CENTER FOR GLOBAL DEVELOPMENT

Modelling the Global Economic Impact of Antimicrobial Resistance in Humans

Amanda M. Countryman and Anthony McDonnell

Abstract

Antimicrobial resistance (AMR) is a complex global challenge that negatively affects human health and has widespread economic consequences. This research investigates the economy-wide effects of AMR in humans by considering five AMR-scenarios to understand the potential global and country-level impacts of resistance. This work simulates the combined impacts of AMR-induced changes in population, healthcare costs, labour, hospitality, and tourism in a computable general equilibrium modeling framework. Findings show absolute changes in global GDP in 2050 ranging from $269 billion with better treatment of bacterial infections, to nearly $990 billion when a combined, four-part intervention approach is employed. Alternatively, results show that global GDP may decline by $1.67 trillion by 2050 with accelerated resistance. There are relatively larger potential gains for lower income countries if combined intervention strategies are pursued, which is driven by positive effects on labour, followed by tourism and hospitality. Conversely, upper-middle- and high-income countries stand to lose relatively more in terms of GDP and welfare if resistance accelerates over time as demand for hospitality and tourism declines in tandem with negative effects on labour. AMR imposes tremendous societal burdens across countries and this work highlights the potential gains that may be achieved if intervention strategies are pursued contrasted with the negative impacts that could occur with a rise in resistance.

WORKING PAPER 713 • JANUARY 2025

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We would like to thank World Bank peer reviewers for their thorough and considered review. The work was improved by incorporating their valuable feedback. We would like to thank CGD and other colleagues who have supported this publication: the CGD communications team for their great work editing and producing this paper, particularly Emily Schabacker and Sara Viglione; Asti Shafira for her support throughout this project; and Charles Kenny and Tim Laurence for their advice and support; the Institute for Health Metrics and Evaluation for sharing their data and working collaboratively with us throughout this project. Finally, this project could not have happened without the support of Professor Dame Sally Davies and the World Organisation for Animal Health. This work was undertaken as part of the EcoAMR series (Health and Economic Impacts of AMR in Humans and Food-Producing Animals), which was funded by the UK Department of Health and Social Care's Fleming Fund using UK aid. The views expressed in this publication are those of the authors and not necessarily those of the UK Department of Health and Social Care.

Amanda M. Countryman and Anthony McDonnell. 2025. "Modelling the Global Economic Impact of Antimicrobial Resistance in Humans." CGD Working Paper 713. Washington, DC: Center for Global Development. https://www.cgdev.org/publication/modelling-global-economic-impact-antimicrobial-resistance-humans

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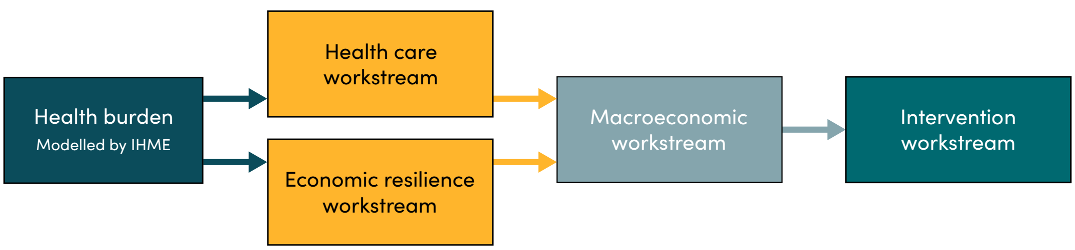
Introduction

Antimicrobial resistance (AMR) leads to 1.14 million deaths annually with an additional 4.71 million lives lost associated with bacterial AMR (GBD, 2024). The combined human health and economic effects of AMR are complex, leading to both direct and indirect effects throughout the global economy with disproportionate impacts for low- and middle-income countries. This research details one component of a multipart study that comprehensively investigates the global economic effects of AMR (McDonnell et al., 2024). The workstream for the broader study is illustrated in Figure 1. Results for the health burden of AMR from the Institute for Health Metrics and Evaluation (IHME) go into two workstreams, one that estimates changes in AMR-related healthcare costs and a second that estimates economic resilience (changes in population, labour, hospitality, and tourism), which are then simulated in an economy-wide model to understand the global macroeconomic impacts of AMR. Each project component is based on projections from five scenarios for the human health burden of AMR modeled by the IHME. Estimates for the costs associated with achieving the AMR scenarios for the intervention workstream are then compared to the economic benefits (or losses) associated with each scenario. The final piece of the full project includes a web-based interactive data dashboard that provides detailed country-level results, summarizes results for World Bank income groups, and allows users to vary assumptions related to AMR to investigate alternative scenarios beyond the analysis.

FIGURE 1. Workstreams used to estimate the health burden of AMR



This report focuses on the macroeconomic modelling workstream of the study and provides a detailed description of the methodology, scenario design, and key results from this work. We employ a computable general equilibrium (CGE) modelling framework to simulate the potential global economic effects of projected changes in AMR in humans. Specifically, we employ the Global Trade Analysis Project (GTAP) version 7 model (Hertel, 1997; Corong et al., 2017) and version 11 database (Aguiar et al., 2023) to simulate the economy-wide effects of AMR including country-specific changes in population, labour, healthcare costs, domestic demand for hospitality and leisure, and tourism.

CGE models are used to analyze economic impacts by simulating interactions between economic agents including regional households, producers, and governments in factor and intermediate markets as well as markets for final goods and services. The GTAP model has been widely used in academia, government, and industry to investigate the economy-wide effects of exogenous shocks in the global economy, including AMR, and other human health events (World Bank, 2017;

Park et al., 2020; Beckman and Countryman, 2021; Beckman et al., 2021). The GTAP data and similarly structured model served as the basis for the World Bank's previous economic estimates of AMR. However, this study considers a more comprehensive set of AMR-related factors to provide further insights into the potential impacts of AMR on the global economy (World Bank, 2017).

AMR-related studies

There is a growing body of work to investigate the epidemiology and global health burden of AMR (Antimicrobial Resistance Collaborators, 2022; Allel et al., 2023a; Collignon et al., 2018; Malik and Bhattacharyya, 2019; Morel et al., 2020; Pulingam et al., 2022) as well as country and regional case studies of AMR burden (Allel et al., 2023b; Antimicrobial Resistance Collaborators, 2023; Collignon et al., 2015; Maugeri et al., 2023; Watkins and Bonomo, 2020; Wozniak et al., 2022; Zhen et al., 2021). While there is an abundance of studies that provide overviews of the threat of AMR, describe knowledge gaps, and pathways to investigate the effects of AMR, there are relatively few studies that explicitly quantify the economy-wide effects of AMR despite the severity of the issue (Ahmad and Khan, 2019; Alividza et al., 2018; Bonelli et al., 2014; Charani et al., 2021; Chokshi 2019; Collignon and Beggs 2019; Coque et al., 2023; de Kraker et al., 2022; Hall et al., 2018; Irfan et al., 2022; Knight et al., 2018; Majumder et al., 2020; Pulingam et al., 2023; Salam et al., 2023; Tang et al., 2023; Vikesland et al., 2019; Watkins and Bonomo, 2020). Roope et al. (2019) and Hillock et al. (2022) detail the need for economic modeling to address the challenges of AMR and inform decision-making for intervention strategies, which is consistent with the theme among AMR-related research studies indicating more research on this human health threat is necessary. There are three primary studies on the global economic impact of AMR including two studies, by KPMG (2014) and RAND (2014), commissioned by the O'Neil Review (2014) and a study by the World Bank (2017). These studies focus on the labour market disruptions from AMR and the costs associated with resistance rather than exploring AMR-induced economic effects associated with intervention strategies. Importantly, both the O'Neill Review and World Bank note substantial AMR-related data limitations and were completed prior to the pivotal GRAM study, the first comprehensive analysis of the disease burden of AMR (Murray et al., 2022). Prior to the GRAM study, there were no global estimates of the health burden caused by resistance, making it very difficult to project future burden, or understand the economic costs. While our work still suffers from uncertainty regarding what the future may hold for AMR, we benefit from substantial advancements in the scientific literature regarding the human health burdens of AMR and potential intervention strategies to combat resistance across countries. Furthermore, our work is the most comprehensive to date, considering not only the *direct* human health effects on population, health care costs, and labour disruptions, but also *indirect* impacts on tourism and demand for hospitality. This framework allows for the simulation of the complex mechanisms by which AMR impacts people and sectors in the economy.

