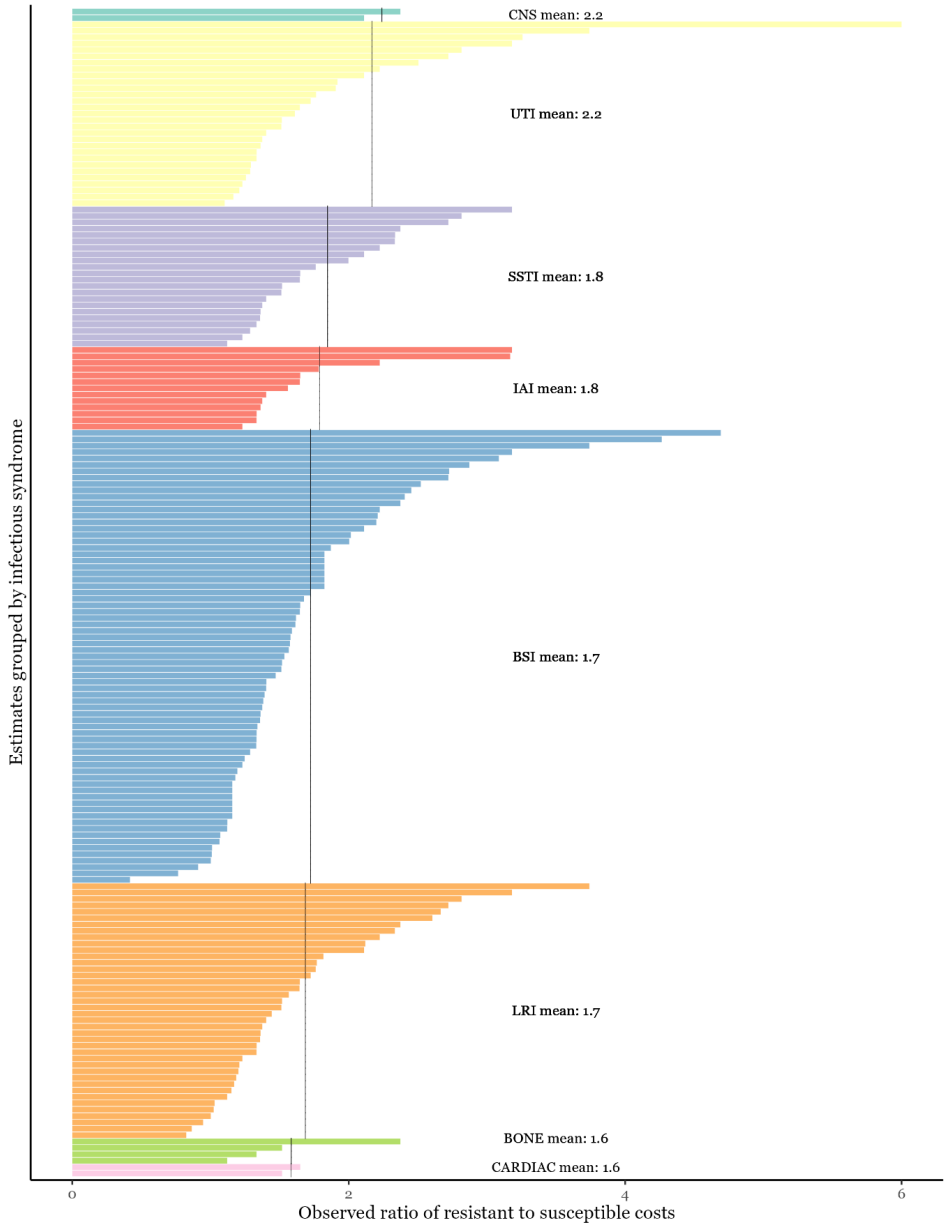


Note: Costs estimated by the headline Linear ElasticNet specification.

3.3 Excess resistant over susceptible costs

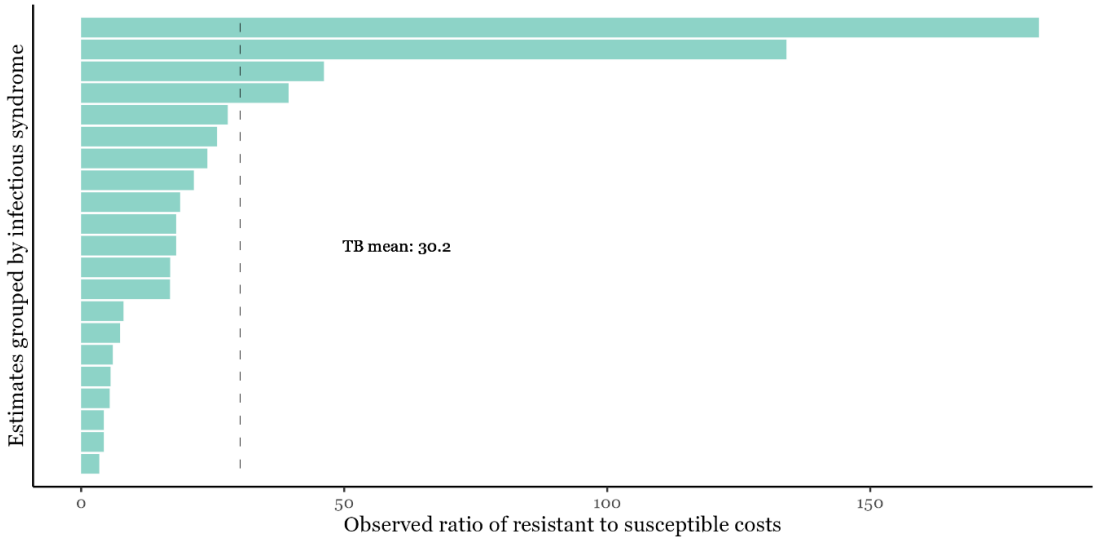
Figure 6 shows the ratio of resistant to susceptible inpatient admission costs reported in the literature. We find that for *TB*, a resistant case costs 30.2 times more to treat than a susceptible case on average, reflecting longer treatment duration and considerably higher treatment intensity. For the other infectious syndromes, the observed ratio of resistant to susceptible costs is between 1.6 and 2.2 on average.

FIGURE 6. Ratio of resistant to susceptible costs observed in the literature for each study reporting both for the same syndrome



Note: One of the values for *urinary tract infection* was truncated to 6 to improve clarity of values for other infectious syndromes. Average reported is the mean.

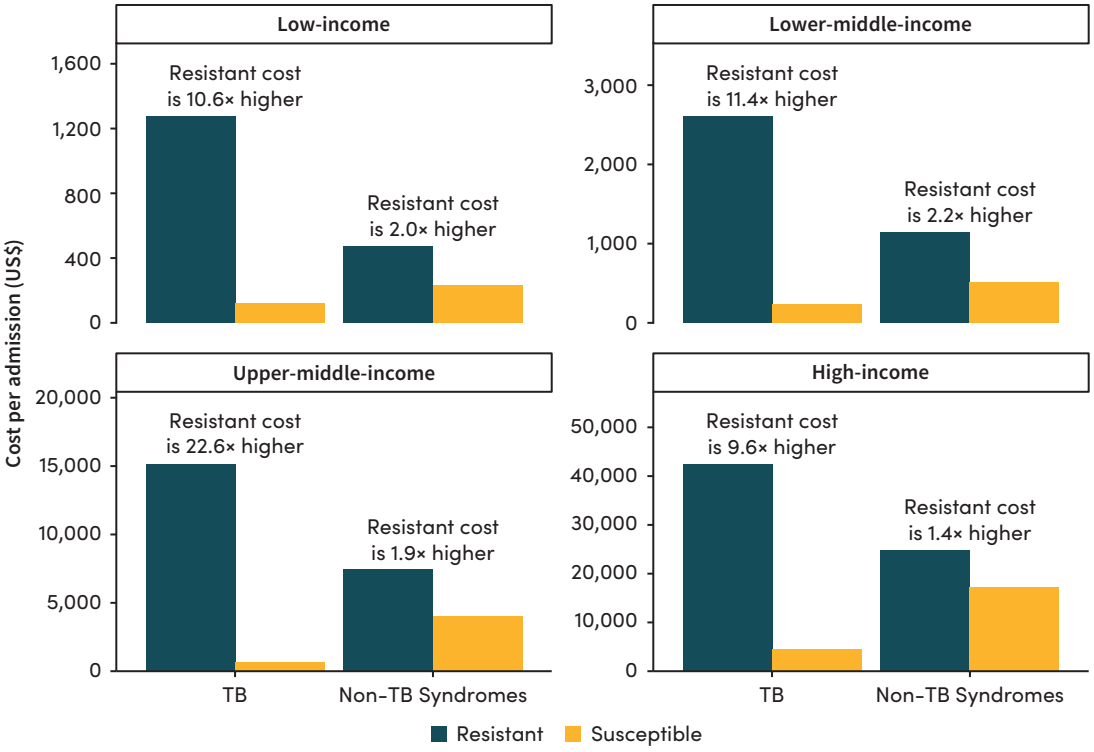
FIGURE 6. (Continued)



Note: TB has been continued in a separate pane due to the observed ratio being considerable higher than for other infectious syndromes. Average reported is the mean.

Figure 7 shows the excess ratio of resistant to susceptible costs emerging from our headline model specification. We estimate that the average for the excess for TB is slightly lower than observed when other factors are controlled for (9.6–22.6x). The aggregated excess for the other infectious syndromes is roughly in line with the observed data (1.4–2.2x). A lower excess is observed in high-income countries, this might be because better access to second line antibiotics decreases the burden of treating resistant infections. It could also be because studies in high-income settings are more likely to use statistical adjustments when estimating the difference between resistant and susceptible costs, which tends to lead to smaller estimates (Nelson et al., 2015).

FIGURE 7. Resistant and susceptible cost per admission estimates, and ratio resistant to susceptible reported in the text

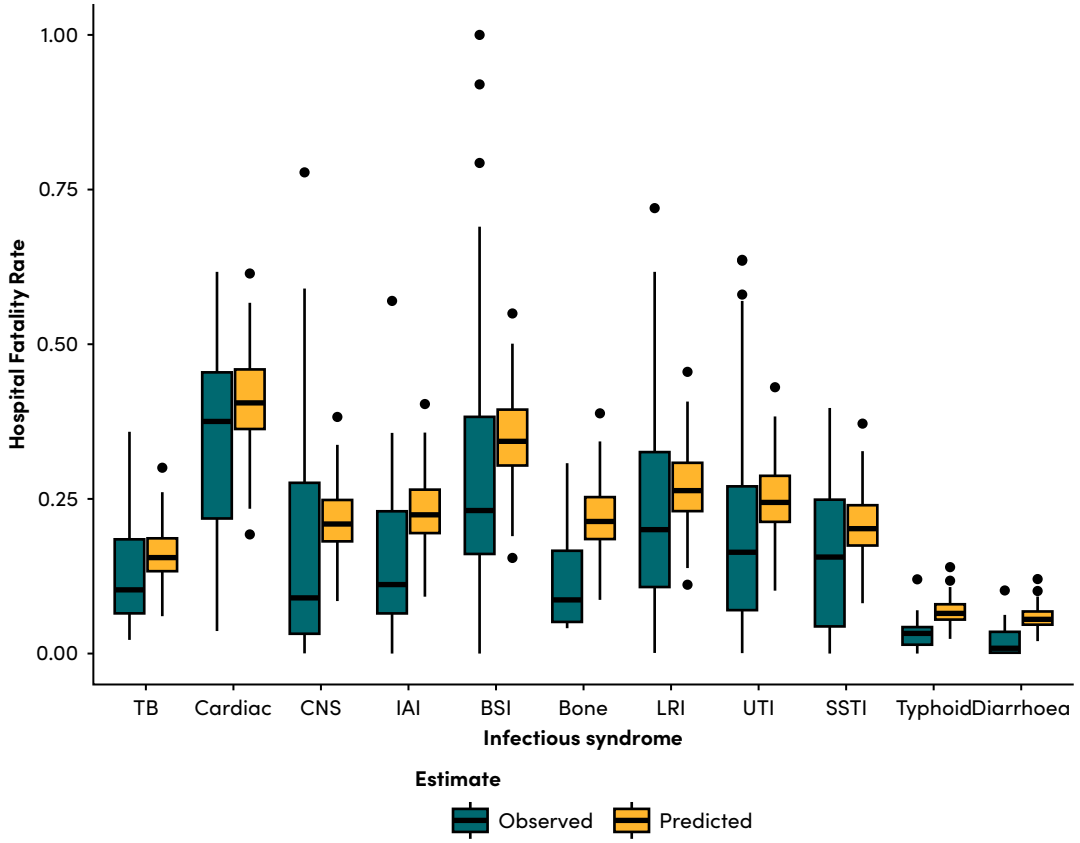


Note: Estimated using the headline estimation specification Linear ElasticNet.

3.4 Hospital fatality rate

Figure 8 shows the distribution of HFR estimates for geographies disaggregated by whether they are observed estimates in the literature or model predictions. Predictions are on average higher than observed values. This is because most research comes from high-income settings, which generally report lower in-hospital fatality rates. Also, the spread around the median is much tighter for predicted values, because though single studies may report very high or very low values of HFR for a given inpatient cohort, the expected overall rate regresses towards the mean/median observed across geographies. Finally, in line with expectations, certain syndromes like *Cardiac* or *BSI* have much higher values of HFR (indicating lower survival rates) than other syndromes like *Diarrhoea* or *Typhoid*.

FIGURE 8. Observed and predicted hospital fatality rate used to convert estimates of deaths into estimates of hospital admissions



Note: Syndromes are ordered by our assumed cost ranking.

3.5 Hospital admission estimates

We estimate that the total number of inpatient admissions (either admissions for community-onset infections or admissions with hospital-acquired infections) is 25.4 million (L: 11.6 million–H: 48.0 million). We compare this to a recent estimate for global admissions from Moses et al. (2019), we use their per capita admission rates to estimate that there were 737.0 million admissions overall globally in 2019. Our estimates therefore suggest that 3.5 percent (L: 1.6 percent–H: 6.5 percent) of global admissions include a resistant infection. Figure 9 shows the breakdown by country, unsurprisingly with populous countries like India and China having the largest volume of inpatient admissions. Figure 10 shows the distribution of the percentage of admissions that have a resistant infection for each country, grouped by WB income groups.

FIGURE 9. Central estimates of number (in thousands) of AMR admissions by country

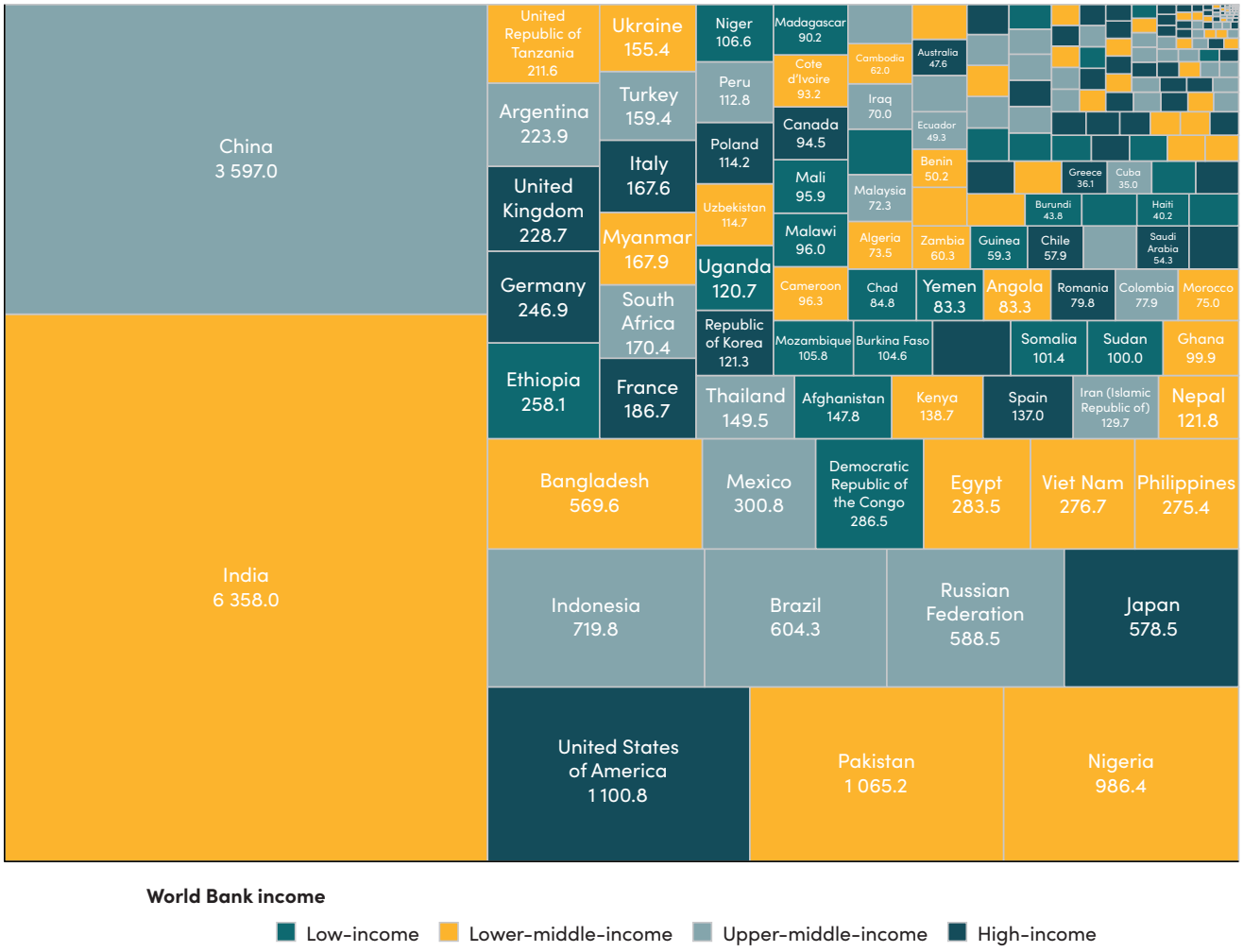
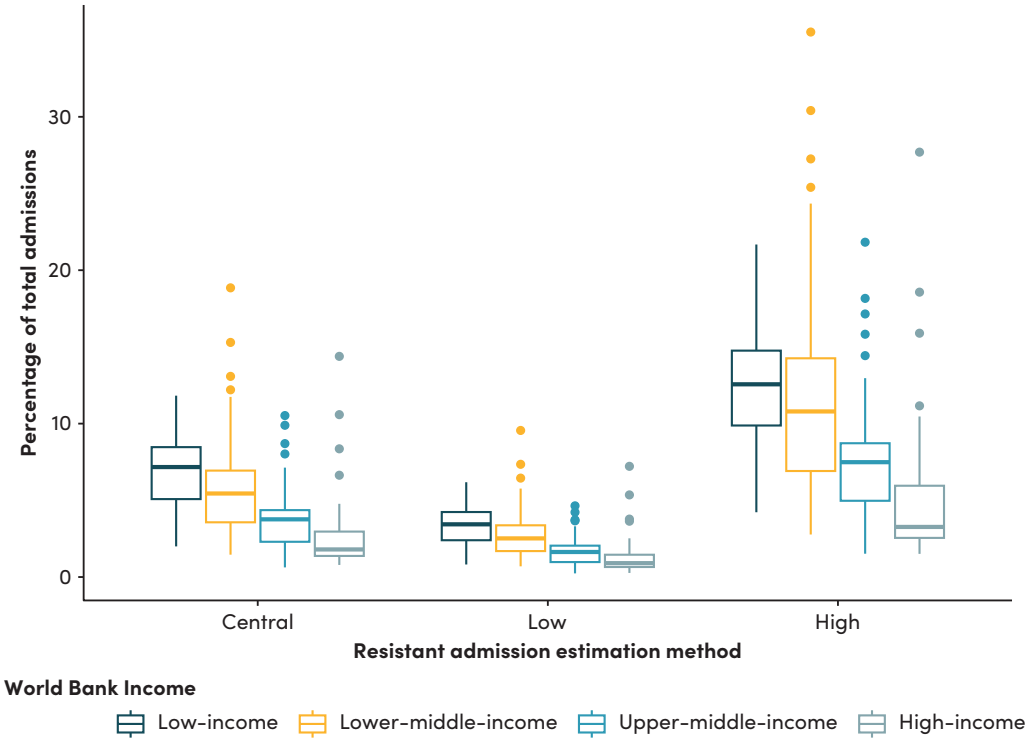


FIGURE 10. For each country modelled, the percentage of total admissions that involve a resistant infection, using the Central, Low and High methods to estimate admissions volumes



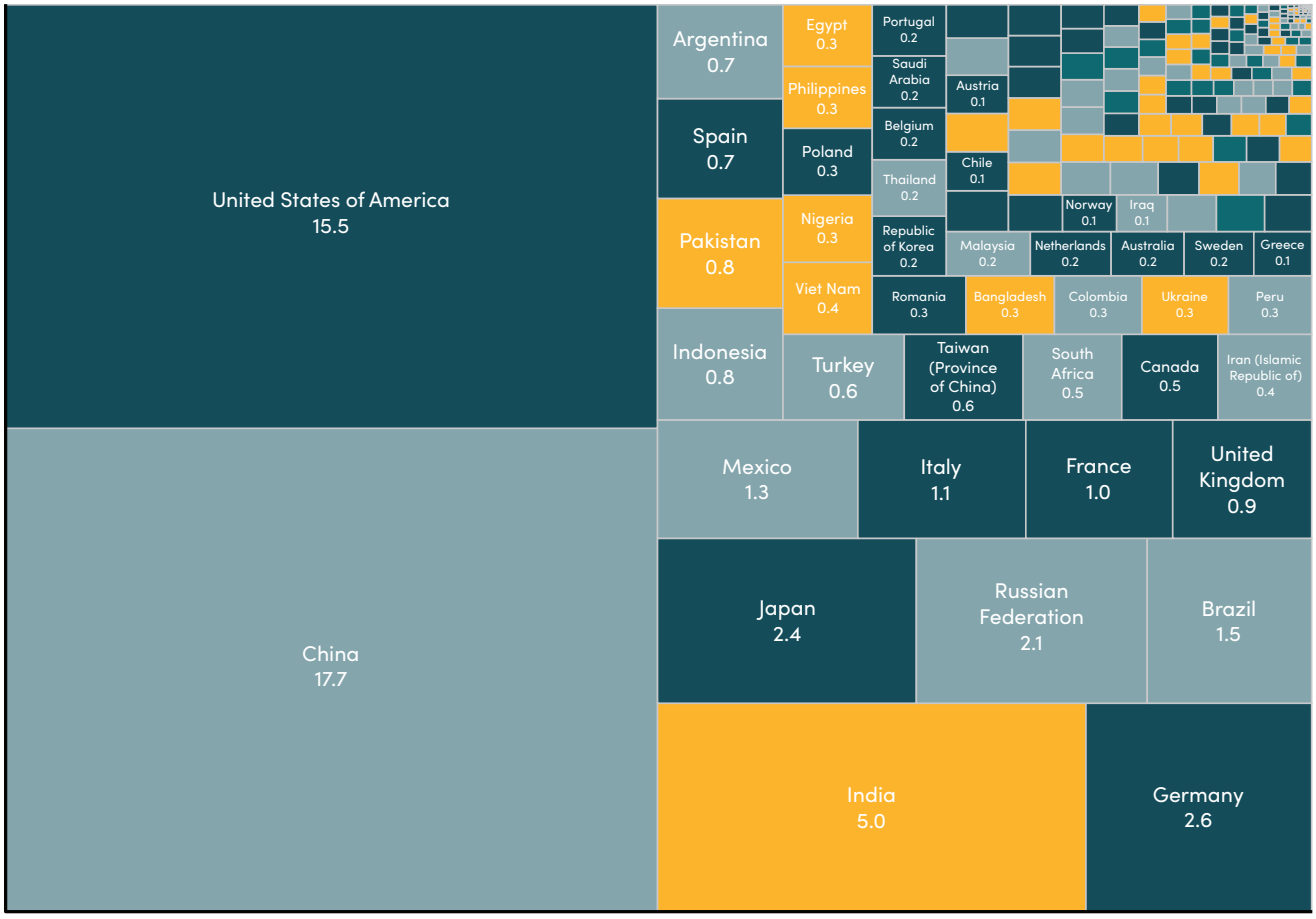
3.6 Overall direct inpatient healthcare costs

The overall excess cost caused by resistance is estimated to be $66.4 billion, or 0.6 percent of global current healthcare expenditure. Table 6 reports total global cost for different approaches of unknown cost estimation. Also accounting for uncertainty in hospital admission volumes, our estimates of total global excess cost due to resistance ranges between $32.0 billion and $156.0 billion (L: 0.3 percent–U: 1.5 percent of healthcare expenditure). Figure 11 shows a *treemap* that shows the breakdown of total global cost by country. The lower total cost of AMR outside of high-income countries is indicative of resource constraints leading to lower treatment intensity, rather than a lower need for healthcare. The countries with the highest total spend are the most populous and those with higher healthcare costs per capita.

TABLE 6. Overall estimates of the direct inpatient cost of AMR

Cost Estimation Model Specification	Excess Resistant Cost (US$ bn)	Resistant Cost Total (US$ bn)
Linear OLS	68.3	167.2
Linear ElasticNet	66.4	168.0
Polynomial ElasticNet	68.3	165.2
XGBoost Base	65.2	164.4
XGBoost Optimised	83.6	182.2

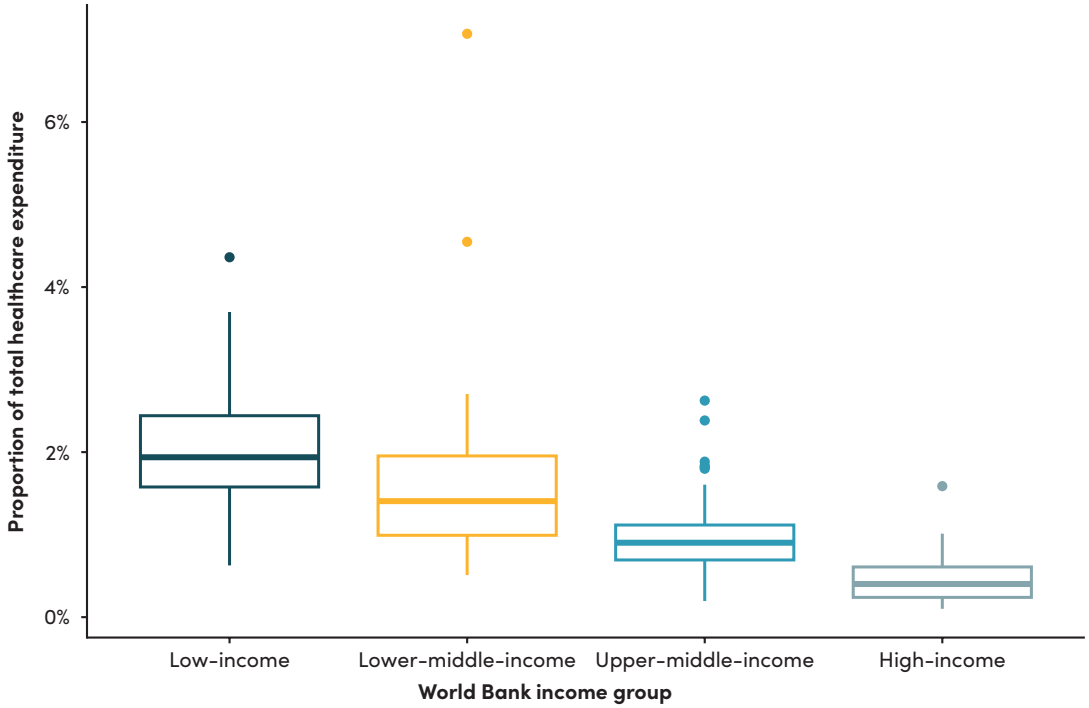
FIGURE 11. Estimated direct excess cost (US$ billions) due to AMR infections in inpatient admissions



The results for the cost of admissions with resistant infections are also reported in Table 6, with Figure A9.1. showing a *treemap* of the top spend for different countries. Here the relevant global range is $80.4 billion to $333.2 billion, or 0.8 percent to 3.2 percent of global healthcare expenditure.

Figure 12 shows the excess cost for AMR as a proportion of healthcare expenditure. It shows that the median excess spend due to resistance is 2.0 percent and 1.5 percent of healthcare expenditure in low and lower-middle-income countries. Upper-middle-income countries spend 1.0 percent and high-income countries spend 0.4 percent. The figure shows that generally low-income or lower-middle-income countries spend disproportionately more of their total healthcare budget on AMR inpatients. Figure A9.3. shows same analysis but for total cost of admissions with an AMR infection. Figures A9.4.–A9.7. shows the same graphs for the alternative cost estimation methods, confirming that the Linear ElasticNet is more conservative than some others. In particular, the Optimised XGBoost model results in high (potentially infeasibly high) estimates of overall excess spend due to resistance in low and lower-middle income countries.

FIGURE 12. Percentage of total healthcare cost due to excess resistance costs in inpatient admissions for each GBD country, grouped by World Bank Income



Note: This shows the results for the headline Linear ElasticNet specification.

Figures A9.8. and A9.9. in Appendix 9 show the breakdown of costs between infectious syndromes. *BSI* (Bloodstream infections) are the greatest contributor to total excess cost. *LRI* is the second most costly. The least costly syndromes are those with the lowest estimates volumes of associated admissions (e.g., *CNS* and *Bone* infections) or those with the lowest estimated cost per admission (*Typhoid* and *Diarrhoea*).

