Assessing the Global Economic and Poverty Effects of Antimicrobial Resistance

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Abstract:

This paper assesses the potential impact of antimicrobial resistance (AMR) on global growth and poverty. We use a global computable general equilibrium model and a microsimulation framework that together capture impact channels related to health, mortality, poverty, 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 AMR, the losses during the period 2015-2050 may add up to 85 trillion dollars in GDP and 23 trillion in global trade (in present value). By 2050, the cost in global GDP could range from 1.0 percent (low case) to 3.7% (high case). AMR is expected to make it harder to eliminate extreme poverty. Under the high AMR scenario, by 2030 an additional 24.1 million would be extremely poor, out of whom 18.7 million live in low-income countries. In general, developing countries will be hurt the most, particularly those with the lowest incomes.

Keywords: pandemics, poverty analysis, dynamic global CGE modeling.

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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). In this regard, 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 scenarios from 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 to use in the simulations.

This paper follows the recent practice but builds and improves on the methodology and assumptions in several critical areas. In particular, it uses a well-defined global general equilibrium model to map the interactions of diseases with health, labor supply, productivity, and the livestock and other sectors within economies over time and across countries through bilateral trade links and resource flows. It traces the global effects on poverty, especially in developing countries, by employing a global microsimulation framework that pulls together and harmonizes the household surveys of over 104 countries. To account for the significant uncertainty about the future progression of AMR, the analysis uses expert microeconomic assessments or meta-studies about key factors on health issues and other areas to form low-, mid-, and high-case scenarios for the severity of its impact. In what follows, we elaborate on the contributions attempted in this analysis.

The magnitude of AMR's future global impact depends on the interactions between the health (care) sector with the rest of the economy within each country and the 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) argue for using a computable general equilibrium (CGE) model to estimate better the full social costs and benefits of the health problem and its policy interventions. The authors apply it to a single economy, the United Kingdom, which by implementation omits global consequences. To the extent that AMR is a global issue, a single-country analysis will fall short of assessing the full costs by omitting cross-country interactions and not addressing how effects differ across different country groupings.

Using first principles, Rudholm (2002) further stressed 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 on the impact of AMR on health and morbidity and calculate global effects by imposing likely changes in labor supplies in different regions. 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] – which are then 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 also do not distinguish producing sectors, comprising mainly of an aggregate output, a single intermediate consumption, and one labor for each region. While noteworthy, the data coverage and quality of the model could have been improved significantly if the authors instead had relied on much more extensive and coherent database like the Global Trade Analysis Project (GTAP) of Purdue University, which has become standard for global CGE modeling. GTAP's SAMs and trade data disaggregate the world into 129 regions (many of which are countries) and 57 production sectors linked by consistent bilateral trade flows.[4] In another global CGE estimation, Keogh-Brown et al. (2009) use the GLOBE model, which makes full use of the GTAP database. They simulate the effect of AMR on the labor supply and productivity, using a sigmoid curve parameterization of the frequency of resistance to estimate the impact of reduced use of antibiotics. However, their analysis relies on an earlier static version of the GLOBE model without the dynamics of later versions. Also, their analysis did not benefit from the microeconomic assessments of AMR's impact on health areas, which were, for example, carefully put together and only available at a later date by Taylor et al. (2014). Finally, none of the previous studies examines the poverty implications of AMR.

To improve on the previous modeling efforts, the analysis of the global impact of AMR in this study uses a dynamic and more recent version of the GLOBE model, GLOBE_DYN (McDonald et al. 2007 and 2013). GLOBE_DYN is a multi-sectoral, multi-country and multi-agent dynamic recursive CGE model that is consistent with neoclassical growth theory, and makes full use of version 8.1 of the GTAP Database version (Narayanan, Aguiar, & McDougall, 2012). 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 when the economy is shocked, compared to the baseline. The ex-ante analysis 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 the Millennium Development Goals (Lofgren et al. 2013). Such models and analysis are also

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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).

increasing 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 linked to a database with harmonized household surveys for over 130 countries from the Global Income Distribution Dynamics (GIDD), a global microsimulation model tool developed at the World Bank (Bourguignon & Bussolo 2013) and Bussolo et al. 2010). 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 Ardnt 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 (KCMP 2014), leading to an increase in public health spending 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 in 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 to the world and the income groups, including countries belonging to low-income, lower middle-income, upper middle-income, and high-income groups. Because the list of possible policy programs and interventions against AMR are many, it is beyond the scope of the paper, but O'Neill (2016) and World Bank (2017) provide excellent discussion. In fact, each infectious disease such as HIV, tuberculosis, or malaria that are likely affected by AMR will need its individual support strategy (see, for examples, Borowitz et al. 2003; Baris 2004; and Lindsay et al. 2004). Even so, 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.