GTAP model structure

The GTAP model is a multi-region, computable general equilibrium model that has been widely used for economic and policy analyses that are economy-wide in nature. The model contains numerous variables related to economic indicators, coefficients, and fixed parameters (including a suite of elasticities). The variables, coefficients, and parameters are incorporated in appropriate model equations according to economic theory to describe the comprehensive interactions between all sectors and agents in the global economy. The theoretical framework of GTAP models the optimizing behavior of agents including firms, households, and government. Households maximize utility given budget constraints, firms minimize costs subject to technology and resource constraints, and the standard model assumes perfect competition where all agents are price takers. The model adopts a representative household in each region and each industry has a representative firm in each region for each sector of the economy. Consumers and producers also pay taxes, and the difference between income and spending is savings (Corong et al., 2017).

The GTAP database has an input-output structure that identifies the supply and use of economic goods, accounting for tradable goods and services that are distinguished by region of origin, and primary factor endowment commodities. Sources of supply are both imported and produced domestically for use by firms for production activities and for final demand, which includes private household and government consumption, investment, and exports. The regional household allocates regional income between private consumption, government consumption and savings to maximize regional utility. Private demand is modeled by the non-homothetic constant difference of elasticities (CDE) functional form, while government demand is modeled by a constant elasticity of substitution (CES) specification (Corong et al., 2017).

The model also accounts for changes in welfare, measured by equivalent variation (EV). EV provides a monetary equivalent equal to the difference between the expenditure required to obtain a new level of utility at initial prices and the level of utility initially available. The unitary regional utility function and optimizing behavior allows for welfare decomposition. Changes in welfare can be decomposed into contributions from terms of trade effects, impacts of induced technological change, allocative efficiency effects, and the contribution of changes in savings and investments. Allocative efficiency includes both the direct effects of the change in efficiency related to production and the indirect changes resulting from the reallocation of factors to sectors with a product of relatively higher marginal social value (Corong et al., 2017; Huff and Hertel, 2001).

For production, each activity combines factors and intermediate (value added) goods to produce output. The production structure includes a sequence of nested constant elasticity of substitution (CES) functions that represent all substitution possibilities across the full set of inputs (Corong et al., 2017). The model also explicitly accounts for bilateral trade given the Armington specification that allows for substitution between domestic and imported goods and product differentiation by import source (Armington, 1969). Accordingly, the domestic price, and composite import price, which is determined by source-specific pricing and import demand elasticities, determine the optimal mix of imported and domestic goods.

Production generates income accumulated by factors that accrues to the regional household and is spent on three sources of final demand: private expenditures, government spending, and savings, which is translated into investment spending. Each source of spending comprises both domestic and import purchases, thereby generating both domestic and export sales by firms. This structure highlights the linkages between all sectors of the economy, across all countries and regions in the world.

The economic analysis for this research benefits from an economy-wide model to understand the impacts of AMR throughout the global supply chain when considering country-specific changes in population, labour, healthcare costs, domestic demand for hospitality and leisure, and tourism. This work employs the standard GTAP model closure which imposes equilibrium in all markets, firms earn zero-profits, the regional household is on its budget constraint, and global investment equals global savings. The global trade balance condition determines the equilibrium world price of a given commodity. For the analysis, we employ the default parameters for the GTAP database with one exception. We modify the region-specific elasticity of transformation (ETRAE) for labour and capital (which are originally -2) and adopt the default value for land (which is equal to -1). This specification limits factor mobility of labour and capital in the model, which constrains the potential for growth in sectors that do not have AMR-related shocks in our scenarios. This modification ensures that there is not abnormal growth in sectors of the economy that do not have explicitly modeled AMR-related shocks. Also, while version 7 of the GTAP model allows for a non-diagonal make matrix in production where each activity can produce more than one commodity, we assume a diagonal make matrix where each activity produces only one unique commodity such that activities equal commodities. We provide a detailed description of relevant market clearing conditions and price linkage equations in Appendix 1.

GTAP database

The GTAP database and model describes economic activity including production, consumption, and international trade for 141 countries, representing more than 96 percent of the world's population and 99 percent of global economic activity. The 52 countries for which national data are not available are included in one of 19 aggregate regions. The GTAP database categorizes the global economy into 65 sectors representing the broad groups of agriculture, manufacturing, and services. In this research, we model 126 regions comprising 122 countries representing 93.0 percent of global population and 98.5 percent of economic activity. We combine remaining countries into four aggregate regions due to data constraints (Table A2.1) and six sectors of economic activity including healthcare; hospitality and leisure; other services; livestock and animal products; other food and agriculture; and a combined grouping of mining, manufacturing, and utilities (Table A2.2).

The first step in our analysis is to generate one base case, business-as-usual scenario to update the GTAP database according to the Intergovernmental Panel on Climate Change (IPCC) sixth assessment report (IPCC-AR6) for three reference years: 2030, 2040, and 2050. We simulate changes in population, labour force participation, and GDP according to the Shared Socioeconomic Pathways (SSP) neutral baseline scenario (SSP2) for each reference year. SSP2 assumes a path forward down the "middle of the road" where economic growth is uneven and progress towards sustainable development is slow with continued societal and environmental challenges. The SSP proposed in this work is widely used in CGE modelling to project the global economy under potential socioeconomic conditions. We then explicitly model country-specific AMR shocks across sectors in the economy for each reference year given AMR shocks and scenarios described below.

AMR shocks

This study simulates the economic impact of country-specific AMR-related shocks[1] across sectors in the economy. We consider country-specific AMR-induced changes in population, healthcare costs, labour, demand for domestic hospitality and tourism as follows:

1. Population: changes in population because of AMR-attributable deaths (from McDonnell, Gulliver and Morton, forthcoming)
2. Healthcare costs: changes in healthcare costs because of AMR-related expenditures (from Laurence et al., 2025)
3. Labour endowment: changes in both direct labour where people leave the labour market because of the burden of resistance and indirect labour when people leave the labour market or change careers to avoid becoming sick from resistance (McDonnell, Gulliver and Morton, forthcoming)
4. Hospitality: AMR-induced changes in expenditures for activities in the high-contact recreational services sector (McDonnell, Gulliver and Morton, forthcoming)
5. Tourism: Changes in tourism with respect to the relative burden of AMR across countries (McDonnell, Gulliver and Morton, forthcoming)

Modelling population and labour

Population and labour endowments are exogenous in the model and can be directly shocked. Country-specific changes in population *pop(r)* for each scenario are simulated based on population projections from the IHME (Vollset et al., 2024). We specify percentage changes in labour endowments across countries *qe("Labour",r)* given output from the expert-elicitation-based Resilience Model (McDonnell, forthcoming) for each AMR scenario.

1 Shock values will be available on request.

Modelling healthcare costs

The healthcare sector is explicitly accounted for in the GTAP database and model and we simulate AMR-related changes given results from the Health Costs Model as changes in the domestic price of the healthcare sector *health*, in each region *r, pds("health",r)* in the model. Given that *pds* is endogenous in the model, we must swap this variable with an exogenous variable to target the specified domestic price for healthcare. Accordingly, we swap *pds("health",r)* with the sector and region-specific technological change variable *aoall("health",r)*. This specification allows technology to change endogenously given an exogenous change in domestic price as is a common approach for price targeting.

Modelling domestic demand for hospitality

We simulate AMR-induced changes in domestic demand for hospitality and leisure given results from the expert-elicitation-based Resilience Model. Hospitality and leisure are represented in the two GTAP sectors accommodation and food services, and recreation and other services. We combine the two sectors in the database for this analysis to account for hospitality and leisure (ie: "*hospitality*"). Domestic demand for hospitality and leisure *qds("hospitality",r)* is endogenous in the model, so we swap *qds("hospitality",r)* with exogenously specified sector and region-specific total factor productivity (TFP) *aoall("hospitality",r)* to directly simulate the AMR-related change in domestic demand. This specification allows technology to change endogenously given an exogenous change in demand as is a common approach for quantity targeting.

Modelling tourism

Tourism is not explicitly accounted for in the GTAP database and tourism expenditures are combined with other cross-border trade flows in goods and services. To account for AMR-related changes in tourism, we follow the approach of the 2020 Asian Development Bank study of COVID-19 impacts on the global economy (Park et al., 2020) and model changes in tourism as share-weighted changes in total output for each country according to the share of tourism in total output and expected AMR-related changes in tourism. We use data for country-specific shares of tourism in GDP from the United Nations Tourism Dashboard (United Nations, 2024) and the expected AMR-related country-specific changes in tourism from the expert elicitation-based Resilience Model to calculate share weighted changes in GDP for each country in the model that are associated with AMR. We introduce a variable in the GTAP model to account for total commodity supply for each region *qcreg(r)* as the weighted sum of commodity output *qc(c,r)* as follows:

$$qcreg(r) = sum\{c, VCBREGSHR(c,r) * qc(c,r)\}.$$

The variable *qcreg(r)* is endogenous given that *qc(c,r)* is endogenous. Accordingly, we swap *qcreg(r)* with region-specific changes in TFP *aoreg(r)* to target the AMR-related changes in tourism. This is a common approach to simulate quantity targeting. For our AMR scenarios, we first target the region-specific share-weighted changes in GDP attributable to changes in tourism from AMR. Then, the associated changes in region-specific TFP that correspond to the GDP targets become the shocks we employ for the AMR scenarios in the analysis. This allows us to specify region-specific changes in TFP that lead to the changes in GDP associated with AMR-induced changes in tourism.