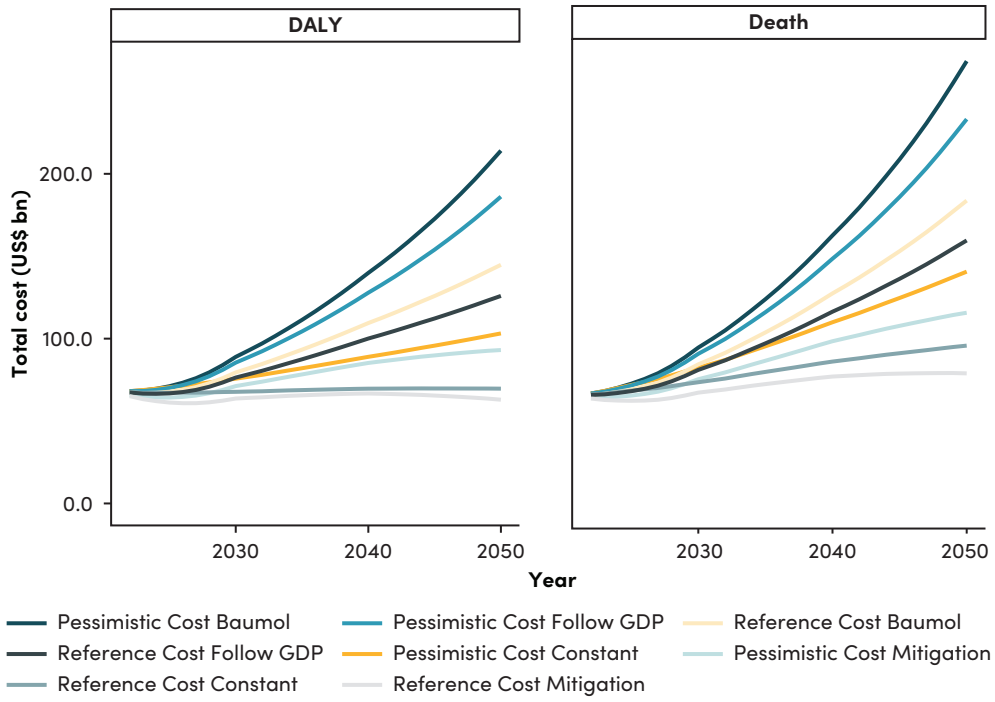
3.7 Future scenarios

3.7.1 Base reference scenarios

Figure 13 shows that excess direct healthcare costs increase substantially in many scenarios, irrespective of the burden metric used to extrapolate cost out to 2050. In the base case for change in cost-per-burden-metric, where treatment intensity (and so cost) increases in line with GDP, overall costs global costs rise in both the accelerated rise in resistance and reference cases. Extrapolating burden using deaths is our headline specification due to data quality, extrapolating cost based on deaths also leads to faster assumed growth, because deaths are forecast to grow faster than other burden metrics.

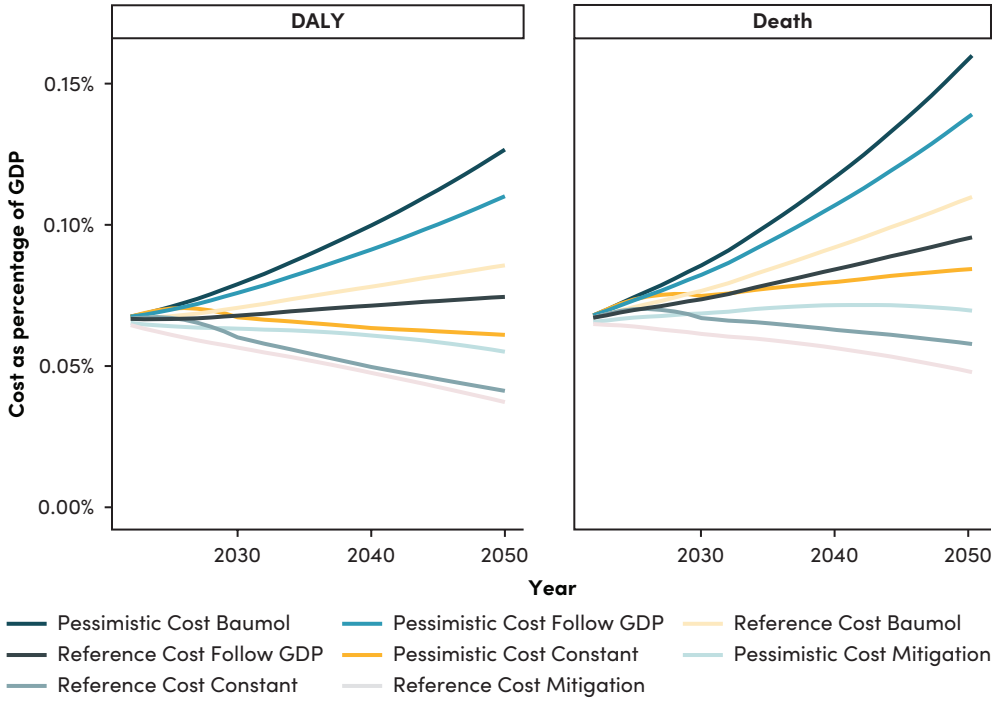
This means that in the scenario deemed most plausible, excess AMR inpatient costs could increase from $66.4 billion to $159.4 billion (L: 59.7 billion–H: 229.4 billion) by 2050 (still reported in US$ 2022). However, other scenarios where burden does not rise or where innovation decreases treatment intensity lead to slower or no increase in direct healthcare expenditure leading to a lower estimate of 59.7 billion. Other scenarios with faster increases in burden (the accelerated rise in resistance case) and faster than inflation growth in costs (the Baumol case) are also plausible leading to the upper sensitivity $323.4 billion. Figure A10.1. shows the headline prospective scenario disaggregated by World Bank Income Groups. In this scenario low-income countries continue to contribute a small percentage the total global cost, this again reflects lower treatment intensity due to resource constraints, rather than less need for healthcare in these settings.

FIGURE 13. Global excess cost of resistant inpatient admissions, by different scenario



Note: All of these scenarios how the mean estimate for a given scenario.

FIGURE 14. Global excess cost of resistant inpatient admissions as a percentage of GDP, by different scenario



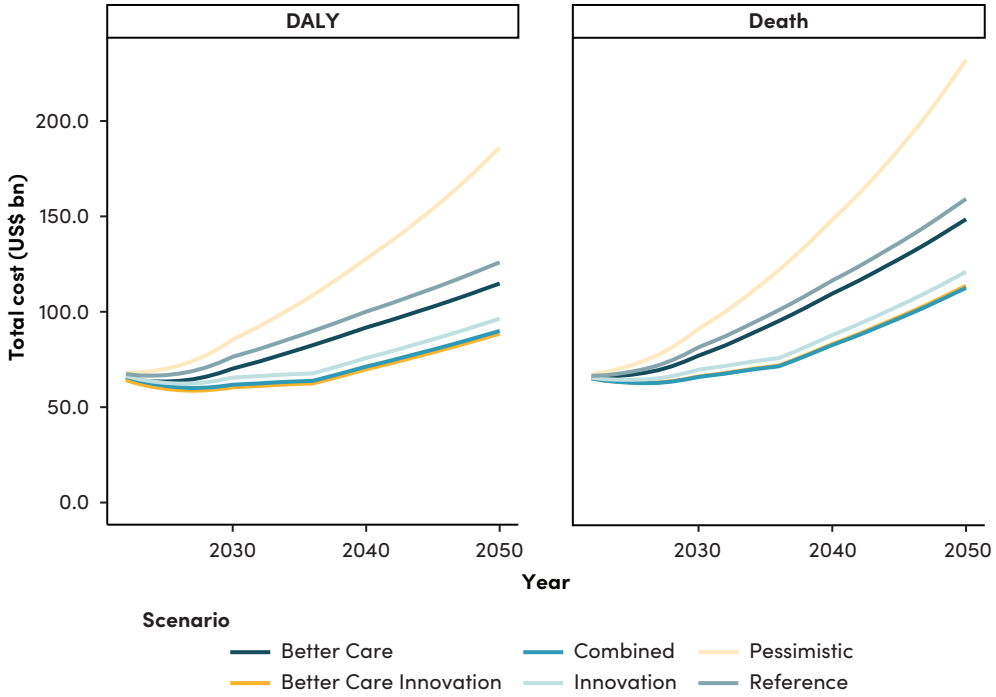
Note: All of these scenarios how the mean estimate for a given scenario.

3.7.2 Intervention scenarios

Figures 15–16 show the impact of interventions on total healthcare expenditure in the base prospective scenario. They show the introduction of a new gram-negative antibiotic (with sufficient access to this antibiotic) could lead to large reductions in direct healthcare cost compared to either the reference or accelerated rise in resistance baseline scenarios for AMR burden. Access to antibiotics also reduces AMR healthcare costs but by a smaller amount, because it has a bigger impact in low-income countries, which contribute less to global healthcare costs. WASH and vaccination also lead to reductions in AMR healthcare cost, but these reductions are more limited. It is important to note that IHME's reference case already involves considerable scaling of these interventions, so the additive impact of additional packages is smaller.

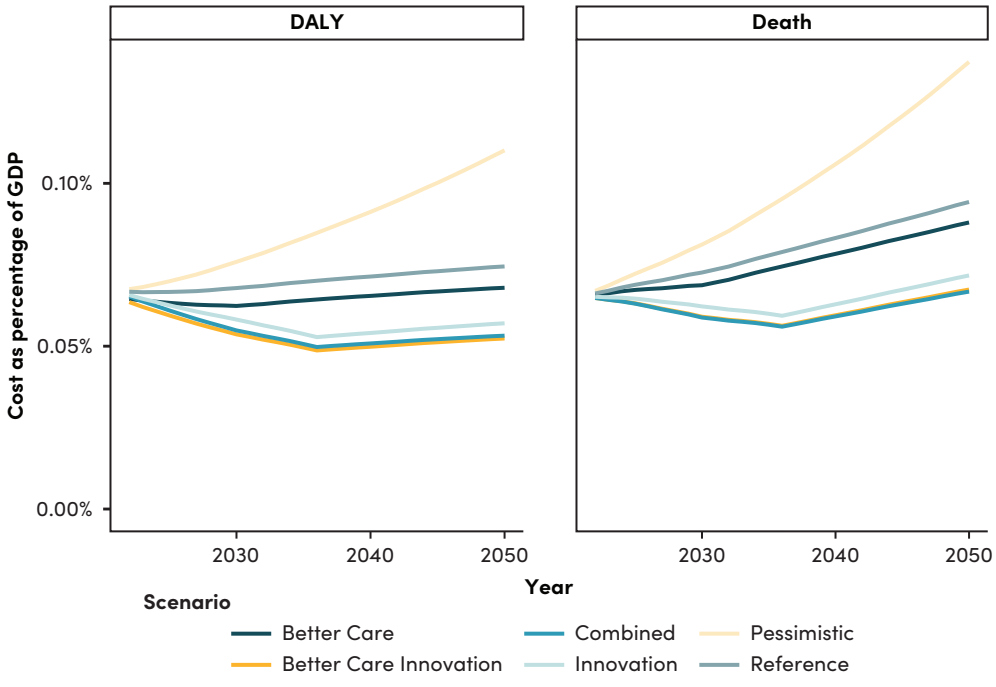
A more comprehensive exploration of the impact of these interventions are available in McDonnell et al. (2024), along with macroeconomics impact and costs of these interventions.

FIGURE 15. Global cost of resistant inpatient admissions, by different intervention scenario



Note: All of these scenarios show the mean estimate for a given scenario.

FIGURE 16. Global cost of resistant inpatient admissions as a proportion of GDP, by different intervention scenario



Note: All of these scenarios show the mean estimate for a given scenario.

4. Discussion

4.1 Strengths and limitations

This is the first study to use bottom-up comparable country estimates of healthcare cost per admission, combined with estimates of admissions numbers, to estimate the overall global direct healthcare cost associated with AMR. This approach has numerous advantages: it ensures estimates of overall health care costs are consistent with relevant micro-costing evidence from the literature. It provides evidence of how global cost may be distributed between different countries now and in the future. It allows future healthcare cost scenarios to be consistent with future disease burden scenarios.

The biggest challenge of this study is managing the considerable global variation in AMR treatment. There are different presentations of illness, a range of different bacterial pathogens which can have varying forms of resistance; additionally, health system structures vary considerably internationally. This diversity means producing consistent global estimates is much more challenging than corresponding national estimates. Where our estimates diverge from more specific studies of infectious syndromes or national estimates, it is likely that other researchers have incorporated more specific data and evidence for their narrower research question, so their estimates should be preferred.

The biggest limitation in our study is that we had to derive our estimates of hospital admissions from estimates of deaths to estimate global admissions consistently with available evidence. Producing these estimates was not the primary focus of the study, but a necessary methodological step as other available measures of burden did not relate closely enough to parts of the healthcare system where costs occur. Continuing to develop these estimates is a key area for future research, preferably with access to large primary admissions datasets.

Another key limitation in our study is that we only disaggregate by infectious syndrome. Other studies may achieve more granular estimates by also incorporating pathogens, resistance type, sub-groups of infectious syndromes or other variables like age. This lack of disaggregation in our study was necessary due with the data and evidence available to us. However, aggregation may lead to disparate forms of evidence being averaged, hiding meaningful variation in the process.

The complexity of the study and lack of available data also mean we synthesise diverse types of evidence in a common framework. While authors leading on their respective literature reviews tried to collect information on sample sizes or standard errors, in the end this information was not available consistently enough to allow us to weight different observed estimates in the literature based on strength. Being flexible about evidence allowed us to achieve much greater geographic coverage of estimates globally, but equal weighting of studies does not represent best practice in evidence synthesis.

4.2 Comparisons to other studies

Tables 7, 8 and 9 report how our results compare to other estimates of cost per admission, number of admissions with a resistant infection and total cost on AMR (either excess or total). Generally, our cost per admission estimates for *Diarrhoea* across LMICs are largely consistent with Baral et al. (2020). *Diarrhoea* is less represented in our dataset (with only 24 cost estimates from the literature) and cost estimates from LMICs more generally are also underrepresented, so it is reassuring to observe consistent results with a previous study for a more uncertain infectious syndrome and set of geographies.

Our starting point for estimating hospital admissions is GBD's estimates of associated deaths. This estimate suggests that 8.7 percent of deaths in 2019 involved a resistant infection. As a result, we estimate that 3.5 percent of admissions involved a resistant infection, which appears intuitive as many admissions for non-AMR causes never (or at least very rarely) result in death. Table 8 shows that when we compare our estimates for admissions to studies estimating the rate of healthcare acquired infections (having made some simplistic adjustments) our results appear to be relatively consistent for both HICs and LMICs.

When comparing our admissions estimates to either Cassini et al. (2019) or Jernigan et al. (2020) who estimate volumes of inpatient admissions with resistant infections for the European Union and United States respectively, our results are higher than these previous studies. Part of this difference may be explained by differences in the pathogens and resistance types included by IHME and these other studies. Also, both of these studies derive their estimates from confirmed cultures of resistant infections; this emphasis on confirmation makes their estimates high quality, but could mean that gaps in testing and reporting lead to underestimates. However, this variation may suggest that our admissions modelling approach leads to overestimates for these geographies.

When comparing our overall cost results to other studies (in Table 9), we find that our estimates are lower than those produced by the most comparable study, carried out by WHO (2024a). Our headline figures are not fully comparable to the WHO's because our headline figure refers to a static analysis of costs in 2022 and theirs is an average figure between 2015–2035. We run an additional scenario 2015–2035 to try to reconcile this. We find in this scenario our estimate is still less than half the value of the WHO's central estimate even using IHME's pessimistic burden scenario. The drivers of this variance are uncertain. However, we think that the most likely drivers are the WHO do not base their prospective scenarios on IHME, so may expect higher growth in admission volumes. WHO also derive their estimates of current patient volumes from Antimicrobial Resistance Collaborators (2022); however, inevitably our studies make different adjustments to estimate how incidence and deaths relate to treatment costs. Finally, potentially their estimated cost per admission may also be higher than ours; their costing methodology is based on the WHO-Choice model (OECD, 2024), so represents full economic cost of admissions. In our cost literature review, we preferred estimates that fully apportioned overheads in the costing of AMR admissions; however, not all studies in our

review did this consistently. Therefore, our estimates will align more closely with relevant parts of the AMR literature, but theirs will universally be based on full economic cost.

Despite our results being lower than WHO (2024a), our results are higher than most previous estimates of AMR costs. For instance, our results are higher than the OECD's previous round of estimates of the 34 OECD countries only. This variance is largely caused by their estimates being based on Cassini et al. (2019), and we have discussed that our estimates of resistant admissions are considerably higher than theirs. Scaling down our cost proportionately to the difference in admission estimates would mean their central estimate was within our range of overall costs. The OECD may also be able to better adjust costs to separate out the cost of the infection than us because underlying studies in the OECD generally report more granular results.

Our results are also somewhat higher than estimates for the United States from both CDC (2019) and Nelson et al (2021). Both of these studies also take a different approach generally, focusing on pathogens when we focus on infectious syndromes. Again, it appears that the variance between our estimates and these studies are likely caused by differences in quantity of AMR admissions underlying our estimates. However, our estimates are lower than Zhen et al. (2021) for the excess cost due to AMR in inpatient settings in China; the key difference between our studies is that they include excess costs due to colonisations as well as symptomatic infections, so unsurprisingly estimate higher excess costs.

Overall, different assumptions, scenarios and methodologies can materially impact the total global cost of AMR, or the breakdown between geographies and syndromes. However, it is clear from reviewing the literature that even within the micro-estimates for one hospital, pathogen, syndrome, resistance combination that different approaches to costing or epidemiological estimation can lead to markedly different estimates. It is unsurprising that there is a greater level of uncertainty when incorporating so many different components in one study.

4.3 Interpretation context

We would caution against comparing overall costs we estimate for different countries and interpreting them as where *need* for AMR intervention is highest. Low-income countries currently have lower treatment intensities for a range of disease areas, including AMR. Quantification of *need* through other metrics (like DALYs) is more appropriate due to the Egalitarian Principle at the heart of the Global Burden of Disease study (GBD, 2013). While not a good approach to quantifying *need* equitably around the world, our estimates of healthcare cost are key for understanding financial flows in the health sector, and the resource demands that AMR may impose on healthcare budgets.

Finally, our estimates only relate to direct inpatient care costs associated with treatment. However, studies like Otter et al. (2017) suggest that direct treatment costs are only a portion of the costs AMR imposes on healthcare services. They note non-treatment defensive spending (like additional

cleaning) and losses from cancelled services as key economic costs. R. Smith & and Coast (2013) also explore the evidence gaps of indirect costs of AMR on the healthcare system. Understanding these indirect costs is an essential area for further research.

TABLE 7. Summary table comparing our cost of admission estimates to previous studies

Cost Per Admission				
Source	**Parameter**	**Our Value**	**Their Value (Adjusted)**	**Definitional Differences**
Baral et al. (2020)	Non-resistant cost per diarrhoea inpatient admission in LMICs	$277	Literature: $194 WHO model: $317 IHME model: $889	We compare our mean LMIC *Diarrhoea* cost per admission to their three methods: literature, modelling using WHO costs, modelling using IHME costs (having inflated their estimates). We also find that 70 percent of our country estimates are within their modelled range for that country.

TABLE 8. Summary table comparing our resistant admission estimates to previous studies

Admission Estimates				
Source	**Parameter**	**Our Value**	**Their Value (Adjusted)**	**Definitional Differences**
Suetens et al. (2018)	Proportion of admissions with resistant infection in HICs	2.1% (1.1%–3.6%)	2.7%	HICs, resistant admissions not reported by author, but illustratively estimated by us, based on secondary assumptions about how their estimates of health care acquired infections might map to all resistant inpatient infections.
Allegranzi et al. (2011)	Proportion of admissions with resistant infection in LMICs	3.9% (1.7%–7.5%)	5.9%	LMICs, resistant admissions not reported by author, but illustratively estimated by us, based on secondary assumptions about how their estimates of health care acquired infections might map to all resistant inpatient infections.
Cassini et al. (2019)	Number of hospital admissions with a resistant infection in the EU	1.54mn (0.81mn–2.67mn)	0.67mn	European Union hospital admissions with resistant infections, where their estimates are for a different range of pathogens and resistance types than those in IHME's estimates.
Jernigan et al. (2020)	Number of hospital admissions with a resistant infection in the US	1.10mn (0.58mn–1.83mn)	0.62mn (0.58mn–0.65mn)	United States hospital admissions with resistant infections, where their estimates are for a different range of pathogens and resistance types than those in IHME's estimates.
Wozniak et al. (2022)	Number of hospital admissions with a resistant infection in Australia	47.6k (23.8k–83.6k)	21.6k (12.1k–33.7k)	Australian hospital admissions with resistant infections, where their estimates are for a narrower range of pathogens and resistance types than IHME's estimates.

TABLE 9. Summary table comparing our estimates of direct healthcare costs to previous studies

Overall Direct Healthcare Cost Estimates				
Source	**Parameter**	**Our Value**	**Their Value (Adjusted)**	**Definitional Differences**
WHO (2024a)	Global total cost of AMR inpatients	2015–35 average Reference: $187.2bn Pessimist.: $201.8bn	$461.0bn	The scope of these values should be equivalent. Methodological differences are explored in the discussion. We have inflated their estimate from 2020 US$ to 2022 for consistency with ours.
OECD (2023)	34 OECD countries cost of AMR inpatients	Total: $91.8bn ($44.4bn–$155.2bn) Excess: $28.0bn ($12.3bn–$49.5bn)	Total: $32.3bn Excess: $6.6bn	The scope of these values should be equivalent. Methodological differences are explored in the discussion. We have inflated their estimate from 2020 US$ to 2022.
CDC (2019)	Excess cost of AMR in the United States	$15.5bn ($7.6bn–28.3bn)	$6.8bn	The scope of these values should be similar; however, CDC cost pathogens individually with differing methodologies for each pathogen. Their quantities are based on CDC estimates whereas ours are based on IHME's, CDC includes fewer pathogen resistance pairs. We aggregated across pathogens (in the scope of both studies) and inflated.
Nelson et al. (2021)	Excess cost of AMR in the United States	$15.5bn ($7.6bn–28.3bn)	$5.4bn ($4.8bn–6.0bn)	The scope of these values should be similar; however, Nelson et al base their estimates on admission numbers from Jerginan et al (2020), who report lower total numbers of admissions. Scaling our admissions down to match theirs would explain most of the variance between our results and theirs. We inflated their numbers from 2017 US$ to 2022.
Zhen et al. (2021)	Excess cost of AMR in China	$17.7bn ($7.8bn–37.7bn)	$33.3bn ($30.0–35.6bn)	The study includes the additional cost of colonisations as well as symptomatic infections, so is expected to lead to a higher estimate of overall cost than our study. They estimate colonisations and infections jointly and so estimate a far higher resistant admission volume. This is associated with a lower excess cost per admission, but on aggregate a higher estimate. We inflated their numbers from 2015 US$ to 2022.
DHSC (2018)	Excess cost of AMR in the United Kingdom	$921mn ($213mn–1,440mn)	$303mn	DHSC's estimate is *at least* £180mn for England. Population upscaling, converting and inflating gives $303mn for the United Kingdom in 2022. There is insufficient information published about the figure to assess comparability of methodologies.

TABLE 9. (Continued)

Overall Direct Healthcare Cost Estimates				
Source	**Parameter**	**Our Value**	**Their Value (Adjusted)**	**Definitional Differences**
Wozniak et al (2022)	Excess cost of AMR in Australia	$180.7mn ($32.9mn–$328.4mn)	$55.1mn ($37.0–$105mn)	Their headline estimate for excess cost is 72.0mn AUD for 2020, we convert and inflate this figure. They model a considerably smaller range of pathogens and resistance types and end up with a considerably lower quantity estimate for admissions, if these aligned then the expenditure estimates would be much closer.
Larsson (2022)	Excess cost of AMR in Sweden	$173mn ($30mn–289mn)	$25mn	Larsson's estimate for 2018 is EUR 21mn (excluding outpatients). This only covers 5 notifiable pathogen resistance combinations, considerably fewer than IHME's. It is also based on confirmed notified infections, so is likely to be lower than modelling.
Su et al. (2020)	Total cost of TB in LMICs	Resistant: $4.5bn ($2.4bn–$7.9bn)	Total: $12.8bn (resistant and susceptible)	This implies resistant TB treatment is 35% of TB treatment cost in LMICs. Where GBD estimate around 6% of TB incidence is drug resistant, and our estimates imply cost per case is considerably higher for resistant cases. If the difference in cost per case is 10:1, then you would expect 39% of TB cost to be resistant.

5. Conclusion

We estimate that the cost per admission with a resistant infection is approximately $100–1,000 in low-income countries, $300–3,000 in lower-middle-income countries, $1,000–10,000 in upper-middle-income countries, and $3,000–30,000 in high-income countries. These costs are approximately double the cost of a comparable admission with a susceptible infection (except for TB, where the cost differential is greater).

We estimate that there are 25.4 million (L: 11.6 million–H: 48.0 million) hospital admissions with an AMR infection globally each year. This is equivalent to 3.5 percent (L: 1.6 percent–H: 6.5 percent) of global admissions. Our estimates of hospital admissions are in line with some systematic reviews on the rate of hospital acquired infections observed in inpatient settings (where we make crude adjustments to draw comparisons), but higher than two high quality studies from the US and European Union respectively.

Our overall estimate of the excess expenditure due to AMR globally is $66.4 billion (L: $32.0 billion–H: $156.0 billion). Despite utilising conservative assumptions, sub-analyses of our estimates compared to previous studies suggest our estimates are broadly consistent but may be at the higher end of the literature. This divergence is largely explained by key previous studies estimating lower numbers of AMR admission volumes than us; however, our methodology for estimating admissions required comparable international data, which those national estimates would not provide.

We find that LMICs spend a higher proportion of their limited healthcare budgets on AMR admissions. Low-income-countries spend 2.0 percent on excess resistant costs and lower-middle-income-countries spend 1.5 percent, whereas high-income-countries spend 0.4 percent.

We estimate that excess expenditure due to AMR is likely to increase; in our reference prospective scenario it increases from around $66.4 billion to $159.4 billion (L: $59.7 billion–H: $229.4 billion). Pessimistic burden scenarios suggest it could feasibly increase by more, though optimistic scenarios suggest it could be roughly constant over time. Antibiotic development, improvements in access and improved coverage of WASH and vaccines have the potential to meaningfully reduce the excess expenditure due to AMR.

Appendix 1: Cost literature review

Overall search strategy and inclusion criteria

We undertook a search of studies in the Tufts Cost Effectiveness Analysis Database and a search of systematic reviews in PubMed to identify relevant cost estimates where the primary studies included in systematic reviews were re-extracted. More details on the overall search strategy including the exact search terms can be found in the **Search Terms** section of this appendix.

1. These abstracts were screened for relevancy for estimating direct cost of AMR cases
2. Any abstracts that passed the screen were then reviewed in full text for relevancy

The scope on this project is global; as such, we decided that stringent methodological standards would not be enforced on extracted papers, as this may exacerbate the lack of evidence currently available in low- and middle-income countries (LMICs). As such, the following pragmatic inclusion criteria for full text were chosen:

1. The year of the cost data is later than 2007, this was relaxed for specific studies where there is a lack of cost evidence from that country or infectious syndrome.
2. Key contextual information is specified, without which the data could not be entered into the model. This key context includes: the infectious syndrome being treated, the healthcare setting, the country, the currency, and the year the costs were collected.
3. Sufficient detail of how costs were estimated to ensure the results are true cost estimates and not just illustrative assumption. Some methodological detail must have been offered. We excluded costs proposed that are purely based on expert elicitation, or are stated without methodology in an opinion or editorial piece. We required sufficient detail of what cost components are included to ensure the costs are somewhat representative of true costs (e.g., drug costs, labour costs etc.); studies of drug cost only were not included.

Search terms

Tufts CEA search terms

("resistance" OR "resistant" OR "MDR" OR "XDR" OR "AMR" OR "AMR")

PubMed search terms

The following search of systematic reviews in PubMed was undertaken.

((“resistance”[Title/Abstract] OR “resistant”[Title/Abstract] OR “MDR”[Title/Abstract] OR “XDR”[Title/Abstract] OR “AMR”[Title/Abstract] OR “AMR”[Title/Abstract] OR “drug resistance, microbial”[MeSH Major Topic])

AND

(“antibiotic”[Title/Abstract] OR “antimicrobial”[Title/Abstract] OR “carbapenems”[Title/Abstract] OR “penicillin”[Title/Abstract] OR “aminopenicillin”[Title/Abstract] OR “aminoglycosides”[Title/Abstract] OR “anti-pseudomonal”[Title/Abstract] OR “fluoroquinolones”[Title/Abstract] OR “macrolide”[Title/Abstract] OR “tuberculosis”[Title/Abstract] OR “methicillin”[Title/Abstract] OR “vancomycin”[Title/Abstract] OR “colistin”[Title/Abstract] OR “amoxycillin”[Title/Abstract] OR “cephalosporins”[Title/Abstract] OR “tetracyclines”[Title/Abstract] OR “sulfonamides”[Title/Abstract] OR “beta-lactams”[Title/Abstract] OR “glycopeptides”[Title/Abstract] OR “oxazolidinones”[Title/Abstract] OR “lincosamides”[Title/Abstract] OR “quinolones”[Title/Abstract] OR “polypeptides”[Title/Abstract] OR “streptogramins”[Title/Abstract] OR “nitrofurans”[Title/Abstract] OR “rifamycins”[Title/Abstract] OR “thiazolylpeptides”[Title/Abstract] OR “beta-lactamase inhibitors”[Title/Abstract])

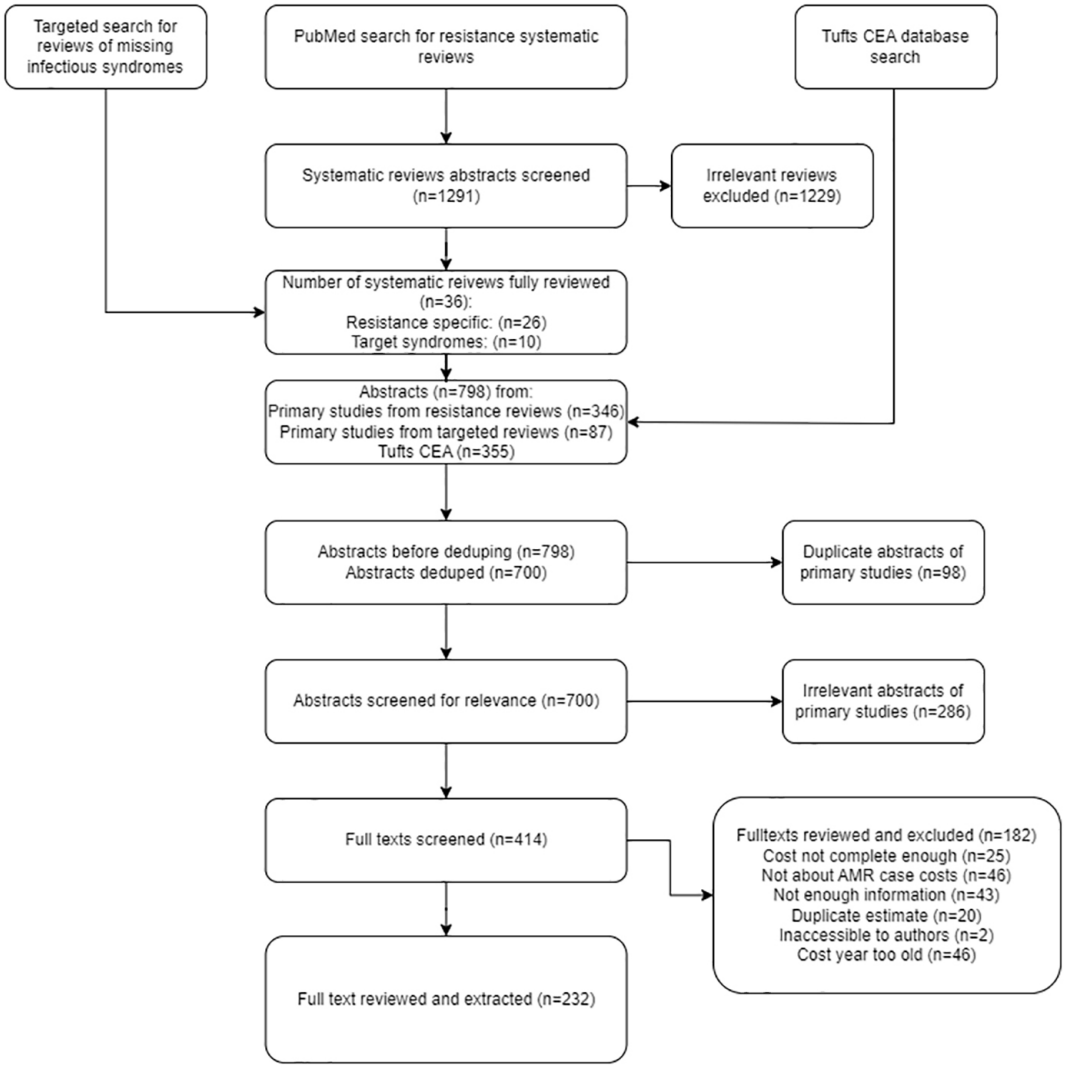
AND

(“economic”[Title/Abstract] OR “cost”[Title/Abstract] OR “CEA”[Title/Abstract] OR “CUA”[Title/Abstract] OR “financial”[Title/Abstract] OR “expenditure”[Title/Abstract] OR “budget”[Title/Abstract] OR “resource”[Title/Abstract] OR “payment”[Title/Abstract])

AND

(“review”[Title/Abstract] OR “review literature as topic”[MeSH Terms] OR “review”[Title/Abstract]))

FIGURE A1.1. Cost estimate search Prisma diagram



Extracted fields from cost papers

Table A1.1. sets out what attributes we attempted to extract from papers (including supplemental materials). This extraction template does not exactly follow any pre-established protocol, because the needs of this study are focused only on costs and need to be interoperable with pre-existing GBD estimates. However, the widely used Consolidated Health Economic Evaluation Reporting Standards (CHEERS) framework by Husereau et al. (2013) and an example health economics systematic review extraction template from Frampton et al. (2016) were used to inform this template.