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 effects on poverty. Section 2 presents the methodology. Section 3 describes the baseline and section 4 the counterfactual simulations and their assumptions. Section 4 summarizes the results. And conclusions are outlined in section 5.

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 employ GLOBE_DYN, a global computable general equilibrium (CGE).[6] GLOBE_DYN, the recursive-dynamic version of GLOBE, is a multi-period, multi-sectoral, multi-country and multi-agent model that is consistent with neoclassical growth theory.

The model is calibrated to the GTAP Database V8.1 (Narayan et al. 2012), which is globally consistent, multi-regional, and multi-sectoral with 2007 as the base year. It includes data on production, consumption, investment, and trade. For poverty analysis, data for the 129 countries/regions are mapped into four income regions based on World Bank country classification: low income, lower middle income, higher middle income, and high income (a geographical classification such as Sub-Saharan Africa will mix higher income countries like South Africa and low-income countries like Niger). As microeconomic assessments of the effects of AMR become more available, further disaggregation and differentiation of countries are certainly possible. The database is also aggregated into six sectors (crops, livestock, mining, processed food, manufacturing, and services.) The model is a member of a family of CGE models that model trade relationships using principles described in the 1-2-3 model (de Melo and Robinson, 1989; Devarajan, *et al.*, 1990) or the standard multisector version for developing countries (Dervis, de Melo, and Robinson, 1982; and Lofgren and Robinson, 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 comparable with the long-term economic projections by the Organization for Economic Co-operation and Development (OECD), such as Gros and Alcidi (2013). It also tracks the future labor supply which is taken as the working-age population (15-64 years of age), without AMR, from the United Nations (2013) medium fertility scenario.

The baseline in the recursive-dynamic model is generated by solving the model on an annual basis with exogenous updates for the following indicators between each solution (imposed as levels or GDP shares): GDP, investment, the fiscal balance (also called government savings), the trade balance (often a deficit in many developing countries), the total supplies of non-capital

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[6] GLOBE has comparative-static (single-period) and recursive-dynamic (multi-period) versions. For detailed descriptions, see McDonald et al. 2007 and 2013, respectively.

factors (skilled and unskilled labor, land, and natural resources), and the volume of government expenditure. In each period, the fiscal balance is cleared via adjustments in household income taxes (treated as lump-sum tax) since government spending is exogenous. The exogenous trade balance is 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 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 to the levels determined in the baseline. Therefore, in the base case, with endogenous GDP and investment, the model reproduces the baseline scenario. In the AMR scenarios, GDP and investment respond to the policy shocks.

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 livestock, increases in government public spending on health care, which is financed by a lump-sum tax on households to maintain fiscal balance (thus reducing household consumption), and an increase in trade and transport margins due to a “fear factor”. 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 in a limited set of macroeconomic indicators by how they differ from the results for 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 works of Bourguignon et al. (2003, 2008) and extends the single-country macro-micro framework in Bourguignon and Savard (2008) to a global setting.[7] Recently, it was further 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 effects of human capital formation (see Cruz et al. 2017). In the global framework, GIDD links a

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

large amount of household data across countries to a global computable general equilibrium (CGE).[8]

In the analysis, GLOBE_DYN provides economy-wide implications of macroeconomic projections under the baseline and different AMR scenarios. The changes in relative prices and factor rewards, including wages of skilled and unskilled workers, under the different scenarios are used as the inputs into the GIDD. The household survey samples are reweighted to take into account the changing household composition due to demographic trends (e.g. aging, education or skill attainment, etc.) as well as effects of AMR on labor supply. When fed with the relative and factor prices as well as the allocation of labor after accounting for the levels after the AMR shocks, the behavioral model at the household level essentially regenerates the household sample surveys across regions with a pattern of household employment, income, and consumption as well as relevant poverty and inequality measures that are consistent with the new prices and wages due to AMR.

III. The Baseline - A World Without AMR

The baseline characterizes "a world without AMR." This scenario means that it follows the long-term economic growth projections at the World Bank. To generate a baseline, information is needed about GDP growth, investment growth, factor supply growth, the evolution of the internal balance (fiscal budget deficit or surplus) and the evolution of the external balance (current account balance). These variables are set exogenously, according to growth forecasts and model closures, and market clearing conditions are appropriately defined:

- When GDP is exogenous, total factor productivity by region must be endogenous. It is assumed that the productivity shock affects value added.