AMR scenarios

We consider five scenarios for the human health burden of AMR from the IHME where all scenarios are compared to the base case in which AMR follows historical trends since 1990. AMR scenarios are as follows and are described fully by the IHME (Vollset et al., 2024) and McDonnell et al. (2024):

- Business-as-usual scenario: assumes that resistance follows historical trends (base case).
- Scenario 1: better treatment of bacterial infections is provided.
- Scenario 2: increased innovation and roll outs of gram-negative antibiotics.
- Scenario 3: better treatment and increased innovation is provided (combining scenarios 1 and 2).
- Scenario 4: improved access to treatments for bacterial infections; increased innovation for gram-negative bacteria; and improved access to vaccines, sanitation and clean water (optimistic scenario).
- Scenario 5 (accelerated rise in resistance scenario): assumes that resistance increases at the rate of increase of the bottom 15 percent of countries (pessimistic scenario).

Results

The main paper for the overall study includes a detailed description of results for each of the five scenarios for all components of the workstream, including macroeconomic effects for the world and by World Bank income group (McDonnell et al., 2024). Additional country-level results for each scenario and results by income group are available on the Center for Global Development virtual interface for the project. Accordingly, this report provides key results as follows. First, global estimates for changes in GDP and economic welfare across all scenarios in 2050 are described. Second, key global results in 2030, 2040, and 2050, in addition to effects across income groups in 2050 for scenario 4: combined interventions, and scenario 5: accelerated resistance through 2050. The contribution of each AMR-related shock to the total global GDP change for scenarios 4 and 5 are subsequently considered. Finally, results conclude with country-level mapping of changes in GDP and economic welfare for scenarios 4 and 5, the optimistic and pessimistic scenarios, respectively. This allows for the consideration of results across scenarios at the global level in 2050, followed by results across all years of analysis and by income groups for 2050 for optimistic and pessimistic scenarios, and concludes with country-level macroeconomic impacts in 2050 for optimistic and pessimistic assumptions regarding resistance. Extensive details regarding the methodology and results from each workstream component are described in Laurence et al. (2024), McDonnell et al. (2024, and Vollset et al. (2024. The main paper does not include the results for economic welfare presented here and in the virtual project interface. Full results for all workstream components by country, income group, and the world will be made publicly available on the CGD virtual interface for the project, and a table of country-level results for each scenario can be found in Appendix 3.

Table 1 provides key global results for all scenarios in the analysis. Columns two and three describe the deaths avoided and health cost reductions for intervention scenarios 1 through 4 and additional deaths and increased health costs for scenario 5 if resistance rises. Total world macroeconomic effects for absolute changes in GDP and economic welfare measured by equivalent variation are included in columns four and five. Considering mortality and health costs, more than 10 million to nearly 110 million deaths could be avoided in tandem with decreased health costs totaling from more than $19 billion to nearly $99 billion depending on the intervention strategy. Alternatively, if resistance rises, there could be nearly 7 million additional deaths and nearly $176 million in additional health costs if resistance rises as modeled for scenario 5. The corresponding positive global macroeconomic effects increase in magnitude from scenarios 1 through 4. The absolute changes in global GDP range from $269 billion for S1, better treatment of bacterial infections, to nearly $990 billion for the combined scenario S4. Conversely, simulation results show that world GDP may decline by $1.67 trillion if resistance rises as modeled for S5. The corresponding positive global welfare effects range from $76 billion in S1 to $250 billion in S4, while S5 leads to simulated welfare declines equal to $-522 billion worldwide.

TABLE 1. Deaths averted, health care cost savings, change in GDP, and economic welfare in 2050 under five AMR scenarios (in billion US$ at 2022 value, except where otherwise indicated.)

Intervention	Deaths Avoided (millions)	Reduction in Health Costs	Change in GDP	Economic Welfare (equivalent variation)
S1: Better treatment of bacterial infections	89.78	19.17	269.16	76.04
S2: Innovation and rollout of gram-negative antibiotics	10.22	83.28	742.85	188.36
S3: Better treatment and innovation	100.01	96.67	959.32	245.41
S4: Combined interventions	109.95	98.62	989.70	250.04
S5: Accelerated rise in resistance scenario	–6.69	–175.74	–1,671.16	–522.55

While it is important to consider the general, overall impacts across scenarios, Tables 2 and 3 allow for richer analysis of scenarios 4 and 5, the optimistic and pessimistic scenarios for potential intervention and resistance, respectively. Scenario 4 assumes the combination of four interventions that include better treatment of infections, increased innovation, improved access to vaccines, and improved access to sanitation and clean water (WASH). Scenario 5 assumes that resistance accelerates at the rate of increase of the bottom 15 percent of countries. Results from the health cost and economic resilience models include estimated changes in health costs, population, labour, tourism, and hospitality that serve as the simulated exogenous shocks (inputs) in the CGE model and are thoroughly discussed in Laurence et al. (2024) and McDonnell et. al. (2024). The optimistic scenario leads to increased global GDP by 0.286 percent ($386.2 billion, 0.467 percent ($784.8 billion, and 0.489 percent ($989.7 billion in 2030, 2040, and 2050, respectively. This corresponds to increased global economic welfare equal to $128.7 billion in 2030, $226.2 billion in 2040, and $250 billion in 2050. While the absolute changes in GDP and welfare are largest for upper-middle and high-income countries, the relative GDP and welfare effects are largest for low- and lower-middle-income countries that have estimated changes in GDP equal to 0.939 percent and 0.975 percent respectively. Results for the pessimistic scenario, S5, differ in that the relative GDP effects are largest for upper-middle-income countries (-1.261 percent decrease in GDPand high-income countries (–0.712 percent decrease in GDPand are much more severe than the relative negative GDP effects for low- and lower-middle-income countries that are less than -0.35 percent for both country groups. The magnitude of the welfare losses across upper-middle- and high-income countries is much larger than the welfare gains from the optimistic scenario, yet the opposite is true for low- and lower-middle-income countries. This illustrates that both lower income country groups are more positively affected by the benefits from the combined intervention scenario relative to the potential negative macroeconomic effects from increased resistance. Conversely, higher income countries have more to lose if resistance is not curtailed. Overall, the global welfare losses from the pessimistic, increased resistance scenario are more than double the welfare gains resulting from combined interventions. As Table A3.1 shows, the global results are not driven by any one country, in part because most of the world's largest economies are closer to the global median.

TABLE 2. Economic impacts in 2030, 2040 and 2050 of the combined scenario (S4)

Names	2030	2040	2050	LICs 2050	LMCs 2050	UMCs 2050	HICs 2050
Change in inpatient costs (USD million)	−34.3	−74.8	−98.6	−2.2	−30.5	−35.2	−30.7
Change in inpatient costs (% all health)	−0.32	−0.58	−0.64	−1.59	−2.31	−0.65	−0.36
Population							
Population change	0.168	0.494	0.765	1.245	1.024	0.475	0.108
Change in population (million)	14.2	44.7	72.0	16.4	40.7	13.5	1.4
Change in economic activity							
Change in total labour	0.23	0.39	0.43	1.01	0.83	0.43	0.29
Change in tourism	0.79	1.20	1.24	3.58	3.05	1.31	0.46
Change in hospitality	0.41	0.62	0.61	0.89	0.89	0.60	0.53
Economic impact							
Total GDP impact (%)	0.286	0.467	0.489	0.939	0.975	0.504	0.322
Total GDP impact (USD billion)	386.2	784.8	989.7	34.2	280.5	353.4	321.6
Welfare Effect (USD billion)	128.7	226.2	250.0	7.30	60.61	87.55	94.58

TABLE 3. Economic impacts in 2030, 2040 and 2050 of the pessimistic scenario (S5)