TABLE A1.1. Attributes to be extracted from papers

Field to be Extracted	Explanation (Where Required)
PubMed ID	No explanation required
Paper title	No explanation required
Paper abstract	No explanation required
DOI	No explanation required
Publication year	Year this version of the paper was published
Pass abstract screen	Yes/no depending on relevancy
Pass full text screen	Yes/no depending on relevancy and inclusion of sufficient information
Cost year	The year for which the costs in the study were estimated, only include latest if multiple years were presented
Perspective label	Whether the perspective is: Healthcare, Wider Government, Societal
Perspective comment	Any other comment clarifying the perspective, e.g., does it include out of pocket payments or social care
Discount rate	A rate (with compounding) applied by economists to adjust future costs for the time value of money
Country	GBD countries and territories are included, full list available from GBD compare
Currency	IMF recognised currencies are allowed
Setting label	Intensive Care Unit (ICU–or ITU in American English), Ward, Hospice, Outpatient or General are allowable
Setting comment	This gives more nuance to the setting if necessary
Patient subgroup	Is the paper focused on a specific subgroup–studies looking at highly specific subgroups only may be excluded; for instance, low CD4 count HIV+ people may have much higher costs than others
Severity subgroup	Is the paper focused on the most severe or less severe patients only?
Sample size	What is the sample size reported if using a survey, microcosting or administrative records? This will not be appropriate for hypothetical modelled cohorts
Cost value	What is the numerical value of the cost in the currency reported? This number may have elements like testing removed compared to the paper's headline figure
General cost comment	Any other comment clarifying the cost not reported above
Cost medicines	Does the cost include medication costs?
Test cost value	The numerical value of the cost per test
Cost test	Does the cost include testing costs? These should be excluded from the general cost value if possible
Cost staff	Does the cost include staff time? Which should ideally include apportioned non-patient facing time (e.g., training) for clinical staff and apportioned time for non-clinical healthcare staff (e.g., receptionists or managers)
Cost overhead	Does the cost include overhead–e.g., plant and property?
Cost non-healthcare gov	Does the cost include other government costs outside of healthcare? These should be stripped out of cost value if possible
Cost other economic	Does the cost include other economic costs outside of healthcare– e.g., productivity? These should be stripped out of cost value if possible
Cost data label	Labels allowed are: Micro costing, Administrative, Costing model, Expert opinion

TABLE A1.1. (Continued)

Field to be Extracted	Explanation (Where Required)
Cost data comment	Greater clarification where papers do not exactly align with a label
Pathogen (GBD)	What pathogen from GBD's list is mentioned: Escherichia coli, Staphylococcus aureus, Klebsiella pneumoniae, Streptococcus pneumoniae, Acinetobacter baumannii, Pseudomonas aeruginosa, Mycobacterium tuberculosis, Enterococcus faecium, Enterobacter spp, Group B Streptococcus, Salmonella enterica serotype Typhi, Enterococcus faecalis, Proteus spp, Other enterococci, Serratia spp, Group A Streptococcus, Citrobacter spp, Haemophilus influenzae, Shigella spp, Non-typhoidal Salmonella, Salmonella enterica serotype Paratyphi, Morganella, and Other
Pathogen (GBD) comment	Any clarification or uncertainty about the application of the pathogen classification
Infectious syndrome (GBD)	What infection syndrome from GBD's list is mentioned: Lower Respiratory Infection+ (LRI+), Blood Stream Infection (BSI), Intraabdominal, Urinary Tract Infection (UTI), Tuberculosis, Skin, Central Nervous System (CNS), Typhoid Fever/Paratyphoid Fever/invasive Non-Typhoidal Salmonella (TF-PF-iNTS), Diarrhoea, Cardiac, Bone+, and Other
Infectious syndrome (GBD) comment	Any clarification or uncertainty about the application of the infectious syndrome classification
Resistance	What type of antibiotic resistance from GBD's list is mentioned: Resistance to 1+, Third Generation Cephalosporins (3GC), Fourth Generation Cephalosporins (4GC), Aminoglycosides, Aminopenicillin, Anti–pseudomonal, Beta-Lactamase inhibitors (BL–BLI), Carbapenems, Fluoroquinolones, Macrolide, Multidrug Resistant (MDR) excluding Extensively Drug Resistant (XDR) in tuberculosis, MDR in S Typhi and S Paratyphi, Meticillin, Monoresistance to Isoniazid (Mono INH), Monoresistance to Rifampicin (Mono RIF), Penicillin, Trimethoprim-Sulfamethoxazole (TMP-SMX), Vancomycin, XDR in tuberculosis, and Other
Resistance comment	Additional clarification about the type of resistance e.g., if it was inferred by treatment failure or lab confirmed in the study

TABLE A1.2. Descriptive statistics about the cost estimates extracted from 232 secondary studies

Variable	N = 911[1]
Cost Year Band	
[1995,2000]	10 (1%)
(2000,2005]	79 (9%)
(2005,2010]	219 (24%)
(2010,2015]	352 (39%)
(2015,2020]	247 (27%)
(2020,2025]	4 (0%)
GBD Infectious Syndrome	
Bacterial infections of the skin and subcutaneous systems	77 (8%)
Bloodstream infections	213 (23%)
Diarrhoea	32 (4%)
Endocarditis and other cardiac infections	7 (1%)
Gonorrhoea and chlamydia	12 (1%)

TABLE A1.2. (Continued)

Variable	N = 911[1]
Infections of bones, joints, and related organs	12 (1%)
Lower respiratory infections and all related infections in the thorax	141 (15%)
Meningitis and other bacterial central nervous system infections	39 (4%)
Other	3 (0%)
Peritoneal and intra-abdominal infections	62 (7%)
Tuberculosis	161 (18%)
Typhoid fever, paratyphoid fever, and invasive non-typhoidal Salmonella	53 (6%)
Urinary tract infections and pyelonephritis	99 (11%)
World Bank Income Level	
Low-income	42 (5%)
Lower-middle-income	104 (11%)
Upper-middle-income	299 (33%)
High-income	466 (51%)
GBD Super Region	
Central Europe, Eastern Europe, and Central Asia	33 (4%)
High-income	450 (49%)
Latin America and Caribbean	58 (6%)
North Africa and Middle East	38 (4%)
South Asia	54 (6%)
Southeast Asia, East Asia, and Oceania	161 (18%)
Sub-Saharan Africa	117 (13%)
Setting Label	
ICU	29 (3%)
Inpatient	754 (83%)
Outpatient	54 (6%)
Testing	74 (8%)
Resistant or comparator	
Resistant	528 (58%)
Base not resistant	352 (39%)
Uninfected Comparator	31 (3%)

Note: [1]n (%).

Standardising cost literature

Costs are adjusted for inflation and exchange rates following method 2 from Turner et al. (2019). Costs from studies are either reported in their own national currency units (NCU), US dollars, international dollars, or euros. These costs are converted back into NCU, where they are inflated to 2022 prices using the World Bank GDP deflator. They are then converted into US dollars using market exchange rates. For typhoid, paratyphoid, and invasive non-typhoidal salmonella there were very few confirmed resistant case cost estimates; as such, half of the typhoid estimates were adjusted

upward and called resistant only cases, and half were adjusted down and called susceptible only. The rate of adjustment was set such that the ratio of case costs should be 1.8:1 as that is the median observed excess cost due to resistance across the other infectious syndromes (excluding TB). Finally, the majority of primary cost estimates from modelling studies or micro-costing studies come from tertiary research hospitals. The WHO Choice Model estimates suggest these hospitals have higher daily inpatient costs; as such, these costs were adjusted downward to those of secondary hospitals in order to be more conservative Bertram & Edejer (2021). This assumes all treatment of AMR cases happens at secondary rather than primary or tertiary settings. Estimates derived from national administrative datasets were not adjusted in the same way, as they were assumed to be derived from more representative data for the average case in a given country.

Appendix 2: Unknown cost estimation

The following statistical methods all involve predicting log transformed adjusted costs.

The regression specification for all models is shown by (1)

$$\begin{aligned}\log(Cost) = {} & \beta_0 + \beta_1 log(CHE) + \beta_2 \log(GDP) + \beta_3 PPP + \beta_4 HAQ + \beta_5 SDI + \beta_6 HospSplit \\ & + \beta_{7-15} GeographyDummies + \beta_{16-26} SyndromeDummies + \beta_{27-29} SettingDummies \\ & + \beta_{30-32} ResistanceDummies + \varepsilon\end{aligned} \quad (1)$$

Where:

- Cost is the cost estimate (post adjustment for inflation and discounting)
- CHE is current health expenditure per capita from the WHO in US$
- GDP is GDP per capita in US$
- PPP is the dollar denominated purchasing power parity
- HAQ is the Health Care Access and Quality index from IHME
- SDI is the SocioDemographic Index from IHME
- HospSplit is the proportion of the patients in the study who were reported to have hospital acquired infections
- GeographyDummies are dummy variables for the 7 GBD super regions, and an additional dummy for the USA
- SyndromeDummies are dummy variables for the IHME infectious syndromes
- SettingDummies are for dummy variables for testing, outpatient, inpatient or intensive care unit (ICU) costs
- ResistanceDummies are dummy variables defining whether the cost is for a resistant case or a non-resistant comparator. It also includes an interaction between resistance and the TB infectious syndrome, because the observed different between resistant and susceptible cases for TB is much higher than other syndromes.

TABLE A2.1. Summary of different models used to estimate unknown costs and how they were optimised

Model Name	Model Type	Lay Description	Hyperparameter Optimisation
Linear OLS	Linear regression model fit with ordinary least squares (R Core Team, 2024)	A very widely used and interpretable statistical approach that estimates linear relationships between variables and applies those relationships to unknown data.	No hyperparameters optimised
Linear ElasticNet	ElasticNet is a linear regression framework with L1 and L2 regularisation. The covariates were min-max scaled before being used to estimate costs. (Friedman et al., 2010)	A variant on a linear regression that penalises estimated linear relationships from being different from 0 (e.g., no relationship). This is to avoid coincidental relationships in observed data being assumed to hold to unknown values.	The Alpha parameter, determining the balance between L1 and L2, is optimized using a grid search across 101 values ranging from 0 to 1, aimed at minimising the Root Mean Squared Logarithmic Error (RMSLE) on the validation set. The Lambda parameter, indicating the degree of regularisation, was chosen through cross-validation exclusively on the training set.
Polynomial ElasticNet	ElasticNet is a linear regression framework with L1 and L2 regularisation. The covariates used to predict costs were interacted, squared and cubed. The covariates were min-max scaled before being used to estimate costs. (Friedman et al, 2010)	A variant on the Linear ElasticNet where more complex transformations of input variables are allowed. This approach is more flexible, as it allows for non-linear relationships between the covariates and cost.	Same as Linear ElasticNet
XGBoost Base	The XGboost model is a tree-based model Chen & Guestrin (2016). We estimate it using the R XGBoost package (Chen & et al, 2024)	Tree-based models split data according to the values of covariates such that similar observed costs end up in the same *leaves* of the tree (e.g., high- income country estimates would likely be grouped with other high-income country estimates). XGBoost combines many trees, where each new tree seeks to explain the remaining variation in the data and averages the results.	The hyperparameters were set at plausible initial values based on having a small dataset (so trees were not allowed to be too deep and risk overfitting).
XGBoost Optimised	A different XGBoost variant.	XGBoost is used again but lots of different starting parameters, which determine how the tree is constructed, were assessed to see which makes the best predictions.	The hyper parameters were optimised using the tune package in R (Kuhn, 2024). 100 rounds of Latin Hypercube Search to explore a wide range of possible hyperparameters (Dupuy et al., 2015). Then a Gaussian process regression was used to propose potentially good new combinations of hyperparameters (Snoek et al., 2012). This process is shown in Figure A2.1. A final specification was selected that was best at minimising validation loss, while avoiding overfitting.

Results of hyperparameter optimisation

In the optimisation, the Linear ElasticNet is more weighted towards L2 regularisation than L1 (Alpha < 0.5) whereas the Polynomial ElasticNet is evenly weighted towards L1 and L2 regularisation (Alpha ≈ 0.5). The level of regularisation in the Linear ElasticNet is higher (Lambda higher), this is unexpected because the Polynomial ElasticNet specification has many more coefficients (as it includes higher order polynomials and interactions), so we expected each of these coefficients to be shrunk towards 0 by a greater extent.

TABLE A2.2. Hyperparameters for ElasticNet

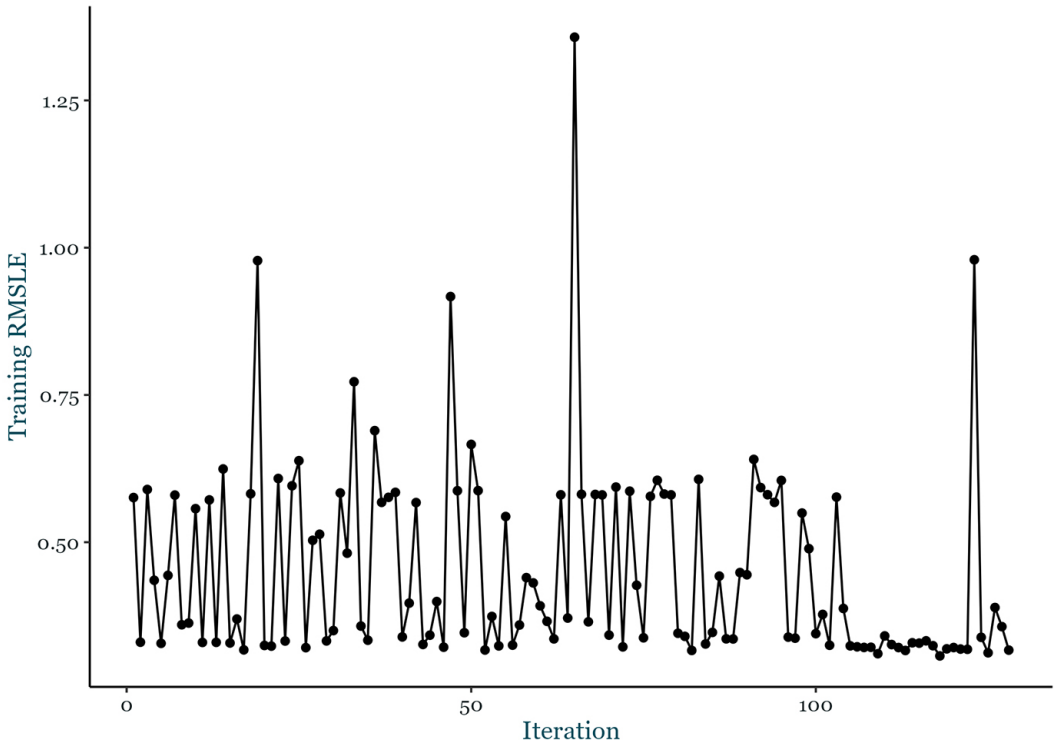
Hyperparameter	Linear ElasticNet	Polynomial ElasticNet
Alpha	0.080	0.460
Lambda	0.076	0.012
Loss	RMSLE	RMSLE

See the XGBoost documentation for definitions and explanations of these XGBoost hpyerparameters. In the optimisation of XGBoost, the learning rate (eta) falls, the min_child_weight increases and the optimisation introduces early stopping if additional trees do not lead to improved performance. All of these should decrease the likelihood of overfitting to the training data. However, the max_depth of trees does increase which could lead to overfitting.

TABLE A2.3. Hyperparameters for XGBoost

Hyperparameter	Baseline XGBoost	Optimised XGB
Eta	0.20	0.15
max_depth	3	8
min_child_weight	1	12
Subsample	1	0.98
colsample_bytree	1	0.64
Gamma	0	0.00
Lambda	1	1
Alpha	0	0
max ntrees	30	100
early stopping patience	Infinite	9
Loss	RMSLE	RMSLE

FIGURE A2.1. Convergence plot of training RMSLE over 100 iterations of Latin hypercube sampling and then Bayesian Optimisation for the final 20 iterations



Validation of unknown costs estimation

Tests 1–4 all apply to validating the different model specifications used to estimate unknown cost per inpatient case (described in 2.2.3). To assess statistical performance (Test 1) 10 percent of the 896 observations were separated into a *validation set*. This validation set is used to choose between different model approaches and optimise hyperparameters of models. It is unlike the *test set*, which is 20 percent of the 896 observations. This was held back until the end of the study and used to report the final accuracy of the headline statistical approach used (Wikipedia, 2024). The remaining 70 percent of the observations is the *training set* used to estimate the models themselves. At the end of the study the chosen specifications were re-run for 100 percent of the observations to improve the performance of all models. The three statistical loss measures used to assess the models are the symmetric mean absolute percentage error (SMAPE), the root mean square logarithmic error (RMSLE) measures, and finally the root measure square error (RMSE) – which is included for completeness but inappropriate for this task as costs being predicted vary by several orders of magnitude.

In terms of statistical performance, it is challenging to assess how *good* estimates are without a baseline. This is a novel dataset. Therefore, no other researchers have demonstrated the possibility of accurately predicting unknown costs with this dataset. An approximate baseline of the best possible

expected performance is constructed based on the variability of the observed data. This variability is measured where there are multiple observations for the same combination of setting, infectious syndrome, country, and resistance type. We estimate the group mean for these observations (where the observed cost is log transformed). A perfect statistical method which minimises the statistical loss would predict the mean for each group. Comparing the deviation between the mean and observed values gives a theoretical minimum value for our measures of statistical loss.

To test the consistency with observed data (Test 2), estimates are visually compared to data and outliers are investigated. To test the feasibility of estimated costs, the following expectations were set up prior to unknown cost estimation:

- Test 3.1) Proportion of predicted costs that are greater than any observed resistant inpatient costs for that World Bank income group.
- Test 3.2) Proportion of predicted costs that are less that any observed resistant inpatient costs for that World Bank income group.
- Test 3.3) Proportion of predicted costs that are greater than 3× GDP per capita. Where 3× GDP per capita is chosen to represent a relatively large amount to spend on a health intervention (Ochalek et al., 2015).
- Test 3.4) Proportion of predicted costs that are less than 0.1× GDP per capita. Which is chosen to be a comparably small amount to spend on a health intervention requiring hospitalisation that may not respond to first line treatment.

Finally, conservatism is judged based on which unknown data estimation technique appear to be materially overestimating costs. This is done by comparing results from the models to each other visually and the overall total estimates that result.

Appendix 3: Epidemiological literature review

Data sources and search strategy

We performed a literature search using PubMed. We focused on quantitative estimates of epidemiological parameters to support the adjustment of IHME's estimates of deaths and incidence into hospital admission estimates. The search strategy is outlined in Table A3.1. Search terms included a combination of title and abstract terms. Due to the wide scope of parameters required and the large number of abstracts found from the search strategy (over 8,500), we narrowed our scope to re-extraction of results from published systematic reviews only.

After screening and extracting data from these systematic reviews, we identified potential gaps in the extracted data, with a focus infectious syndromes and geographic areas. To fill in these gaps, we screened additional abstracts from studies reporting inpatient costs from the cost extraction literature review.

Outcome parameters

The authors identified key parameters that needed to be extracted. These included:

1. Hospital fatality rate (HFR)
2. Infection hospitalisation rate (IHR)
3. Hospitalisation rate
4. Case fatality rate (CFR)

Other parameters that were extracted if reported in the selected publications were:

1. Case ascertainment rate (outpatient and inpatient)
2. Population attributable fraction
3. Test positivity rate

The definitions considered for these parameters are shown in Table 2. The lower priority parameters would have been required to extend the modelling to capture outpatient treatment and testing costs, but these we excluded due to a lack of cost estimates in those settings.

TABLE A3.1. Search terms for the epidemiological literature review

Pubmed
Search: ("hospitalisation"[Title/Abstract] OR "IHR"[Title/Abstract] OR "infection hospitalisation rate"[Title/Abstract] OR "hospitalised"[Title/Abstract] OR "incidence"[Title/Abstract] OR "HFR"[Title/Abstract] OR "case fatality rate"[Title/Abstract] OR "hospital fatality rate"[Title/Abstract]) AND ("AMR"[Title/Abstract] OR "MDRO"[Title/Abstract] OR "MDR"[Title/Abstract] OR "XDR"[Title/Abstract] OR "AMR"[Title/Abstract] OR "resistan*"[Title/Abstract]) AND ("antibiotic"[Title/Abstract] OR "antimicrobial"[Title/Abstract] OR "carbapenems"[Title/Abstract] OR "penicillin"[Title/Abstract] OR "aminopenicillin"[Title/Abstract] OR "aminoglycosides"[Title/Abstract] OR "anti-pseudomonal"[Title/Abstract] OR "fluoroquinolones"[Title/Abstract] OR "macrolide"[Title/Abstract] OR "tuberculosis"[Title/Abstract] OR "methicillin"[Title/Abstract] OR "vancomycin"[Title/Abstract] OR "colistin"[Title/Abstract] OR "amoxycillin"[Title/Abstract] OR "cephalosporins"[Title/Abstract] OR "tetracyclines"[Title/Abstract] OR "sulfonamides"[Title/Abstract] OR "beta-lactams"[Title/Abstract] OR "glycopeptides"[Title/Abstract] OR "oxazolidinones"[Title/Abstract] OR "lincosamides"[Title/Abstract] OR "quinolones"[Title/Abstract] OR "polypeptides"[Title/Abstract] OR "streptogramins"[Title/Abstract] OR "nitrofurans"[Title/Abstract] OR "rifamycins"[Title/Abstract] OR "thiazolylpeptides"[Title/Abstract] OR "beta-lactamase inhibitors"[Title/Abstract])

TABLE A3.2. Definition of the outcome parameter of interest

Parameter of Interest	Definition	Priority for Extraction
Hospital fatality rate (HFR)	Proportion of patients admitted who die in hospital (or shortly after in some studies)	High
Infection hospitalisation rate (IHR)	Proportion of incident infections that are admitted to hospital admission or acquire the infection in hospital	High
Case ascertainment rate outpatient	Proportion of incident infections that are diagnosed by healthcare or are otherwise confirmed by testing	Low
Case ascertainment rate inpatient	Proportion of hospital acquired infections that are confirmed through testing or other diagnostic criteria	Low
Test positivity rate	Proportion of total tests that are positive	Low

Study selection and eligibility criteria

Search results were imported into Endnote (Clarivate, Philadelphia, United States), where duplicate records were identified and removed. For the remaining records, abstracts were first screened for potential relevance and then full texts of potentially relevant publications were retrieved and assessed.

We considered limiting the study to the epidemiological parameters of resistant cases of infectious syndromes only. Unfortunately, there is no literature for many infectious syndromes and geographies.

Publications were selected based on the following inclusion criteria:

- Presented data on at least one of the specified outcome parameters of interest defined above.
- Reported on at least one of the infectious syndromes defined by the GBD study Antimicrobial Resistance Collaborators (2022). Studies that reported pooled results for outcomes of interest across multiple infectious syndromes were extracted and assigned to each of those infectious syndromes, this may bias syndromes to appear more similar than they would be otherwise:
    1. Bacterial infections of the skin and subcutaneous systems (SSTI)
    2. Bloodstream infections (BSI)
    3. Diarrhoea
    4. Endocarditis or other cardiac infections (Cardiac)
    5. Infections of the bones, joint, and related organs (Bone)
    6. Lower respiratory infections (LRI) and all related infections in the thorax
    7. Meningitis and other bacterial central nervous system infections (CNS)
    8. Peritoneal and intra-abdominal infections (IAI)
    9. Tuberculosis (TB)
    10. Typhoid fever, paratyphoid fever, and invasive non-typhoidal Salmonella
    11. Urinary tract infections (UTIs)

There were no criteria or restrictions applied on year of publication, gender of study participants, geographic location (all GBD regions were included), age groups, or language of publication.

Data extraction and synthesis

Screened records that were noted as eligible were extracted. C list of variables extracted is outlined in Table A3.3. During the data extraction phase, some decisions were made to refine estimates for the final model. This involved (1) reporting pooled estimates from across infectious syndromes or geographical areas to individual syndromes and geographical regions; (2) extracting all-cause mortality instead of infection specific mortality; (3) considering studied conducted in hospitals as involving inpatient populations, unless specified; (4) reporting the GBD region based on the country of research, and categorising it following the GBD regional classification.

TABLE A3.3. Extraction template with the attributes extracted from papers and supplementary materials when needed

Field Extracted	Explanation (where Required)
PubMed ID	No explanation required
DOI	No explanation required
Paper title	No explanation required
Publication year	Year the paper was published
Paper abstract	No explanation required
Added	Original/Added depending on whether the publication was found from the PubMed search or added later as a single article
Pass abstract screen (Yes/No)	Yes/No depending on relevancy
Abstract screen comment	Any comments for excluding an abstract
Pass full text screen (Yes/No)	Yes/No depending on relevancy and inclusion of sufficient information
Full text comment	Any comments for excluding full text
Paper year	Time period when the study was conducted
GBD region	High-income/Latin America & Caribbean/Sub-Saharan Africa/North Africa & Middle East/South East Asia/South Asia/Central Europe/Eastern Europe and Central Asia/Global depending on the geographical location of the study. If only the country was specified, the region was found based on the GBD location hierarchy.
Region, comment	Any comments on the regions
Country	GBD countries and territories are included, full list available from GBD compare
Study type	Study design–e.g., Cohort study, cross-sectional study, case-control study, prevalence study. This was only reported for the added records since original studies were all systematic reviews
Sample size	Sample size for the study
Age-group	Age included in the study. In some, instances this was grouped into infant/children/adults and age limits were included when available
Hospital or community onset	Hospital/community depending on the patient cohort in the study acquired their infection in hospital or community settings
Patient population	If specified in the study, details were added on whether the participants were inpatient/outpatient/ICU/Ward/Hospice/Other inpatient/General/testing
Severity sub-set	Any additional complications or infections considered in the study, if reported. For example, patient with COVID-19, HIV positive patients.
Infectious syndrome	What infection syndrome from GBD's list is mentioned: Bacterial infections of the skin and subcutaneous systems, Bloodstream infections (BSI), Diarrhoea, Endocarditis or other cardiac infections, Infections of the bones, joint, and related organs, Lower respiratory infections (LRI), Meningitis and other bacterial central nervous system infections, Peritoneal and intra-abdominal infections, Tuberculosis (TB), Typhoid fever/paratyphoid fever/invasive non-typhoidal Salmonella, Urinary tract infections (UTIs), and Other.
Infectious syndrome comment	Any details or clarification on the infectious syndrome classification

TABLE A3.3. (Continued)

Field Extracted	Explanation (where Required)
Pathogen	What pathogen from GBD's list is mentioned: Acinetobacter baumannii, Enterobacter spp, Enterococcus faecalis, Escherichia coli, Group A Streptococcus, Group B Streptococcus, Klebsiella pneumoniae, other enterococci, Proteus spp., Pseudomonas aeruginosa, Staphylococcus aerus, Citrobacter spp., Enterococcus faecium, non-typhoidal Salmonella, Salmonella Typhi, Serratia spp., Streptococcus pneumoniae, Shigella spp., Neisseria gonorrhoeae, Haemophilus influenzae, Mycobacterium tuberculosis, Salmonella Paratyphi, Morganella spp., Other
Pathogen comment	Any details or clarification on the pathogen classification. If "Other" was selected for the pathogen label, the comment was used to provide further information
Resistance	What type of antibiotic resistance from GBD's list is mentioned: Aminoglycosides, Anti-pseudomonal penicillin/Beta-Lactamase inhibitors, Beta Lactam/Beta-lactamase inhibitors, Carbapenems, Fluoroquinolones, fourth-generation cephalosporins, third-generation cephalosporins, aminopenicillin, macrolide, methicillin, penicillin, trimethoprim-Sulfamethoxazol, vancomycin, multi-drug resistance in Salmonella Typhi and Paratyphi, extensive drug resistance in TB, isoniazid mono-resistance, multi-drug resistance excluding extensive drug resistance in TB, rifampicin mono-resistance, other
Resistance comment	Additional clarification about the type of resistance e.g., if it was inferred by treatment failure or lab confirmed in the study. If "Other" was selected for the resistance label, the comment was used to provide further information
Aggregated syndrome	Specify if the GBD syndromes were aggregated
Parameter of interest	IHR/HFR/Case ascertainment rates inpatient/Case ascertainment rates outpatient/Test positivity rate depending on the parameters reported in the study
Numerator	Explanation of the numerator value to calculate the parameter of interest
Denominator	Explanation of the denominator value to calculate the parameter of interest
Value	Value reported in the paper for the parameter of interest
Upper Value	Upper value reported in the paper for the parameter of interest
Lower Value	Lower value reported in the paper for the parameter of interest
Variable, comment	Any additional clarification about value reported

Search results

The study selection process is shown in the Prisma flowchart (Figure A3.1.). A total of 401 systematic reviews were identified in PubMed. After de-duplication and abstract screening, 67 unique citations were identified as relevant or potentially relevant for further screening. Full-text screening of these citations identified 38 relevant systematic reviews. Screening of eligible articles and reviews from studies reporting inpatient costs from the cost extraction literature review yielded an additional 147 publication. This resulted in 185 publications included (38 from the PubMed search and 147 from the additional screening).

