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Assessing the Global Economic and Poverty Effects of Antimicrobial Resistance

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Abstract

This paper assesses the potential impact of antimicrobial resistance on global economic growth and poverty. The analysis uses a global computable general equilibrium model and a microsimulation framework that together capture impact channels related to health, mortality, labor productivity, health care financing, and production in the livestock and other sectors. The effects spread across countries via trade flows that may be affected by new trade restrictions. Relative to a world without antimicrobial resistance, the losses during 2015–50 may sum to $85 trillion in gross domestic product and $23 trillion in global trade (in present value). By 2050, the cost in global gross domestic product could range from 1.1 percent (low case) to 3.8 percent (high case). Antimicrobial resistance is expected to make it more difficult to eliminate extreme poverty. Under the high antimicrobial resistance scenario, by 2030, an additional 24.1 million people would be extremely poor, of whom 18.7 million live in low-income countries. In general, developing countries will be hurt the most, especially those with the lowest incomes.

This paper is a joint product of the Development Prospects Group, Development Economics and the Health Nutrition and Population Global Practice Group. It is part of a larger effort by the World Bank to provide open access to its research and make a contribution to development policy discussions around the world. Policy Research Working Papers are also posted on the Web at http://econ.worldbank.org. The corresponding authors may be contacted at dgo@worldbank.org and thier@usna.edu.

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[1] Syud Amer Ahmed: The World Bank; Enis Barış: The World Bank; Delfin S. Go: The World Bank; Hans Lofgren: The World Bank; Israel Osorio-Rodarte: The World Bank; and Karen Thierfelder: U.S. Naval Academy. The paper is part of the background analysis for the World Bank report, *Drug Resistant Infections – A Threat to Our Economic Future,* a discussion draft presented by Jim Kim to the United Nations in September 2016, and the final report issued in March 2017. The paper was prepared collaboratively between DEC Prospects Group and the Global Practice on Health, Nutrition, and Population (HNP) at the World Bank. It benefitted partly from funding from HNP and the Strategic Research Program on Infectious Diseases. We thank Olga Jonas, Henning Tarp Jensen, Csilla Lakatos, Maryla, Maliszewska,Donald Edward Shriber, Jason Nassios and other participants at the 20th Annual Conference on Global Economic Analysis on June 8, 2017 and the World Bank seminar on June 13, 2017 for suggestions and suggestions. The corresponding authors are Delfin Go (dgo@worldbank.org) and Karen Thierfelder (thier@usna.edu).

I. Introduction

The 2014 Ebola outbreak in Guinea, Liberia, and Sierra Leone calls attention to the painful economic and human costs of pandemics if the spread is unchecked (World Bank 2014). Drug-impervious infections from antimicrobial resistance (AMR) are particularly worrisome because the risks are substantial but yet uncertain. Like climate change, AMR is a slowly unfolding future shock. Its impact will depend not only on its progression, its detrimental impact on human health and morbidity, livestock production, and many other unforeseen effects, but also on the policy measures taken today and in the future. For these reasons, recent studies have relied on forward-looking simulations based on increasingly complex economic models to capture the interactions of AMR with human health and the economy; microeconomic assessments of the impact of AMR on labor supply and productivity provide plausible assumptions for these simulations.

This paper advances the methodology used to analyze the economic impacts of AMR. First, it uses a well-defined global general equilibrium model with channels for AMR to affect the economy through health costs, labor supply, labor productivity, livestock production and trade costs. Sectors interact within economies and across countries through bilateral trade links and resource flows. Second, it traces the global effects on poverty, especially in developing countries, by employing a global microsimulation framework that draws on harmonized household surveys that cover around 85% of world population. Finally, to account for the significant uncertainty about the future progression of AMR, the analysis uses expert microeconomic and or meta-studies to form low-, mid-, and high-case scenarios for the severity of its impact via explicit channels. In what follows, we elaborate on the contributions of our analysis.

The magnitude of AMR's future global impact depends on the interactions between the health (care) sector and the rest of the economy within each country and further repercussions across countries and regions. To capture not just the many health related issues caused by AMR, but their significant spill-over effects on other sectors of the economy, Smith et al. (2005) use a computable general equilibrium (CGE) model of the United Kingdom to estimate the full social costs and benefits of this health problem and its policy interventions. However, because they do not use a global model, they exclude cross-country interactions and do not address how effects differ across countries.

Using first principles, Rudholm (2002) stresses that, without a global view, the actions by individual countries that take the actions of their neighbors as exogenous would together lead to a suboptimal allocation of global resources. The paper focuses mainly on conceptual arguments and derivations in support of the need for a global perspective, thus leaving the empirical analysis to others. Taylor et al. (2014) combine good microeconomic assessments of AMR's impact on human health with a global CGE analysis to estimate the impact with a worldwide perspective. They conduct a careful meta-analysis of results from various research studies on the impact of AMR on health and morbidity to determine likely changes in labor supplies in different regions. They construct a simple global computable general equilibrium (CGE) model with one sector in each region to analyze the effects of labor supply changes. Their database comes from disparate sources: 10 social accounting matrices (SAMs) mostly from the International Food Policy Research Institute (three for Sub-Saharan Africa, six for Latin America, and one for the Middle East and North Africa)[2] plus an aggregated input-output table for a high-income region derived from the World Input-Output Database.[3] This information is scaled to match the macroeconomic aggregates of the pertinent regions and linked by trade flows from the Directions of Trade database of the International Monetary Fund. The resulting SAMs do not distinguish producing sectors, comprising mainly of aggregate output, a single intermediate consumption, and one labor category for each region. In particular, the study does not make use of a more disaggregated and consistent database like that of the Global Trade Analysis Project (GTAP) of Purdue University, which has become standard for global CGE modeling.[4]

Keogh-Brown et al. (2009) use a global model with sector detail to evaluate the labor supply and productivity effects of AMR. Unlike Taylor et al. (2014), they use a model with multiple sectors (GLOBE, see McDonald et al. 2007) and a globally consistent database of GTAP. Rather than use detailed meta-studies to determine the appropriate labor supply shocks, they use a sigmoid curve parameterization of the frequency of resistance to estimate the impact of reduced use of antibiotics. Also, their analysis relies on a static version of the GLOBE model which does not describe how the impact of AMR evolves over time.

To improve on the previous modeling efforts, the analysis of the global impact of AMR in this study uses GLOBE_DYN (McDonald et al. 2013), a multi-sectoral, multi-country and multi-agent dynamic recursive CGE model that is consistent with neoclassical growth theory and uses GTAP data. A range of possible AMR incidence scenarios is compared to a baseline scenario, with the marginal effects of AMR measured as the difference in the evolution of economic variables between the scenarios with AMR incidence and the baseline. This ex-ante approach follows the rich tradition of using CGE analysis to examine policy issues in developing countries,[5] such as trade reform in India (Go and Mitra 1999), carbon tax and climate change in South Africa (Deverajan et al. 2010), or policies to speed up progress on the Millennium Development Goals (Lofgren et al. 2013). Such models and analysis are also increasingly applied to examine the forward-looking effects of complex global issues, such as the long-term effects of international trade agreements like the Doha Development Round (Hertel et al. 2009) or global migration (Ahmed et al. 2016b).