Names	2030	2040	2050	LICs 2050	LMCs 2050	UMCs 2050	HICs 2050
Change in inpatient costs (USD million)	24.3	78.5	175.7	1.6	10.9	93.6	69.7
Change in inpatient costs (% all health)	0.23	0.61	1.14	1.16	0.83	1.72	0.82
Population							
Population change	−0.004	−0.018	−0.043	−0.042	−0.032	−0.059	−0.040
Change in population (million)	−0.4	−1.7	−4.0	−0.5	−1.2	−1.7	−0.5
Change in economic activity							
Change in total labour	−0.13	−0.30	−0.51	−0.23	−0.16	−0.61	−0.55
Change in tourism	−0.47	−1.18	−2.13	−0.59	−0.17	−3.78	−1.26
Change in hospitality	−0.30	−0.71	−1.25	−0.64	−0.50	−1.48	−1.34
Economic impact							
Total GDP impact (%)	−0.194	−0.471	−0.825	−0.342	−0.221	−1.261	−0.712
Total GDP impact (USD billion)	−261.7	−790.3	−1,671.2	−12.4	−63.7	−883.8	−711.2
Welfare (USD billion)	−108.6	−282.5	−522.6	−2.47	−13.95	−277.92	−228.20

Further analysis with Table 4 reveals the relative importance of each of the five simulated AMR-related shocks for the GDP effects from Scenarios 4 and 5. For both the optimistic and pessimistic scenarios, the combined effects of labour, tourism, and hospitality contribute approximately 85 percent of the total GDP change. Population shocks are the most minor contributor to overall GDP changes, followed by changes in health costs for both scenarios. For scenario 4, labour is the most important driver of macroeconomic effects and contributes more than 35 percent of the overall change in GDP, followed by tourism (26 percent and hospitality (22 percent When considering scenario 5 when resistance rises, tourism is the largest driver of GDP effects and corresponds to 31 percent of the overall GDP change, followed by hospitality (27 percent and labour (25 percent This indicates that behavioral changes determined by the resilience model are most impactful on the economy in the case where resistance rises and people decrease demand for hospitality and tourism related activities. Alternatively, labour effects stand out as the pivotal driver for positive GDP effects when combined intervention strategies are pursued.

TABLE 4. Scenarios driving GDP changes: Scenarios 4 and 5 in 2050

Measure	S4: Total Impact	S4: Percentage of GDP Change	S5: Total Impact	S5: Percentage of GDP Change
GDP change	0.489	100.0	−0.825	100.0
Population	0.009	1.9	−0.001	0.1
Health	0.070	14.4	−0.130	15.7
Labour	0.173	35.3	−0.210	25.4
Tourism	0.128	26.3	−0.259	31.4
Hospitality	0.108	22.2	−0.227	27.4

Finally, country-level results for the optimistic and pessimistic scenarios are shown in Figures 2 and 3. The left-side maps show the percentage change in GDP for each scenario, while the right-hand maps show welfare as a share of GDP to describe the relative GDP and welfare impacts across countries. The country-level results for the combined scenario illustrate how the positive effects from combined interventions have GDP and welfare effects that are relatively larger across low- and lower-middle-income countries in Africa, Asia, and South America with more modest relative effects on higher income countries in North America and Europe. On the other hand, increased resistance in scenario 5 corresponds to higher income countries in North America and Europe being relatively more negatively affected in terms of GDP and welfare changes if resistance is not curtailed. Detailed country-level results across scenarios and years can be further explored on the virtual platform as previously described. Furthermore, McDonnell et al. (2024) provides a detailed comparison of results from this work to existing studies.

FIGURE 2. Country-level economic impacts in 2050 for the combined scenario (S4)

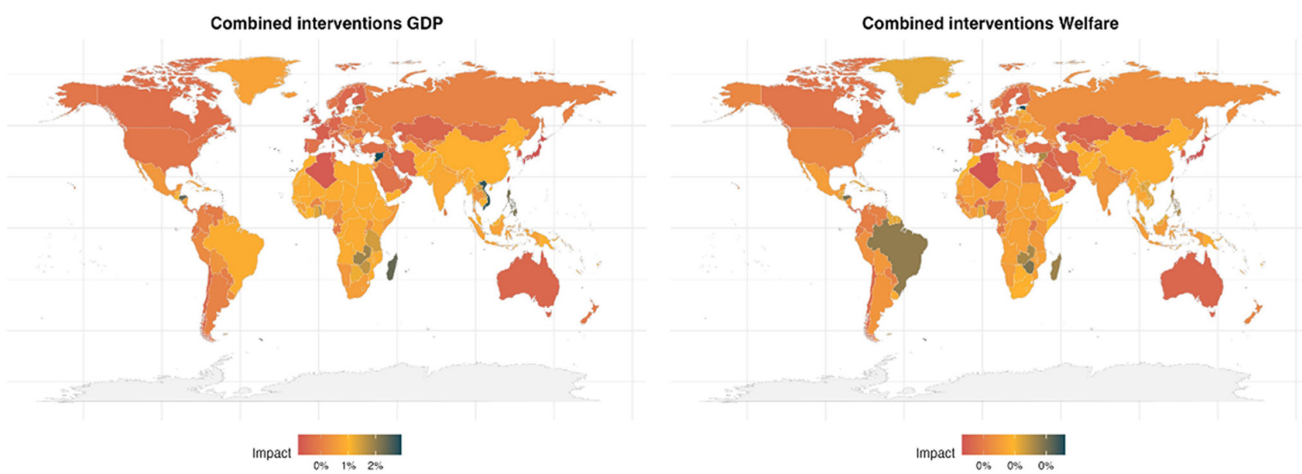
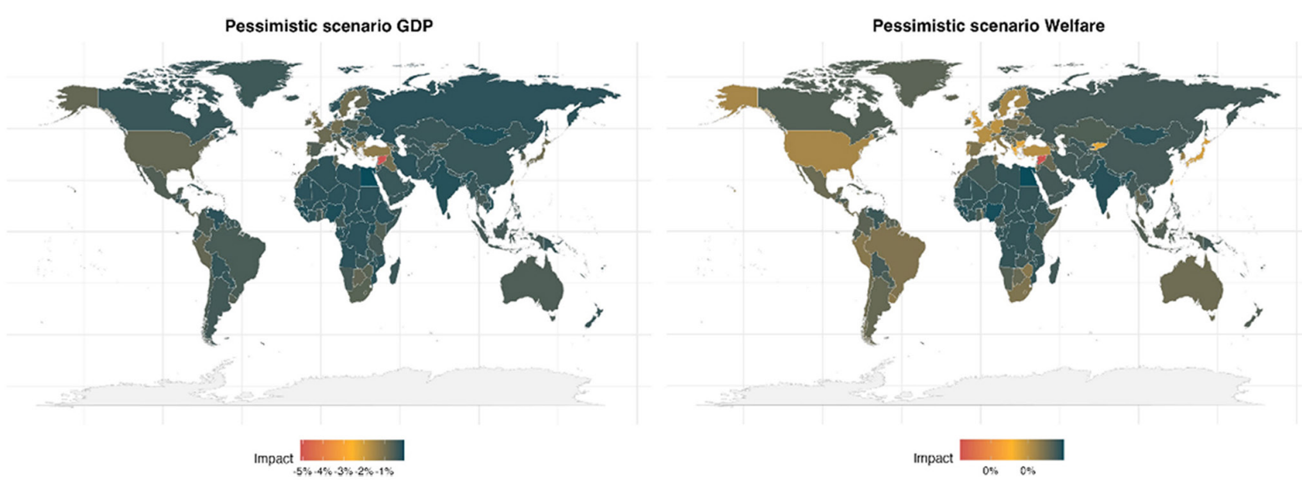


FIGURE 3. Country-level economic impacts in 2050 for the pessimistic scenario (S5)



Modelling limitations

The GTAP model is extensively employed for economy-wide analyses; yet the methodology has limitations that are common to many CGE models. The model employed for this analysis is static in nature and does not capture dynamic effects over time; perfect competition is assumed for all markets, which does not necessarily reflect the features of markets that are imperfectly competitive; and full employment assumptions do not permit potential unemployment effects in labour markets across countries. Also, the aggregation of sectors, regions, and factors of production for this research can mask potential heterogeneity within aggregated groups. Economy-wide results are also sensitive to the assumed parameter values. The limitations of the GTAP model are described by Bekkers et al. (2018), Burfisher (2021), Hertel (1997), Dixon and Jorgenson (2013), and Valenzuela et al. (2008), which provide critical insights into the challenges of CGE modelling and the specific constraints of the GTAP framework. Despite limitations, the methodology and modelling assumptions are widely accepted and employed for economy-wide analysis. Furthermore, there are limitations to this research beyond the CGE modelling structure and assumptions that relate to the highly uncertain future effects of AMR on the economy. While this research is the most comprehensive analysis of global economy-wide effects of AMR and investigates five possible scenarios relative to a business-as-usual world where AMR follows historical trends, the future of AMR-related impacts on population, health care, labour, and activities related to hospitality and tourism are unknown. This highlights the need for continued research on the economic impacts of AMR to continually inform decision-making for this immense human health threat.