FIGURE A3.1. Prisma flowchart for epidemiological article selection

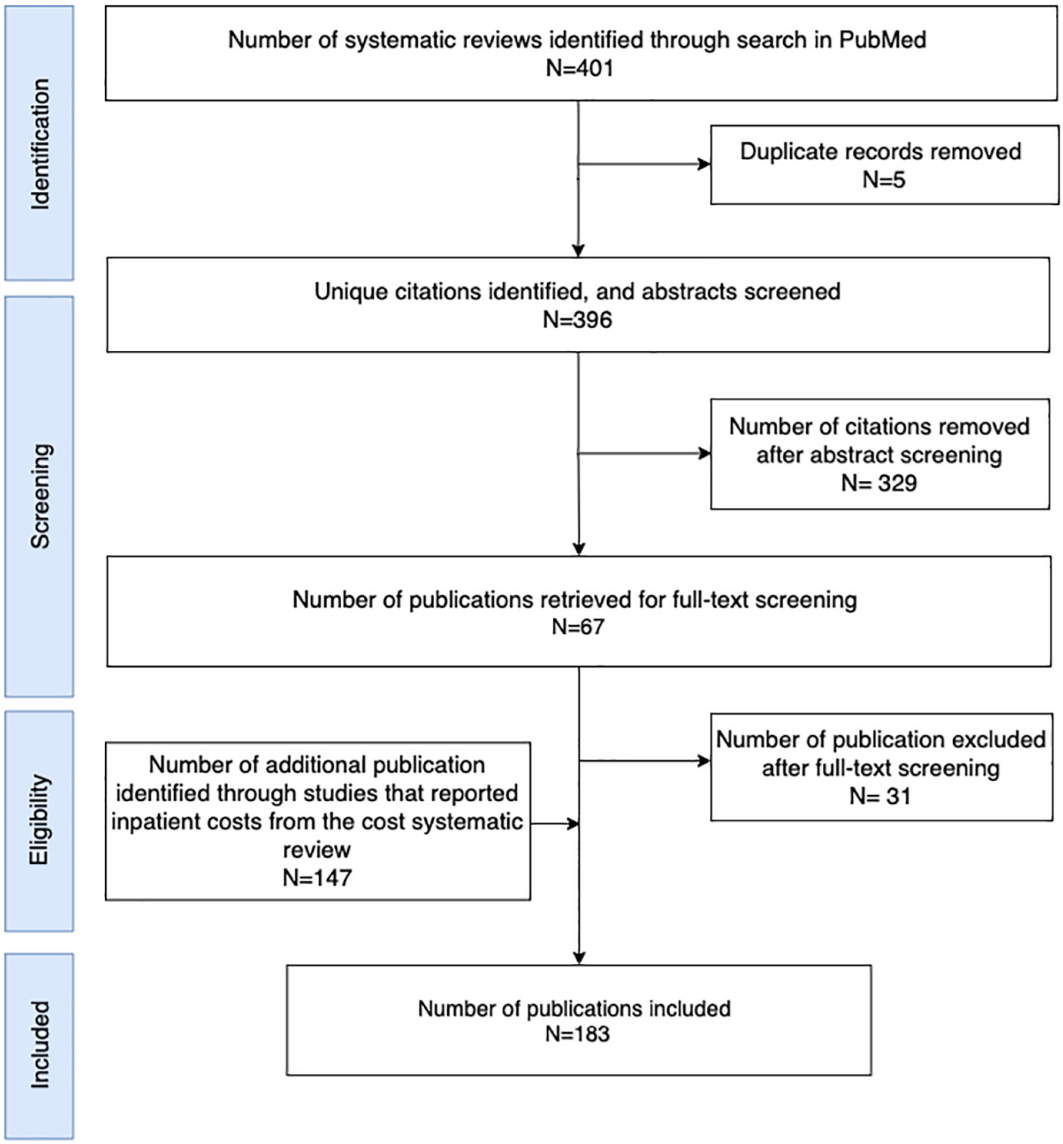


TABLE A3.4. Descriptive summary of the epidemiological literature

Variable	N (%) Total N = 608
Publication year band	
1995–2000	9 (1.7%)
2001–2005	5 (0.9%)
2006–2010	57 (10.6%)
2011–2015	118 (21.5%)
2016–2020	170 (31.6%)
2021–2024	180 (33.4%)
GBD infectious syndrome	
Bacterial infections of the skin and subcutaneous systems	25 (4.6%)
Bloodstream infections	166 (30.8%)
Diarrhoea	31 (5.8%)
Endocarditis and other cardiac infections	9 (1.7%)
Infections of bones, joints, and related organs	4 (0.7%)
Lower respiratory infections and all related infections in the thorax	102 (18.9%)
Meningitis and other bacterial central nervous system infections	16 (3.0%)
Peritoneal and intra-abdominal infections	23 (4.3%)
Tuberculosis	35 (6.5%)
Typhoid fever, paratyphoid fever, and iNTS	30 (5.6%)
Urinary tract infections and pyelonephritis	61 (11.3%)
Other	33 (6.1%)
GBD region	
High-income	25 (4.6%)
Latin America & Caribbean	166 (30.8%)
Sub-Saharan Africa	31 (5.8%)
North Africa & Middle East	9 (1.7%)
South East Asia	4 (0.7%)
East Asia and Oceania	102 (18.9%)
South Asia	16 (3.0%)
Central Europe	23 (4.3%)
Eastern Europe and Central Asia	35 (6.5%)
Global	30 (5.6%)
Setting label	
ICU	30 (5.6%)
Inpatient	424 (78.8%)
Outpatient	9 (1.7%)
General	10(1.9%)
Not specified	66 (12.2%)
Outcome parameter	
Infection hospitalisation rate (IHR)	8 (1.5%)
Hospital fatality rate (HFR)	450 (83.5%)
Case fatality rate (CFR)	49 (9.1%)
Case ascertainment rate	7 (1.3%)
Test positivity	10 (1.9%)

Unknown Hospital Fatality Rate estimation

We fit a multilevel model to estimate unknown HFR values using the glmmTMB package in R (Brooks et al., 2017). Because HFR is a proportion (bounded by 0 and 1) a Beta distribution is used for the likelihood. The following model specification is fit shown by (2).

$$logit(HFR) = \beta_0 + \beta_1 HAQ + \beta_{2-13} SyndromeDummies + \alpha_1 SuperRegion + \alpha_2 \left(Region | SuperRegion\right) + \alpha_3 \left(Country | Region\right) \quad (2)$$

Where:

- HFR is the hospital fatality rate
- HAQ is the Health Care Access and Quality index from IHME for a given country
- SyndromeDummies are fixed effects for the IHME infectious syndromes
- The terms SuperRegion, Region, Country are GBD geographies, they are arranged in a hierarchical structure. Where the coefficients are denoted α rather than β to indicate they are random rather than fixed effects.

The hierarchical structure means data from a region or sub-region disproportionately affects the estimates of unknown values for that location group. It also allows for estimates at the region, super-region or global level to be included, even if not specific to a given country. The inclusion of HAQ allows for within region differences in health system quality to be reflected in the final estimates.

TABLE A3.5. Assumptions for IHR for different infectious syndromes

Infectious Syndrome	GBD Super Region	Infection Hospitalisation Rate
Ssti	Southeast Asia, East Asia, and Oceania	0.010
Ssti	Central Europe, Eastern Europe, and Central Asia	0.010
Ssti	High-income	0.020
Ssti	Latin America and Caribbean	0.010
Ssti	North Africa and Middle East	0.010
Ssti	South Asia	0.010
Ssti	Sub-Saharan Africa	0.010
Bsi	Southeast Asia, East Asia, and Oceania	0.500
Bsi	Central Europe, Eastern Europe, and Central Asia	0.500
Bsi	High-income	0.750
Bsi	Latin America and Caribbean	0.500
Bsi	North Africa and Middle East	0.500
Bsi	South Asia	0.500
Bsi	Sub-Saharan Africa	0.250
Diarrhoea	Southeast Asia, East Asia, and Oceania	0.005
Diarrhoea	Central Europe, Eastern Europe, and Central Asia	0.005
Diarrhoea	High-income	0.010
Diarrhoea	Latin America and Caribbean	0.005

TABLE A3.5. (Continued)

Infectious Syndrome	GBD Super Region	Infection Hospitalisation Rate
Diarrhoea	North Africa and Middle East	0.005
Diarrhoea	South Asia	0.005
Diarrhoea	Sub-Saharan Africa	0.005
Cardiac	Southeast Asia, East Asia, and Oceania	0.800
Cardiac	Central Europe, Eastern Europe, and Central Asia	0.800
Cardiac	High-income	1.000
Cardiac	Latin America and Caribbean	0.800
Cardiac	North Africa and Middle East	0.800
Cardiac	South Asia	0.800
Cardiac	Sub-Saharan Africa	0.600
Bone	Southeast Asia, East Asia, and Oceania	0.500
Bone	Central Europe, Eastern Europe, and Central Asia	0.500
Bone	High-income	0.750
Bone	Latin America and Caribbean	0.500
Bone	North Africa and Middle East	0.500
Bone	South Asia	0.500
Bone	Sub-Saharan Africa	0.250
Lri	Southeast Asia, East Asia, and Oceania	0.200
Lri	Central Europe, Eastern Europe, and Central Asia	0.200
Lri	High-income	0.300
Lri	Latin America and Caribbean	0.200
Lri	North Africa and Middle East	0.200
Lri	South Asia	0.200
Lri	Sub-Saharan Africa	0.100
Cns	Southeast Asia, East Asia, and Oceania	0.500
Cns	Central Europe, Eastern Europe, and Central Asia	0.500
Cns	High-income	0.750
Cns	Latin America and Caribbean	0.500
Cns	North Africa and Middle East	0.500
Cns	South Asia	0.500
Cns	Sub-Saharan Africa	0.250
Iai	Southeast Asia, East Asia, and Oceania	0.500
Iai	Central Europe, Eastern Europe, and Central Asia	0.500
Iai	High-income	0.750
Iai	Latin America and Caribbean	0.500
Iai	North Africa and Middle East	0.500
Iai	South Asia	0.500
Iai	Sub-Saharan Africa	0.250
Tb	Southeast Asia, East Asia, and Oceania	0.750
Tb	Central Europe, Eastern Europe, and Central Asia	0.750
Tb	High-income	1.000

TABLE A3.5. (Continued)

Infectious Syndrome	GBD Super Region	Infection Hospitalisation Rate
Tb	Latin America and Caribbean	0.750
Tb	North Africa and Middle East	0.750
Tb	South Asia	0.750
Tb	Sub-Saharan Africa	0.500
Typhoid	Southeast Asia, East Asia, and Oceania	0.100
Typhoid	Central Europe, Eastern Europe, and Central Asia	0.100
Typhoid	High-income	0.200
Typhoid	Latin America and Caribbean	0.100
Typhoid	North Africa and Middle East	0.100
Typhoid	South Asia	0.100
Typhoid	Sub-Saharan Africa	0.100
Uti	Southeast Asia, East Asia, and Oceania	0.010
Uti	Central Europe, Eastern Europe, and Central Asia	0.010
Uti	High-income	0.020
Uti	Latin America and Caribbean	0.010
Uti	North Africa and Middle East	0.010
Uti	South Asia	0.010
Uti	Sub-Saharan Africa	0.005

Appendix 4: Mathematical derivation of the *core disease to cost model*

Every parameter in the model could have subscript j,k to signify the different GBD infectious syndromes and GBD country for which these costs are being estimated. These are excluded here to simplify notation. Firstly, we adjust GBD's estimates of infection incidence by the infection hospitalisation rate to give an initial estimate of hospital admissions.

$$H_1 = I \times IHR \tag{3}$$

Where:

- H_1 is the number of hospital admissions for a given infectious syndrome in a given GBD country.
- I is incidence from IHME's estimates for a given infectious syndrome in a given GBD country.
- IHR is the infection hospitalisation rate taken from the literature, and assumptions made across countries

Then we estimate hospital admission again using GBD's estimates of deaths.

$$H_2 = \frac{D}{HFR} \tag{4}$$

Where:

- H_2 is an alternative estimate of the number of hospital admissions for a given infectious syndrome in a given GBD country.
- D is number of deaths from IHME's estimates for a given infectious syndrome in a given GBD country.
- HFR is the hospital fatality rate taken from the literature, this is estimated for every country using a multilevel modelling approach.

Then we combine these create estimates of hospital admissions

$$H = f(H_1, H_2) \tag{5}$$

Where:

- f is a function e.g., a flat or geometric average that will be used to estimate total admissions. We use a weighted geometric specification in our headline method, weighting toward the death-derived estimate.

Total direct inpatient healthcare expenditure is then estimated:

$$\mathrm{E}_H = H \times P_H \tag{6}$$

Where:

- E_H is the total expenditure on inpatient care and P_H is the cost per admission.

Appendix 5: Supporting methodology information on prospective scenarios

Cost per burden scenarios

Countries may spend different amounts on AMR healthcare as they develop economically. We estimate this relationship using the cross-sectional estimates produced for 2022 in methodology sections 2.1–2.4. The regression specification is simple:

$$\ln(\text{Cost}) = \beta_0 + \beta_1 \ln(\text{GDP}) + \varepsilon \quad (7)$$

Where:

- Cost is the cost of AMR spent by a country per unit of burden (for each of IHME's burden metrics run separately)
- GDP is gross domestic product per capita
- Ln is the natural logarithm (unlike other parts of this paper where log base 10 is used)

The resulting estimate β_1 is an estimate of the elasticity of expenditure on AMR with respect to national income. This is similar to an income elasticity of healthcare expenditure, though the expenditure is normalised by burden metric, rather than per capita. Costa-Font et al. (2011) review the challenges of estimating the income elasticity of healthcare expenditure. The specification set out in equation (7) is a very basic specification compared to the more detailed econometric approaches generally taken; however, this relationship is not a core focus of this study, just a necessary approximate calculation to support prospective scenarios.

The results shown in Table A5.1. are that as spend per death increases by $0.84 for every $1 increase in GDP per capita. Our estimate falls just outside the range of $0.40 to $0.80 reported by Costa-Font et al. (2011). Our estimate is probably higher than their range because many of the uncontrolled potential confounders in estimating this relationship e.g., the level of prepayment for healthcare is correlated with GDP per capita.

The increase in spend per DALY is higher, but this is largely because of disproportionate falls in infant mortality in the poorest countries as they develop. This means the DALYs fall faster than deaths, so spend per DALY should rise faster.

TABLE A5.1. Relationship between GDP per capita and expenditure per burden metric

Metric	Coefficient
Death	0.84
DALY	1.10

In the base case we assume that as countries develop economically their spend on AMR healthcare per unit of AMR burden will increase $0.84 for every $1.00 increase in GDP per capita. This means that in future scenarios where spend per burden metric is assumed to increase in line with GDP, that increase is a roughly linear relationship.

Historically, growth healthcare expenditure has tended to outpace GDP growth (Baumol & Bowen (1965); Newhouse (1992); Ginsburg (2008); S. Smith et al. (2009); Baumol et al. (2012); Licchetta & Stelmach (2016)). Different authors cite different drivers; but two that are common are increased treatment intensity (Smith et al, 2009) and lower relative productivity growth in healthcare compared to other sectors (Baumol and Bowen, 1965; Baumol et al, 2012). It is therefore possible that growth in real spending on AMR per death (or DALY) could outpace GDP growth. To reflect this possibility, a scenario where an extra 0.5 percent growth in expenditure is included annually out to 2050, this is chosen as a conservative lower bound of the additional growth in healthcare spend compared to GDP observed in the literature.

However, even if overall healthcare expenditure tends to rise, specific innovations may reduce the overall cost of treatment for a given case of a disease. For instance, new treatments for AMR cases could reduce the need for costly hospital stays while patients recover from their infection. To simulate this potential decrease in costs, we allow the cost spent per death (or DALY) by 2050 to decrease to half the current level, approximately the amount that might be spent on susceptible rather than resistant cases.

We also have a reference scenario where cost per burden stays constant for completeness, which is not consistent with expected growth GDP per capita across most countries.

Appendix 6: Model interpretation and performance on the tests

The results of the regression for predicting unknown costs are shown in Table A6.1. Using the Linear OLS model the following covariates are positively correlated with costs and statistically significant: IHME's HAQ index, healthcare expenditure, resistance (and resistance interacted with *TB*), the proportion of infections in the study that are hospital acquired, the USA and South Asia dummy variables, and the *CNS* infectious syndrome. The significant negative covariates are costs estimated for outpatient treatment or testing, *Diarrhoea* syndrome dummy and the High-Income dummy. As shown in Table A6.2, generally, the Linear ElasticNet model has similar signs for the coefficients on covariates, as the Linear OLS model. However, statistical significance is not defined for this regression method.

Figure A6.1. and Figure A6.2. show the importance charts for the XGBoost specifications. The charts show the 10 covariates that have the most influence on the model's predictions. These are very similar to the list of statistically significant regression covariates. However, SDI, GDP per capita, PPP and the year the costs were collected are important in these models (but not significant in the Linear model) and the geography dummies are not important (but some are significant in the Linear model).

Table 4 also reports the author's scores for the 5 model specifications on our 5 different tests described in section 2.1. In terms of statistical performance, Table 3 summarises the performance of each of the models on the validation set. The Optimised XGBoost model performs best on predicting unseen costs in the validation set according to the RMLSE and second best for SMAPE, which are the most appropriate measures. There is still some distance between the performance of any of our specifications and the illustrative baseline we estimate based on the data variability.

Aside from statistical performance, we use Figures A7.1.–A7.5., to assess if different models appear to have systematic bias or if there is particularly poor performance for given values. The Linear ElasticNet model performs best on this test. Outlier detection is assessed by comparing estimated values to expectations based on the tests 3.1–3.4 reported in Appendix 3. Figure 3 summarises performance against these tests; it shows that only 5 percent of the estimates from the Linear ElasticNet model are outside these prior expectations, compared to 8 percent for the Linear model and over 10 percent for the other three models. It also shows that the Linear ElasticNet never makes unexpected predictions that are different from other models. Figures A7.7.–A7.11. show the breakdown of expectations for each model. The most common expectation broken is estimated costs being less than 0.1× GDP per capita, indicating this might not have been a reasonable prior expectation. The Optimised XGBoost model is the only model that regularly predicts admission costs above 3× GDP per capita, suggesting this model may be less conservative. Figures A8.1. and A8.2. also show this, with the regression models plotting a linear relationship between GDP per capita and admission costs, but the XGBoost specifications estimating potentially infeasibly high values where our data is sparse in LMICs.

TABLE A6.1. Linear OLS Regression Results Table

	OLS	SE
(Intercept)	0.40	(0.43)
HAQ	1.36***	(0.33)
SDI	−0.23	(0.52)
PPP in dollars	−0.10	(0.20)
Log GDP per capita	0.15	(0.20)
Log healthcare expenditure per capita	0.47*	(0.20)
Resistant TB interaction	0.89***	(0.10)
Proportion of infections hospital acquired	0.34***	(0.05)
Cost year	0.00	(0.00)
High-income	−0.22*	(0.10)
Latin America and Caribbean	0.21	(0.11)
North Africa and Middle East	0.17	(0.10)
South Asia	0.32**	(0.12)
Southeast Asia	0.13	(0.09)
Sub Saharan Africa	0.08	(0.12)
USA	0.62***	(0.08)
BSI	0.22	(0.12)
Cardiac	0.21	(0.20)
CNS	0.41**	(0.15)
Diarrhoea	−0.33*	(0.15)
IAI	0.07	(0.13)
LRI	0.14	(0.13)
SSTI	−0.03	(0.13)
TB	−0.11	(0.16)
Typhoid	−0.02	(0.15)
UTI	−0.11	(0.13)
Outpatient	−1.15***	(0.07)
ICU	0.07	(0.08)
Testing	−1.85***	(0.06)
Resistant	0.32***	(0.03)
Uninfected	0.01	(0.43)
Num.Obs.	896	
R^2	0.85	
R^2 Adj.	0.85	
RMSLE	0.41	

Notes: High-income to Sub Saharan Africa are the GBD-region dummies, Eastern Europe and Central Asia is the reference dummy. USA is a dummy variable for whether the study is in the United States specifically. BSI to UTI are infectious syndrome related dummies, bone infection is the reference dummy. ICU to Testing are setting dummies, where Inpatient is the reference group. Resistant and Uninfected are dummies for whether the specific cost estimate is for resistant infections or relevant comparators, Susceptible is the reference dummy. *** means statistically significant at the 0.1% level, ** is 1% and * is 5% significance.

TABLE A6.2. All regression models for comparison

	OLS	*Linear ElasticNet	*Polynomial ElasticNet
(Intercept)	0.402	2.075	1.881
HAQ	1.365***	0.359	0.554
SDI	−0.233	0.285	0.000
PPP in dollars	−0.100	0.000	0.330
Log GDP per capita	0.151	0.377	0.506
Log healthcare expenditure per capita	0.465*	0.714	0.828
Resistant TB interaction	0.889***	0.663	0.717
Proportion of infections hospital acquired	0.338***	0.331	0.077
Cost year	−0.004	0.000	0.273
High-income	−0.216*	0.000	0.000
Latin America and Caribbean	0.207	0.097	0.000
North Africa and Middle East	0.170	0.050	0.000
South Asia	0.321**	0.000	0.000
Southeast Asia	0.127	0.041	−0.373
Sub Saharan Africa	0.081	−0.144	0.000
USA	0.615***	0.550	0.081
BSI	0.219	0.125	0.000
Cardiac	0.208	0.000	0.000
CNS	0.406**	0.241	0.000
Diarrhoea	−0.332*	−0.386	0.000
IAI	0.067	0.000	0.000
LRI	0.141	0.045	0.000
SSTI	−0.031	−0.032	0.000
TB	−0.110	0.000	0.000
Typhoid	−0.024	−0.107	0.000
UTI	−0.114	−0.129	0.000
Outpatient	−1.145***	−1.109	−0.379
ICU	0.068	0.082	0.000
Testing	−1.853***	−1.787	−0.337
Resistant	0.318***	0.288	0.254
Uninfected	0.014	0.000	0.000
			Interaction and poly terms not listed

Notes: The covariates have been min-max scaled for these specifications, so coefficient size is not directly comparable.
*** means statistically significant at the 0.1% level, ** is 1% and * is 5% significance.

FIGURE A6.1. Base XGBoost top covariates for predicting inpatient admission cost

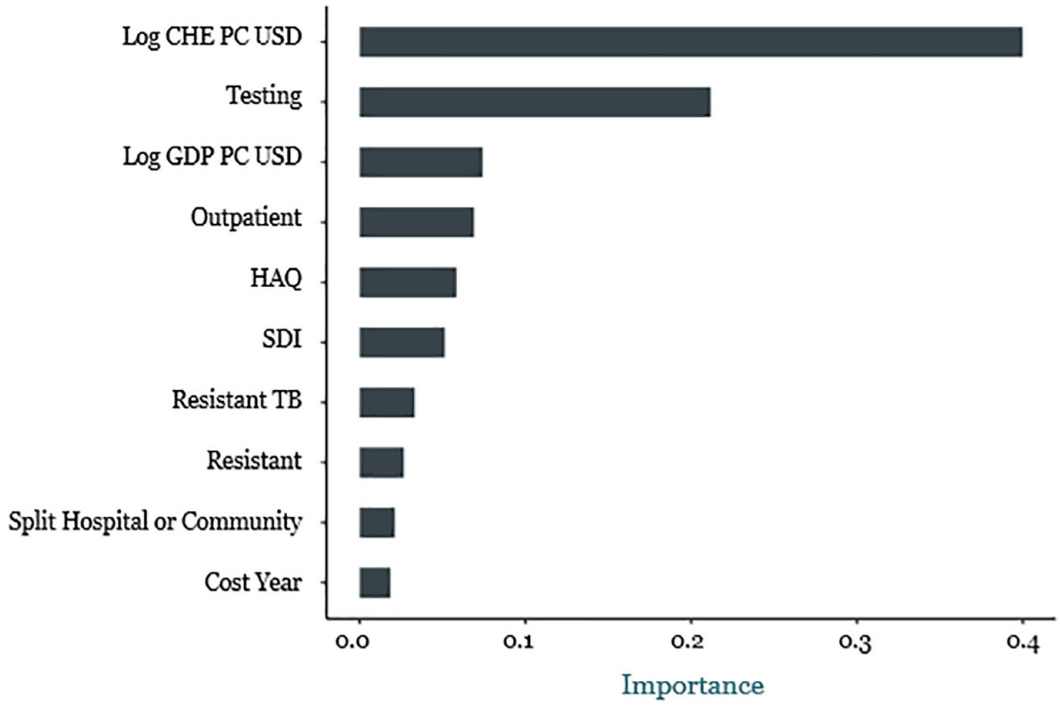
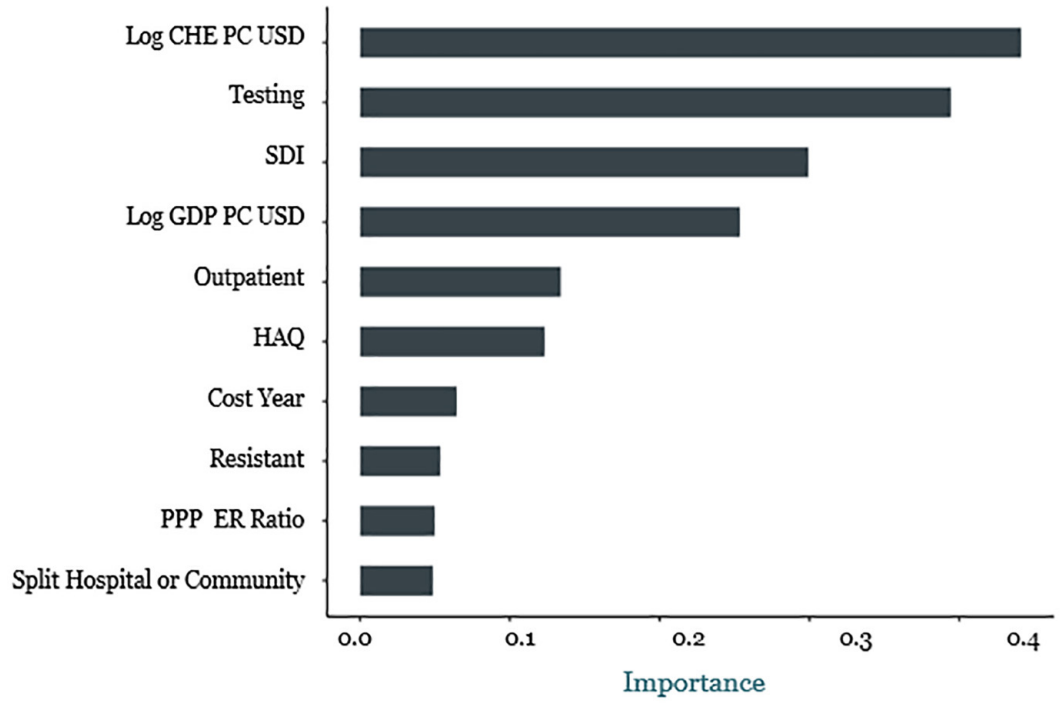


FIGURE A6.2. Optimised XGBoost top covariates for predicting inpatient admission cost



Appendix 7: Validation of models against tests of suitability

FIGURE A7.1. Observed values compared to predictions by the Linear OLS model on the validation set

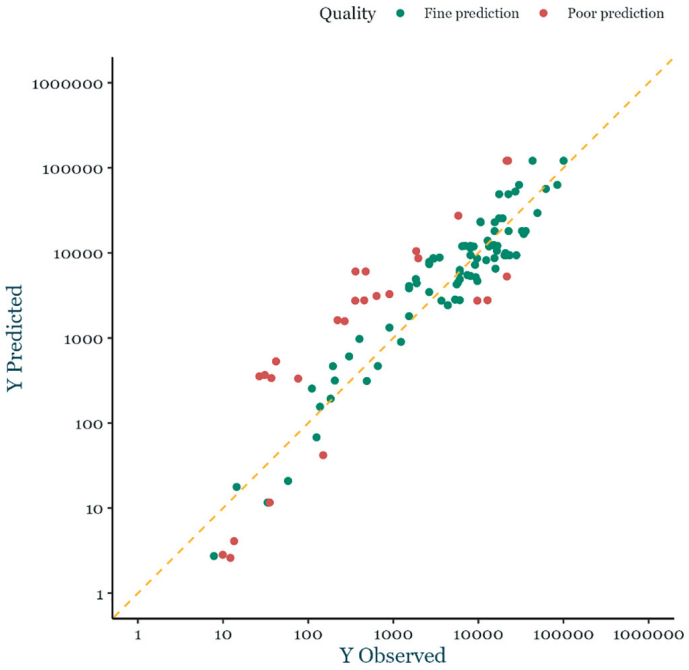


FIGURE A7.2. Observed values compared to predictions by the Linear ElasticNet model on the validation set