To analyze the effects of AMR on global poverty, the results of the GLOBE_DYN model are passed on to the Global Income Distribution Dynamics (GIDD), a World Bank global

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[2] Listed in Appendix C, *Ibid*.
[3] Ibid; Timmer (2012).
[4] See www.gtap.org for more information.
[5] See, for example, the survey in Devarajan and Robinson (2013).

microsimulation framework with a database that draws on harmonized household surveys with consistent definition of labor skills based on education for 104 countries(Bourguignon and Bussolo 2013 and Cruz et al. 2017). The integration of global CGE and microsimulation analysis follows several recent applications. For example, Ahmed et al. (2016a) examine the significance of Sub-Saharan Africa's demographic dividend for its future growth and poverty. Devarajan et al. (2015) stress-test Africa's recent growth and poverty performance. Indeed, our analysis indicates that the poverty angle is an important factor: AMR will result in a noteworthy increase in extreme poverty due to the disproportionate negative GDP impact of AMR on low-income countries.

The analysis covers multiple impact channels, including others not considered in earlier research. First, it takes into account the microeconomic assessments by Taylor et al. (2014) of possible human health costs in the form of increased morbidity and mortality. Second, it expands the analysis in several ways to consider lessons learned from assessments of infectious diseases based on simulation modeling and other methods. Specifically, the analysis also considers: an additional impact on labor productivity as in the case of HIV/AIDS (Kambou et al. 1992; and Arndt and Lewis 2001) and influenza (Keogh-Brown et al. 2010; Burns et al. 2006; World Bank 2006; and McKibbin and Sidorenko 2006); increased morbidity and mortality in the livestock sector, leading to lower productivity and lower supply (Laxminarayan et al. 2015); rising demands for health care due to AMR (KPMG 2014), leading to an increase in public health spending that is financed by a lump-sum tax on households to maintain fiscal balance; and possible restrictions on global food trade arising from a "fear factor," represented by an increase in trade and transport margins, as in the recent Ebola epidemic in West Africa (World Bank 2014).

The focus of the paper is the estimation of the potential impact of AMR on the world as a whole and four income regions defined by the level of per-capita income (following the classification of the World Bank.) The income regions include countries belonging to low-income, lower middle-income, upper middle-income, and high-income groups. The list of possible policy programs and interventions against AMR are many, and it is beyond the scope of this paper to cover them in detail. O'Neill (2016) and World Bank (2017) provide excellent reviews. In fact, each infectious disease that is likely to be affected by AMR (such as HIV, tuberculosis, or malaria) will need its disease-specific support strategy (see, for example, Borowitz et al. 2003, Baris 2004, and Lindsay et al. 2004), in addition a set of AMR-specific (e.g., improved rapid diagnostics, new antibiotics for short term, and combined treatment options, etc.) and AMR-sensitive multi-sectoral policy measures and interventions (e.g., expanded health coverage, improved antibiotic stewardship, and water and environment management as discussed in World Bank 2017). Even so, our low case can be interpreted to correspond to an effective outcome of policy measures taken today and in the future; the high case for lack of policy effectiveness.

In what follows, we estimate the global impact of AMR with the features described above: a well-defined global CGE model that has dynamics and makes full use of the GTAP database, the inclusion of both microeconomic assessments on health and other channels of shock, and analysis of the poverty implications. Section 2 describes the methodology while sections 3 and 4 present the baseline and the counterfactual simulation analysis. The results are summarized in section 5, and conclusions are offered in section 6.

II. Methodology

The GLOBE-DYN model

The magnitude of AMR's future global impact depends on many variables with uncertain evolution and with repercussions that may be felt throughout the global economy. To be able to consider the combined consequences of alternative expert estimates and meta-analysis of influencing factors, we use a recursive dynamic global CGE model, GLOBE_DYN, calibrated to GTAP data, v8.1.

Regions are mapped into four income regions based on the current World Bank country classification: low income, lower middle income, higher middle income, and high income.[6] As microeconomic assessments of the effects of AMR become more available, further disaggregation and differentiation of countries are certainly possible. The database is aggregated into six sectors (crops, livestock, mining, processed food, manufacturing, and services). The model is a member of a family of CGE models that models trade relationships using principles described in the 1-2-3 model (de Melo and Robinson, 1989; Devarajan, *et al*., 1990) or the standard multi-sectoral version for developing countries (Dervis, de Melo, and Robinson, 1982; and Lofgren *et al*., 2002).

A baseline scenario is defined to track the economic trends of "a world without AMR," which essentially resembles the long-term growth projections of the World Bank (2016). These projections are similar to the long-term economic projections by research institutions in Europe, such as Fouré et al. (2012 and 2013) and Gros and Alcidi (2013). It also tracks the future labor supply, which is taken as the working-age population (15-64 years of age), drawing from the demographic projections and medium fertility scenario of the United Nations (2013).

The baseline in the recursive-dynamic model is generated by solving the model on an annual basis with exogenous updates between each solution for the following indicators (imposed as levels or GDP shares): GDP, investment, the real level of government expenditure, the fiscal balance (also called government savings), the trade balance (a deficit in most developing countries), and the total supplies of non-capital factors (skilled and unskilled labor, land, and natural resources). In each period, the fiscal balance is cleared via adjustments in household income taxes (treated as lump-sum tax). The exogenous trade balances are achieved via adjustments in real exchange rates. Markets for outputs and factors are cleared via price (or wage) adjustments The capital stock is updated endogenously: for any period after the base year, it is

[6] Unlike Taylor et al. (2014), we avoided a geographical classification since the different regions would have included countries at different income levels. For example, if Sub-Saharan Africa were a region, then it would have brought together a relatively high-income country like South Africa and a low-income country like Niger.

defined as the supply of capital in the last period plus investment in new capital in the last period minus depreciation. To generate the exogenous path for GDP and investment, total factor productivity and savings rates are determined endogenously in each period. After generating the baseline, GDP and investment become endogenous, while total factor productivity (TFP) and savings rates are exogenous, set at the levels determined in the baseline. In the AMR scenarios, GDP and investment respond to the policy shocks, as would be expected.[7]

Against the baseline economic projections of no AMR, the AMR-induced shocks are introduced. Since both the baseline and what-if counterfactual or AMR simulations contain the same underlying economic projections, their differences isolate the effects of the critical factors that define the AMR impact of each scenario. The analysis is based on the differences between the AMR scenarios and the baseline for selected key variables. The economic impact of AMR occurs primarily through four channels: changes in the labor supply, changes in TFP in the livestock sector, increases in government public spending on health care, and an increase in trade and transport margins due to a "fear factor." The rise in societal health care cost due to AMR is first reflected as an elevation in public spending. However, the public finance rule for clearing the fiscal balance means that they are ultimately paid for by households through a direct tax, in effect becoming out-of-pocket expenditures of households. Through this modeling mechanism, the net-of-tax income falls, reducing every consumption items in the household budget and causing impoverishing effects on households. As the net-of-tax income falls, so does the level of household savings for financing its contributions to total investment. These AMR-induced shocks give rise to economy-wide interactions within and between regions and over time, resulting in changes in production, consumption, investment trade, output prices, and factor wages. We summarize these outcomes by showing how selected macroeconomic indicators differ from the baseline.