Conclusion

This report details the methodological approach to understand the potential macroeconomic effects of AMR-induced changes in the economy by 2050 as part of a larger study to investigate the complex economic changes that may arise in a future world that pursues various AMR intervention strategies or permits resistance rates to accelerate over time. This research simulates five AMR-scenarios in a CGE modeling framework to understand the potential global and country-level impacts of AMR and explores key results for global changes across scenarios in 2030, 2040, and 2050, and provides results by income group in 2050 for the optimistic, combined intervention scenario and the pessimistic scenario that assumes accelerated resistance through 2050. The absolute changes in global GDP range from $269 billion with better treatment of bacterial infections, to nearly $990 billion when a combined, four-part intervention approach is employed. Simulation results also show that global GDP may decline by $1.67 trillion by 2050 with accelerated resistance. Overall, results highlight the relatively larger potential gains for lower income countries if combined intervention strategies are pursued, which is driven by positive changes in labour, followed by tourism and hospitality effects. Conversely, upper-middle- and high-income countries stand to lose relatively more in terms of GDP and welfare if resistance accelerates over time as people demand fewer hospitality and tourism services in tandem with negative labour effects because of AMR.

The negative effects of AMR impose tremendous societal burdens across countries and this work highlights the potential gains that may be achieved if intervention strategies are pursued, contrasted with the negative impacts that may result from a future with a rise in resistance. Additional work in the full study explores the costs to achieve the gains inherent in each intervention scenario and finds overwhelming benefits that are 28 times higher than expected implementation costs for increased innovation and roll outs of gram-negative antibiotics. Importantly, there are both disproportionate positive effects of interventions and costs required to achieve intervention strategies that affect lower- and lower-middle-income countries by relatively larger magnitudes than higher income countries. Substantial gains are possible with global coordination, yet there is potential for tremendous global losses if resistance is not curtailed. This highlights the need for careful consideration of various intervention strategies and how higher income countries can support efforts to tackle the global threat of AMR.

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Appendix 1. GTAP modelling specifications

Market clearing conditions and price linkage equations in the GTAP model

First, we describe market clearing and key price linkage equations to show the relationship between output, demand, prices, and total factor productivity that are relevant for our scenario design. While version 7 of the GTAP model allows for a non-diagonal make matrix in production where each activity can produce more than one commodity, we assume a diagonal make matrix where each activity produces only one unique commodity such that activities equal commodities. This causes activity-related prices to be equal to the respective commodity-related prices, and commodity-related output to equal associated activity-related output as described where relevant.

We begin with the equilibrium condition in the market for goods that requires market supply of good c, *qc(c,r)*, to be equal to domestic demand by all agents *qds(c,r)* plus total exports *qxs(c,r,d)* and margin services *qst(c,r)*:

*qc(c,r) = DSSHR(c,r) * qds(c,r) + sum{d,REG,XSSHR(c,r,d) * qxs(c,r,d)} + IF[c in MARG, STSHR(c,r) * qst(c,r)] + tradslack(c,r).*

Domestic demand by all agents is the sum of firm demand *qfd(c,a,r)*, private household demand *qpd(c,r)*, government demand *qgd(c,r)*, and investment demand *qid(c,r)*:

*qds(c,r) = sum{a,ACTS, FDCSHR(c,a,r) * qfd(c,a,r)} + PDCSHR(c,r) * qpd(c,r) + GDCSHR(c,r) * qgd(c,r) + IDCSHR(c,r) * qid(c,r).*

Demand by each agent (firms, private households, government, investment) is determined by a Constant Elasticity of Substitution specification with an Armington structure to determine demand for domestically produced goods and imports that specifies corresponding prices for domestic goods and aggregate prices. Domestic demand by each agent is a function of total demand by each agent and agent-specific prices. For example, private household domestic demand *qpd(c,r)* is a function of total private household demand *qpa(c,r)*, the domestic price of private household consumption *ppd(c,r)*, and the aggregate price of private household consumption *ppa(c,r)*:

*qpd(c,r) = qpa(c,r) – ESUBD(c,r) * (ppd(c,r) – ppa(c,r)).*

All agent prices are linked to the price of domestically supplied commodities *pds(c,r)* and agent-specific taxes on domestically produced goods. For example, the domestic price of private household consumption *ppd(c,r)*, is a function of the price of domestically supplied commodities *pds(c,r)* and exogenously determined taxes on private household purchases of domestically supplied commodities *tpd(c,r)*:

ppd(c,r) = pds(c,r) + tpd(c,r).

The diagonal make matrix in production leads to the price of domestically supplied commodities *pds(c,r)* being equal to the output price of activities *pb(a,r)* such that *pds(c,r) = pb(a,r)*.

The following equation shows the basic (tax-inclusiveprice of output for each activity *pb(a,r)* as a function of the basic price of each commodity produced by each activity *pca(c,a,r)*:

$$pb(a,r) = sum\{c, MAKEBACTSHR(c,a,r) * pca(c,a,r)\}.$$

Accordingly, the following equation links the domestic market price *pds(c,r)* to the basic price of each commodity *pca(c,a,r)*

$$pds(c,r) = sum\{c, MAKEBACTSHR(c,a,r) * pca(c,a,r)\}$$

The following equation links the basic price *pca(c,a,r)* and supply price *ps(c,a,r)* of each commodity given exogenous output taxes *to(c,a,r)*:

$$pca(c,a,r) = ps(c,a,r) + to(c,a,r)$$

Again, the diagonal make matrix leads to the supply price of each commodity *ps(c,a,r)* being equal to the price of each activity *po(a,r)* so that *ps(c,a,r) = po(a,r)*.

The industry zero profit equation shows the relationship between output price *po(a,r)* and total factor productivity (TFP*ao(a,r)*, the price of factors *pfe(e,a,r)* and their respective productivity changes *afe(e,a,r)* and *ava(e,a,r)*, the intermediate input prices *pfa(c,a,r)* and associated productivity changes *afa(c,a,r) – aint(a,r)*:

$$po(a,r) + ao(a,r) = sum\{e,ENDW, STC(e,a,r) * [pfe(e,a,r) - afe(e,a,r) - ava(a,r)]\} + sum\{c,COMM, STC(c,a,r) * [pfa(c,a,r) - afa(c,a,r) - aint(a,r)]\} + profitslack(a,r).$$

Finally, the total change in TFP is a function of sector-specific changes in technology *aosec(a)*, region-specific changes in technology *aoreg(r)* and/or sector and region-specific changes in technology *aoall(a,r)* that all allow for a Hicks-neutral change in output of activities which are equal to corresponding changes in output of commodities given the diagonal make matrix of production.

$$ao(a,r) = aosec(a) + aoreg(r) + aoall(a,r).$$

The technological change variables are all exogenous in the GTAP model and are the variables that we swap with relevant endogenous variables for our AMR-scenarios.

Appendix 2. Tables

TABLE A2.1. Regional aggregation

Region	Description	Region	Description	Region	Description
aus	Australia	hti	Haiti	arm	Armenia
nzl	New Zealand	jam	Jamaica	aze	Azerbaijan
chk	China and Hong Kong	tto	Trinidad and Tobago	geo	Georgia
jpn	Japan	aut	Austria	bhr	Bahrain
kor	South Korea	bel	Belgium	irn	Iran
mng	Mongolia	bgr	Bulgaria	irq	Iraq
twn	Taiwan	hrv	Croatia	isr	Israel
brn	Brunei Darussalam	cyp	Cyprus	jor	Jordan
idn	Indonesia	cze	Czechia	kwt	Kuwait
lao	Laos	dnk	Denmark	omn	Oman
mys	Malaysia	est	Estonia	qat	Qatar
phl	Philippines	fin	Finland	sau	Saudi Arabia
sgp	Singapore	fra	France	syr	Syria
tha	Thailand	deu	Germany	tur	Turkiye
vnm	Viet Nam	grc	Greece	are	United Arab Emirates
bgd	Bangladesh	hun	Hungary	dza	Algeria
ind	India	irl	Ireland	egy	Egypt
npl	Nepal	ita	Italy	mar	Morocco
pak	Pakistan	lva	Latvia	tun	Tunisia
lka	Sri Lanka	ltu	Lithuania	bfa	Burkina Faso
can	Canada	lux	Luxembourg	cmr	Cameroon
usa	United States of America	mlt	Malta	civ	Cote d'Ivoire
mex	Mexico	nld	Netherlands	gha	Ghana
arg	Argentina	pol	Poland	gin	Guinea
bol	Bolivia	prt	Portugal	nga	Nigeria
bra	Brazil	rou	Romania	sen	Senegal
chl	Chile	svk	Slovakia	tgo	Togo
col	Colombia	svn	Slovenia	gab	Gabon
ecu	Ecuador	esp	Spain	ken	Kenya
pry	Paraguay	swe	Sweden	mdg	Madagascar
per	Peru	gbr	United Kingdom	mus	Mauritius
ury	Uruguay	che	Switzerland	rwa	Rwanda
ven	Venezuela	nor	Norway	tza	Tanzania
cri	Costa Rica	alb	Albania	uga	Uganda
gtm	Guatemala	srb	Serbia	zmb	Zambia
hnd	Honduras	blr	Belarus	zwe	Zimbabwe
nic	Nicaragua	rus	Russia	bwa	Botswana
pan	Panama	ukr	Ukraine	swz	Eswatini
slv	El Salvador	kaz	Kazakhstan	nam	Namibia
dom	Dominican Republic	kgz	Kyrgyzstan	zaf	South Africa