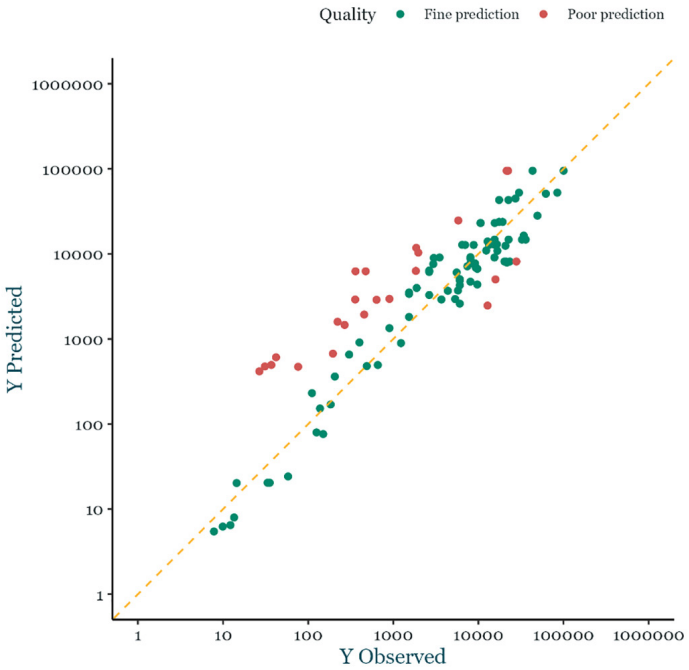


FIGURE A7.3. Observed values compared to predictions by the Polynomial ElasticNet model on the validation set

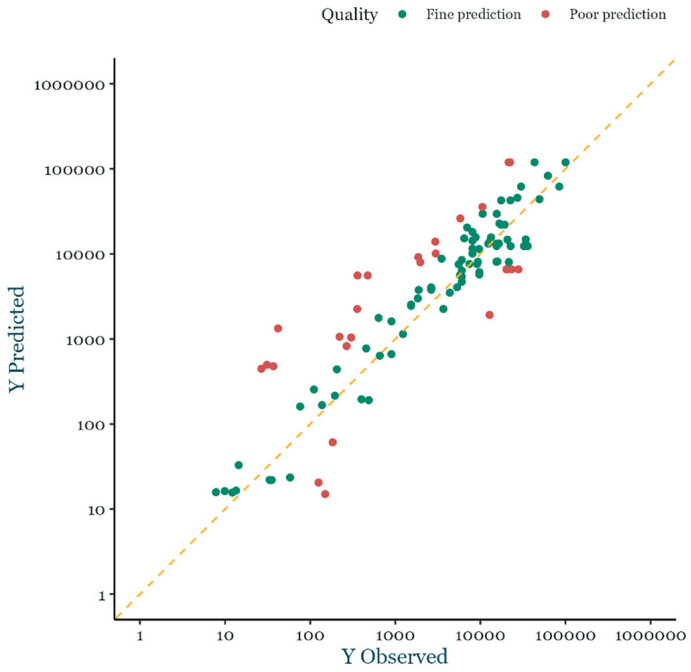


FIGURE A7.4. Observed values compared to predictions by the Base XGBoost model on the validation set

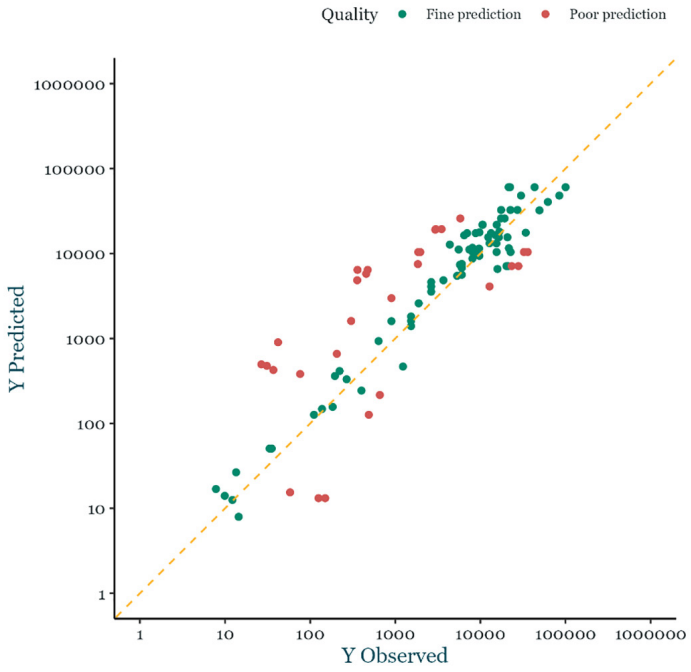


FIGURE A7.5. Observed values compared to predictions by the Optimised XGBoost model on the validation set

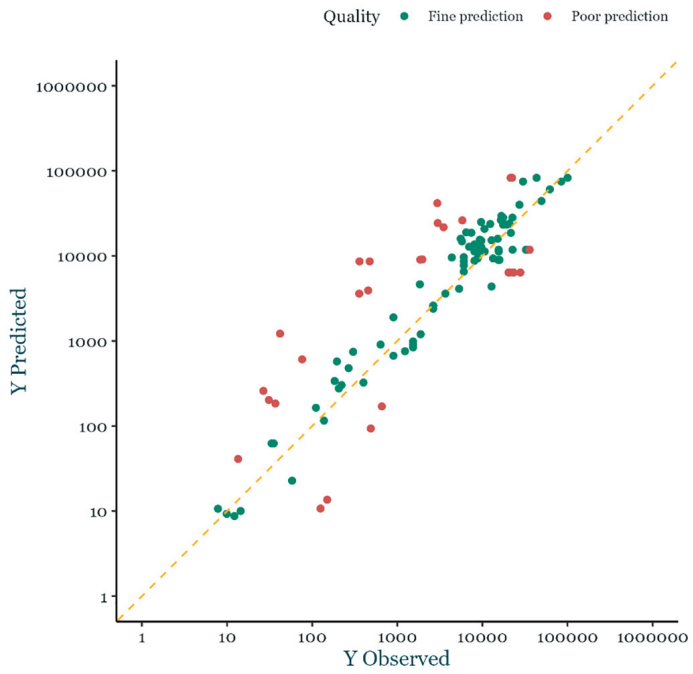


FIGURE A7.6. Percentage of predictions out of expected range total (that and other models) or unique (only for that model) (Figure 3 over again)

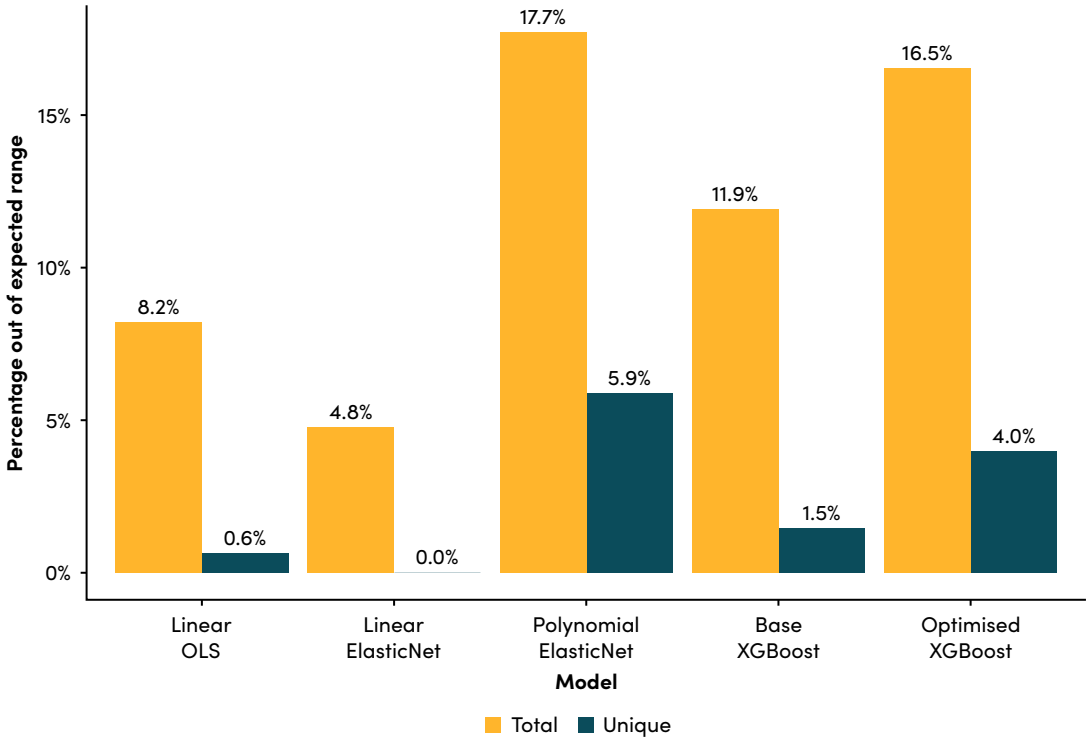


FIGURE A7.7. Linear OLS model percentage of inpatient cost estimates out of expected range

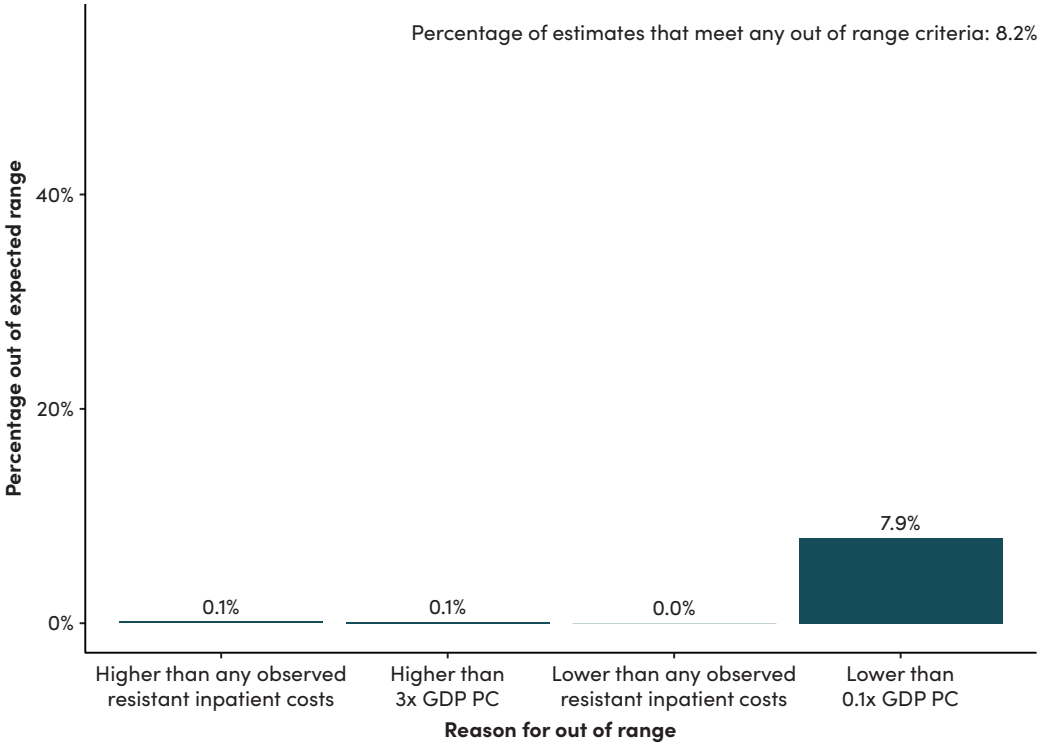


FIGURE A7.8. Linear ElasticNet model percentage of inpatient cost estimates out of expected range

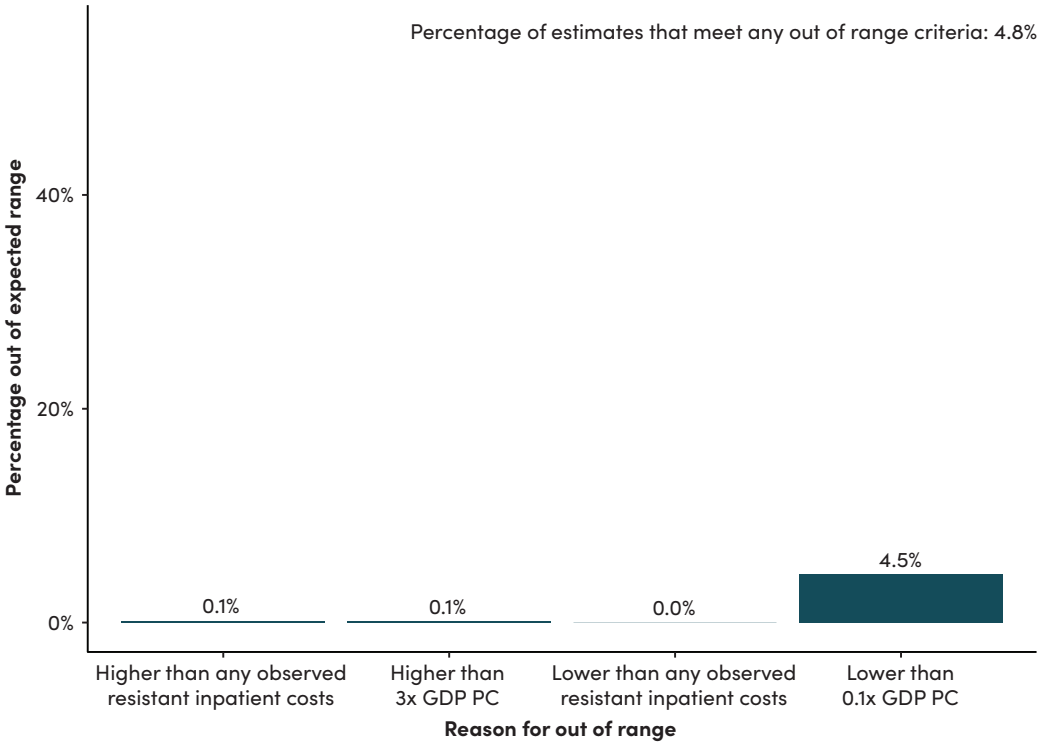


FIGURE A7.9. Polynomial ElasticNet model percentage of inpatient cost estimates out of expected range

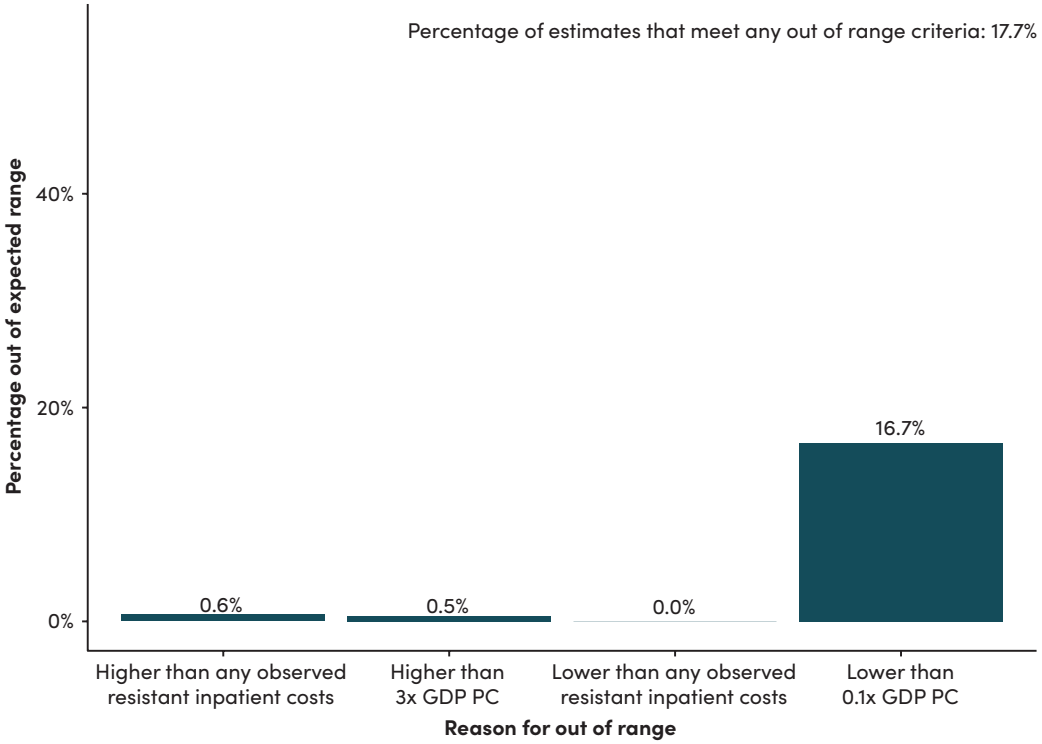


FIGURE A7.10. Base XGBoost model percentage of inpatient cost estimates out of expected range

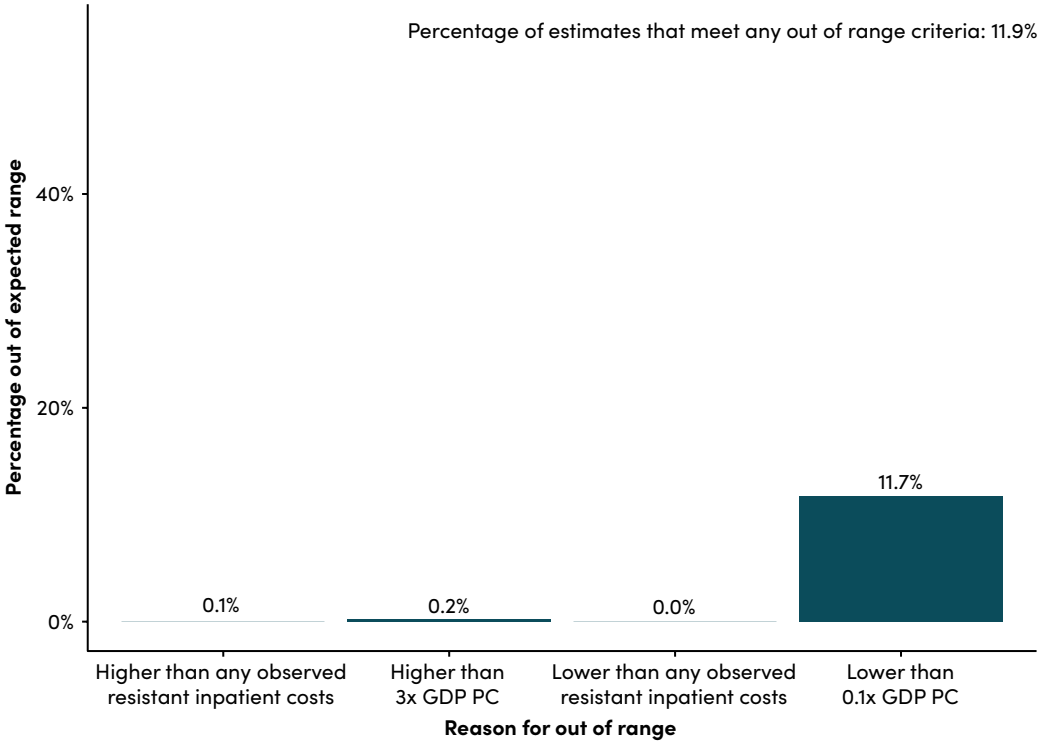
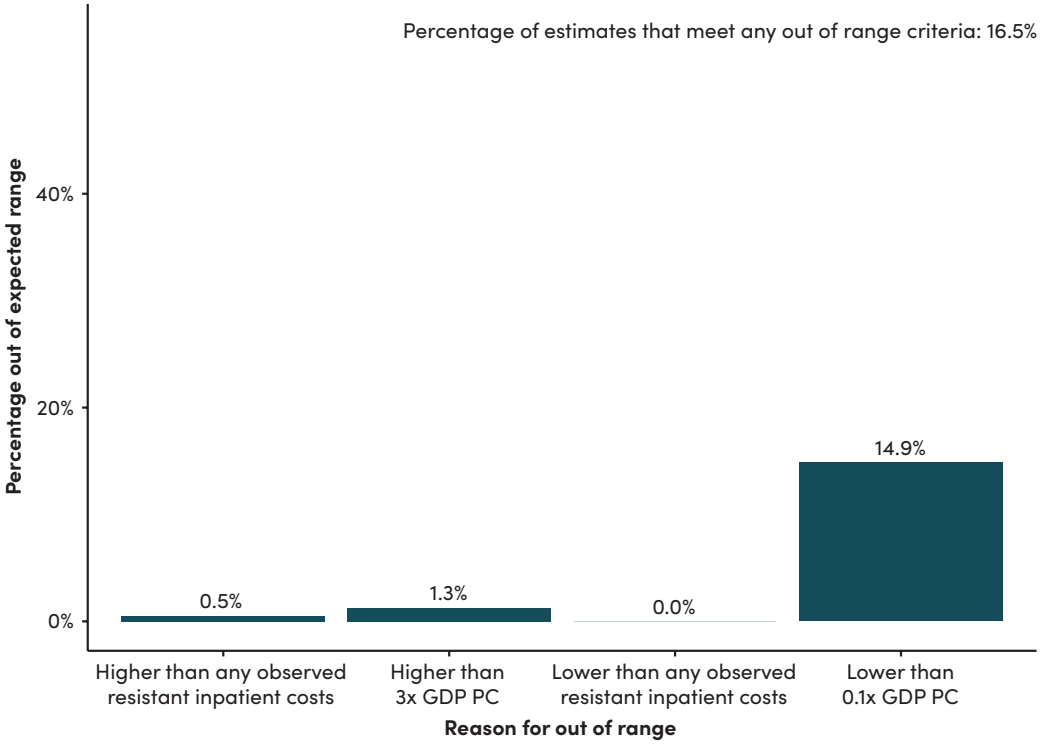


FIGURE A7.11. Optimised XGBoost model percentage of inpatient cost estimates out of expected range



Appendix 8: Results for the cost per inpatient admission

FIGURE A8.1. Comparison of models for bloodstream infection, where estimated cost is plotted against GDP per capita

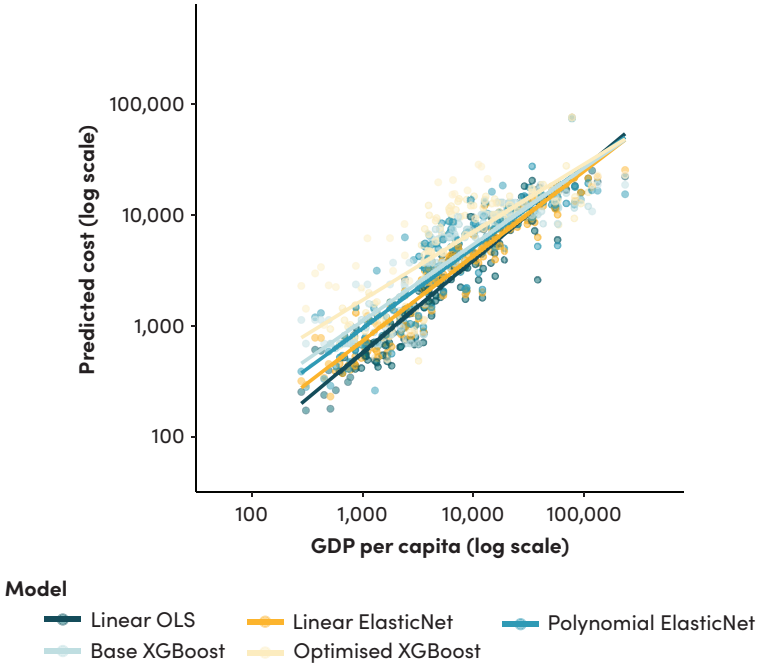
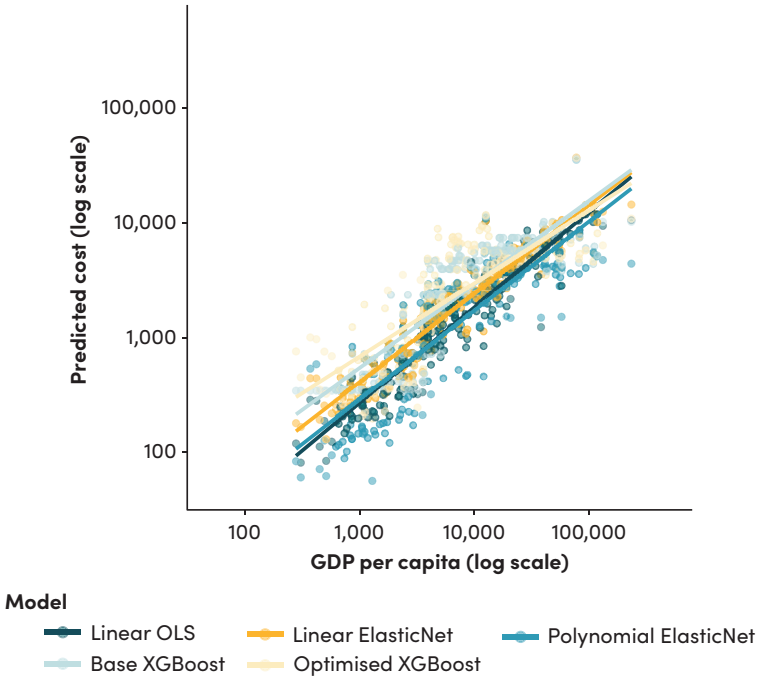
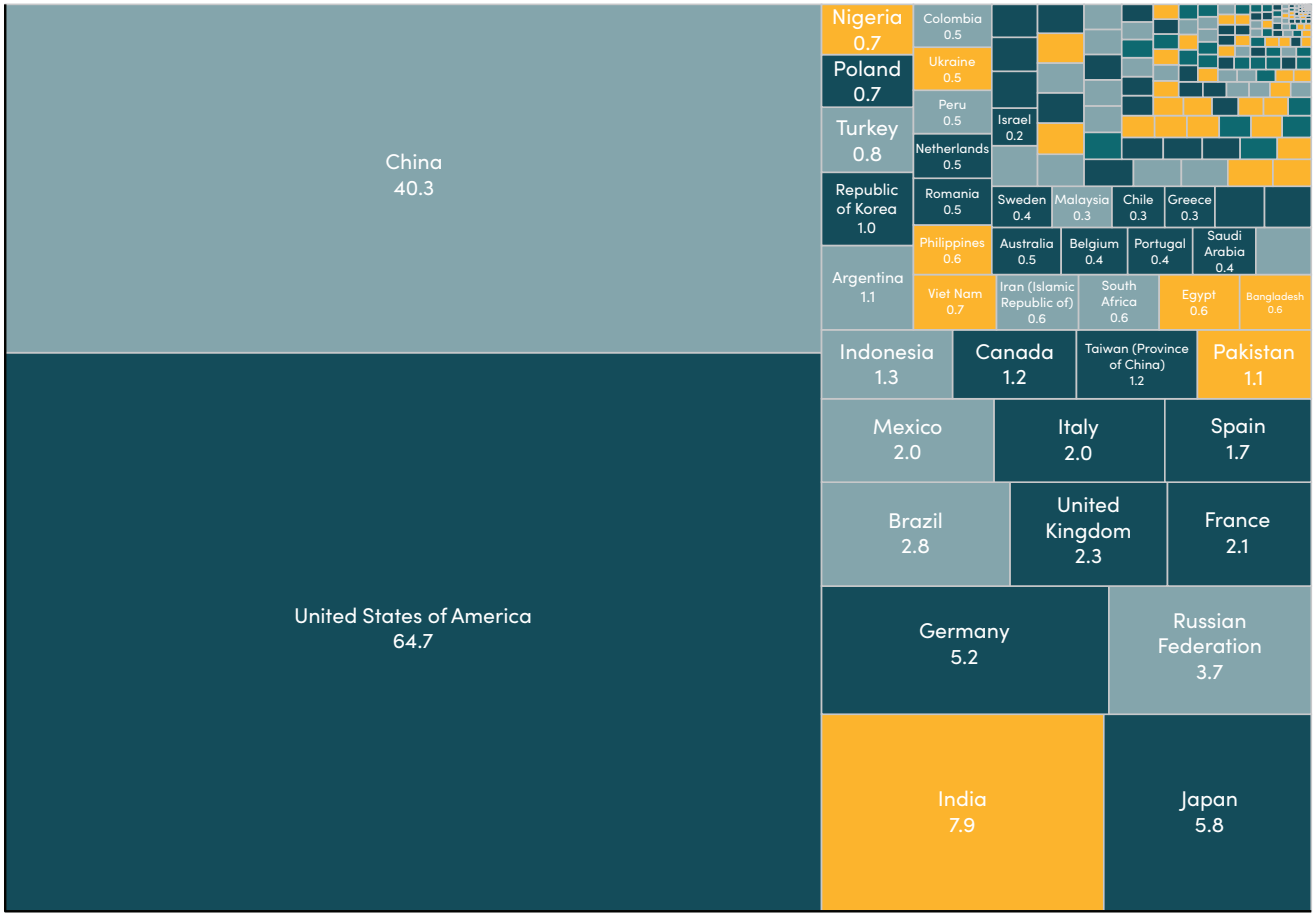


FIGURE A8.2. Comparison of models for urinary tract infections, where estimated cost is plotted against GDP per capita



Appendix 9: Overall estimates

FIGURE A9.1. Estimated direct cost (US$ billions) of inpatient admissions with AMR infections



World Bank income

Low-income Lower-middle-income Upper-middle-income High-income

FIGURE A9.2. Linear ElasticNet percentage of total healthcare cost due to excess resistance costs in inpatient admissions for each GBD country, grouped by World Bank Income (Figure 12 over again)