The GIDD model

To look at poverty implications of AMR, we use the results of the GLOBE_DYN as input to the Global Income Distribution Dynamics (GIDD) microsimulation model. GIDD's extensive coverage of microdata from household surveys permits the ex-ante investigation of issues not easily tractable with other methods, especially across countries. GIDD follows the tradition of microsimulation analysis of Bourguignon and Bussolo (2013), which extends the single-country macro-micro framework in Bourguignon and Savard (2008) to a global setting.[8] Recently, it was updated to provide a consistent treatment of labor and its skill composition based on educational attainment of household members for 104 countries to model the income distribution and poverty

[7] This procedure assures that, if the model were resolved with these new assumptions and without any additional policy shock, the baseline results would be replicated exactly. That is, the fact that the results for the AMR scenarios deviate from the baseline reflects the policy shocks, not the change in assumptions.

[8] For more details, see Bourguignon and Bussolo (2013), Bussolo et al. (2010), and Cruz et al. (2017).

effects of human capital formation (see Cruz et al. 2017). In our global setting, the household survey data in the updated GIDD spans 85% of the global population.[9]

In the analysis, GLOBE_DYN provides economy-wide implications of macroeconomic projections under the baseline and the different AMR scenarios. For each scenario, the evolution of relative prices and factor rewards, including wages of skilled and unskilled workers in agriculture and non-agriculture sectors are passed on as inputs to the GIDD. Over time, GIDD generates reweighted household surveys that account for the changing household composition due to demographic trends (e.g. aging, education or skill attainment, etc.) as well as changes in the labor supply from population growth and AMR-related mortality. Drawing on this information, the behavioral model at the household level regenerates new patterns of household employment, income, and consumption in the household sample surveys across regions and over time to reflect the effects of the baseline and AMR scenarios. Using these results, GIDD computes the poverty and inequality indicators for each scenario.

III. The Baseline - A World Without AMR

The baseline characterizes "a world without AMR," which follows the current long-term economic growth projections of the World Bank. It is based on data on GDP growth, investment growth, factor supply growth, the evolution of the internal balance (fiscal budget deficit or surplus), and the evolution of the external (current account) balance. To generate general equilibrium solutions that are consistent with these projections, the baseline makes the following assumptions regarding macro closures and conditions for market clearing:

- Regional TFP is made endogenous to track generate exogenous regional GDP levels. Changes in TFP directly affect value added (or GDP at factor cost).

- Adjustments in regional savings rates make sure that, in each region, total savings are sufficient to finance investment, defined as exogenous shares of GDP to match the projections of the World Bank's *Global Economic Prospects* (GEP). With regard to investment, the analysis uses GEP investment data and forecasts for the period 2008-2017. A steady-state GDP investment share of 20% is assumed in all regions in 2030 and beyond. A linear adjustment is imposed between 2017 and 2030, linking projected 2017 values to the steady state.

[9] In single-country applications of microsimulation such as the Philippines (Bourguignon and Savard 2008) or South Africa (Go et al. 2010), the availability of richer data sets has made it possible to use an income-generation model with an elaborate occupational-choice behavioral module at the household level. That approach permits wages and employment probability of individuals to become the functions of diverse household characteristics, such as age, gender, the level of schooling, years of work experience, sector of employment, location (urban or rural, family size, and additional household data.

- Household incomes taxes adjust to make sure that the exogenous fiscal deficit, defined as a share of GDP, is realized. Government expenditure refers only to current expenditure or government consumption, and the fiscal deficit excludes public capital spending. In this sense, a positive fiscal balance contributes to a pool of savings to finance total investment in the economy. Other tax rates are fixed so that other tax revenues will change to the extent that the tax bases to which they are applied change over time. For example, tariff revenue will change when import values change, given the exogenous tariff rates.

- The real exchange rate adjusts to realize the exogenous external balance (also a fixed GDP share). As assumed, this balance adjusts exogenously at a slow pace such that it would reach a value of zero after 100 years.

- In the factor markets, wages and rents adjust to bring about equilibrium, i.e. making sure that total endogenous demands match exogenous projections of labor or the accumulation of capital stock. The supplies of land and natural resources are fixed at the base level. The supplies of labor depend on demographic changes that define the working-age populations (UN 2013). The split between skilled and unskilled labor is based on the level of education as projected in World Bank (2015) and Ahmed et al. (2017). For capital, the supply growth is endogenous; given an initial stock, it is determined by investment values, depreciation, and the price per unit of new capital (which depends on endogenous input prices).[10]

IV. Defining the AMR Shocks in the Counterfactual Simulations

Given that AMR presents a current and future threat, how much economic resources should the world invest in reducing this threat? The answer depends on the economic costs of the expected impacts of AMR. The simulations of impacts reported in this paper are based on a review of recent simulations by other research groups, information on actual impacts of AMR to date, and on expectations about its spread. As in the baseline, the projection period ends in 2050, well within the lifetimes of present-day children and young people.

This analysis uses expert assessments of key factors to form low-, middle-, and high-case scenarios to address the significant uncertainties about the future progression of AMR and to provide a range of the uncertain severity of its impact. The low case can be interpreted to correspond to an effective outcome of policy measures taken today and in the future; the high case for lack of policy effectiveness.[11] In the simulations, the changes in savings and region-wide effects are driven by the effects over time on labor supplies, investment, output, and relative prices. These factors in turn change trade flows between regions and the relative and global prices of

[10] See McDonald et al (2013) for the equations used in the capital updating each period.
[11] The list of possible policy programs and actions against AMR are many and beyond the scope of the paper. For more information, see O'Neill (2016) and World Bank (2017).

commodities that are traded internationally, which add further rounds of global repercussions. The modeling work carried out for this analysis ensures that impacts on prices, factors of production, and sector outputs are consistently modeled, across sectors and countries, and over time.

Our scenario designs draw on recent studies of AMR that provide well-documented estimates of the individual factors and channels affected by AMR as listed and described next. Moreover, among the studies, we only use those that can be used as inputs and assumptions within our general equilibrium framework.

Declines in labor supplies

Of the recent estimates of the impact of AMR on global mortality, the RAND Europe study by Taylor et al. (2014) includes well-defined projections; like our study, theirs also extends to 2050. That study provides increased mortality resulting from resistance to antibiotics for three main pathogens (bacteria): *Escherichia coli* (popularly known as *E.coli*), *Klebsiella pneumoniae* (nasty pneumonia with drug-resistant complications), and *Staphylococcus aureus* (or Staph infection), each of which contributes to the spread and worsening of infectious diseases. The constraints of data and analysis limit the projections of mortality only from three infectious diseases: HIV, Tuberculosis, and Malaria. Even so, the study allows for differences in fatality rate for each disease in low-income regions like Sub-Saharan Africa and high-income regions like OECD.