TABLE A2.1. (Continued)

Region	Description	Region	Description	Region	Description
roo	Rest of Asia and Oceania: Rest of Oceania; Rest of East Asia; Cambodia; Rest of Southeast Asia; Afghanistan; Rest of South Asia; Lebanon; State of Palestine; Rest of Western Asia; Rest of the World	tjk	Tajikistan	rof	Rest of Africa: Rest of North Africa; Benin; Mali; Niger; Rest of Western Africa; Central African Republic; Chad; Congo; Democratic Republic of the Congo; Equatorial Guinea; Rest of South and Central Africa; Comoros; Ethiopia; Malawi; Mozambique; Sudan; Rest of Eastern Africa; Rest of South African Customs Union
		Uzb	Uzbekistan		
roa	Rest of Americas: Rest of North America; Rest of South America; Rest of Central America; Caribbean	roe	Rest of Europe: Rest of EFTA; Rest of Eastern Europe; Rest of Europe		

Source: GTAPv11 Database and Authors' Specifications.

TABLE A2.2. Sectoral aggregation

Sector	Description
Healthcare	Human health and social work
Hospitality and Leisure	Accommodation, Food and services; Recreational and other services
Other Services	Trade; Transport; Water transport; Air transport; Warehousing and support activities; Communication; Financial services; Insurance; Real estate activities; Business services; Education; Dwellings
Livestock and Animal Products	Bovine cattle, sheep and goats; Animal products; Raw milk; Wool, silk-worm cocoons; Fishing; Bovine meat products; Meat products; Dairy products
Other Agricultural and Food Products	Paddy rice; Wheat; Cereal grains; Vegetables, fruit, nuts; Oil seeds; Sugar cane, sugar beet; Plant-based fibers; Other agricultural products; Vegetable oils and fats; Processed rice; Sugar; Food products; Beverages and tobacco products
Manufacturing, Mining, and Utilities	Forestry; Coal; Oil; Gas; Minerals; Textiles; Wearing apparel; Leather products; Wood products; Paper products, publishing; Petroleum, coal products; Chemical products; Basic pharmaceutical products; Rubber and plastic products; Mineral products; Ferrous metals; Metals; Metal products; Computer, electronic and optic; Electrical equipment; Machinery and equipment; Motor vehicles and parts; Transport equipment; Manufactures; Electricity; Gas manufacture, distribution; Water; Construction

Source: GTAPv11 Database and Authors' Specifications.

Appendix 3. Results by country

TABLE A3.1. Macroeconomic impact of each scenario in 2050, in million USD (2022) and as a percentage of GDP

Location	Innovation and Rollout of Gram-Negative Antibiotics	Better Treatment of Bacterial Infections	Better Treatment and Innovation	Combined Interventions	Pessimistic Scenario
Albania	$15.6 (0.43%)	$3.7 (0.1%)	$18.6 (0.52%)	$17.6 (0.49%)	–$57.7 (–1.6%)
Algeria	$47.0 (0.12%)	$23.1 (0.06%)	$67.4 (0.17%)	$59.1 (0.15%)	–$96.0 (–0.24%)
Argentina	$407.4 (0.3%)	$333.0 (0.25%)	$685.5 (0.51%)	$696.7 (0.52%)	–$547.1 (–0.41%)
Armenia	$21.7 (0.51%)	$8.8 (0.21%)	$29.9 (0.71%)	$31.1 (0.74%)	–$28.4 (–0.67%)
Australia	$870.8 (0.26%)	–$0.8 (0%)	$874.7 (0.26%)	$866.4 (0.26%)	–$1,796.4 (–0.53%)
Austria	$385.2 (0.51%)	–$5.0 (–0.01%)	$356.4 (0.47%)	$358.8 (0.48%)	–$170.3 (–0.23%)
Azerbaijan	$27.8 (0.29%)	$17.1 (0.18%)	$42.5 (0.44%)	$43.2 (0.44%)	–$43.2 (–0.44%)
Bahrain	$29.3 (0.34%)	$7.9 (0.09%)	$36.8 (0.42%)	$38.5 (0.44%)	–$42.4 (–0.49%)
Bangladesh	$1,123.1 (0.57%)	$580.4 (0.3%)	$1,540.5 (0.79%)	$1,651.0 (0.84%)	–$542.1 (–0.28%)
Belarus	$41.9 (0.46%)	$6.7 (0.07%)	$46.4 (0.51%)	$47.5 (0.53%)	–$45.2 (–0.5%)
Belgium	$190.7 (0.21%)	$8.9 (0.01%)	$196.2 (0.21%)	$200.4 (0.22%)	–$425.9 (–0.46%)
Bolivia	$47.0 (0.41%)	$44.3 (0.39%)	$80.9 (0.7%)	$80.8 (0.7%)	–$33.1 (–0.29%)
Botswana	$21.0 (0.38%)	$40.3 (0.73%)	$55.3 (1%)	$60.4 (1.09%)	–$40.4 (–0.73%)
Brazil	$3,018.7 (0.55%)	$2,526.2 (0.46%)	$5,128.7 (0.93%)	$5,207.9 (0.94%)	–$2,689.4 (–0.49%)
Brunei Darussalam	$7.8 (0.32%)	$3.2 (0.14%)	$10.1 (0.42%)	$10.2 (0.42%)	–$4.1 (–0.17%)
Bulgaria	$92.8 (0.68%)	$16.4 (0.12%)	$107.8 (0.79%)	$99.8 (0.73%)	–$182.4 (–1.34%)
Burkina Faso	$24.7 (0.23%)	$28.1 (0.26%)	$49.0 (0.46%)	$61.5 (0.57%)	–$26.2 (–0.24%)
Côte d’Ivoire	$133.9 (0.38%)	$170.8 (0.48%)	$276.0 (0.78%)	$358.5 (1.01%)	–$85.5 (–0.24%)
Cameroon	$46.4 (0.23%)	$63.4 (0.32%)	$100.3 (0.51%)	$124.0 (0.63%)	–$75.8 (–0.38%)
Canada	$1,269.4 (0.35%)	$8.8 (0%)	$1,252.6 (0.34%)	$1,273.5 (0.35%)	–$1,188.4 (–0.32%)
Chile	$130.7 (0.21%)	$53.2 (0.09%)	$176.3 (0.28%)	$183.2 (0.29%)	–$325.4 (–0.52%)
China	$12,396.9 (0.31%)	$3,304.2 (0.08%)	$14,943.0 (0.37%)	$14,831.6 (0.37%)	–$72,195.5 (–1.8%)
Colombia	$382.0 (0.37%)	$191.9 (0.18%)	$537.5 (0.52%)	$547.6 (0.53%)	–$524.4 (–0.5%)
Costa Rica	$57.9 (0.3%)	$27.8 (0.15%)	$82.1 (0.43%)	$83.8 (0.44%)	–$125.7 (–0.66%)
Croatia	$89.1 (0.77%)	–$0.3 (0%)	$85.1 (0.74%)	$80.8 (0.7%)	–$51.6 (–0.45%)
Cyprus	$28.8 (0.46%)	–$2.1 (–0.03%)	$26.4 (0.42%)	$25.6 (0.41%)	–$130.2 (–2.08%)
Czechia	$175.3 (0.44%)	$4.2 (0.01%)	$175.4 (0.44%)	$171.5 (0.43%)	–$81.9 (–0.21%)
Denmark	$183.1 (0.29%)	$5.6 (0.01%)	$185.0 (0.3%)	$181.5 (0.29%)	–$234.0 (–0.37%)
Dominican Republic	$154.9 (0.46%)	$101.5 (0.3%)	$247.0 (0.74%)	$276.9 (0.83%)	–$216.6 (–0.65%)
Ecuador	$68.1 (0.26%)	$51.3 (0.19%)	$111.8 (0.42%)	$112.8 (0.42%)	–$98.2 (–0.37%)
Egypt	$1,113.8 (0.76%)	$315.6 (0.22%)	$1,365.1 (0.93%)	$1,385.2 (0.95%)	–$55.9 (–0.04%)
El Salvador	$37.9 (0.55%)	$23.8 (0.34%)	$58.1 (0.84%)	$60.7 (0.88%)	–$53.1 (–0.77%)
Estonia	$78.3 (1.42%)	$2.2 (0.04%)	$80.6 (1.46%)	$81.9 (1.48%)	–$16.0 (–0.29%)
Eswatini	$2.4 (0.16%)	$6.0 (0.41%)	$7.7 (0.52%)	$8.1 (0.55%)	–$2.5 (–0.17%)
Finland	$111.8 (0.25%)	–$1.2 (0%)	$110.8 (0.25%)	$110.2 (0.25%)	–$328.1 (–0.74%)
France	$918.9 (0.19%)	$27.7 (0.01%)	$917.1 (0.19%)	$905.1 (0.19%)	–$3,964.8 (–0.83%)
Gabon	$9.7 (0.21%)	$10.5 (0.22%)	$18.1 (0.39%)	$20.9 (0.45%)	–$9.7 (–0.21%)