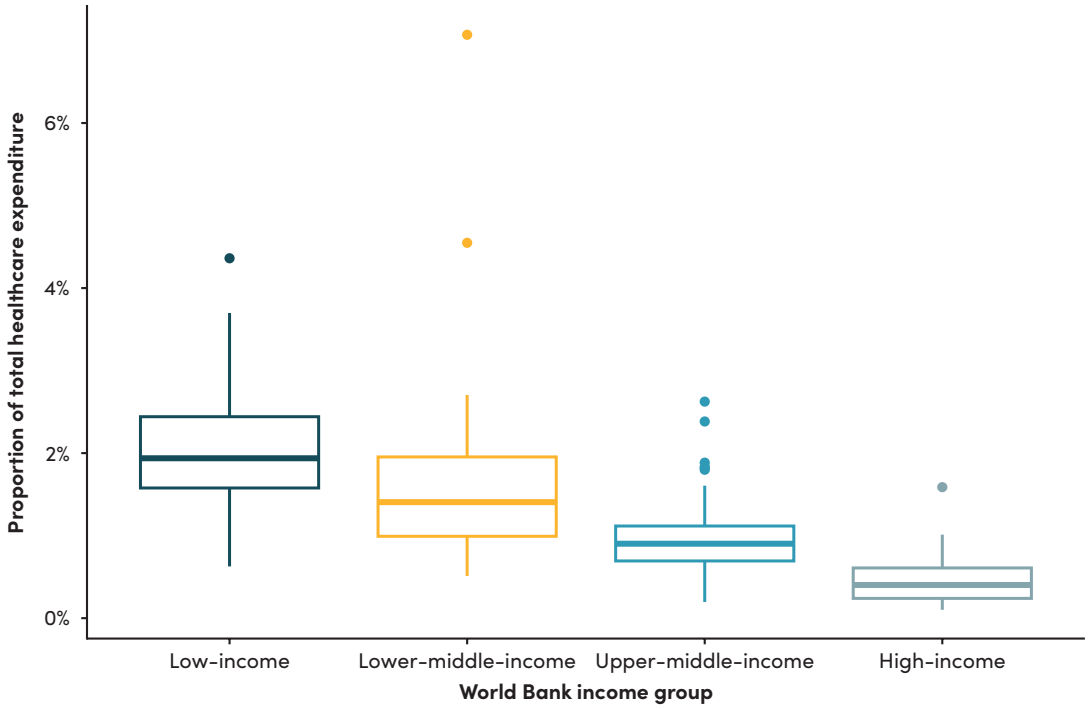


FIGURE A9.3. Linear ElasticNet percentage of total healthcare cost due to inpatient admissions with a resistant infection for each GBD country, grouped by World Bank Income

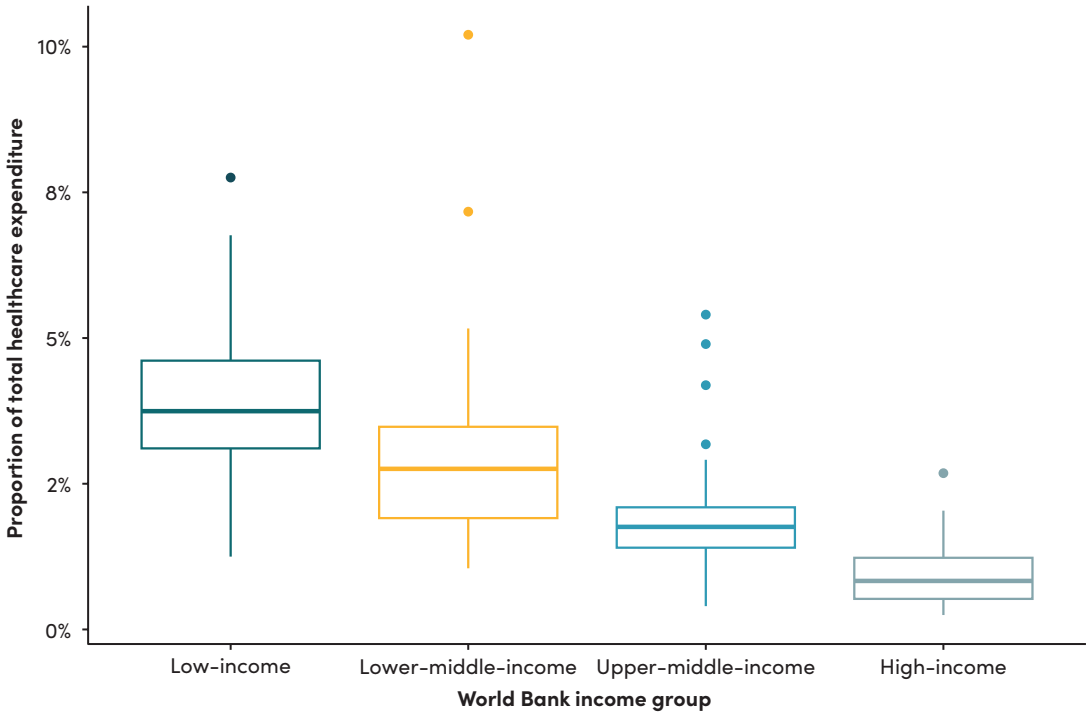


FIGURE A9.4. Linear OLS percentage of total healthcare cost due to excess resistance costs in inpatient admissions for each GBD country, grouped by World Bank Income

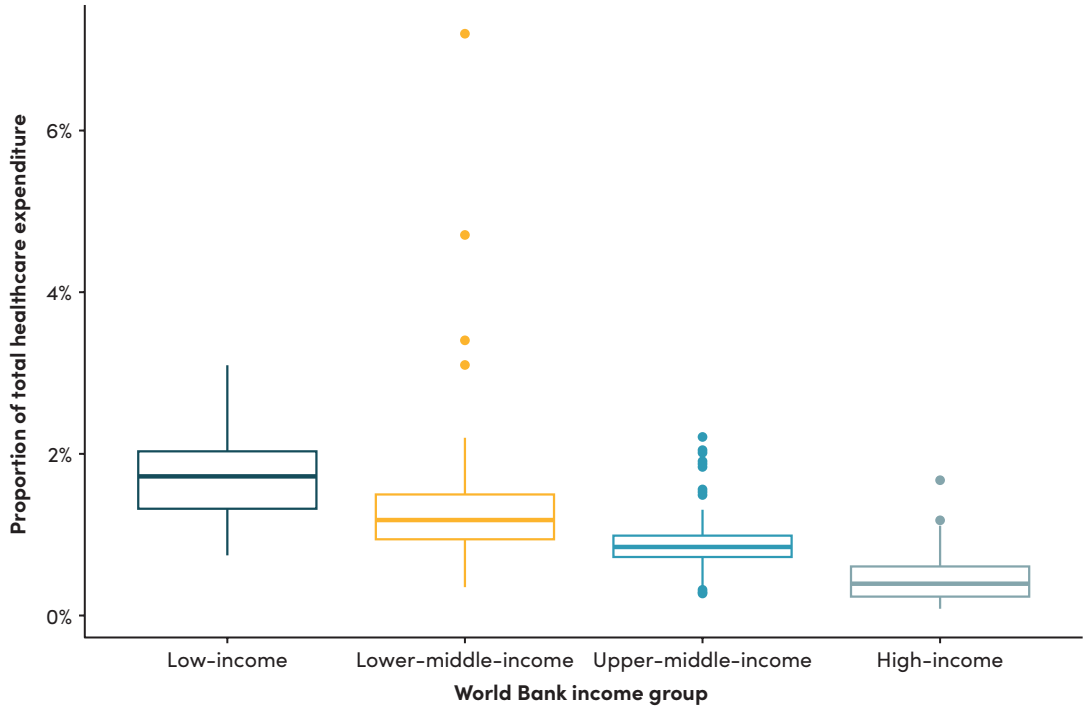


FIGURE A9.5. Polynomial ElasticNet percentage of total healthcare cost due to excess resistance costs in inpatient admissions for each GBD country, grouped by World Bank Income

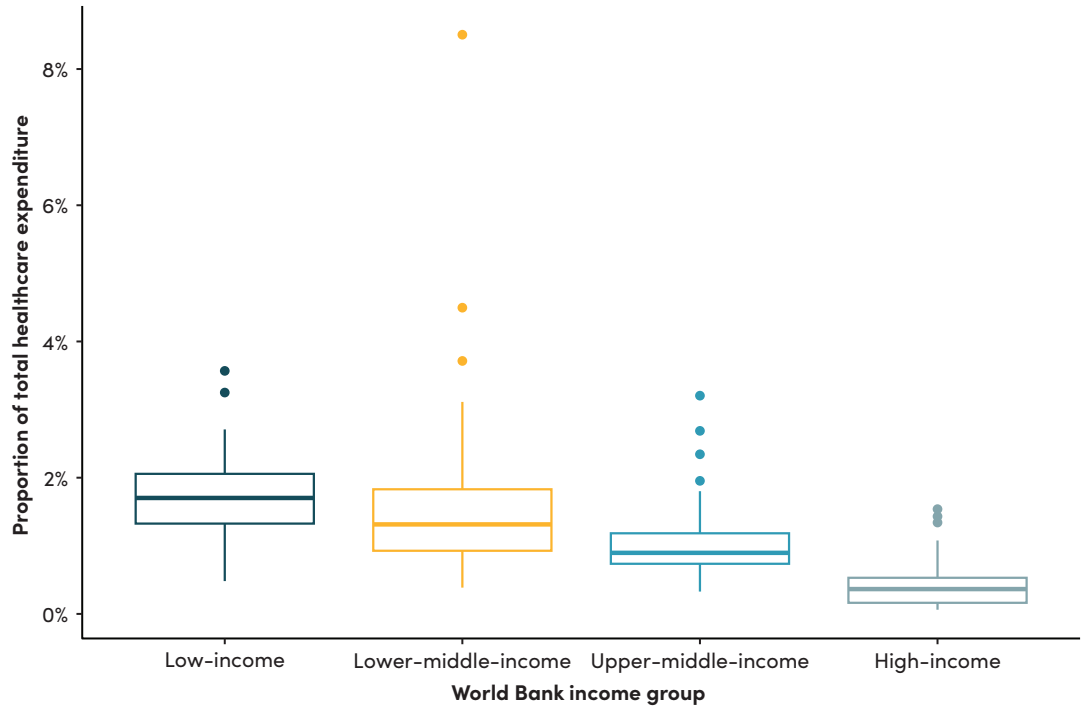


FIGURE A9.6. Base XGBoost percentage of total healthcare cost due to excess resistance costs in inpatient admissions for each GBD country, grouped by World Bank Income

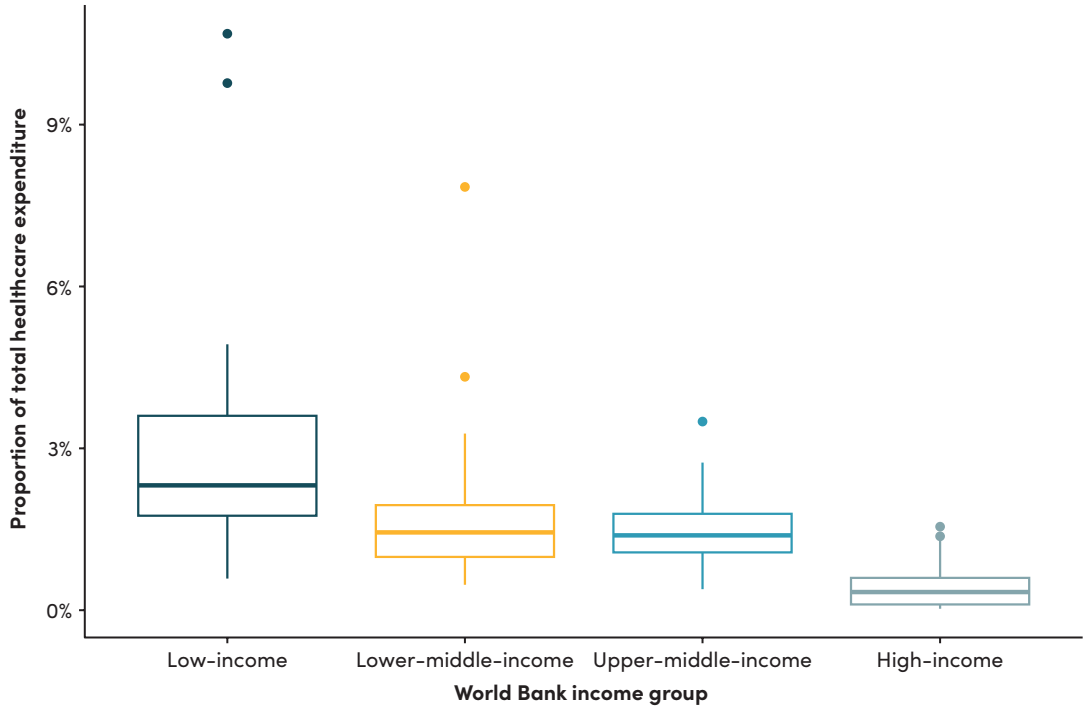


FIGURE A9.7. Optimised XGBoost percentage of total healthcare cost due to excess resistance costs in inpatient admissions for each GBD country, grouped by World Bank Income

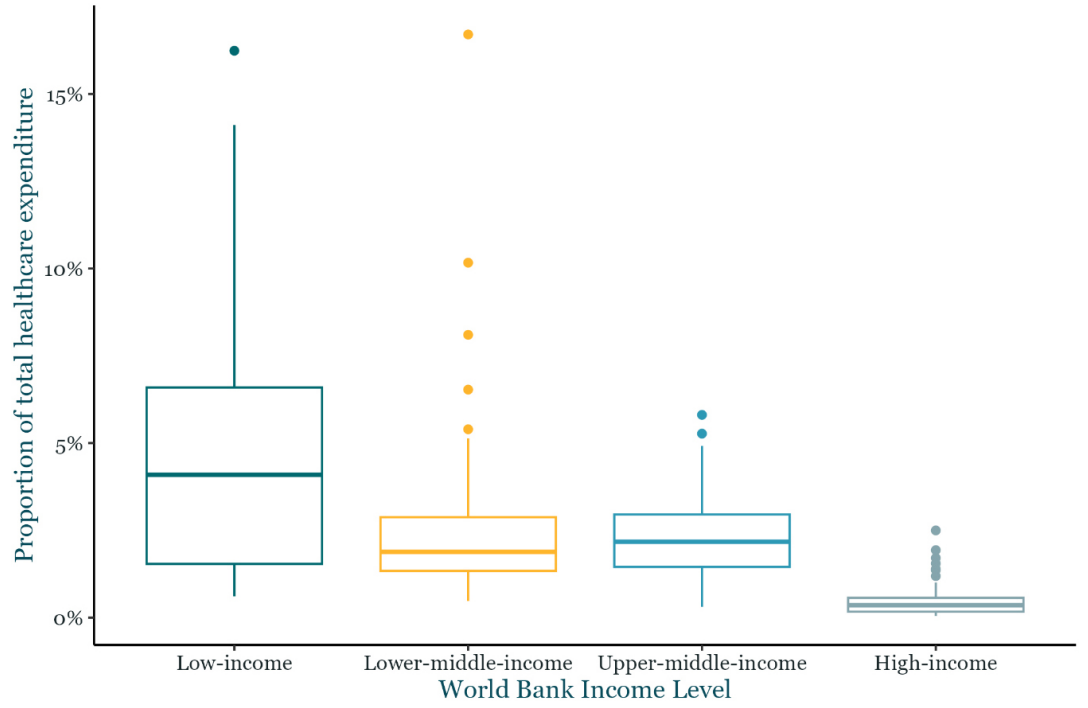


FIGURE A9.8. Break down of total excess resistance cost by infectious syndrome

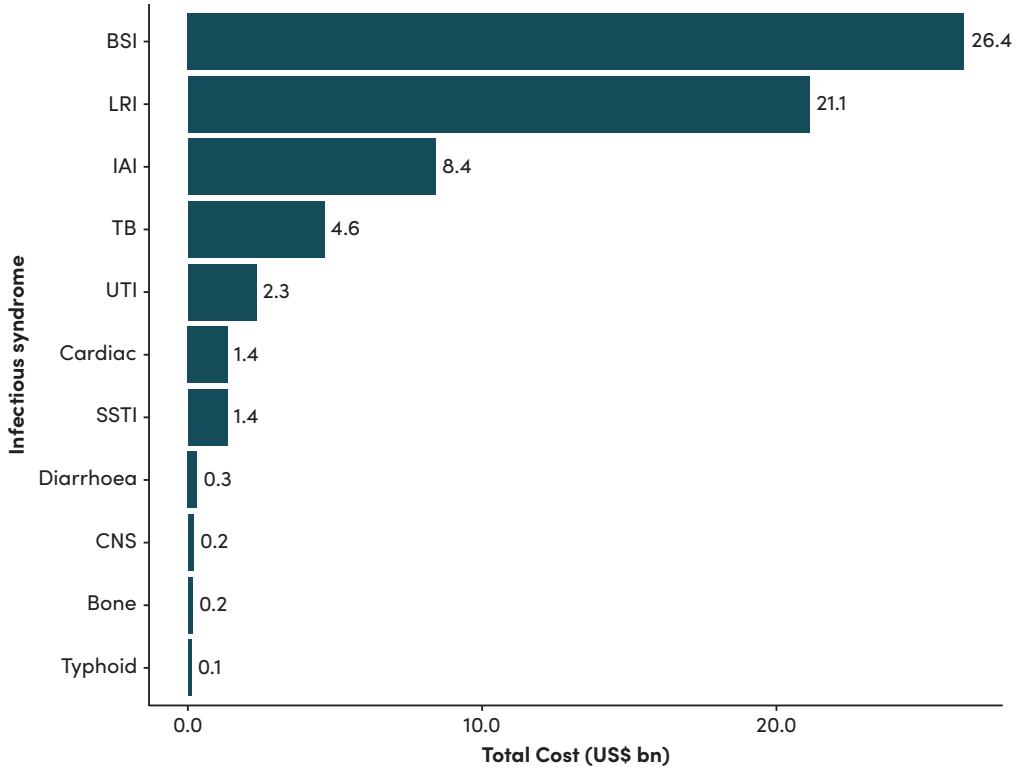
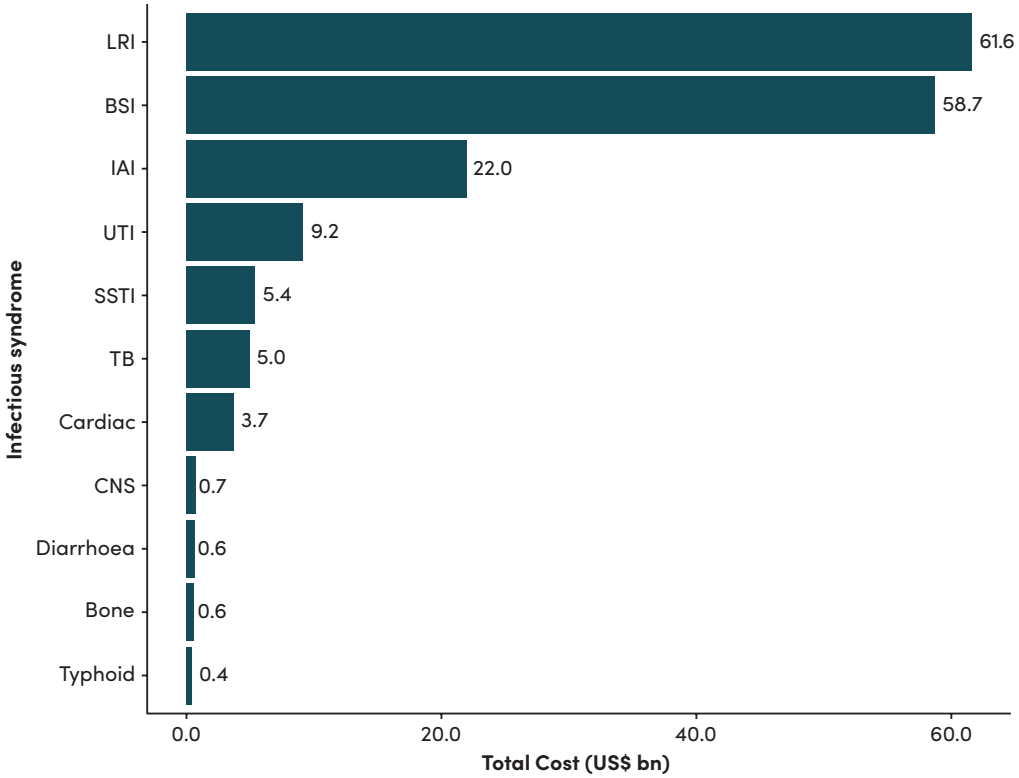


FIGURE A9.9. Break down of total resistant admission cost by infectious syndrome



Appendix 10: Future scenarios

FIGURE A10.1. Contribution of current WB income groups to overall global excess inpatient healthcare costs due to AMR, base case

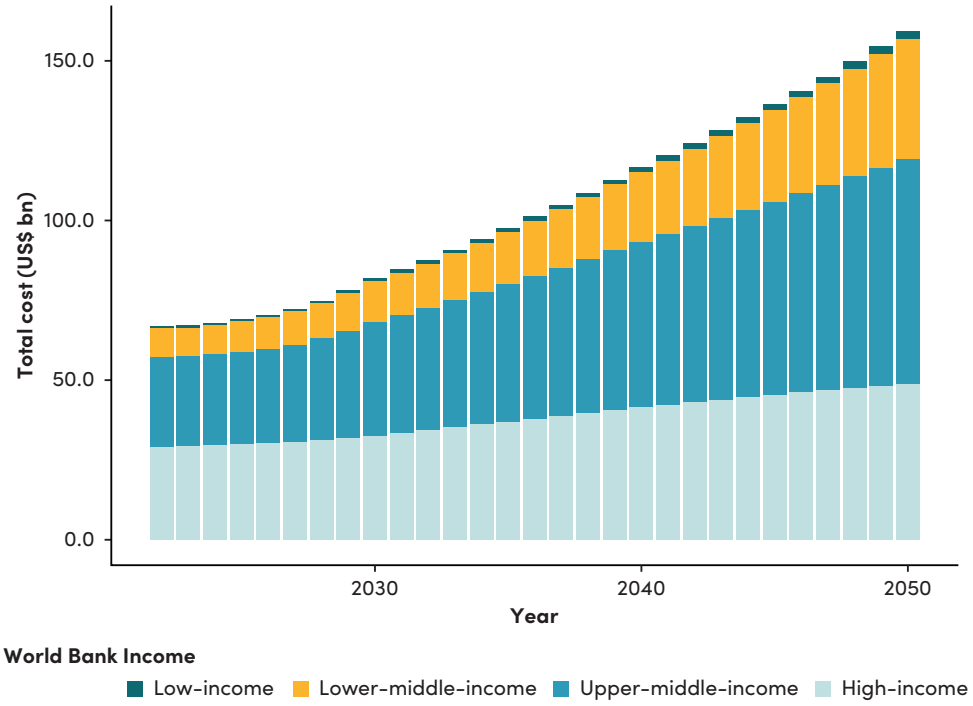
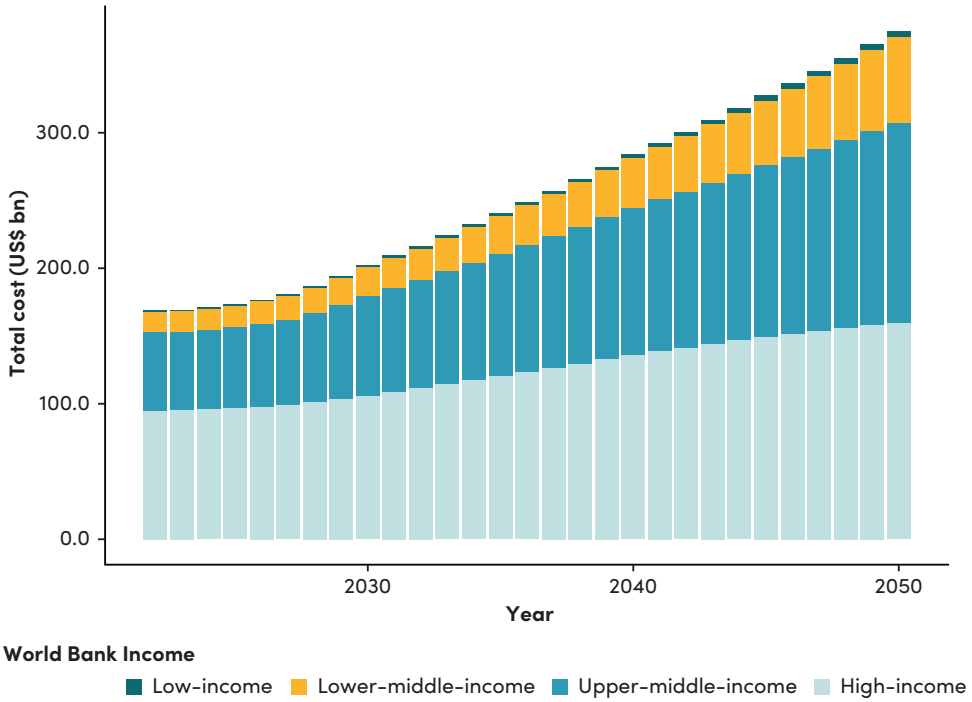


FIGURE A10.2. Contribution of current WB income groups to overall inpatient healthcare cost with resistant infections, base case



Appendix 11: Summary of country level results

This appendix contains estimates of the four key results from the study. These estimates are based on uncertain modelling, and so are subject to considerable uncertainty, which has been approximated in (L:, U:). National estimates based on local data may be more likely to represent the true cost of AMR. If national estimates are unavailable, these estimates may offer an indication based on globally available evidence, combined in an evidence- based framework.

GBD Country	Excess Cost Per Admission US$ (2022)	Admissions with AMR (2022)	Excess Expenditure US$ Millions (2022)	Total Expenditure US$ Millions (2022)	Excess Expenditure US$ Millions (2050)	Total Expenditure US$ Millions (2050)
Afghanistan	331 (L: 272 – U: 931)	147,762 (L: 68,253 – U: 311,268)	48.9 (L: 18.6 – U: 289.7)	98.4 (L: 31.4 – U: 426.8)	188.7 (L: 58.4 – U: 322.5)	387.6 (L: 120.1 – U: 662.6)
Albania	1,727 (L: 1,686 – U: 5,902)	6,556 (L: 2,573 – U: 14,066)	11.3 (L: 4.3 – U: 83.0)	23.3 (L: 9.0 – U: 118.1)	21.3 (L: 8.1 – U: 31.2)	44.4 (L: 17.0 – U: 65.1)
Algeria	1,303 (L: 1,302 – U: 4,381)	73,468 (L: 28,918 – U: 168,857)	95.7 (L: 37.7 – U: 739.7)	196.3 (L: 72.0 – U: 1,072.0)	205.8 (L: 75.2 – U: 306.5)	423.7 (L: 154.8 – U: 630.9)
American Samoa	1,580 (L: 1,157 – U: 4,403)	137 (L: 59 – U: 281)	0.2 (L: 0.1 – U: 1.2)	0.4 (L: 0.1 – U: 1.7)	0.1 (L: 0.0 – U: 0.2)	0.2 (L: 0.1 – U: 0.3)
Andorra	5,791 (L: 3,629 – U: 5,791)	192 (L: 97 – U: 381)	1.1 (L: 0.4 – U: 2.2)	2.3 (L: 0.9 – U: 5.1)	1.7 (L: 0.5 – U: 2.7)	3.4 (L: 1.0 – U: 5.5)
Angola	415 (L: 283 – U: 550)	83,276 (L: 40,900 – U: 151,932)	34.6 (L: 11.6 – U: 83.5)	65.5 (L: 18.1 – U: 120.2)	46.1 (L: 17.2 – U: 72.1)	86.4 (L: 32.2 – U: 135.1)
Antigua and Barbuda	2,955 (L: 2,907 – U: 4,045)	237 (L: 112 – U: 453)	0.7 (L: 0.3 – U: 1.8)	1.4 (L: 0.6 – U: 3.0)	1.8 (L: 0.7 – U: 2.6)	3.7 (L: 1.5 – U: 5.4)
Argentina	2,944 (L: 1,608 – U: 4,568)	223,939 (L: 134,831 – U: 345,271)	659.3 (L: 216.8 – U: 1,577.4)	1,098.4 (L: 391.2 – U: 2,269.8)	1,547.7 (L: 624.7 – U: 2,184.9)	2,612.4 (L: 1,054.4 – U: 3,687.7)
Armenia	1,865 (L: 1,722 – U: 6,536)	9,282 (L: 4,194 – U: 16,191)	17.3 (L: 7.2 – U: 105.8)	33.8 (L: 13.8 – U: 150.3)	43.2 (L: 16.9 – U: 62.6)	85.8 (L: 33.7 – U: 124.4)
Australia	3,796 (L: 1,379 – U: 3,927)	47,596 (L: 23,835 – U: 83,624)	180.7 (L: 32.9 – U: 328.4)	464.3 (L: 128.1 – U: 818.7)	344.3 (L: 128.7 – U: 464.8)	888.9 (L: 332.4 – U: 1,200.1)
Austria	6,985 (L: 2,689 – U: 7,084)	19,054 (L: 8,943 – U: 36,492)	133.1 (L: 24.1 – U: 258.5)	272.7 (L: 82.7 – U: 515.4)	266.6 (L: 101.0 – U: 363.7)	549.2 (L: 208.0 – U: 749.2)
Azerbaijan	1,636 (L: 1,201 – U: 4,274)	26,652 (L: 12,064 – U: 52,418)	43.6 (L: 14.5 – U: 224.1)	78.7 (L: 24.4 – U: 326.4)	62.0 (L: 24.2 – U: 92.8)	111.9 (L: 43.7 – U: 167.4)
Bahamas	3,811 (L: 2,341 – U: 5,647)	1,007 (L: 495 – U: 1,955)	3.8 (L: 1.2 – U: 11.0)	7.8 (L: 2.4 – U: 17.5)	7.0 (L: 2.7 – U: 10.4)	14.3 (L: 5.5 – U: 21.2)
Bahrain	3,322 (L: 3,322 – U: 4,566)	1,758 (L: 683 – U: 3,993)	5.8 (L: 2.3 – U: 18.2)	11.9 (L: 4.2 – U: 34.7)	25.7 (L: 10.5 – U: 36.8)	52.7 (L: 21.4 – U: 75.2)
Bangladesh	509 (L: 350 – U: 738)	569,629 (L: 219,892 – U: 1,240,062)	290.1 (L: 76.9 – U: 915.6)	560.8 (L: 118.1 – U: 1,824.5)	1,421.8 (L: 535.8 – U: 2,082.2)	2,811.0 (L: 1,059.3 – U: 4,116.8)
Barbados	3,053 (L: 1,159 – U: 3,874)	1,406 (L: 728 – U: 2,402)	4.3 (L: 0.8 – U: 9.3)	8.8 (L: 1.8 – U: 16.1)	7.6 (L: 2.8 – U: 11.4)	15.8 (L: 5.9 – U: 23.7)

(Continued)