- The model is investment driven, with the level of investment by region set to match *Global Economic Prospects* (GEP) projections at the World Bank. In the closure setting, this requires that investment is held constant. The savings rate by region adjusts to generate the savings needed to meet the level of investment. Note, GEP forecasts of investment are available until 2017, and the baseline is from 2008 to 2050. It is assumed that the ratio of investment to GDP is at a steady state value of 0.20 in 2030 and beyond, with a linear adjustment between 2018 and 2030.

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[8] In single country applications of microsimulation such as the Philippines (Bourguignon and Savard 2008) or South Africa (Go et al. 2010), the availability of data enables an income-generation model with an elaborate occupational-choice behavioral model 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, urban or rural area, family size, head of household (or not), etc.

- The fiscal deficit, or internal balance, is a fixed share of GDP, accounting for changes in GDP over time. The closure in the base model has the internal balanced fixed at the base value. For baseline updates, the internal balance is fixed as a share of GDP in each period. Government expenditures is a fixed share of GDP, and household income taxes adjust, taking account the fixed government savings and the endogenous government revenue from other taxes.[9]

- The external balance is fixed and adjusts each period to reach a steady state of zero 100 years from the base year. The closure in the base model has the external balanced fixed, and the exchange rate adjusts.

- In factor markets, the total supply of land, skilled labor, and unskilled labor are held constant and assigned forecast values. The supply of land and natural resources are fixed in the baseline at the base level. The supplies of skilled and unskilled labor increase at rates found in UN projections of the growth in working age population. The nominal wage adjusts to satisfy equilibrium in these factor markets.

- Capital available each period is determined from private investment and depreciation. [10]

IV. Defining the AMR Shocks in the Counterfactual Simulations

Given that AMR presents a current and future threat, how much of its economic resources should the world invest in reducing this threat? The answer depends on the economic costs of the impacts that AMR is expected to have. The simulations of impacts reported in his 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. 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 for the severity of its impact to address the significant uncertainty about the future progression of AMR. As mentioned, three sets of key factors are defined to form a low-, mid-, and high-case scenario to provide a range of 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;

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[9] Changes in other tax revenue arise because the tax rate is constant and the quantity against which the tax rate is applied adjusts. For example, tariff revenue will change when imports change, given the exogenous tariff rates. In the case of household income taxes, the tax rate adjusts to ensure that total government revenue equals total government spending, given the fixed budget deficit.

[10] See McDonald et al (2013b) for the equations used in the capital updating each period.

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 on labor supply, investment, and output over time, and relative prices of various sector goods. These factors in turn change trade flows between regions and the world relative prices of commodities, 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, across 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, such as the deterioration of human health and labor productivity, increases in health care costs; declines in livestock production; and restrictions on global food trade arising from fear. Moreover, among the studies, we only use those that can be considered within the economic framework described above, giving emphasis to estimates that can be used as inputs and assumptions of general equilibrium models. As to the timing of the shocks, the assumptions for labor supply are described under item 1 below; for the other channels, the shocks start after 2020 and reach full force in 2030 (as defined below. Our assumptions for the different channels were defined as follows:

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 very well-defined projections; like our study, theirs also extends to 2050. According to their study, increased mortality results 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 contribute to the spread and worsening of three infectious diseases: HIV, Tuberculosis, and Malaria.

The reductions in labor supply under the different scenarios are defined in efficiency units and include the effects of morbidity (reflected in a loss of days due to illness). The low-case scenario corresponds to the “sc1” case in the RAND study for 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 Rand report also distinguishes between 0% resistance rate (sc0) and the current rate of resistance (sc00). After testing, however, the implied labor supplies in the zero rate are numerically indistinguishable from the projected levels of working population for the world or regions selected. Hence, we do not make the delineation relative to the baseline simulation. Finally, the mortality figures are mapped from the geographical regions of the RAND study into World Bank income regions for our study. More

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[11] The list of possible policy programs and actions against AMR are many and beyond the scope of the paper, but they are available in O’Neill (2016) and World Bank (2017).

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 total number of deaths corresponds to 2.3 percent 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, which wiped out 40 to 60 percent 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 to1.5 percent. In Burns et al. (2006), the fall in labor productivity that the authors calibrated in the case of the avian flu range from 1.4 percent for high-income countries to 1.9 percent for Sub-Sahara. In World Bank (2006) and McKibbin and Sidorenko (2006), the potential output losses imply a much higher (or more than double) productivity decline. Hence, we use a figure of 1.5 percent for our low case and scale it up to 3 and 4.5 percent for the middle and high cases, respectively.