Following Taylor et al. (2014), the reductions in labor supply under the different scenarios in this study are defined in efficiency units and include the effects of morbidity (reflected in a loss of working days due to illness). The low-case scenario corresponds to the "sc1" case in the RAND study with a 5% AMR resistance rate at the starting period or year 0; the middle-case to "sc4", which projects a current rate of resistance before year 15 and 40% from year 15; and a the high case to "sc5," which projects a current rate of resistance before year 15 and 100% from year 15. We avoid the extreme cases of absolute resistance (sc6 and sc7). The "current rate of resistance" refers to the fact that AMR is already underway and that its effects are already registered in the historical estimates of the population for the base year (2007) to 2016, albeit still in small quantities. Hence, the Rand report distinguishes between 0% resistance rate (sc0) and the current rate of resistance (sc00). After testing, however, the estimated labor supplies that are corrected to have the zero rate (the world without AMR) are numerically indistinguishable from the uncorrected UN demographic projections in the significant digits for the unit of population chosen (in millions). Hence, we do not make the delineation, and the baseline simulation in our paper uses the UN population projections, which for all practical purposes is the world without AMR. Finally, the mortality figures are mapped from the geographical regions of the RAND study into World Bank income regions for our study. More specifically, Sub-Saharan Africa is in our low-income region, high-income corresponds directly to our high-income region, while their other regions are split across our lower middle-income and higher middle-income regions.

The RAND study reports the number of deaths only for workers (or labor supply). Applying the fatality rates of the working age population (labor) to the non-working age (the young and the old who are outside the labor force), we derive the number of deaths for the total population. The resulting number of deaths for workers and the total population are as follows: (a) low case: 11 and 18 million, respectively; (b) middle case: 74 and 117 million, respectively; and (c) high case: 137 and 214 million, respectively. The number of deaths is influenced by the fact that the global population is growing. For the high case, the yearly total number of deaths corresponds to 2.3% of the UN-projected population in 2050. To provide some historical context, the influenza pandemics of 1918-1919 (also known as the Spanish Flu or La Grippe) killed between 20 and 40 million people, which was more than those killed in World War I (Barry 2005); the bubonic plague of the 14th century (commonly called the Black Death) killed between 50 to 200 million, wiping out 40-60% of Europe's population at the time (Benedictow 2007).

Fall in labor productivity

In Smith et al. (2005), the influenza case in Keogh-Brown et al. (2010), and the HIV/AIDS case in Kambou et al. (1992), labor productivity is expected to fall by about 1.0-1.5%. In Burns et al. (2006), the fall in labor productivity in the case of the avian flu ranges from 1.4% for high-income countries to 1.9% for Sub-Saharan Africa. In World Bank (2006) and McKibbin and Sidorenko (2006), the potential output losses imply a much higher (or more than double) decline in labor productivity. Hence, we use a figure of 1.5% for our low case and scale it up to 3% and 4.5% for the middle and high cases, respectively. Because of the potential snowballing effect of AMR, these numbers could be very conservative.

Rise in health care cost

KPMG (2014) projects that prolonged and secondary health care costs, such as the extra number of hospital days, could rise significantly. According to our assessment, these costs may double the shares of total health expenditure in GDP, which in 2010 were as follows for our regions: low-income 5.4%, lower middle-income 4.2%, higher middle-income 6.1%, and high-income 12.7%. In dollar terms, these increases are amplified over time given GDP growth. To capture the global- and economy-wide repercussions of rising health cost, these cost increases are translated into additional government spending on services, paid for by a direct tax on households, thus maintaining an unchanged fiscal balance. The resulting decline in household post-tax income leads to reductions in consumption, savings, and investment, reducing GDP and trade.

Reduction in livestock production

Following the meta-analysis of various studies by Laxminarayan et al. (2015) (particularly for cattle in the more recent of the two periods under investigation), we impose the following declines in total productivity in the livestock sector: low case 3%, middle case 5%, and high case 7%.

Global restrictions on livestock trade

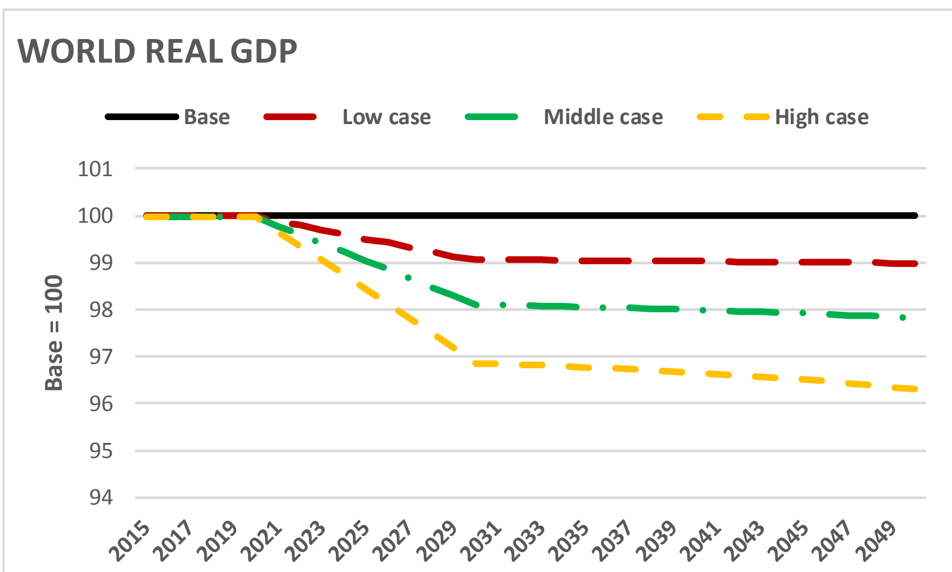
Not unlike the impact of the 2014 Ebola epidemic (World Bank 2014), increased AMR is likely to have a disproportionately strong negative impact on trade in livestock products due to border restrictions arising from the fear factor. In the simulations, we capture this via the following increases in trade and transport margins: low case 5%, middle case 10%, and high case 15%.

V. Results

Impacts of AMR on the Global Economy

The simulated impacts of AMR on global GDP in 2017-2050 are shown in Figure 1. Compared to the baseline case, in the optimistic "low-AMR" scenario, the global economic output is projected to be 1.0% lower by 2030 and 1.1% lower by 2050. In the pessimistic "high-AMR" scenario, it would be 3.2% lower in 2030 and 3.8% lower in 2050.[12] In the "low-AMR" case, the costs, as measured by the reduction in GDP compared to the base case, will be a significant economic burden, while in the "high-AMR" scenario, the costs can be considered severe, especially since the costly impact endures over time.

Figure 1: Substantial and Protracted Shortfalls in Global Economic Output



Given that the simulations were done using a general equilibrium model, economies do adjust to price signals caused by the AMR shocks. These adjustments lead to a reallocation of resources and a different pattern of new investments and capital accumulation. These model characteristics explain the flattening out of the trajectories after 2040 in Figure 1; by this time much of the adjustment of the world economy to shifts in relative prices and reallocation among

[12] The "high-AMR" case presented here is similar to the results of the modeling done for the UK Review on AMR, "Antimicrobial Resistance: Tackling a Crisis for the Health and Wealth of Nations, December 2014: including (1) Taylor et al. Estimating the Economic Costs of Antimicrobial Resistance: Model and Results, Santa Monica, CAA: RAND Corporation and (2) KPMG, "The Global Economic Impact of Anti-Microbial Resistance."

sectors would have occurred. After that, growth factors coming from capital accumulation and labor growth start to prevail, resulting in an essentially constant shortfall relative to the base case during the last decade before 2050.