GBD Country	Excess Cost Per Admission US$ (2022)	Admissions with AMR (2022)	Excess Expenditure US$ Millions (2022)	Total Expenditure US$ Millions (2022)	Excess Expenditure US$ Millions (2050)	Total Expenditure US$ Millions (2050)
Belarus	2,828 (L: 2,699 - U: 4,010)	31,155 (L: 13,288 - U: 58,177)	88.1 (L: 35.9 - U: 233.3)	141.1 (L: 57.7 - U: 417.1)	103.4 (L: 38.0 - U: 150.7)	166.3 (L: 61.1 - U: 242.4)
Belgium	6,400 (L: 2,489 - U: 6,400)	33,828 (L: 18,157 - U: 60,018)	216.5 (L: 45.2 - U: 379.8)	444.6 (L: 156.5 - U: 779.8)	316.1 (L: 111.5 - U: 463.2)	651.8 (L: 230.0 - U: 955.2)
Belize	1,381 (L: 1,272 - U: 2,302)	772 (L: 355 - U: 1,565)	1.1 (L: 0.5 - U: 3.6)	2.2 (L: 0.9 - U: 5.0)	10.5 (L: 4.1 - U: 15.1)	22.2 (L: 8.7 - U: 31.9)
Benin	224 (L: 180 - U: 487)	50,181 (L: 25,788 - U: 88,136)	11.3 (L: 4.6 - U: 43.0)	22.2 (L: 7.4 - U: 56.2)	32.2 (L: 11.5 - U: 50.1)	64.3 (L: 23.0 - U: 100.2)
Bermuda	7,136 (L: 1,654 - U: 10,383)	165 (L: 76 - U: 311)	1.2 (L: 0.1 - U: 3.2)	2.4 (L: 0.6 - U: 6.2)	0.6 (L: 0.2 - U: 0.9)	1.1 (L: 0.4 - U: 1.7)
Bhutan	664 (L: 432 - U: 1,053)	2,463 (L: 930 - U: 5,976)	1.6 (L: 0.4 - U: 6.3)	3.1 (L: 0.6 - U: 12.4)	3.1 (L: 1.2 - U: 4.5)	5.9 (L: 2.2 - U: 8.4)
Bolivia (Plurinational State of)	1,129 (L: 947 - U: 1,609)	44,849 (L: 21,021 - U: 90,981)	50.6 (L: 19.9 - U: 146.4)	99.8 (L: 37.3 - U: 254.0)	139.7 (L: 53.5 - U: 208.9)	278.8 (L: 106.8 - U: 417.1)
Bosnia and Herzegovina	1,944 (L: 1,936 - U: 5,503)	8,824 (L: 3,638 - U: 16,186)	17.2 (L: 7.0 - U: 89.1)	35.3 (L: 14.5 - U: 140.2)	56.4 (L: 21.0 - U: 85.3)	118.7 (L: 44.3 - U: 179.5)
Botswana	1,285 (L: 969 - U: 6,042)	6,407 (L: 3,239 - U: 12,184)	8.2 (L: 3.1 - U: 73.6)	13.7 (L: 4.4 - U: 84.8)	18.9 (L: 7.0 - U: 28.5)	32.0 (L: 11.9 - U: 48.1)
Brazil	2,515 (L: 2,341 - U: 3,941)	604,293 (L: 300,863 - U: 1,135,450)	1,519.5 (L: 704.2 - U: 4,474.9)	2,777.3 (L: 1,325.8 - U: 7,492.7)	5,361.0 (L: 1,979.2 - U: 7,971.4)	9,961.2 (L: 3,677.5 - U: 14,811.4)
Brunei Darussalam	2,548 (L: 1,101 - U: 5,601)	747 (L: 344 - U: 1,555)	1.9 (L: 0.4 - U: 8.7)	3.9 (L: 0.7 - U: 12.8)	7.6 (L: 3.0 - U: 10.8)	15.6 (L: 6.1 - U: 22.1)
Bulgaria	2,417 (L: 2,168 - U: 4,218)	27,077 (L: 12,508 - U: 46,705)	65.5 (L: 27.1 - U: 197.0)	133.6 (L: 55.0 - U: 312.7)	71.2 (L: 27.1 - U: 100.9)	147.3 (L: 56.2 - U: 208.9)
Burkina Faso	202 (L: 166 - U: 286)	104,554 (L: 55,989 - U: 170,028)	21.2 (L: 9.3 - U: 48.7)	40.6 (L: 14.9 - U: 67.4)	48.8 (L: 15.6 - U: 80.6)	95.0 (L: 30.3 - U: 157.0)
Burundi	136 (L: 106 - U: 775)	43,759 (L: 19,343 - U: 82,638)	5.9 (L: 2.0 - U: 64.1)	11.3 (L: 3.2 - U: 81.3)	52.6 (L: 18.8 - U: 81.2)	103.2 (L: 36.8 - U: 159.4)
Cabo Verde	673 (L: 553 - U: 1,709)	1,367 (L: 669 - U: 2,370)	0.9 (L: 0.4 - U: 4.1)	1.8 (L: 0.6 - U: 5.7)	1.3 (L: 0.5 - U: 1.9)	2.5 (L: 1.0 - U: 3.7)

(Continued)

GBD Country	Excess Cost Per Admission US$ (2022)	Admissions with AMR (2022)	Excess Expenditure US$ Millions (2022)	Total Expenditure US$ Millions (2022)	Excess Expenditure US$ Millions (2050)	Total Expenditure US$ Millions (2050)
Cambodia	620 (L: 290 - U: 626)	61,987 (L: 31,419 - U: 116,815)	38.4 (L: 9.1 - U: 73.1)	74.4 (L: 14.2 - U: 141.6)	200.5 (L: 75.6 - U: 296.9)	397.3 (L: 149.8 - U: 588.4)
Cameroon	303 (L: 236 - U: 387)	96,335 (L: 47,967 - U: 171,728)	29.1 (L: 11.3 - U: 66.4)	56.1 (L: 17.8 - U: 99.5)	69.6 (L: 24.5 - U: 109.9)	136.2 (L: 48.0 - U: 215.0)
Canada	4,884 (L: 3,101 - U: 5,182)	94,478 (L: 51,955 - U: 149,098)	461.4 (L: 161.1 - U: 772.7)	1,210.7 (L: 463.3 - U: 1,922.3)	993.1 (L: 386.2 - U: 1,349.5)	2,611.1 (L: 1,015.5 - U: 3,547.9)
Central African Republic	172 (L: 104 - U: 474)	28,748 (L: 14,965 - U: 49,245)	4.9 (L: 1.6 - U: 23.3)	9.0 (L: 2.3 - U: 28.9)	13.9 (L: 4.7 - U: 23.0)	25.9 (L: 8.8 - U: 42.7)
Chad	166 (L: 118 - U: 373)	84,840 (L: 44,570 - U: 134,205)	14.1 (L: 5.3 - U: 50.1)	28.1 (L: 8.5 - U: 65.2)	22.1 (L: 7.5 - U: 36.2)	44.1 (L: 15.0 - U: 72.4)
Chile	2,347 (L: 1,169 - U: 2,347)	57,895 (L: 30,521 - U: 105,278)	135.9 (L: 35.7 - U: 246.6)	307.8 (L: 121.6 - U: 644.6)	345.4 (L: 132.7 - U: 475.8)	790.2 (L: 303.6 - U: 1,088.4)
China	4,909 (L: 4,909 - U: 5,364)	3,596,968 (L: 1,532,040 - U: 7,024,562)	17,657.7 (L: 7,752.7 - U: 37,676.7)	40,320.9 (L: 17,705.0 - U: 86,062.8)	43,953.5 (L: 16,468.3 - U: 62,596.7)	102,116.8 (L: 38,260.6 - U: 145,430.6)
Colombia	3,682 (L: 3,431 - U: 6,321)	77,932 (L: 33,266 - U: 176,023)	286.9 (L: 114.2 - U: 1,112.6)	476.0 (L: 194.8 - U: 1,676.4)	1,071.9 (L: 393.4 - U: 1,556.7)	1,809.0 (L: 664.0 - U: 2,627.0)
Comoros	407 (L: 231 - U: 490)	2,456 (L: 1,117 - U: 4,861)	1.0 (L: 0.3 - U: 2.4)	1.8 (L: 0.4 - U: 3.8)	5.0 (L: 1.8 - U: 7.6)	9.2 (L: 3.3 - U: 14.0)
Congo	464 (L: 287 - U: 632)	13,876 (L: 6,770 - U: 25,521)	6.4 (L: 1.9 - U: 16.1)	12.3 (L: 3.1 - U: 22.7)	15.1 (L: 5.5 - U: 22.8)	29.2 (L: 10.7 - U: 44.0)
Cook Islands	1,231 (L: 691 - U: 1,705)	59 (L: 27 - U: 127)	0.1 (L: 0.0 - U: 0.2)	0.1 (L: 0.0 - U: 0.4)	0.1 (L: 0.0 - U: 0.1)	0.2 (L: 0.1 - U: 0.3)
Costa Rica	2,782 (L: 2,751 - U: 4,807)	10,107 (L: 4,181 - U: 21,393)	28.1 (L: 11.5 - U: 102.8)	57.7 (L: 23.6 - U: 181.9)	98.0 (L: 37.0 - U: 141.8)	204.7 (L: 77.4 - U: 296.1)
Cote d'Ivoire	351 (L: 280 - U: 355)	93,189 (L: 49,313 - U: 167,960)	32.7 (L: 13.8 - U: 59.6)	64.2 (L: 20.5 - U: 115.3)	83.4 (L: 28.9 - U: 132.8)	166.5 (L: 57.7 - U: 265.3)
Croatia	3,247 (L: 2,195 - U: 4,347)	12,724 (L: 5,722 - U: 21,925)	41.3 (L: 12.6 - U: 95.3)	85.0 (L: 33.0 - U: 188.6)	85.8 (L: 33.5 - U: 117.7)	179.3 (L: 70.1 - U: 245.9)
Cuba	2,733 (L: 2,733 - U: 4,936)	34,999 (L: 16,934 - U: 65,929)	95.6 (L: 46.6 - U: 325.5)	196.8 (L: 83.2 - U: 507.9)	407.8 (L: 150.2 - U: 611.1)	857.7 (L: 316.0 - U: 1,285.4)

(Continued)

GBD Country	Excess Cost Per Admission US$ (2022)	Admissions with AMR (2022)	Excess Expenditure US$ Millions (2022)	Total Expenditure US$ Millions (2022)	Excess Expenditure US$ Millions (2050)	Total Expenditure US$ Millions (2050)
Cyprus	4,193 (L: 2,134 - U: 4,193)	3,189 (L: 1,566 - U: 5,693)	13.4 (L: 3.3 - U: 23.8)	27.4 (L: 9.8 - U: 48.9)	32.5 (L: 12.7 - U: 45.7)	67.5 (L: 26.3 - U: 94.7)
Czechia	4,298 (L: 2,168 - U: 5,922)	26,938 (L: 12,874 - U: 46,360)	115.8 (L: 27.9 - U: 274.5)	238.4 (L: 83.2 - U: 528.0)	189.2 (L: 74.0 - U: 264.5)	392.0 (L: 153.3 - U: 548.2)
Democratic People's Republic of Korea	609 (L: 473 - U: 1,376)	70,214 (L: 30,395 - U: 139,976)	42.8 (L: 14.4 - U: 192.6)	81.7 (L: 25.9 - U: 259.4)	247.7 (L: 91.7 - U: 362.6)	485.0 (L: 179.5 - U: 710.0)
Democratic Republic of the Congo	222 (L: 149 - U: 460)	286,549 (L: 140,937 - U: 529,295)	63.7 (L: 21.0 - U: 243.2)	115.0 (L: 30.4 - U: 298.8)	189.5 (L: 60.9 - U: 312.7)	348.1 (L: 111.9 - U: 574.3)
Denmark	7,397 (L: 2,768 - U: 8,686)	13,087 (L: 6,949 - U: 23,446)	96.8 (L: 19.2 - U: 203.7)	199.6 (L: 57.4 - U: 371.0)	176.4 (L: 68.8 - U: 240.8)	365.3 (L: 142.5 - U: 498.5)
Djibouti	427 (L: 272 - U: 433)	3,828 (L: 1,776 - U: 7,392)	1.6 (L: 0.5 - U: 3.2)	2.9 (L: 0.7 - U: 5.6)	3.0 (L: 1.1 - U: 4.8)	5.4 (L: 1.9 - U: 8.6)
Dominica	1,759 (L: 1,384 - U: 6,788)	246 (L: 117 - U: 454)	0.4 (L: 0.2 - U: 3.1)	0.9 (L: 0.3 - U: 4.0)	1.8 (L: 0.7 - U: 2.6)	3.7 (L: 1.4 - U: 5.5)
Dominican Republic	1,624 (L: 1,587 - U: 4,166)	25,592 (L: 10,462 - U: 55,593)	41.6 (L: 16.6 - U: 231.6)	84.8 (L: 31.7 - U: 309.4)	118.5 (L: 45.4 - U: 180.5)	245.9 (L: 94.3 - U: 374.6)
Ecuador	1,844 (L: 1,805 - U: 8,025)	49,297 (L: 21,614 - U: 101,295)	90.9 (L: 39.0 - U: 812.8)	177.9 (L: 76.6 - U: 1,120.0)	236.1 (L: 90.3 - U: 340.3)	466.6 (L: 178.4 - U: 672.7)
Egypt	1,087 (L: 988 - U: 8,223)	283,493 (L: 108,832 - U: 617,889)	308.1 (L: 107.5 - U: 5,080.7)	630.2 (L: 205.6 - U: 6,848.8)	1,180.5 (L: 443.8 - U: 1,773.6)	2,441.9 (L: 918.0 - U: 3,668.7)
El Salvador	1,525 (L: 1,506 - U: 2,617)	16,975 (L: 7,484 - U: 35,370)	25.9 (L: 11.3 - U: 92.6)	53.1 (L: 23.1 - U: 153.2)	66.5 (L: 23.1 - U: 102.8)	138.6 (L: 48.1 - U: 214.4)
Equatorial Guinea	918 (L: 766 - U: 3,275)	2,650 (L: 1,121 - U: 6,039)	2.4 (L: 0.9 - U: 19.8)	4.6 (L: 1.4 - U: 25.2)	4.4 (L: 1.4 - U: 7.6)	8.2 (L: 2.7 - U: 14.3)
Eritrea	148 (L: 87 - U: 554)	25,252 (L: 10,731 - U: 51,881)	3.7 (L: 0.9 - U: 28.7)	6.6 (L: 1.4 - U: 35.5)	35.8 (L: 10.5 - U: 66.5)	65.5 (L: 19.3 - U: 121.8)
Estonia	4,608 (L: 2,889 - U: 5,321)	2,902 (L: 1,292 - U: 5,637)	13.4 (L: 3.7 - U: 30.0)	25.5 (L: 9.1 - U: 54.7)	22.2 (L: 8.4 - U: 32.2)	42.7 (L: 16.2 - U: 61.9)

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GBD Country	Excess Cost Per Admission US$ (2022)	Admissions with AMR (2022)	Excess Expenditure US$ Millions (2022)	Total Expenditure US$ Millions (2022)	Excess Expenditure US$ Millions (2050)	Total Expenditure US$ Millions (2050)
Eswatini	963 (L: 647 – U: 1,945)	4,133 (L: 1,971 – U: 7,628)	4.0 (L: 1.3 – U: 14.8)	6.3 (L: 1.8 – U: 19.8)	8.7 (L: 2.9 – U: 14.0)	14.0 (L: 4.7 – U: 22.4)
Ethiopia	385 (L: 255 – U: 470)	258,103 (L: 124,776 – U: 485,270)	99.3 (L: 31.8 – U: 228.3)	143.9 (L: 46.9 – U: 289.3)	425.4 (L: 157.5 – U: 687.7)	628.4 (L: 232.6 – U: 1,015.9)
Fiji	1,283 (L: 960 – U: 2,749)	2,346 (L: 1,015 – U: 4,758)	3.0 (L: 1.0 – U: 13.1)	5.6 (L: 1.6 – U: 16.2)	2.6 (L: 1.0 – U: 4.0)	4.8 (L: 1.8 – U: 7.3)
Finland	6,434 (L: 2,860 – U: 6,434)	10,284 (L: 4,951 – U: 18,691)	66.2 (L: 14.2 – U: 119.3)	135.8 (L: 41.8 – U: 244.8)	87.7 (L: 31.1 – U: 131.0)	181.3 (L: 64.3 – U: 270.9)
France	5,222 (L: 1,821 – U: 5,276)	186,713 (L: 97,206 – U: 333,813)	975.0 (L: 177.0 – U: 1,761.2)	2,117.9 (L: 563.1 – U: 3,753.3)	1,490.0 (L: 553.6 – U: 2,103.7)	3,268.1 (L: 1,214.3 – U: 4,614.3)
Gabon	954 (L: 671 – U: 3,457)	4,095 (L: 1,874 – U: 7,714)	3.9 (L: 1.3 – U: 26.7)	7.3 (L: 2.0 – U: 33.2)	7.4 (L: 2.5 – U: 11.7)	13.9 (L: 4.7 – U: 22.0)
Gambia	218 (L: 184 – U: 731)	8,303 (L: 4,364 – U: 13,815)	1.8 (L: 0.8 – U: 10.1)	3.6 (L: 1.3 – U: 12.3)	4.5 (L: 1.6 – U: 7.0)	9.1 (L: 3.3 – U: 14.2)
Georgia	1,598 (L: 1,445 – U: 6,310)	12,891 (L: 5,588 – U: 24,137)	20.6 (L: 8.1 – U: 152.3)	41.1 (L: 14.6 – U: 211.2)	40.2 (L: 15.2 – U: 56.3)	81.7 (L: 30.8 – U: 114.3)
Germany	10,675 (L: 9,437 – U: 10,675)	246,925 (L: 131,925 – U: 435,979)	2,635.9 (L: 1,244.9 – U: 4,559.3)	5,222.3 (L: 2,449.7 – U: 9,213.9)	3,163.9 (L: 1,139.5 – U: 4,502.7)	6,303.6 (L: 2,270.3 – U: 8,971.0)
Ghana	399 (L: 303 – U: 777)	99,883 (L: 48,896 – U: 177,697)	39.8 (L: 14.8 – U: 138.0)	78.5 (L: 24.0 – U: 168.7)	126.3 (L: 45.8 – U: 191.7)	253.0 (L: 91.7 – U: 383.8)
Greece	3,970 (L: 2,072 – U: 3,970)	36,059 (L: 19,407 – U: 64,462)	143.2 (L: 40.2 – U: 253.8)	293.0 (L: 117.4 – U: 552.9)	268.8 (L: 100.7 – U: 372.5)	559.2 (L: 209.4 – U: 774.9)
Greenland	4,260 (L: 1,860 – U: 7,124)	167 (L: 81 – U: 321)	0.7 (L: 0.2 – U: 2.3)	1.4 (L: 0.3 – U: 3.2)	0.7 (L: 0.3 – U: 1.1)	1.4 (L: 0.5 – U: 2.1)
Grenada	1,928 (L: 1,820 – U: 10,573)	324 (L: 161 – U: 593)	0.6 (L: 0.3 – U: 6.3)	1.3 (L: 0.6 – U: 7.7)	2.1 (L: 0.8 – U: 3.1)	4.5 (L: 1.7 – U: 6.4)
Guam	3,529 (L: 3,066 – U: 6,096)	383 (L: 166 – U: 804)	1.4 (L: 0.5 – U: 4.9)	2.8 (L: 1.0 – U: 7.2)	0.5 (L: 0.2 – U: 0.8)	1.0 (L: 0.3 – U: 1.4)
Guatemala	1,185 (L: 1,153 – U: 2,169)	55,128 (L: 26,060 – U: 111,222)	65.3 (L: 30.0 – U: 241.2)	133.6 (L: 57.5 – U: 331.8)	227.1 (L: 91.2 – U: 329.1)	473.0 (L: 189.9 – U: 685.6)

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Guinea	241 (L: 181 – U: 288)	59,251 (L: 30,347 – U: 100,215)	14.3 (L: 5.5 – U: 28.9)	28.5 (L: 8.8 – U: 48.1)	25.8 (L: 9.5 – U: 40.0)	52.1 (L: 19.2 – U: 80.8)
Guinea-Bissau	227 (L: 157 – U: 288)	6,237 (L: 3,323 – U: 10,645)	1.4 (L: 0.5 – U: 3.1)	2.8 (L: 0.8 – U: 4.8)	4.3 (L: 1.5 – U: 6.7)	8.7 (L: 3.0 – U: 13.6)
Guyana	1,905 (L: 1,666 – U: 4,126)	2,397 (L: 1,112 – U: 4,851)	4.6 (L: 1.9 – U: 20.0)	9.4 (L: 3.6 – U: 32.3)	6.4 (L: 2.3 – U: 9.9)	13.3 (L: 4.7 – U: 20.5)
Haiti	426 (L: 234 – U: 427)	40,205 (L: 18,339 – U: 83,923)	17.1 (L: 4.3 – U: 35.8)	35.1 (L: 7.3 – U: 73.4)	40.1 (L: 13.5 – U: 67.5)	83.4 (L: 28.2 – U: 140.4)
Honduras	960 (L: 812 – U: 1,119)	23,430 (L: 9,886 – U: 50,240)	22.5 (L: 8.0 – U: 56.2)	45.3 (L: 12.9 – U: 114.2)	75.1 (L: 28.4 – U: 113.5)	153.7 (L: 58.1 – U: 232.2)
Hungary	3,018 (L: 2,925 – U: 3,611)	30,308 (L: 13,854 – U: 51,923)	91.5 (L: 40.5 – U: 187.5)	189.1 (L: 86.6 – U: 428.0)	161.8 (L: 63.4 – U: 224.6)	338.1 (L: 132.5 – U: 469.5)
Iceland	8,650 (L: 1,774 – U: 9,114)	563 (L: 279 – U: 1,068)	4.9 (L: 0.5 – U: 9.7)	10.0 (L: 1.9 – U: 18.7)	3.8 (L: 1.3 – U: 5.8)	7.5 (L: 2.6 – U: 11.4)
India	787 (L: 787 – U: 1,377)	6,357,998 (L: 2,589,734 – U: 12,385,146)	5,003.3 (L: 2,132.7 – U: 17,060.3)	7,885.0 (L: 2,941.7 – U: 21,650.4)	23,974.7 (L: 9,098.5 – U: 34,899.0)	38,609.1 (L: 14,652.3 – U: 56,201.6)
Indonesia	1,091 (L: 544 – U: 1,696)	719,830 (L: 307,460 – U: 1,247,742)	785.7 (L: 167.2 – U: 2,116.7)	1,281.9 (L: 255.6 – U: 2,442.9)	2,342.7 (L: 894.6 – U: 3,571.8)	3,882.4 (L: 1,482.6 – U: 5,919.3)
Iran (Islamic Republic of)	3,465 (L: 3,409 – U: 7,964)	129,717 (L: 51,279 – U: 290,614)	449.5 (L: 174.8 – U: 2,314.6)	643.0 (L: 251.7 – U: 3,181.3)	1,736.0 (L: 652.5 – U: 2,658.8)	2,518.5 (L: 946.5 – U: 3,857.1)
Iraq	1,492 (L: 1,492 – U: 3,865)	70,036 (L: 25,944 – U: 171,280)	104.5 (L: 39.4 – U: 662.0)	211.4 (L: 69.7 – U: 974.3)	350.3 (L: 114.6 – U: 577.0)	720.0 (L: 235.7 – U: 1,186.2)
Ireland	8,521 (L: 2,270 – U: 8,863)	10,882 (L: 5,857 – U: 19,818)	92.7 (L: 13.3 – U: 175.7)	190.5 (L: 45.8 – U: 345.0)	211.4 (L: 78.5 – U: 301.2)	438.5 (L: 162.9 – U: 624.7)
Israel	4,666 (L: 2,098 – U: 4,724)	19,483 (L: 9,095 – U: 39,974)	90.9 (L: 19.1 – U: 188.8)	244.5 (L: 70.3 – U: 502.7)	183.4 (L: 65.9 – U: 265.3)	497.2 (L: 178.8 – U: 719.3)
Italy	6,651 (L: 6,196 – U: 6,945)	167,615 (L: 83,801 – U: 311,048)	1,114.7 (L: 519.2 – U: 2,160.4)	2,019.5 (L: 910.7 – U: 3,726.2)	1,947.8 (L: 670.9 – U: 2,837.4)	3,570.5 (L: 1,229.8 – U: 5,201.3)
Jamaica	1,665 (L: 1,596 – U: 4,275)	7,122 (L: 3,053 – U: 14,874)	11.9 (L: 4.9 – U: 63.6)	24.4 (L: 9.4 – U: 99.1)	31.6 (L: 11.8 – U: 50.3)	66.0 (L: 24.6 – U: 104.9)

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Japan	4,134 (L: 2,901 – U: 4,708)	578,534 (L: 359,650 – U: 877,645)	2,391.8 (L: 1,043.4 – U: 4,131.5)	5,797.3 (L: 3,111.3 – U: 9,152.6)	2,962.9 (L: 999.2 – U: 4,309.1)	7,274.7 (L: 2,453.2 – U: 10,579.9)
Jordan	1,528 (L: 1,319 – U: 1,671)	14,600 (L: 5,548 – U: 35,312)	22.3 (L: 7.3 – U: 59.0)	45.8 (L: 14.5 – U: 117.9)	87.7 (L: 30.0 – U: 133.3)	180.9 (L: 62.0 – U: 275.0)
Kazakhstan	2,121 (L: 1,888 – U: 5,303)	47,673 (L: 22,707 – U: 88,896)	101.1 (L: 42.9 – U: 471.4)	183.4 (L: 69.7 – U: 656.2)	174.2 (L: 70.6 – U: 251.7)	318.5 (L: 129.1 – U: 460.2)
Kenya	477 (L: 305 – U: 477)	138,662 (L: 66,309 – U: 241,836)	66.1 (L: 20.2 – U: 112.8)	99.8 (L: 30.0 – U: 171.1)	198.3 (L: 77.6 – U: 285.3)	305.2 (L: 119.4 – U: 438.9)
Kiribati	640 (L: 374 – U: 1,540)	376 (L: 166 – U: 757)	0.2 (L: 0.1 – U: 1.2)	0.5 (L: 0.1 – U: 1.9)	0.5 (L: 0.2 – U: 0.7)	1.0 (L: 0.4 – U: 1.5)
Kuwait	4,999 (L: 3,016 – U: 7,522)	5,175 (L: 2,249 – U: 11,486)	25.9 (L: 6.8 – U: 86.4)	53.0 (L: 17.3 – U: 165.3)	85.7 (L: 29.3 – U: 132.8)	174.2 (L: 59.6 – U: 270.0)
Kyrgyzstan	997 (L: 773 – U: 2,493)	14,241 (L: 6,810 – U: 27,871)	14.2 (L: 5.3 – U: 69.5)	23.3 (L: 7.6 – U: 98.0)	36.3 (L: 13.6 – U: 53.7)	60.3 (L: 22.6 – U: 89.1)
Lao People's Democratic Republic	498 (L: 299 – U: 761)	16,700 (L: 7,840 – U: 34,619)	8.3 (L: 2.3 – U: 26.4)	16.3 (L: 4.3 – U: 35.0)	33.9 (L: 12.3 – U: 50.5)	67.9 (L: 24.6 – U: 101.1)
Latvia	3,945 (L: 3,248 – U: 4,807)	5,933 (L: 2,716 – U: 10,977)	23.4 (L: 8.8 – U: 52.8)	44.7 (L: 16.3 – U: 110.9)	32.3 (L: 13.1 – U: 44.2)	62.4 (L: 25.3 – U: 85.3)
Lebanon	1,563 (L: 1,562 – U: 1,870)	9,105 (L: 3,708 – U: 21,143)	14.2 (L: 5.8 – U: 39.5)	33.6 (L: 13.7 – U: 96.0)	58.5 (L: 20.9 – U: 87.6)	141.1 (L: 50.5 – U: 211.3)
Lesotho	462 (L: 277 – U: 713)	8,725 (L: 4,497 – U: 15,219)	4.0 (L: 1.2 – U: 10.9)	6.6 (L: 1.7 – U: 12.8)	8.1 (L: 2.9 – U: 12.7)	13.5 (L: 4.8 – U: 21.3)
Liberia	307 (L: 235 – U: 364)	13,590 (L: 6,418 – U: 25,323)	4.2 (L: 1.5 – U: 9.2)	8.3 (L: 2.5 – U: 17.0)	16.6 (L: 5.7 – U: 27.2)	33.8 (L: 11.5 – U: 55.3)
Libya	1,480 (L: 1,466 – U: 2,166)	11,790 (L: 4,595 – U: 26,703)	17.4 (L: 6.7 – U: 57.8)	35.7 (L: 11.7 – U: 97.0)	18.6 (L: 6.3 – U: 29.8)	36.4 (L: 12.2 – U: 58.1)
Lithuania	3,953 (L: 3,312 – U: 4,621)	9,106 (L: 4,135 – U: 17,237)	36.0 (L: 13.7 – U: 79.7)	68.6 (L: 25.3 – U: 129.7)	58.5 (L: 22.7 – U: 82.0)	112.7 (L: 43.8 – U: 158.0)
Luxembourg	8,787 (L: 5,357 – U: 8,787)	1,252 (L: 620 – U: 2,366)	11.0 (L: 3.3 – U: 20.5)	22.6 (L: 7.2 – U: 42.0)	16.5 (L: 6.7 – U: 22.5)	33.7 (L: 13.6 – U: 45.8)