Rise in healthcare cost

KCMP (2014) projects that prolonged and secondary healthcare costs, such as the extra number of hospital days, could rise significantly. According to our assessment, these costs may double the share of total health expenditure in GDP, which in 2010 were as follows for our regions: low-income 5.4 percent, lower middle-income 4.2 percent, higher middle-income 6.1 percent, and high-income 12.7 percent. 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 lump-sum 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 percent, middle case 5 percent, and high case 7 percent.

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 percent, middle case 10 percent, and high case 15 percent.

V. Results

Impacts of AMR on the Global Economy

The results of the simulations of AMR impacts on global GDP in 2017-2050 are shown in Figure 1. In the optimistic "low-AMR" scenario, the global economic output is projected to be 1.0 percent lower by 2030 and 1.1 percent lower by 2050 than the baseline case. In the pessimistic "high-AMR" scenario, the global economic output would be 3.2 percent lower in 2030 and then would fall short further so that in 2050, world GDP would be 3.8 percent smaller than in the base case.[12] In the "low-AMR" case, the costs, as measured by the reduction in GDP from 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 endure over time.

Given that the simulations were done using a dynamic, multicountry, multisector, general equilibrium model with neoclassical growth features, economies do adjust to price signals caused by the AMR shocks. These adjustments lead to a reallocation of resources and to new investments (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 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 decade to 2050.

The costly impacts of AMR are not distributed equally among countries at different levels of per capita income. As seen in Table 1, the negative impact in low-income countries is more pronounced than in high-income countries. The two main reasons for this difference are a higher

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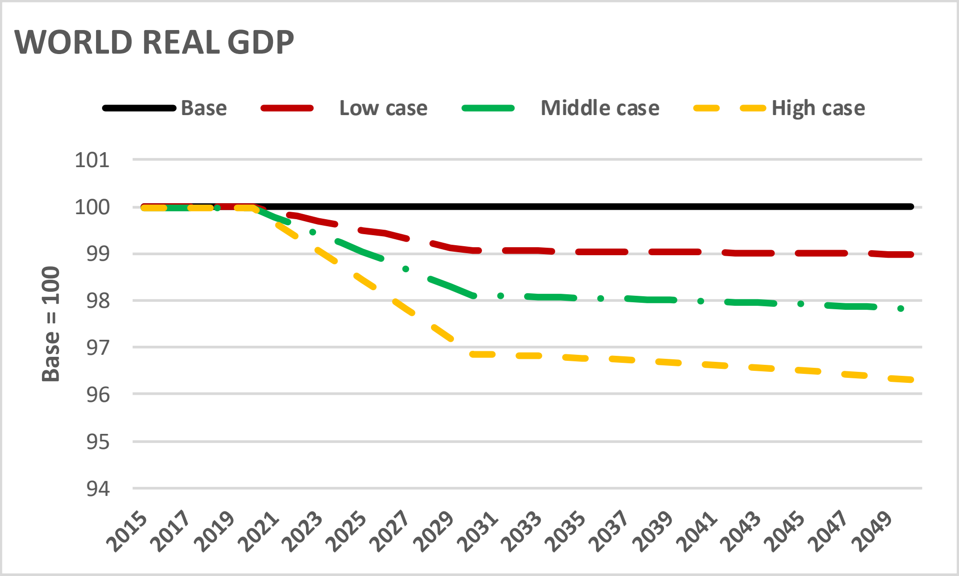
[12] The "high-AMR" case presented here is similar to the results of the modelling done for the UK Review on AMR, "Antimicrobial Resistance: Tackling a Crisis for the Health and Wealth of Nations, December 2014: including (1) Taylor et al. Estimating the Economic Costs of Antimicrobial Resistance: Model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

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 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 3.8% for the high-income region. For the world as a whole, the corresponding decline in GDP is 4% or 6.5 trillion.