The costly impacts of AMR are not distributed equally among countries at different levels of per capita income. As shown in Table 1, the negative impact is more pronounced in low-income countries. The two main reasons for this difference are a higher incidence of infectious diseases as well as a higher dependence on labor incomes in low-income countries than in high-income countries. In the high-case scenario, the simulated real GDP shortfalls in 2050 are 5.6% for the low-income region, 4.4% for the two middle-income regions, and 3.1% for the high-income region. For the world as a whole, this corresponds to a GDP decline of 3.8% or 6.1 trillion.

Impacts of AMR on International Trade

Figure 2 shows the simulated impact of AMR on world trade (exports). By 2050, the volume of real global exports may be below the base-case values by 1.1% in the "low-AMR" scenario and by 3.7% in the "high-AMR" scenario. The pattern of impacts over time follows the pattern of impacts of AMR on GDP. Trade in livestock and livestock products are vulnerable to AMR not only because of impacts on productivity of untreatable disease but also because the "fear factor" results in disruptions of trade (such as bans on imports) in response to disease outbreaks. These effects do not noticeably affect the total trade flows, however, because of the small share of livestock and livestock products in world exports. Instead, the effects of broad declines across all economic sectors dominate the simulation results for trade flows.

Table 2 provides additional details. AMR will also lead to a severe decline in the exports of low-income countries in 2050. In the high-case scenario, the projected declines in real exports equal 5.2% for low-income countries, about 4.2% for the two regions of middle-income countries, and 3.1% for high-income countries. The decline in global trade amounts to 3.7% or 1.7 trillion dollars.

Figure 2: AMR Impact on World Trade

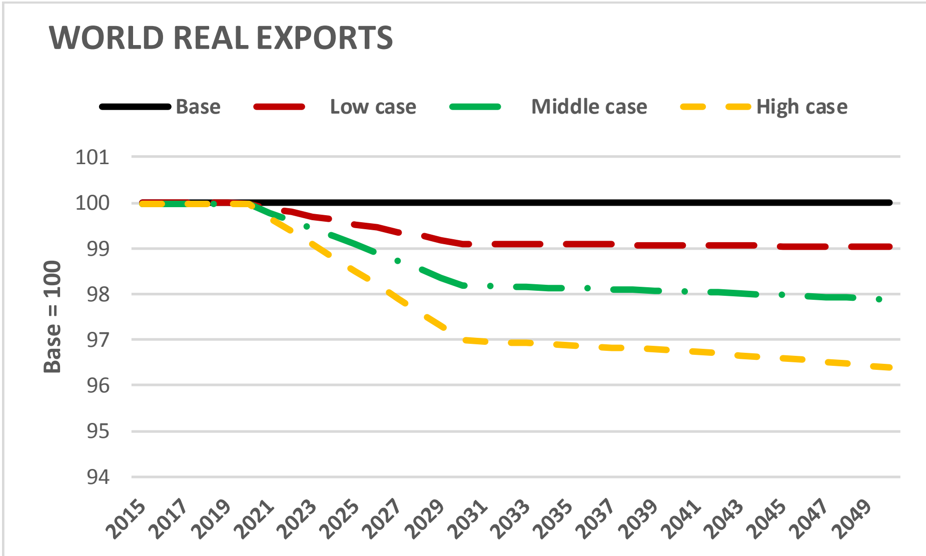
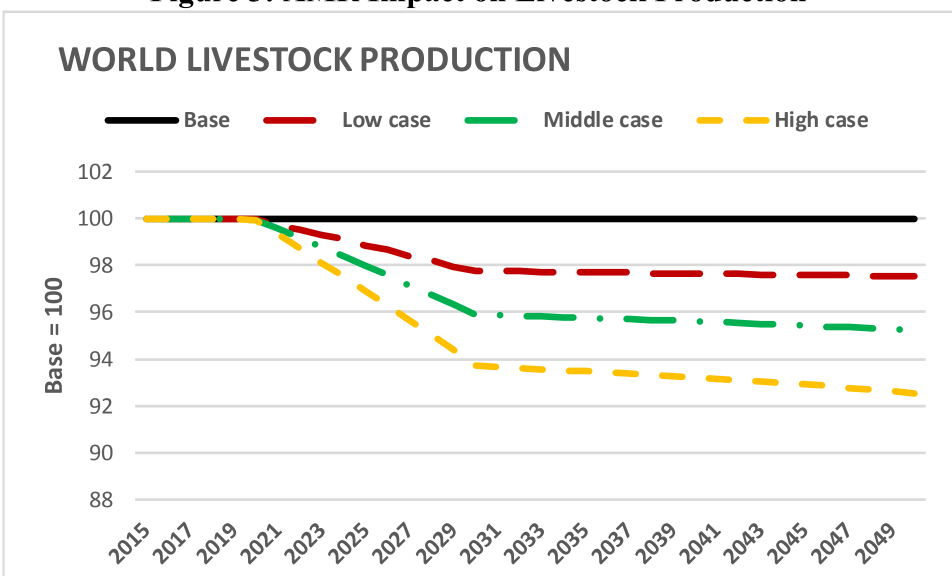


Figure 3: AMR Impact on Livestock Production



Impacts of AMR on Livestock Production

The shocks to the livestock sector were modeled as both a decrease in productivity because of the greater prevalence of untreatable disease and as a reduction in its exports due to restrictions imposed by its trading partners. This trade-related behavior could include a so-called "fear factor" and contributes to the reductions in livestock production by making it less profitable. Livestock is a small part of the global economy (about 2% of world GDP), so its reduced productivity has a minor influence on global indicators. The sector is relatively more important in the economies and exports of low- and lower-middle-income countries than in the wealthier countries, however. Also, the sector plays a substantial development role and makes a major contribution to nutrition, especially for children and women of reproductive age. AMR will worsen animal health, and this is expected to reduce these benefits as well as undermine the welfare of animal owners and others in the sector, both by increasing the variability of incomes because of the more frequent and severe infections and by reducing the levels of incomes.

Table 3 provides the impact across income regions. Trade reductions from a “fear factor” will further reduce livestock production, especially for the low-income countries. For our high case, the decline in livestock production by 2050 is 11.1% for low-income countries, 7% - 9% for middle-income countries, and about 6% for high-income countries. The global decline is 7.6%.