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Madagascar	167 (L: 113 – U: 769)	90,191 (L: 43,223 – U: 162,483)	15.0 (L: 4.9 – U: 124.9)	29.2 (L: 7.8 – U: 158.9)	44.2 (L: 16.5 – U: 67.7)	87.2 (L: 32.6 – U: 133.5)
Malawi	205 (L: 125 – U: 241)	95,974 (L: 52,295 – U: 147,580)	19.6 (L: 6.5 – U: 35.6)	38.5 (L: 11.5 – U: 59.6)	55.6 (L: 20.8 – U: 83.7)	110.7 (L: 41.5 – U: 166.7)
Malaysia	2,879 (L: 2,595 – U: 7,871)	72,257 (L: 32,996 – U: 142,569)	208.0 (L: 85.6 – U: 1,122.2)	349.0 (L: 137.6 – U: 1,549.8)	594.2 (L: 238.8 – U: 809.2)	1,008.7 (L: 405.4 – U: 1,373.6)
Maldives	2,144 (L: 2,142 – U: 4,367)	566 (L: 217 – U: 1,350)	1.2 (L: 0.5 – U: 5.9)	2.5 (L: 0.9 – U: 9.6)	1.8 (L: 0.7 – U: 2.6)	3.4 (L: 1.3 – U: 5.1)
Mali	187 (L: 181 – U: 591)	95,919 (L: 51,694 – U: 156,488)	18.0 (L: 9.4 – U: 92.5)	36.1 (L: 15.3 – U: 119.2)	32.9 (L: 11.7 – U: 51.8)	66.9 (L: 23.9 – U: 105.3)
Malta	5,519 (L: 1,973 – U: 5,519)	1,345 (L: 706 – U: 2,523)	7.4 (L: 1.4 – U: 13.9)	15.3 (L: 4.8 – U: 28.4)	14.0 (L: 5.0 – U: 20.4)	29.0 (L: 10.4 – U: 42.3)
Marshall Islands	1,022 (L: 721 – U: 3,906)	163 (L: 72 – U: 358)	0.2 (L: 0.1 – U: 1.4)	0.3 (L: 0.1 – U: 1.8)	0.2 (L: 0.1 – U: 0.3)	0.4 (L: 0.2 – U: 0.7)
Mauritania	401 (L: 334 – U: 613)	11,061 (L: 5,124 – U: 21,627)	4.4 (L: 1.7 – U: 13.3)	8.9 (L: 2.4 – U: 17.4)	7.1 (L: 2.6 – U: 11.4)	14.3 (L: 5.3 – U: 23.0)
Mauritius	1,869 (L: 1,853 – U: 5,943)	3,488 (L: 1,577 – U: 6,634)	6.5 (L: 2.9 – U: 39.4)	13.4 (L: 5.7 – U: 54.7)	17.4 (L: 6.8 – U: 26.4)	36.4 (L: 14.3 – U: 55.3)
Mexico	4,420 (L: 3,988 – U: 11,291)	300,753 (L: 142,589 – U: 587,854)	1,329.4 (L: 568.7 – U: 6,637.7)	2,040.4 (L: 882.5 – U: 8,504.9)	3,062.1 (L: 1,269.3 – U: 4,183.7)	4,742.2 (L: 1,965.7 – U: 6,479.1)
Micronesia (Federated States of)	1,030 (L: 702 – U: 2,614)	297 (L: 127 – U: 763)	0.3 (L: 0.1 – U: 2.0)	0.6 (L: 0.2 – U: 3.2)	0.4 (L: 0.1 – U: 0.6)	0.7 (L: 0.3 – U: 1.1)
Monaco	10,518 (L: 5,012 – U: 10,518)	156 (L: 82 – U: 279)	1.6 (L: 0.4 – U: 2.9)	3.4 (L: 0.9 – U: 6.0)	0.4 (L: 0.1 – U: 0.6)	0.8 (L: 0.3 – U: 1.2)
Mongolia	1,302 (L: 969 – U: 3,115)	11,453 (L: 5,216 – U: 22,379)	14.9 (L: 5.1 – U: 69.7)	27.2 (L: 8.6 – U: 91.8)	45.4 (L: 17.7 – U: 65.7)	83.6 (L: 32.5 – U: 120.8)
Montenegro	2,701 (L: 2,687 – U: 3,587)	1,506 (L: 633 – U: 2,750)	4.1 (L: 1.7 – U: 9.9)	8.4 (L: 3.6 – U: 22.2)	11.2 (L: 4.5 – U: 15.6)	23.4 (L: 9.5 – U: 32.9)
Morocco	982 (L: 960 – U: 1,694)	74,982 (L: 30,354 – U: 167,767)	73.7 (L: 29.1 – U: 284.2)	146.8 (L: 54.6 – U: 429.6)	228.6 (L: 84.9 – U: 326.4)	463.2 (L: 172.1 – U: 661.4)

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Mozambique	213 (L: 162 - U: 336)	105,781 (L: 54,066 - U: 188,805)	22.5 (L: 8.8 - U: 63.4)	42.5 (L: 13.8 - U: 85.7)	86.5 (L: 31.1 - U: 134.4)	167.4 (L: 60.2 - U: 260.1)
Myanmar	565 (L: 351 - U: 743)	167,874 (L: 80,655 - U: 333,768)	94.8 (L: 28.3 - U: 247.9)	172.7 (L: 49.4 - U: 343.8)	439.5 (L: 169.7 - U: 643.1)	819.5 (L: 316.5 - U: 1,199.1)
Namibia	1,149 (L: 892 - U: 3,103)	7,106 (L: 3,426 - U: 13,816)	8.2 (L: 3.1 - U: 42.9)	13.6 (L: 4.2 - U: 58.8)	18.7 (L: 6.7 - U: 29.3)	31.7 (L: 11.3 - U: 49.7)
Nauru	1,915 (L: 1,595 - U: 4,414)	22 (L: 10 - U: 51)	0.0 (L: 0.0 - U: 0.2)	0.1 (L: 0.0 - U: 0.4)	0.0 (L: 0.0 - U: 0.0)	0.0 (L: 0.0 - U: 0.1)
Nepal	433 (L: 367 - U: 591)	121,777 (L: 51,187 - U: 257,590)	52.7 (L: 18.8 - U: 152.3)	101.5 (L: 29.1 - U: 294.5)	194.2 (L: 71.2 - U: 298.9)	382.4 (L: 140.1 - U: 588.4)
Netherlands	5,327 (L: 1,991 - U: 6,324)	37,543 (L: 20,244 - U: 65,308)	200.0 (L: 40.3 - U: 413.0)	496.1 (L: 110.9 - U: 884.8)	419.1 (L: 151.7 - U: 585.6)	1,044.9 (L: 378.3 - U: 1,460.0)
New Zealand	7,801 (L: 2,745 - U: 7,801)	9,672 (L: 4,374 - U: 19,719)	75.4 (L: 12.0 - U: 153.3)	128.6 (L: 29.2 - U: 261.8)	163.6 (L: 61.9 - U: 225.2)	279.6 (L: 105.7 - U: 384.9)
Nicaragua	1,018 (L: 971 - U: 1,740)	12,124 (L: 5,226 - U: 25,374)	12.3 (L: 5.1 - U: 44.2)	25.1 (L: 8.2 - U: 90.8)	53.9 (L: 18.8 - U: 85.6)	111.9 (L: 39.1 - U: 177.6)
Niger	158 (L: 138 - U: 515)	106,582 (L: 55,373 - U: 180,744)	16.8 (L: 7.6 - U: 93.1)	33.6 (L: 12.4 - U: 122.8)	52.0 (L: 16.7 - U: 88.5)	105.6 (L: 34.0 - U: 179.7)
Nigeria	340 (L: 240 - U: 499)	986,379 (L: 495,402 - U: 1,548,867)	335.8 (L: 118.7 - U: 772.8)	654.4 (L: 187.8 - U: 1,041.7)	592.8 (L: 196.7 - U: 917.2)	1,165.0 (L: 386.5 - U: 1,802.5)
Niue	1,364 (L: 1,184 - U: 5,289)	7 (L: 3 - U: 13)	0.0 (L: 0.0 - U: 0.1)	0.0 (L: 0.0 - U: 0.1)	0.0 (L: 0.0 - U: 0.0)	0.0 (L: 0.0 - U: 0.0)
North Macedonia	1,792 (L: 1,767 - U: 5,629)	5,805 (L: 2,290 - U: 11,182)	10.4 (L: 4.0 - U: 62.9)	21.4 (L: 7.8 - U: 91.5)	57.2 (L: 21.5 - U: 84.4)	120.6 (L: 45.4 - U: 178.0)
Northern Mariana Islands	3,045 (L: 3,015 - U: 5,414)	121 (L: 56 - U: 238)	0.4 (L: 0.2 - U: 1.3)	0.7 (L: 0.3 - U: 2.0)	0.3 (L: 0.1 - U: 0.4)	0.5 (L: 0.2 - U: 0.7)
Norway	9,950 (L: 3,486 - U: 10,014)	11,193 (L: 5,685 - U: 19,689)	111.4 (L: 19.8 - U: 197.2)	220.5 (L: 56.6 - U: 387.2)	197.9 (L: 71.2 - U: 293.0)	391.0 (L: 140.8 - U: 579.1)
Oman	3,188 (L: 3,177 - U: 4,333)	4,544 (L: 1,768 - U: 10,810)	14.5 (L: 5.6 - U: 46.8)	29.6 (L: 11.5 - U: 82.4)	62.1 (L: 22.4 - U: 96.0)	127.0 (L: 45.8 - U: 196.4)

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Pakistan	724 (L: 700 – U: 1,942)	1,065,250 (L: 448,498 – U: 2,239,522)	771.0 (L: 313.8 – U: 4,348.1)	1,112.9 (L: 440.3 – U: 5,476.7)	3,263.6 (L: 1,245.0 – U: 5,007.3)	4,815.1 (L: 1,836.9 – U: 7,387.8)
Palau	2,511 (L: 2,410 – U: 6,528)	84 (L: 42 – U: 161)	0.2 (L: 0.1 – U: 1.1)	0.4 (L: 0.2 – U: 1.3)	0.1 (L: 0.0 – U: 0.2)	0.2 (L: 0.1 – U: 0.3)
Palestine	1,205 (L: 914 – U: 1,656)	7,897 (L: 3,050 – U: 18,428)	9.5 (L: 2.8 – U: 30.5)	19.6 (L: 5.7 – U: 49.0)	17.6 (L: 6.8 – U: 28.2)	35.8 (L: 13.7 – U: 57.4)
Panama	3,241 (L: 3,194 – U: 4,987)	8,187 (L: 3,380 – U: 18,008)	26.5 (L: 10.8 – U: 89.8)	53.4 (L: 21.8 – U: 182.6)	54.9 (L: 20.1 – U: 82.8)	111.6 (L: 40.8 – U: 168.2)
Papua New Guinea	514 (L: 162 – U: 518)	31,467 (L: 14,534 – U: 65,602)	16.2 (L: 2.4 – U: 34.0)	31.8 (L: 4.1 – U: 66.6)	35.1 (L: 11.1 – U: 59.0)	69.3 (L: 21.8 – U: 116.5)
Paraguay	1,614 (L: 1,595 – U: 4,734)	15,159 (L: 6,377 – U: 32,840)	24.5 (L: 10.2 – U: 155.5)	49.5 (L: 20.0 – U: 229.8)	87.4 (L: 31.5 – U: 135.0)	179.9 (L: 64.8 – U: 277.6)
Peru	2,417 (L: 2,324 – U: 2,916)	112,793 (L: 49,787 – U: 250,660)	272.6 (L: 115.7 – U: 731.0)	481.6 (L: 213.7 – U: 1,199.3)	709.5 (L: 262.8 – U: 1,063.5)	1,269.3 (L: 470.2 – U: 1,902.8)
Philippines	1,124 (L: 975 – U: 1,720)	275,432 (L: 145,520 – U: 498,443)	309.6 (L: 141.9 – U: 857.5)	550.5 (L: 216.9 – U: 1,315.1)	1,439.8 (L: 524.5 – U: 2,070.4)	2,611.4 (L: 951.3 – U: 3,755.2)
Poland	2,928 (L: 2,635 – U: 3,334)	114,190 (L: 58,307 – U: 189,166)	334.3 (L: 153.6 – U: 630.6)	685.7 (L: 329.3 – U: 1,651.4)	723.6 (L: 288.4 – U: 986.1)	1,505.4 (L: 600.1 – U: 2,051.6)
Portugal	4,125 (L: 2,295 – U: 4,158)	51,402 (L: 30,401 – U: 78,653)	212.0 (L: 69.8 – U: 327.1)	435.0 (L: 183.7 – U: 670.2)	317.0 (L: 112.3 – U: 488.6)	657.7 (L: 233.0 – U: 1,013.6)
Puerto Rico	4,439 (L: 3,137 – U: 5,887)	13,224 (L: 6,441 – U: 23,740)	58.7 (L: 20.2 – U: 139.8)	120.9 (L: 51.5 – U: 269.2)	102.1 (L: 37.9 – U: 149.3)	212.6 (L: 78.8 – U: 310.8)
Qatar	5,426 (L: 3,370 – U: 7,822)	1,939 (L: 654 – U: 5,231)	10.5 (L: 2.2 – U: 40.9)	21.5 (L: 5.8 – U: 78.1)	63.7 (L: 22.7 – U: 94.9)	126.9 (L: 45.3 – U: 189.0)
Republic of Korea	2,040 (L: 1,480 – U: 2,357)	121,304 (L: 62,045 – U: 217,427)	247.5 (L: 91.8 – U: 512.6)	954.0 (L: 400.8 – U: 1,734.9)	855.4 (L: 303.8 – U: 1,210.3)	3,339.1 (L: 1,185.9 – U: 4,724.3)
Republic of Moldova	1,556 (L: 1,477 – U: 1,556)	13,948 (L: 6,732 – U: 24,314)	21.7 (L: 9.9 – U: 37.7)	39.2 (L: 16.0 – U: 84.2)	132.6 (L: 49.5 – U: 201.6)	246.4 (L: 92.1 – U: 374.6)
Romania	3,853 (L: 3,731 – U: 4,760)	79,816 (L: 37,516 – U: 143,655)	307.5 (L: 140.0 – U: 683.8)	519.4 (L: 237.2 – U: 1,355.9)	421.4 (L: 167.3 – U: 613.0)	720.7 (L: 286.2 – U: 1,048.3)

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Russian Federation	3,625 (L: 3,625 - U: 5,081)	588,518 (L: 292,344 - U: 1,028,953)	2,133.6 (L: 1,170.4 - U: 5,228.0)	3,677.2 (L: 1,835.8 - U: 7,788.7)	3,501.2 (L: 1,392.9 - U: 4,904.6)	6,068.9 (L: 2,414.4 - U: 8,501.5)
Rwanda	278 (L: 212 - U: 305)	38,300 (L: 18,402 - U: 70,224)	10.7 (L: 3.9 - U: 21.4)	20.9 (L: 6.2 - U: 38.3)	38.3 (L: 13.8 - U: 57.9)	76.4 (L: 27.6 - U: 115.6)
Saint Kitts and Nevis	2,437 (L: 2,178 - U: 4,722)	179 (L: 84 - U: 415)	0.4 (L: 0.2 - U: 2.0)	0.9 (L: 0.4 - U: 3.1)	1.3 (L: 0.5 - U: 1.9)	2.8 (L: 1.1 - U: 4.1)
Saint Lucia	2,148 (L: 2,129 - U: 7,211)	504 (L: 239 - U: 965)	1.1 (L: 0.5 - U: 7.0)	2.2 (L: 1.0 - U: 9.9)	3.6 (L: 1.3 - U: 5.4)	7.5 (L: 2.8 - U: 11.3)
Saint Vincent and the Grenadines	1,522 (L: 1,369 - U: 4,183)	347 (L: 166 - U: 653)	0.5 (L: 0.2 - U: 2.7)	1.1 (L: 0.4 - U: 3.7)	2.5 (L: 1.0 - U: 3.5)	5.3 (L: 2.1 - U: 7.4)
Samoa	1,026 (L: 732 - U: 1,806)	502 (L: 210 - U: 1,132)	0.5 (L: 0.2 - U: 2.0)	1.0 (L: 0.3 - U: 3.2)	0.8 (L: 0.3 - U: 1.1)	1.6 (L: 0.6 - U: 2.3)
San Marino	6,703 (L: 3,061 - U: 6,703)	89 (L: 38 - U: 190)	0.6 (L: 0.1 - U: 1.3)	1.2 (L: 0.3 - U: 2.6)	0.5 (L: 0.2 - U: 0.9)	1.0 (L: 0.3 - U: 1.7)
Sao Tome and Principe	536 (L: 344 - U: 1,710)	582 (L: 288 - U: 1,048)	0.3 (L: 0.1 - U: 1.8)	0.6 (L: 0.2 - U: 2.5)	0.5 (L: 0.2 - U: 0.8)	1.0 (L: 0.4 - U: 1.5)
Saudi Arabia	3,955 (L: 3,942 - U: 4,834)	54,335 (L: 22,043 - U: 129,045)	214.9 (L: 86.9 - U: 623.8)	422.3 (L: 156.2 - U: 1,116.7)	832.9 (L: 288.7 - U: 1,264.2)	1,642.3 (L: 569.2 - U: 2,492.7)
Senegal	199 (L: 147 - U: 199)	37,096 (L: 18,359 - U: 71,004)	7.4 (L: 2.7 - U: 13.9)	14.0 (L: 4.6 - U: 26.2)	21.5 (L: 7.8 - U: 32.5)	41.5 (L: 15.0 - U: 62.8)
Serbia	2,126 (L: 2,021 - U: 4,238)	31,849 (L: 14,426 - U: 55,185)	67.7 (L: 29.1 - U: 233.9)	139.3 (L: 60.2 - U: 454.5)	134.4 (L: 53.4 - U: 194.1)	281.5 (L: 111.9 - U: 406.5)
Seychelles	2,027 (L: 1,887 - U: 4,981)	350 (L: 177 - U: 614)	0.7 (L: 0.3 - U: 3.1)	1.5 (L: 0.6 - U: 4.6)	0.4 (L: 0.2 - U: 0.7)	0.8 (L: 0.3 - U: 1.3)
Sierra Leone	195 (L: 157 - U: 795)	34,766 (L: 17,815 - U: 61,013)	6.8 (L: 2.8 - U: 48.5)	13.4 (L: 4.5 - U: 61.9)	34.3 (L: 11.7 - U: 54.9)	69.6 (L: 23.7 - U: 111.3)
Singapore	8,202 (L: 5,918 - U: 8,202)	13,594 (L: 8,800 - U: 21,602)	111.5 (L: 52.1 - U: 176.0)	213.6 (L: 113.1 - U: 336.8)	284.8 (L: 97.4 - U: 420.8)	543.0 (L: 185.6 - U: 802.2)
Slovakia	3,309 (L: 2,250 - U: 3,754)	17,221 (L: 8,161 - U: 31,011)	57.0 (L: 18.4 - U: 116.4)	117.4 (L: 43.4 - U: 261.7)	105.1 (L: 37.4 - U: 154.7)	218.9 (L: 78.0 - U: 322.3)

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Slovenia	4,900 (L: 2,020 – U: 7,571)	5,113 (L: 2,369 – U: 8,692)	25.1 (L: 4.8 – U: 65.8)	51.6 (L: 15.6 – U: 126.8)	41.6 (L: 16.2 – U: 59.6)	86.3 (L: 33.6 – U: 123.9)
Solomon Islands	516 (L: 245 – U: 525)	2,322 (L: 1,139 – U: 4,951)	1.2 (L: 0.3 – U: 2.6)	2.5 (L: 0.4 – U: 5.3)	2.5 (L: 0.9 – U: 4.1)	5.2 (L: 1.8 – U: 8.4)
Somalia	112 (L: 86 – U: 455)	101,422 (L: 50,483 – U: 175,077)	11.4 (L: 4.3 – U: 79.7)	20.9 (L: 6.5 – U: 97.8)	73.0 (L: 22.2 – U: 139.9)	137.2 (L: 41.7 – U: 262.9)
South Africa	2,776 (L: 2,476 – U: 10,394)	170,423 (L: 93,859 – U: 268,857)	473.1 (L: 232.4 – U: 2,794.6)	631.5 (L: 271.3 – U: 3,186.0)	893.3 (L: 369.3 – U: 1,233.2)	1,207.1 (L: 499.1 – U: 1,666.4)
South Sudan	261 (L: 75 – U: 298)	42,546 (L: 21,493 – U: 75,042)	11.1 (L: 1.6 – U: 22.3)	21.8 (L: 2.6 – U: 39.2)	30.0 (L: 8.2 – U: 56.2)	59.8 (L: 16.4 – U: 112.0)
Spain	5,121 (L: 3,275 – U: 5,298)	137,007 (L: 74,228 – U: 242,738)	701.6 (L: 243.1 – U: 1,286.1)	1,731.9 (L: 744.9 – U: 3,063.8)	1,425.0 (L: 530.3 – U: 2,029.9)	3,548.3 (L: 1,320.6 – U: 5,054.7)
Sri Lanka	1,025 (L: 638 – U: 2,118)	45,787 (L: 18,378 – U: 97,138)	46.9 (L: 11.7 – U: 205.7)	96.2 (L: 18.9 – U: 330.8)	182.1 (L: 62.8 – U: 305.2)	380.1 (L: 131.0 – U: 637.0)
Sudan	440 (L: 309 – U: 616)	100,038 (L: 39,346 – U: 238,615)	44.0 (L: 12.1 – U: 147.0)	89.8 (L: 21.2 – U: 216.1)	207.1 (L: 71.5 – U: 335.1)	432.5 (L: 149.3 – U: 699.9)
Suriname	1,276 (L: 1,041 – U: 4,575)	1,673 (L: 789 – U: 3,128)	2.1 (L: 0.8 – U: 14.3)	4.4 (L: 1.6 – U: 19.2)	15.9 (L: 5.6 – U: 24.8)	33.6 (L: 11.9 – U: 52.3)
Sweden	7,269 (L: 2,321 – U: 7,301)	23,753 (L: 12,976 – U: 39,535)	172.7 (L: 30.1 – U: 288.6)	352.3 (L: 102.5 – U: 580.2)	253.6 (L: 91.8 – U: 358.9)	520.3 (L: 188.4 – U: 736.5)
Switzerland	8,725 (L: 3,900 – U: 8,920)	16,280 (L: 8,082 – U: 29,214)	142.0 (L: 31.5 – U: 260.6)	289.1 (L: 64.9 – U: 514.8)	281.6 (L: 98.8 – U: 399.7)	574.4 (L: 201.6 – U: 815.4)
Syrian Arab Republic	312 (L: 251 – U: 1,238)	33,430 (L: 13,425 – U: 72,107)	10.4 (L: 3.4 – U: 89.3)	21.5 (L: 6.5 – U: 109.0)	207.5 (L: 59.9 – U: 597.5)	439.8 (L: 127.0 – U: 1,266.3)
Taiwan (Province of China)	5,522 (L: 2,981 – U: 10,041)	103,221 (L: 49,768 – U: 183,746)	570.0 (L: 148.3 – U: 1,845.0)	1,182.8 (L: 426.2 – U: 3,665.0)	981.7 (L: 334.0 – U: 1,495.7)	2,048.5 (L: 696.9 – U: 3,121.0)
Tajikistan	671 (L: 448 – U: 2,487)	23,480 (L: 10,620 – U: 50,215)	15.8 (L: 4.8 – U: 124.9)	27.3 (L: 7.4 – U: 165.6)	42.6 (L: 15.6 – U: 65.5)	75.0 (L: 27.4 – U: 115.4)
Thailand	1,567 (L: 1,398 – U: 1,669)	149,517 (L: 67,631 – U: 316,956)	234.3 (L: 94.6 – U: 529.0)	370.7 (L: 142.7 – U: 844.8)	803.4 (L: 279.9 – U: 1,363.2)	1,293.2 (L: 450.6 – U: 2,194.4)

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Timor-Leste	774 (L: 605 – U: 1,064)	3,069 (L: 1,338 – U: 8,599)	2.4 (L: 0.8 – U: 9.2)	4.7 (L: 1.5 – U: 14.7)	3.7 (L: 1.3 – U: 5.5)	7.5 (L: 2.7 – U: 11.1)
Togo	258 (L: 194 – U: 290)	24,679 (L: 12,110 – U: 44,078)	6.4 (L: 2.3 – U: 12.8)	12.6 (L: 3.5 – U: 22.6)	20.4 (L: 7.2 – U: 32.4)	41.0 (L: 14.6 – U: 65.0)
Tokelau	1,076 (L: 905 – U: 2,718)	4 (L: 2 – U: 8)	0.0 (L: 0.0 – U: 0.0)	0.0 (L: 0.0 – U: 0.0)	0.0 (L: 0.0 – U: 0.0)	0.0 (L: 0.0 – U: 0.0)
Tonga	1,075 (L: 811 – U: 2,709)	316 (L: 145 – U: 618)	0.3 (L: 0.1 – U: 1.7)	0.7 (L: 0.2 – U: 2.3)	0.4 (L: 0.1 – U: 0.6)	0.8 (L: 0.3 – U: 1.1)
Trinidad and Tobago	3,000 (L: 2,918 – U: 4,241)	4,083 (L: 1,749 – U: 8,331)	12.2 (L: 5.1 – U: 35.3)	25.2 (L: 10.1 – U: 59.0)	22.4 (L: 8.0 – U: 34.3)	46.6 (L: 16.6 – U: 71.3)
Tunisia	1,388 (L: 1,388 – U: 3,325)	20,807 (L: 7,536 – U: 48,912)	28.9 (L: 10.6 – U: 162.6)	59.1 (L: 18.6 – U: 282.9)	87.4 (L: 30.6 – U: 137.3)	181.5 (L: 63.7 – U: 285.3)
Turkey	3,649 (L: 3,617 – U: 6,903)	159,440 (L: 66,503 – U: 339,162)	581.8 (L: 240.5 – U: 2,341.3)	848.0 (L: 350.1 – U: 3,149.5)	1,867.5 (L: 723.3 – U: 2,694.4)	2,774.9 (L: 1,074.6 – U: 4,003.4)
Turkmenistan	1,837 (L: 1,234 – U: 11,745)	13,449 (L: 6,507 – U: 26,455)	24.7 (L: 8.0 – U: 310.7)	44.9 (L: 13.8 – U: 366.5)	15.6 (L: 5.4 – U: 25.2)	27.1 (L: 9.4 – U: 43.9)
Tuvalu	1,324 (L: 1,077 – U: 3,439)	35 (L: 15 – U: 72)	0.0 (L: 0.0 – U: 0.2)	0.1 (L: 0.0 – U: 0.4)	0.1 (L: 0.0 – U: 0.1)	0.1 (L: 0.0 – U: 0.1)
Uganda	263 (L: 209 – U: 322)	120,731 (L: 58,361 – U: 228,404)	31.8 (L: 12.2 – U: 73.7)	60.2 (L: 19.5 – U: 115.1)	84.5 (L: 29.2 – U: 132.5)	162.4 (L: 56.1 – U: 254.7)
Ukraine	1,828 (L: 1,580 – U: 2,103)	155,381 (L: 71,932 – U: 285,181)	284.0 (L: 113.7 – U: 599.8)	477.9 (L: 172.9 – U: 1,261.8)	590.5 (L: 194.8 – U: 1,018.3)	1,009.6 (L: 333.0 – U: 1,741.0)
United Arab Emirates	4,684 (L: 3,766 – U: 6,191)	9,404 (L: 3,430 – U: 24,249)	44.0 (L: 12.9 – U: 150.1)	89.6 (L: 26.4 – U: 241.4)	432.9 (L: 153.3 – U: 663.5)	876.5 (L: 310.3 – U: 1,343.3)
United Kingdom	4,031 (L: 1,581 – U: 4,031)	228,705 (L: 135,322 – U: 361,149)	921.9 (L: 213.9 – U: 1,440.0)	2,319.3 (L: 891.7 – U: 3,632.5)	1,500.5 (L: 568.0 – U: 2,101.0)	3,806.6 (L: 1,441.1 – U: 5,330.1)
United Republic of Tanzania	268 (L: 198 – U: 421)	211,603 (L: 106,242 – U: 378,055)	56.7 (L: 21.0 – U: 159.2)	105.3 (L: 33.4 – U: 190.1)	170.7 (L: 61.8 – U: 258.1)	323.0 (L: 116.9 – U: 488.4)
United States Virgin Islands	4,736 (L: 3,038 – U: 5,974)	397 (L: 193 – U: 707)	1.9 (L: 0.6 – U: 4.2)	3.9 (L: 1.0 – U: 7.5)	2.5 (L: 1.0 – U: 3.7)	5.1 (L: 1.9 – U: 7.6)

(Continued)

GBD Country	Excess Cost Per Admission US$ (2022)	Admissions with AMR (2022)	Excess Expenditure US$ Millions (2022)	Total Expenditure US$ Millions (2022)	Excess Expenditure US$ Millions (2050)	Total Expenditure US$ Millions (2050)
United States of America	14,054 (L: 13,233 - U: 15,397)	1,100,753 (L: 575,566 - U: 1,833,859)	15,470.3 (L: 7,616.4 - U: 28,236.3)	64,660.7 (L: 31,757.5 - U: 109,113.6)	25,709.5 (L: 9,786.0 - U: 34,801.3)	107,949.8 (L: 41,089.6 - U: 146,124.8)
Uruguay	3,458 (L: 1,770 - U: 4,727)	13,958 (L: 7,655 - U: 23,472)	48.3 (L: 13.6 - U: 110.9)	78.5 (L: 24.8 - U: 155.6)	83.2 (L: 32.3 - U: 117.0)	137.1 (L: 53.2 - U: 192.8)
Uzbekistan	1,161 (L: 720 - U: 3,780)	114,682 (L: 57,438 - U: 200,656)	133.2 (L: 41.3 - U: 758.4)	206.2 (L: 61.1 - U: 925.6)	411.5 (L: 131.4 - U: 723.1)	650.0 (L: 207.5 - U: 1,142.2)
Vanuatu	639 (L: 286 - U: 645)	718 (L: 322 - U: 1,592)	0.5 (L: 0.1 - U: 1.0)	0.9 (L: 0.1 - U: 2.1)	0.8 (L: 0.3 - U: 1.2)	1.7 (L: 0.7 - U: 2.5)
Venezuela (Bolivarian Republic of)	2,141 (L: 2,118 - U: 4,300)	60,412 (L: 24,164 - U: 133,408)	129.4 (L: 51.2 - U: 573.7)	262.9 (L: 104.2 - U: 922.9)	306.5 (L: 109.3 - U: 477.0)	628.0 (L: 223.9 - U: 977.4)
Viet Nam	1,303 (L: 606 - U: 1,454)	276,698 (L: 117,571 - U: 562,070)	360.4 (L: 71.2 - U: 817.0)	650.8 (L: 106.0 - U: 1,497.4)	1,607.8 (L: 612.9 - U: 2,292.4)	2,953.9 (L: 1,126.1 - U: 4,211.9)
Yemen	321 (L: 222 - U: 450)	83,311 (L: 32,210 - U: 205,551)	26.8 (L: 7.1 - U: 92.4)	54.7 (L: 12.9 - U: 137.2)	242.3 (L: 55.3 - U: 821.6)	506.6 (L: 115.6 - U: 1,717.9)
Zambia	359 (L: 242 - U: 591)	60,284 (L: 29,248 - U: 107,616)	21.6 (L: 7.1 - U: 63.6)	41.4 (L: 11.3 - U: 78.4)	69.4 (L: 23.9 - U: 107.3)	134.8 (L: 46.5 - U: 208.4)
Zimbabwe	331 (L: 163 - U: 451)	50,853 (L: 28,752 - U: 86,411)	16.8 (L: 4.7 - U: 39.0)	30.7 (L: 7.2 - U: 53.1)	20.4 (L: 7.3 - U: 32.3)	37.4 (L: 13.4 - U: 59.2)

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