Figure 1: Substantial and Protracted Shortfalls in Global Economic Output

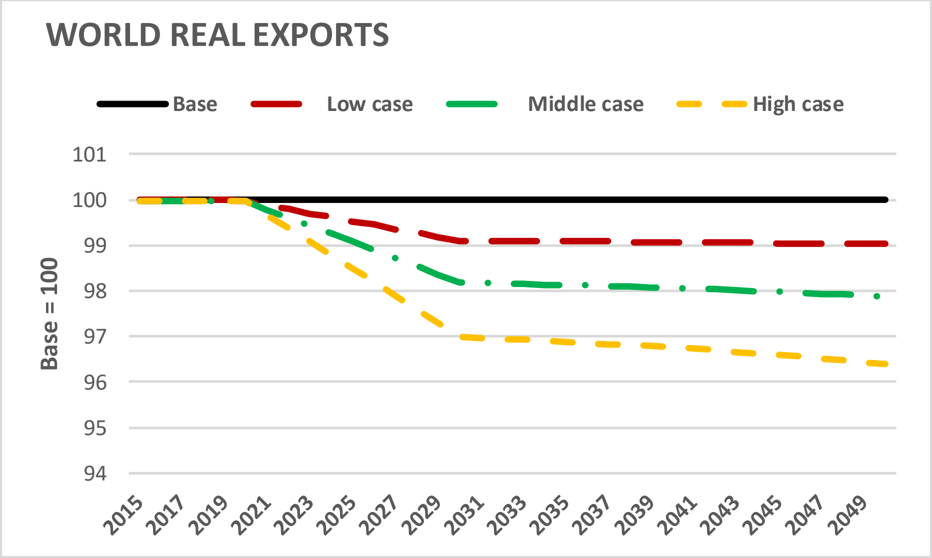


Impacts of AMR on International Trade

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 percent in the “low-AMR” scenario and by 3.8 percent 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 impact 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 materially affect the simulations of 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 5.1% for low-income countries, 4.2% for middle-income countries, and 3.7% 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

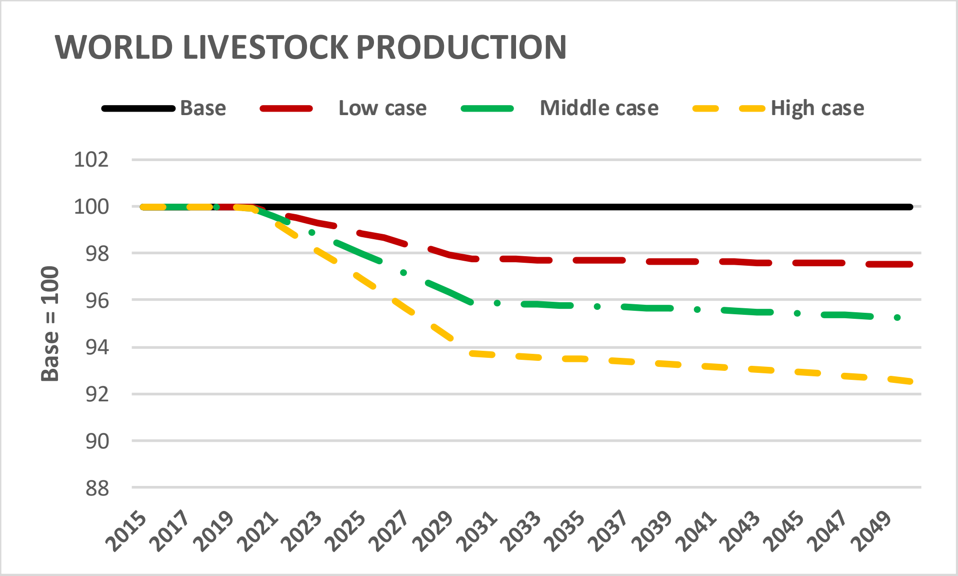


Impacts of AMR on Livestock Production

The shocks to livestock production 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. Livestock is a small part of the global economy (about 2 percent of world GDP), so its reduced productivity has a minor influence on the overall simulations results. 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 the animals' 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% for low-income countries; 7-9% for middle-income countries, and about 6% for high-income countries.

Figure 3: AMR Impact on Livestock Production



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 3 illustrate a range of outcomes. In the high-AMR scenario, health care expenditures in 2050 would be as much as 25 percent higher than the baseline values for low-income countries, 15 percent higher for middle-income countries and 6 percent higher for high-income countries. Globally, annual expenditures would be 8 percent 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 expenditure would be $0.33 trillion annually 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 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 extra health care costs during the entire projection period are $4 trillion if the low-AMR case is avoided and $1.1 trillion if the high-AMR case is avoided.[13]

Like the GDP and trade, health expenditures will rise most dramatically in developing countries (Table 4). For the high case, by 2050, the extra health spending induced by AMR over the baseline will come to about 20% for low-income countries, 15% for the lower middle-income