Impacts of AMR on Health Care Expenditures

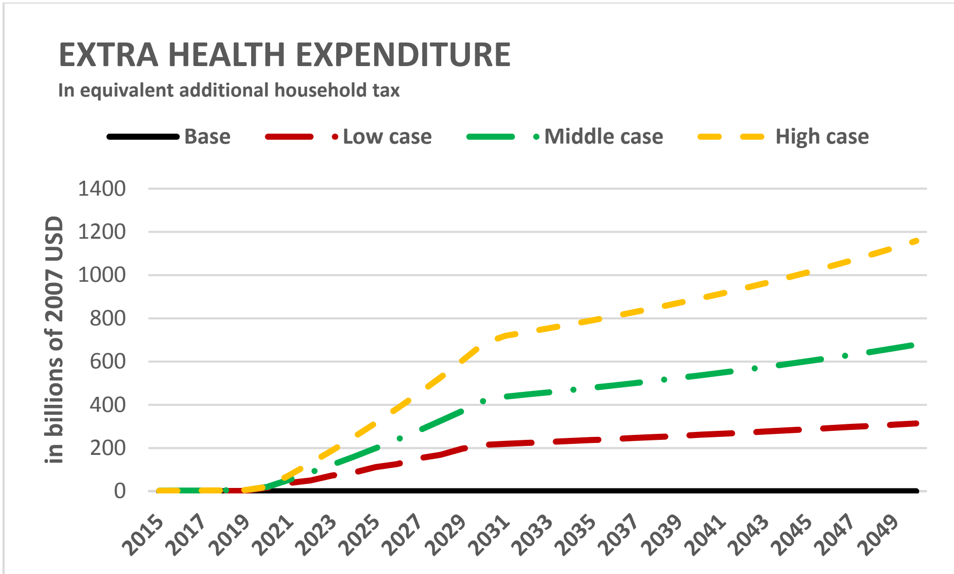
Health care expenditures (both public and private) would increase in tandem with the rising disease burdens. The trends shown in figure 4 illustrate a range of outcomes. As in the GDP and trade effects, the impact on health spending is also strongest for developing countries, where they will rise most dramatically (Table 4). In the high-AMR scenario, health care expenditures in 2050 would be as much as 25.3% higher than the baseline values for low-income countries, 15% -16% higher for middle-income countries, and 6.2% higher for high-income countries. Globally, annual expenditures would be 8% higher than in the base case in 2050.

The additional expenditures in 2050 would be $1.2 trillion annually in the high-AMR scenario. In the low-AMR scenario, the additional health care expenses would be $0.33 trillion in 2050. Since the modeling ensures that these expenditures are not made unless they are financed, there would be a decline in consumption. This decline will mean a reduction in the population’s well-being because resources that could have been devoted to reducing poverty or other goals will have to be diverted to financing the extra costs of a larger health sector coping with a larger disease burden. The cumulative savings of AMR containment (in terms of avoiding extra health care costs) during the entire projection period are about $4 trillion in the low-AMR case and $10.8 trillion in the high-AMR case (see present value tests in Table 5).[13]

Although the increase in spending levels is higher the higher the income of the region, the added expenditures would likely be much more regressive and impoverishing in lower income settings where the additional health expenditures constitute a larger chunk of the household budget and likely out-of-pocket because of the lack of universal health coverage/financial protection.

Figure 4: AMR Impact on Additional Health Care Cost

[13] The two figures are present values of simulated cumulative extra health care expenditures for the period 2017-2050, using a 3.5% discount rate. Use of a discount rate ensures that later amounts have less weight in the total than earlier amounts. For instance, in the high-AMR case, the extra expenditure is $1.2 trillion in 2050. Because 2050 is in the relatively distant future, the present value is $0.35 trillion, which is added to the cumulative total.



Cumulative economic cost

To summarize the cumulative economic cost, we derive the present values (PVs) of the differences for three key economic variables between the AMR scenarios and the baseline, using four alternative social discount rates.[14] These PVs summarize the cost of different degrees of inaction against AMR, as reflected by the three scenarios. In practice, different views and social discount rates are employed by countries and multilateral agencies. The annex in Go et al. (2013) surveys some of the discount rates and their implications for welfare results. In the current analysis, we employ three rates: A low rate of 1.4%, similar to the environment study by Stern (2007), which yields higher PVs for the economic losses caused by AMR, thus spurring societal actions that may protect future generations; an intermediate rate of 3.5%, which is the rate used by HM Treasury (2003); and a high rate of 5.5% (as in Nordhaus 2007). To provide a higher extreme for the PV of the AMR costs, we also compute the results for a rate of zero.

Table 5 summarizes the present values for the cumulative economic impact in terms of losses in GDP and trade, as well as additional health costs. Using a discount rate similar to the one used in climate change for long-term shock, the losses (present value) during the period 2015-2050 may add up to 85 trillion dollars in GDP and 23 trillion dollars in global trade relative to a world without AMR. For an intermediate discount rate of 3.5%, the corresponding figures are still high at 54 and 14 trillion, respectively. In comparison, O'Neill (2016) estimates an economic cost of at least 100 trillion USD, which would match the high case and a discount rate between 0% and 1.4% in this analysis. The O'Neill number comes from the Taylor et al. (2014) study for one of

[14] A social discount rate, which may differ from market rate, is typically used to derive a net present value as a summary measure of the impact of projects with streams of economic benefits and costs that are uneven over time.

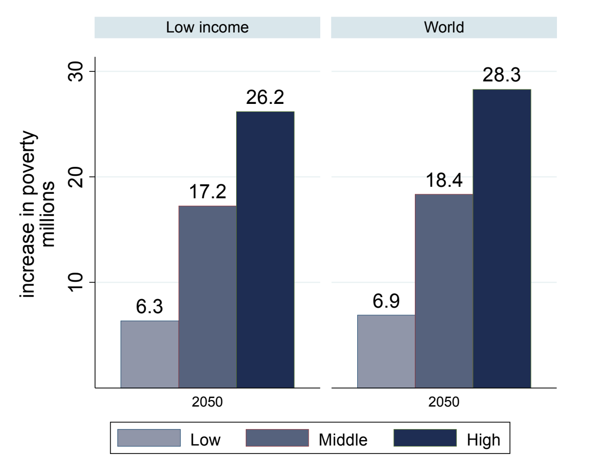
the worst scenarios (sc6) in which the GDP loss is cumulated over 40 years without discounting. Note, however, that O'Neill's figure is only for losses due to the reduction of labor supply.

Impacts of AMR on Poverty

The impact of AMR on economic growth will result in a pronounced increase in extreme poverty. The main reason is the disproportionate impact of AMR on low-income countries, which experience substantial and protracted shortfalls in economic output and other negative economy-wide repercussions from the combined effects of the shocks in labor supply, labor productivity, trade, livestock production, and health care cost. The economic repercussions and effects on factor prices (e.g. wages) of each scenario will alter the income distribution of countries in each income region, from which we calculate the poverty indicators through the GIDD framework.

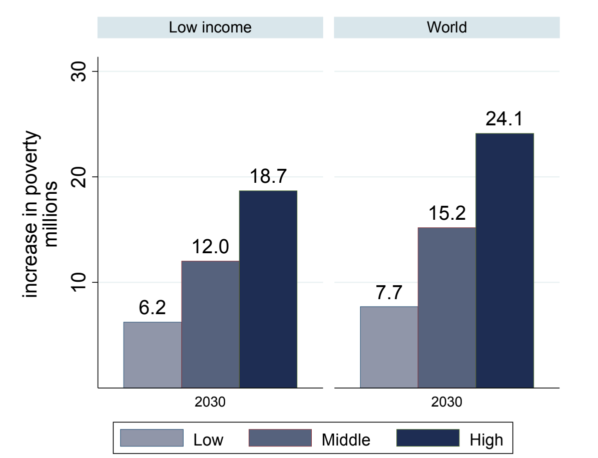
The results suggest the following: Of the additional 28.3 million people in extreme poverty in 2050 under the high-AMR scenario, the vast majority (26.2 million) lives in low-income countries (Figure 5). In the baseline scenario, the world is broadly on track to eliminate extreme poverty (at $1.90/day) by 2030, reaching close to the target of less than 3% of people in extreme poverty. Because of AMR, however, the target would be harder to reach: there could be an additional 24.1 million of extremely poor by 2030 in the high-AMR scenario, of whom 18.7 would be in low-income countries. Tables 6 and 7 have additional poverty estimates.