TABLE A3.1. (Continued)

Location	Innovation and Rollout of Gram-Negative Antibiotics	Better Treatment of Bacterial Infections	Better Treatment and Innovation	Combined Interventions	Pessimistic Scenario
Georgia	$28.8 (0.46%)	$17.8 (0.28%)	$44.4 (0.7%)	$49.2 (0.78%)	–$47.1 (–0.75%)
Germany	$1,660.2 (0.27%)	$0.3 (0%)	$1,645.4 (0.27%)	$1,609.7 (0.27%)	–$5,432.0 (–0.9%)
Ghana	$159.7 (0.52%)	$173.8 (0.57%)	$299.2 (0.97%)	$356.6 (1.16%)	–$115.7 (–0.38%)
Greece	$189.8 (0.46%)	–$9.2 (–0.02%)	$175.5 (0.43%)	$166.7 (0.41%)	–$440.5 (–1.07%)
Guatemala	$170.9 (0.59%)	$148.2 (0.51%)	$286.0 (0.99%)	$293.5 (1.01%)	–$104.1 (–0.36%)
Guinea	$26.1 (0.33%)	$32.4 (0.41%)	$51.4 (0.64%)	$64.5 (0.81%)	–$11.1 (–0.14%)
Haiti	$23.2 (0.46%)	$24.8 (0.5%)	$43.2 (0.86%)	$42.8 (0.86%)	–$13.5 (–0.27%)
Honduras	$112.9 (1.16%)	$63.1 (0.65%)	$162.7 (1.67%)	$167.3 (1.71%)	–$35.3 (–0.36%)
Hungary	$211.9 (0.68%)	$12.3 (0.04%)	$220.6 (0.71%)	$212.4 (0.68%)	–$88.8 (–0.28%)
India	$6,608.2 (0.49%)	$5,897.8 (0.44%)	$11,234.6 (0.84%)	$12,086.2 (0.9%)	–$2,180.4 (–0.16%)
Indonesia	$1,540.8 (0.41%)	$1,057.6 (0.28%)	$2,504.5 (0.67%)	$3,155.7 (0.84%)	–$1,726.8 (–0.46%)
Iran	$237.4 (0.23%)	$60.9 (0.06%)	$294.7 (0.28%)	$292.0 (0.28%)	–$228.4 (–0.22%)
Iraq	$451.6 (0.45%)	$98.4 (0.1%)	$544.8 (0.54%)	$473.2 (0.47%)	–$940.9 (–0.94%)
Ireland	$221.7 (0.19%)	–$13.2 (–0.01%)	$202.0 (0.18%)	$214.8 (0.19%)	–$796.0 (–0.69%)
Israel	$285.9 (0.24%)	$2.2 (0%)	$288.8 (0.24%)	$279.3 (0.23%)	–$1,231.1 (–1.02%)
Italy	$1,058.4 (0.32%)	–$7.4 (0%)	$1,028.8 (0.31%)	$1,011.3 (0.31%)	–$1,898.3 (–0.58%)
Jamaica	$24.0 (0.75%)	$10.0 (0.31%)	$31.9 (0.99%)	$31.3 (0.98%)	–$19.7 (–0.61%)
Japan	$591.3 (0.08%)	$29.7 (0%)	$575.3 (0.08%)	$593.2 (0.08%)	–$6,573.8 (–0.9%)
Jordan	$87.3 (0.65%)	$15.6 (0.12%)	$102.9 (0.77%)	$102.8 (0.76%)	–$56.9 (–0.42%)
Kazakhstan	$81.2 (0.18%)	$39.8 (0.09%)	$117.3 (0.26%)	$118.5 (0.26%)	–$148.5 (–0.33%)
Kenya	$137.4 (0.3%)	$277.3 (0.6%)	$390.9 (0.84%)	$419.5 (0.9%)	–$264.5 (–0.57%)
Kuwait	$27.2 (0.1%)	$4.2 (0.02%)	$30.8 (0.11%)	$32.4 (0.12%)	–$81.0 (–0.29%)
Kyrgyzstan	$14.8 (0.51%)	$6.6 (0.23%)	$20.4 (0.7%)	$19.9 (0.68%)	–$17.7 (–0.61%)
Lao People's Democratic Republic	$53.1 (0.73%)	$34.6 (0.47%)	$80.9 (1.11%)	$88.7 (1.22%)	–$17.0 (–0.23%)
Latvia	$33.4 (0.61%)	$5.0 (0.09%)	$37.9 (0.69%)	$37.9 (0.7%)	–$33.7 (–0.62%)
Lithuania	$41.7 (0.47%)	$6.7 (0.07%)	$47.9 (0.54%)	$48.1 (0.54%)	–$23.3 (–0.26%)
Luxembourg	$33.3 (0.26%)	$0.9 (0.01%)	$33.4 (0.26%)	$32.6 (0.26%)	–$67.0 (–0.53%)
Madagascar	$55.3 (0.76%)	$65.1 (0.9%)	$105.2 (1.45%)	$122.8 (1.7%)	–$25.8 (–0.36%)
Malaysia	$522.5 (0.54%)	$480.8 (0.49%)	$934.2 (0.96%)	$1,030.8 (1.06%)	–$418.1 (–0.43%)
Malta	$20.5 (0.53%)	–$1.2 (–0.03%)	$18.8 (0.49%)	$17.0 (0.44%)	–$41.9 (–1.09%)
Mauritius	$9.6 (0.27%)	$6.0 (0.17%)	$14.5 (0.41%)	$15.2 (0.43%)	–$27.7 (–0.79%)
Mexico	$1,250.8 (0.43%)	$905.1 (0.31%)	$2,052.8 (0.7%)	$2,146.9 (0.73%)	–$1,643.2 (–0.56%)
Mongolia	$10.1 (0.24%)	$6.4 (0.15%)	$14.9 (0.35%)	$15.7 (0.37%)	–$5.7 (–0.13%)
Morocco	$256.2 (0.72%)	$103.4 (0.29%)	$339.7 (0.95%)	$353.3 (0.99%)	–$214.8 (–0.6%)
Namibia	$11.1 (0.28%)	$21.1 (0.54%)	$28.8 (0.74%)	$28.6 (0.73%)	–$17.7 (–0.46%)
Nepal	$74.9 (0.49%)	$49.5 (0.33%)	$110.1 (0.73%)	$122.1 (0.81%)	–$53.5 (–0.35%)
Netherlands	$807.8 (0.52%)	$17.7 (0.01%)	$802.6 (0.52%)	$790.4 (0.51%)	–$515.9 (–0.33%)
New Zealand	$232.9 (0.47%)	–$2.8 (–0.01%)	$213.6 (0.43%)	$209.8 (0.43%)	–$158.8 (–0.32%)
Nicaragua	$27.6 (0.53%)	$15.1 (0.29%)	$40.5 (0.77%)	$42.5 (0.81%)	–$34.0 (–0.65%)

TABLE A3.1. (Continued)