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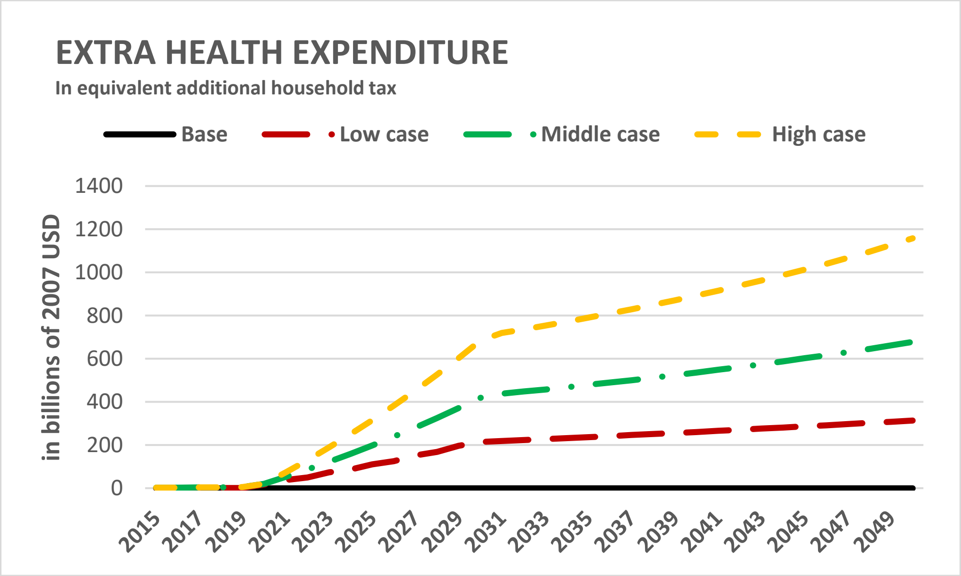
[13] Both are the present value of extra health care expenditures in the simulations, cumulative total in 2017-2050, and using a 3.5% discount rate. Use of a discount rate ensures that later amounts have less weight in the total than earlier amounts. For instance, in the high-AMR case, the extra expenditure is $1.2 trillion in 2050. Because 2050 is in the relatively distant future, the present value is $0.35 trillion, which is the amount that is included in the $1.1 trillion total.

countries, 12% for the upper middle-income countries, and 6% for the high-income countries. Dollar-wise, the amount is higher the higher the income of the region.

Figure 4: AMR Impact on Additional Health Care Cost



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 scenarios and the baseline, using four alternative social discount rates.[14] In our analysis, 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 percent, similar to the environment study by Stern (2007), which yields higher PVs for the economic losses caused by AMR to spur societal actions and protect future generations; an intermediate rate of 3.5 percent, which is the rate used by HM Treasury (2003); and a high rate of 5.5 percent (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 loss regarding output, trade, livestock, or additional health cost. 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 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,

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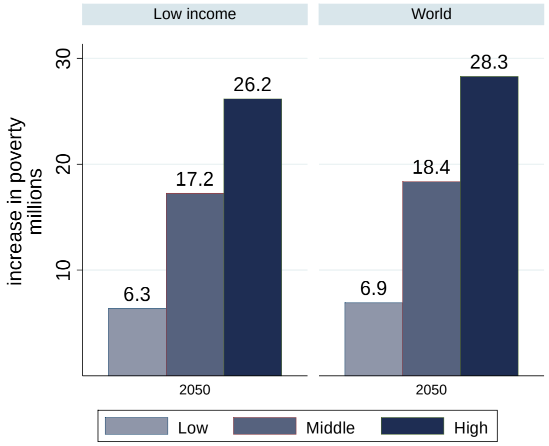
[14] A social discount rate, which may differ from market rate, is typically used to derive a net present value as a summary measure of the impact of projects with streams of economic benefits and costs that are uneven over time.

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 RAND (2014) study for one of the worst scenarios (sc6) in which GDP loss is cumulated over 40 years without discounting. Note, however, that that figure is only for losses due to the reduction of labor supply.

Impacts of AMR on Poverty

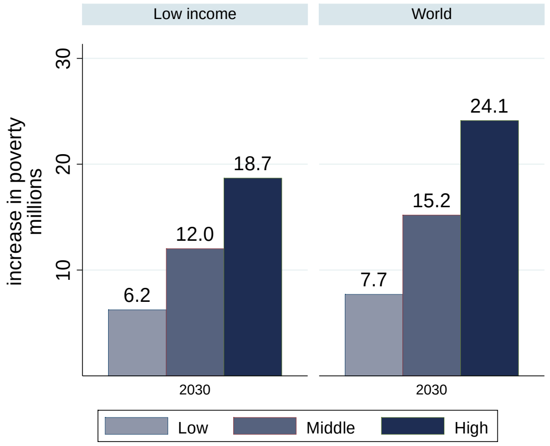
The impact of AMR on economic growth will result in a pronounced increase in extreme poverty. The main reason is the disproportionate impact of AMR on the economics of low-income countries (see Table 1) which experience substantial and protracted shortfalls in economic output. Of the additional 28.3 million people living in extreme poverty in 2050 in the high-AMR scenario, the vast majority (26.2 million) would live in low-income countries (Figure 4). 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 percent of people living in extreme poverty. Because of AMR, however, the target 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. Table 4 has 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 scenario