Figure 5. AMR Impact on extreme poverty (PPP$1.90/day) by 2050 in low-income countries and the world, under low-, mid-, and high-case scenarios



Source: Simulation results and authors' calculations

Figure 6. AMR Impact on extreme poverty (PPP$1.90/day) by 2030 in low-income countries and the world, under low-, mid-, and high-case scenarios



VI. Conclusions

In this paper, we revisit the AMR pandemic, assessing its potential impact. Compared to earlier work, our analysis presents several improvements. We use a recursive dynamic global computable general equilibrium model with a well-defined global database to map the interactions of diseases with multiple channels of impact, covering not only the deterioration of human health and mortality, but also the effects on labor productivity, health care costs, productivity in the livestock sector, and global food trade, which is restricted by fear. We simulate the economy-wide repercussions within economies as well as their cost and spread over time and across countries through trade and resource flows. We also trace the global effects on poverty, especially in developing countries, by employing a microsimulation framework that draws on household survey data with global coverage.

Relative to a world without AMR, the losses during the period 2015-2050 may add up to 85 trillion dollars in GDP and 23 trillion dollars in global trade (in present value). By 2050, the cost in global GDP could range from 1% (low case) to 3.8% (high case). Because of AMR, the target of eliminating extreme poverty would be harder to reach: there could be an additional 24.1 million extremely poor people by 2030 in the high-AMR scenario, of whom 18.7 would be in low-income countries. In general, developing countries will be hurt the most, particularly those with the lowest incomes.

Our analysis shows that the GDP loss due to AMR is most severe for low-income countries. In the high-case scenario, the real GDP of the low-income region in 2050 could fall 5.6% below the baseline; similarly, 4.4% for the two middle-income regions and 3.1% for the high-income region. For the world as a whole, the corresponding decline in GDP is 3.8% or 6.1 trillion dollars.

With regard to trade, AMR will also lead to a severe decline for low-income countries. Compared to a world without AMR, for the high-case scenario, the projected declines in real exports by 2050 equal 5.2% for low-income countries, about 4.2% for middle-income countries, and 3.1% for high-income countries. The decline in global trade amounts to 3.7% or 1.7 trillion dollars.

Likewise, health expenditures will rise most dramatically in developing countries. For the high case, by 2050, the extra health spending induced by AMR over the baseline will come to about 25.3% for low-income countries, 16.0% for the lower middle-income countries, 14.7% for the upper middle-income countries, and 6.2% for the high-income countries. Although the extra spending measured in dollars is higher the higher the income of the region, the added expenditures would likely be much more regressive and impoverishing in lower income settings where the additional expenditures constitute a larger chunk of the household budget and likely out-of-pocket because of the lack of universal health coverage/financial protection.

For the livestock sectors, trade reductions from a “fear factor” will further reduce production, also here most strongly for low-income countries. For our high case, the decline in livestock production by 2050 is 11.1% for low-income countries; 7% - 9% for middle-income countries, and about 6% for high-income countries.

Despite the improvements undertaken in the present analysis, we have several suggestions for future research. Because AMR is an evolving future threat, improving the basis and particulars of the underlying assumptions will yield better estimates of the impact. These include the links between all potential pathogens and infectious diseases, and how these may affect mortality and labor productivity in varied countries; the implications on health care cost, public versus private, by the level of income among countries and households within countries; and better estimates of the effects on livestock production by type of animals. Regarding the methodology, a better framework is needed to model the snowballing effects of multiple factors and their uncertain propagation and interactions.

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Table 1: AMR impact on real GDP relative to a world without AMR

Region by income level	Difference in trillions of 2007 USD			Percent deviation		
	2020	2030	2050	2020	2030	2050
Low Income						
Low case	-0.001	-0.021	-0.064	-0.1%	-1.0%	-1.2%
Middle case	-0.001	-0.044	-0.187	-0.1%	-2.2%	-3.6%
High case	-0.001	-0.071	-0.291	-0.1%	-3.6%	-5.6%
Lower Middle Income						
Low case	-0.003	-0.118	-0.364	-0.1%	-1.0%	-1.3%
Middle case	-0.004	-0.232	-0.750	-0.1%	-1.9%	-2.6%
High case	-0.004	-0.377	-1.268	-0.1%	-3.1%	-4.4%
Upper Middle Income						
Low case	-0.022	-0.312	-0.662	-0.1%	-1.0%	-1.4%
Middle case	-0.025	-0.577	-1.280	-0.1%	-1.9%	-2.7%
High case	-0.025	-0.933	-2.066	-0.1%	-3.1%	-4.4%
Middle Income Total						
Low case	-0.025	-0.431	-1.027	-0.1%	-1.0%	-1.4%
Middle case	-0.028	-0.809	-2.030	-0.1%	-1.9%	-2.7%
High case	-0.028	-1.309	-3.334	-0.1%	-3.1%	-4.4%
High Income						
Low case	0.001	-0.578	-0.664	0.0%	-0.9%	-0.8%
Middle case	-0.014	-1.191	-1.436	0.0%	-1.9%	-1.8%
High case	-0.014	-1.980	-2.481	0.0%	-3.2%	-3.1%
World						
Low case	-0.026	-1.030	-1.754	0.0%	-1.0%	-1.1%
Middle case	-0.043	-2.045	-3.653	-0.1%	-1.9%	-2.3%
High case	-0.043	-3.360	-6.107	-0.1%	-3.2%	-3.8%

Source: Simulation results and authors' calculations

Table 2: AMR impact on trade (real exports) relative to a world without AMR

Region by income level	Difference in trillions of 2007 USD			Percent deviation		
	2020	2030	2050	2020	2030	2050
Low Income						
Low case	0.000	-0.006	-0.018	-0.1%	-1.0%	-1.1%
Middle case	0.000	-0.013	-0.053	-0.1%	-2.0%	-3.3%
High case	0.000	-0.020	-0.083	-0.1%	-3.2%	-5.2%
Lower Middle Income						
Low case	-0.001	-0.029	-0.092	-0.1%	-0.9%	-1.2%
Middle case	-0.001	-0.058	-0.191	-0.1%	-1.8%	-2.5%
High case	-0.001	-0.095	-0.325	-0.1%	-2.9%	-4.2%
Upper Middle Income						
Low case	-0.006	-0.081	-0.173	-0.1%	-1.0%	-1.3%
Middle case	-0.007	-0.150	-0.338	-0.1%	-1.8%	-2.6%
High case	-0.007	-0.244	-0.550	-0.1%	-3.0%	-4.3%
Middle Income Total						
Low case	-0.007	-0.110	-0.265	-0.1%	-1.0%	-1.3%
Middle case	-0.008	-0.208	-0.530	-0.1%	-1.8%	-2.6%
High case	-0.008	-0.339	-0.875	-0.1%	-3.0%	-4.2%
High Income						
Low case	-0.001	-0.153	-0.187	0.0%	-0.9%	-0.8%
Middle case	-0.005	-0.314	-0.405	0.0%	-1.9%	-1.8%
High case	-0.005	-0.522	-0.698	0.0%	-3.1%	-3.1%
World						
Low case	-0.009	-0.269	-0.470	0.0%	-0.9%	-1.1%
Middle case	-0.013	-0.535	-0.987	-0.1%	-1.9%	-2.2%
High case	-0.013	-0.881	-1.655	-0.1%	-3.1%	-3.7%