Location	Innovation and Rollout of Gram-Negative Antibiotics	Better Treatment of Bacterial Infections	Better Treatment and Innovation	Combined Interventions	Pessimistic Scenario
Nigeria	$557.9 (0.34%)	$563.8 (0.35%)	$995.7 (0.62%)	$1,284.3 (0.79%)	–$204.0 (–0.13%)
Norway	$341.0 (0.43%)	–$2.7 (0%)	$332.1 (0.42%)	$322.4 (0.41%)	–$194.0 (–0.25%)
Oman	$52.2 (0.24%)	$21.2 (0.1%)	$70.9 (0.33%)	$67.3 (0.31%)	–$61.5 (–0.28%)
Pakistan	$1,183.1 (0.66%)	$770.4 (0.43%)	$1,708.8 (0.96%)	$1,798.0 (1.01%)	–$400.4 (–0.22%)
Panama	$37.4 (0.19%)	$34.2 (0.17%)	$63.4 (0.32%)	$62.0 (0.32%)	–$170.9 (–0.87%)
Paraguay	$38.1 (0.32%)	$26.4 (0.22%)	$59.7 (0.5%)	$58.9 (0.49%)	–$34.4 (–0.29%)
Peru	$161.6 (0.26%)	$206.7 (0.34%)	$342.0 (0.56%)	$370.1 (0.6%)	–$461.7 (–0.75%)
Philippines	$1,400.1 (0.83%)	$1,401.9 (0.83%)	$2,472.7 (1.47%)	$2,702.1 (1.61%)	–$633.7 (–0.38%)
Poland	$646.2 (0.51%)	$99.6 (0.08%)	$729.9 (0.58%)	$737.9 (0.58%)	–$651.8 (–0.51%)
Portugal	$91.8 (0.2%)	–$1.7 (0%)	$84.0 (0.18%)	$83.0 (0.18%)	–$386.5 (–0.84%)
Qatar	$72.6 (0.21%)	$5.6 (0.02%)	$75.1 (0.22%)	$73.8 (0.21%)	–$52.5 (–0.15%)
Republic of Korea	$637.1 (0.22%)	$8.1 (0%)	$642.8 (0.22%)	$564.7 (0.19%)	–$1,997.0 (–0.68%)
Rest of Africa	$1,186.5 (0.41%)	$1,363.5 (0.48%)	$2,300.8 (0.8%)	$2,677.7 (0.93%)	–$641.8 (–0.22%)
Rest of Americas	$249.0 (0.61%)	$96.4 (0.24%)	$327.7 (0.81%)	$341.8 (0.84%)	–$148.3 (–0.37%)
Rest of Asia and Oceania	$807.1 (0.65%)	$501.3 (0.4%)	$1,182.4 (0.95%)	$1,212.5 (0.98%)	–$408.0 (–0.33%)
Rest of Europe	$150.6 (0.67%)	$24.2 (0.11%)	$172.5 (0.77%)	$172.8 (0.77%)	–$83.5 (–0.37%)
Romania	$133.1 (0.29%)	$33.9 (0.07%)	$162.1 (0.35%)	$159.7 (0.35%)	–$194.7 (–0.42%)
Russian Federation	$1,336.7 (0.43%)	$240.4 (0.08%)	$1,563.0 (0.5%)	$1,611.3 (0.52%)	–$719.8 (–0.23%)
Rwanda	$18.7 (0.25%)	$25.0 (0.33%)	$39.4 (0.52%)	$45.4 (0.6%)	–$17.4 (–0.23%)
Saudi Arabia	$453.8 (0.23%)	$201.3 (0.1%)	$642.0 (0.33%)	$722.7 (0.37%)	–$607.6 (–0.31%)
Senegal	$77.4 (0.54%)	$64.4 (0.45%)	$126.5 (0.88%)	$139.9 (0.98%)	–$59.2 (–0.41%)
Serbia	$84.0 (0.63%)	$8.0 (0.06%)	$88.4 (0.66%)	$88.1 (0.66%)	–$82.0 (–0.61%)
Singapore	$121.3 (0.18%)	$5.0 (0.01%)	$123.0 (0.18%)	$123.4 (0.18%)	–$394.6 (–0.58%)
Slovakia	$70.8 (0.35%)	$9.2 (0.05%)	$77.8 (0.39%)	$73.6 (0.37%)	–$81.6 (–0.41%)
Slovenia	$46.8 (0.47%)	–$0.8 (–0.01%)	$42.2 (0.42%)	$38.4 (0.38%)	–$68.8 (–0.69%)
South Africa	$276.9 (0.29%)	$437.9 (0.45%)	$675.3 (0.7%)	$775.8 (0.8%)	–$614.7 (–0.64%)
Spain	$1,003.5 (0.38%)	–$2.5 (0%)	$980.8 (0.37%)	$971.5 (0.37%)	–$1,452.6 (–0.55%)
Sri Lanka	$86.8 (0.44%)	$27.6 (0.14%)	$108.1 (0.55%)	$98.5 (0.5%)	–$77.1 (–0.39%)
Sweden	$326.9 (0.29%)	–$0.3 (0%)	$320.6 (0.28%)	$309.9 (0.27%)	–$1,016.9 (–0.89%)
Switzerland	$518.8 (0.43%)	$20.3 (0.02%)	$522.0 (0.43%)	$517.4 (0.43%)	–$417.1 (–0.34%)
Syrian Arab Republic	$133.9 (1.6%)	$29.1 (0.35%)	$157.7 (1.88%)	$165.3 (1.97%)	–$429.3 (–5.12%)
Taiwan	$178.4 (0.18%)	$43.2 (0.04%)	$210.0 (0.21%)	$203.3 (0.2%)	–$1,296.2 (–1.29%)
Tajikistan	$12.2 (0.28%)	$11.2 (0.26%)	$20.6 (0.47%)	$20.6 (0.47%)	–$12.8 (–0.29%)
Thailand	$485.9 (0.45%)	$325.5 (0.3%)	$761.4 (0.71%)	$778.5 (0.72%)	–$505.6 (–0.47%)
Togo	$26.6 (0.63%)	$31.7 (0.75%)	$52.4 (1.24%)	$64.4 (1.52%)	–$29.2 (–0.69%)
Trinidad and Tobago	$17.0 (0.44%)	$9.7 (0.25%)	$25.7 (0.66%)	$25.9 (0.66%)	–$14.5 (–0.37%)
Tunisia	$38.8 (0.37%)	$12.4 (0.12%)	$49.5 (0.47%)	$42.8 (0.41%)	–$67.1 (–0.64%)

TABLE A3.1. (Continued)

Location	Innovation and Rollout of Gram-Negative Antibiotics	Better Treatment of Bacterial Infections	Better Treatment and Innovation	Combined Interventions	Pessimistic Scenario
Turkiye	$824.0 (0.3%)	$312.4 (0.11%)	$1,098.3 (0.39%)	$1,032.4 (0.37%)	–$3,420.7 (–1.23%)
Uganda	$67.7 (0.3%)	$77.2 (0.35%)	$126.1 (0.57%)	$155.5 (0.7%)	–$37.7 (–0.17%)
Ukraine	$128.2 (0.5%)	$36.1 (0.14%)	$160.3 (0.62%)	$140.9 (0.54%)	–$52.5 (–0.2%)
United Arab Emirates	$391.2 (0.37%)	$169.6 (0.16%)	$542.5 (0.52%)	$501.8 (0.48%)	–$384.1 (–0.37%)
United Kingdom of Great Britai	$1,212.9 (0.22%)	$16.5 (0%)	$1,216.8 (0.22%)	$1,184.4 (0.21%)	–$5,861.2 (–1.06%)
United Republic of Tanzania	$219.9 (0.52%)	$268.4 (0.64%)	$433.1 (1.03%)	$512.8 (1.22%)	–$181.1 (–0.43%)
United States of America	$14,876.5 (0.38%)	$781.1 (0.02%)	$15,622.9 (0.4%)	$15,572.9 (0.4%)	–$29,568.7 (–0.75%)
Uruguay	$60.2 (0.45%)	$27.2 (0.21%)	$84.1 (0.63%)	$84.9 (0.64%)	–$80.9 (–0.61%)
Uzbekistan	$78.8 (0.25%)	$52.8 (0.17%)	$124.2 (0.39%)	$129.0 (0.4%)	–$96.7 (–0.3%)
Venezuela (Bolivarian Republic)	$393.5 (0.59%)	$180.9 (0.27%)	$543.5 (0.81%)	$306.9 (0.46%)	–$153.6 (–0.23%)
Viet Nam	$1,698.5 (1.37%)	$538.9 (0.44%)	$2,189.1 (1.77%)	$2,334.1 (1.89%)	–$227.7 (–0.18%)
Zambia	$99.0 (0.78%)	$89.7 (0.71%)	$162.3 (1.28%)	$184.2 (1.45%)	–$42.8 (–0.34%)
Zimbabwe	$21.9 (0.38%)	$49.9 (0.87%)	$65.0 (1.13%)	$74.6 (1.29%)	–$35.8 (–0.62%)