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 scenario



VI. Conclusions

In this paper, we revisit the AMR question resulting from a growing stock of bacteria resistant to antibiotics by assessing its potential impact with several contributions. We use a global computable general equilibrium model with a well-defined global database to map the interactions of diseases with several channels of impact. We examine not just the deterioration of human health and mortality issues but also labor productivity, rising health care cost, a decline in livestock, and fear-induced restrictions on global food trade. We simulate the economy-wide repercussions within economies as well as their cost and spread over time and across countries through bilateral trade links and resource flows. We also trace the global effects on poverty, especially in developing countries, by employing a global microsimulation framework that pulls together and harmonizes the household surveys of over 104 countries.

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 in global trade (in present value). By 2050, the cost in global GDP could range from 1 percent (low case) to 3.7% (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. Other key findings from our analysis:

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 3.8% for the high-income region. For the world as a whole, the corresponding decline in GDP is 4% or 6.5 trillion.

AMR will also lead to a severe decline in the exports of low-income countries in 2050. Compared to a world without AMR, for the high-case scenario, the projected declines in real exports equal 5.1% for low-income countries, 4.2% for middle-income countries, and 3.7% 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 20% for low-income countries, 15% for the lower middle-income countries, 12% for the upper middle-income countries, and 6% for the high-income countries. Dollar-wise, the amount is higher the higher the income of the region.

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% for low-income countries; 7-9% for middle-income countries, and about 6% for high-income countries.

References:

Ahmed, Amer S., Marcio Cruz, Delfin S. Go, Maryla Maliszewska, and Israel Osorio-Rodarte. 2016a. "How Significant Is Africa's Demographic Dividend for Its Future Growth and Poverty Reduction?" *Review of Development Economics.* DOI:10.1111/rode.12227 (online version).

Ahmed, Amer S., Delfin S. Go, and Dirk Willenbockel. 2016b. "Global Migration Revisited: Short-Term Pains, Long-Term Gains, and the Potential of South-South Migration." World Bank Policy Research Working Paper 7628, April 2016.

Arndt, Channing and Jeffrey D. Lewis, 2001. "The HIV/AIDS pandemic in South Africa: sectoral impacts and unemployment," *Journal of International Development*, 13(4): 427-449.

Baris, E. and M. Ezzati. 2004. "Should Interventions to Reduce Respirable Pollutants be Linked to Tuberculous Control Program?" *British Medical Journal.* 329:1090-3.

Borowitz, B., E. Wiley, F. Saadah, and E. Baris. 2003. "Responding to HIV/AIDS in East Asia and Pacific Region: A Strategy Note for the World Bank. Discussion Paper, the World Bank.

Bourguignon, François, and Maurizio Bussolo. 2013. "Income Distribution in Computable General Equilibrium Modeling." In Dixon, P.B. and D.W. Jorgenson, eds., *Handbook of Computable General Equilibrium Modeling.* North Holland, Elsevier B.V., pp. 1383–1437.

Bussolo, Maurizio, Rafael E De Hoyos, and Denis Medvedev. 2010. "Economic Growth and Income Distribution: Linking Macro-Economic Models with Household Survey Data at the Global Level." Article. *International Journal of Microsimulation* 3 (1): 92–103. http://ideas.repec.org/a/ijm/journl/v3y2010i1p92-103.htm

Bourguignon, François, and L. Savard. 2008. "Distributional Effects of Trade Reform: An Integrated Macro-Micro Model Applied to the Philippines." In F. Bourguignon, L. Pereira, and M. Bussolo (Eds.) *The Impact of Macroeconomic Policies on Poverty and Income Distribution.* Palgrave and the World Bank, Washington DC. Pp. 177-212.

Bourguignon, François and Luiz Pereira da Silva. 2003. *The Impact of Economic Policies on Poverty and Income Distribution – Evaluation Techniques and Tools.* Oxford University Press.