Source: Simulation results and authors' calculations

Table 3: AMR impact on livestock production relative to a world without AMR

Region by income level	Difference in trillions of 2007 USD			Percent deviation		
	2020	2030	2050	2020	2030	2050
Low Income						
Low case	0.000	-0.002	-0.006	-0.2%	-2.9%	-3.1%
Middle case	0.000	-0.004	-0.015	-0.2%	-5.5%	-7.4%
High case	0.000	-0.006	-0.022	-0.2%	-8.2%	-11.1%
Lower Middle Income						
Low case	0.000	-0.018	-0.043	-0.1%	-2.9%	-3.1%
Middle case	0.000	-0.033	-0.080	-0.1%	-5.2%	-5.8%
High case	0.000	-0.048	-0.123	-0.1%	-7.7%	-8.9%
Upper Middle Income						
Low case	-0.001	-0.027	-0.048	-0.1%	-2.2%	-2.5%
Middle case	-0.001	-0.048	-0.088	-0.2%	-3.8%	-4.6%
High case	-0.001	-0.072	-0.136	-0.2%	-5.8%	-7.1%
Middle Income Total						
Low case	-0.001	-0.045	-0.091	-0.1%	-2.4%	-2.8%
Middle case	-0.001	-0.080	-0.168	-0.1%	-4.3%	-5.1%
High case	-0.001	-0.121	-0.259	-0.1%	-6.5%	-7.8%
High Income						
Low case	0.000	-0.013	-0.016	0.0%	-1.9%	-1.8%
Middle case	0.000	-0.025	-0.033	-0.1%	-3.7%	-3.6%
High case	0.000	-0.040	-0.053	-0.1%	-5.8%	-5.9%
World						
Low case	-0.001	-0.061	-0.114	-0.1%	-2.3%	-2.6%
Middle case	-0.002	-0.110	-0.216	-0.1%	-4.2%	-4.9%
High case	-0.002	-0.167	-0.335	-0.1%	-6.3%	-7.6%

Source: Simulation results and authors' calculations

Table 4: AMR impact on health expenditure relative to a world without AMR

Region by income level	Difference in trillions of 2007 USD			Percent deviation		
	2020	2030	2050	2020	2030	2050
Low Income						
Low case	0.001	0.005	0.014	1.5%	4.3%	5.5%
Middle case	0.001	0.009	0.038	1.5%	7.9%	15.5%
High case	0.001	0.014	0.062	1.5%	11.9%	25.3%
Lower Middle Income						
Low case	0.002	0.013	0.036	0.6%	3.1%	4.4%
Middle case	0.002	0.023	0.075	0.7%	5.7%	9.3%
High case	0.002	0.038	0.128	0.7%	9.2%	16.0%
Upper Middle Income						
Low case	0.007	0.038	0.075	1.0%	3.9%	4.5%
Middle case	0.008	0.066	0.148	1.1%	6.6%	8.9%
High case	0.008	0.104	0.245	1.1%	10.5%	14.7%
Middle Income Total						
Low case	0.009	0.051	0.110	0.9%	3.6%	4.5%
Middle case	0.010	0.089	0.223	1.0%	6.4%	9.0%
High case	0.010	0.141	0.374	1.0%	10.1%	15.1%
High Income						
Low case	0.008	0.162	0.201	0.1%	1.9%	1.7%
Middle case	0.011	0.323	0.429	0.2%	3.9%	3.6%
High case	0.011	0.531	0.735	0.2%	6.3%	6.2%
World						
Low case	0.018	0.218	0.325	0.2%	2.2%	2.2%
Middle case	0.022	0.422	0.690	0.3%	4.3%	4.7%
High case	0.022	0.687	1.170	0.3%	6.9%	8.0%

Source: Simulation results and authors' calculations

Table 5: Cumulative global economic cost of AMR
under alternative social discount rate, in trillion 2007 USD

	Social discount rate			
Scenario	0%	1.4%	3.5%	5.5%
I. GDP				
Low case	-40.4	-29.3	-18.7	-12.7
Middle case	-74.5	-53.7	-34.0	-22.7
High case	-118.6	-85.4	-53.7	-35.7
II. Exports				
Low case	-10.8	-7.8	-5.0	-3.4
Middle case	-19.9	-14.3	-9.0	-6.0
High case	-31.7	-22.8	-14.3	-9.5
III. Household tax to finance extra health expenditure				
Low case	8.0	5.8	3.8	2.6
Middle case	14.8	10.7	6.8	4.6
High case	23.6	17.1	10.8	7.2

Source: Simulation results and authors' calculations

Table 6. Poverty results from AMR (PPP$1.90/day)

	Headcount (%)	Additional poverty (millions of people)			Population millions	Population % of World	Population covered in surveys, %
	Base	Low	Middle	High			
2030							
Low income	24.67	6.2	12.0	18.7	927.7	10.9	69.56
Lower middle income	1.19	1.3	2.8	4.5	3,541.6	41.7	91.06
Upper middle income	0.25	0.1	0.3	0.5	2,781.1	32.7	91.09
Middle income total	0.77	1.4	3.0	5.1	6,322.8	74.4	91.07
World	3.37	7.7	15.2	24.1	8,499.5	100.0	86.35
2050							
Low income	9.80	6.3	17.2	26.2	1,399.9	14.4	70.59
Lower middle income	0.22	0.4	0.8	1.4	4,202.3	43.2	90.91
Upper middle income	0.08	0.1	0.1	0.2	2,835.7	29.2	90.56
Middle income total	0.16	6.8	18.2	27.8	7,038.0	72.4	90.77
World	1.61	6.9	18.4	28.3	9,725.7	100.0	85.87

Source: Simulation results and authors' calculations

Table 7. Poverty results from AMR (PPP$3.10/day)

	Headcount %, (PPP$1.90/day)				Population millions	Population % of World	Population covered in surveys, %
	Base	Low	Middle	High			
2030							
Low income	45.70	46.57	47.47	48.43	927.7	10.9	69.56
Lower middle income	4.92	5.10	5.29	5.54	3,541.6	41.7	91.06
Upper middle income	0.81	0.83	0.85	0.88	2,781.1	32.7	91.09
Middle income total	3.11	3.22	3.33	3.49	6,322.8	74.4	91.07
World	7.47	7.65	7.83	8.06	8,499.5	100.0	86.35
2050							
Low income	23.75	24.44	25.80	26.96	1,399.9	14.4	70.59
Lower middle income	0.87	0.91	0.96	1.02	4,202.3	43.2	90.91
Upper middle income	0.28	0.30	0.30	0.32	2,835.7	29.2	90.56
Middle income total	0.63	0.67	0.69	0.73	7,038.0	72.4	87.42
World	3.99	4.12	4.34	4.54	9,725.7	100.0	85.87

Source: Simulation results and authors' calculations