Burns, Andrew, Hans Timmer, and Dominique van der Mensbrugghe (2006). "The Potential Economic Impacts of the avian flu: an assessment using the World Bank's Linkage Model." mimeo. The World Bank.

Cruz, Marcio, Delfin S. Go, and Israel Osorio-Rodarte. 2017. "Modeling the poverty and distribution effects of human capital formation across countries: using a new database about labor skills and wages in GIDD 2.0." *forthcoming.*

de Melo, James and Sherman Robinson. 1989. “Product Differentiation and the Treatment of Foreign Trade in Computable General Equilibrium Models of Small Economies.” *Journal of International Economics*, Vol 27, pp 47-67.

Dervis, K., J. de Melo, and S. Robinson (1982). *General Equilibrium Models for Development Policy.* Cambridge University Press and World Bank, New York.

Devarajan, Shantayanan and Sherman Robinson. 2013. “Contribution of Computable General Equilibirum Modeling to Policy Formulation in Developing Countries.” In Dixon, P.B. and D.W. Jorgenson, eds., *Handbook of Computable General Equilibrium Modeling.* North Holland, Elsevier B.V., pp. 277-301.

Devarajan, Shantayanan, Delfin S. Go, Sherman Robinson, and Karen Thierfelder. 2011. “Tax Policy to Reduce Carbon Emissions in a Distorted Economy: Illustrations from a South Africa CGE Model." *The B.E. Journal of Economic Analysis and Policy,* 11(1)1: 1-21. Also, as World Bank Policy Research Working Paper 4933, May 2009.

Devarajan, Sherman, Jeffrey D. Lewis, and Sherman Robinson. 1990. “Policy Lessons from Trade-Focused, Two-Sector Models”, *Journal of Policy Modeling*, Vol 12, pp 625-657.

Go, Delfin S., Marna Kearney, Vijdan Korman, Sherman Robinson, and Karen Thierfelder. 2011. “Wage Subsidy and Labor Market Flexibility in South Africa.” *Journal of Development Studies*, 46(9), 2011, pp. 1481-1502. Also, as Economic Research Southern Africa (ERSA) Working Paper 114 (January 2009) and World Bank Policy Research Working Paper 4871 (March 2009).

Go, Delfin S. and Pradeep Mitra. 1999. “Trade Liberalization, Fiscal Adjustment and Exchange Rate Policy in India.” In Ranis, G. and L. Raut (Eds.) *Trade, Growth, and Development.* North-Holland, Amsterdam, pp. 229-72.

Gros, D. and C. Alcidi, 2013. *The Global Economy in 2030: Trends and Strategies in 2030*, Brussels: Centre for European Policy Studies (CEPS).

Kambou, Gerard, Shantayanan Devarajan, and Mead Over, 1992. “The Economic Impact of AIDS in an African Country: Simulations with a Computable General Equilibrium Model of Cameroon,” *Journal of African Economies,* 1(1): 109-130.

KPMG. 2014. *The Global Economic Impact of Anti-microbial Resistance.* A KCMP LLP study at the United Kingdom.

Keogh-Brown, Marcus Richard, Richard D. Smith, John W. Edmunds, and Philippe Beutels. 2010. “The macroeconomic impact of pandemic influenza: estimates from models of the United Kingdom, France, Belgium and The Netherlands.” *The European Journal of Health Economics.* 11(6):543-54.

Keogh-Brown, Marcus, Scott McDonald, Richard Smith, Melisa Martinez-Alvarez, and Jo Coast. 2009. “Global CGE modeling of antibiotic resistance: an application of the

GLOBE model. Paper presented to the 12th Annual Conference on Global Economic Analysis, June 10-12, 2009, Santiago, Chile.

Hertel, T., R. Keeney, M. Ivanic, and L.A. Winter. 2009. “Why Isn’t the Doha Development Agenda More Poverty Friendly?” *Review of Development Economics.* 13:543-59.

Laxminarayan, R., T. Van Boeckel and A. Teillant (2015), “The Economic Costs of Withdrawing Antimicrobial Growth Promoters from the Livestock Sector”, OECD Food, Agriculture and Fisheries Papers, No. 78, OECD Publishing. http://dx.doi.org/10.1787/5js64kst5wvl-en

Lindsay, S., M. Kirby, E. Baris, and R. Bos. 2004. “Environmental Management for Malaria Control in the East Asia and Pacific Region. Discussion Paper, the World Bank.

Lofgren, Hans, martin Cicowiez, and Carolina Diaz-Bonilla. 2013. “MAMS – A Computable General Equilibrium Model for Developing Country Strategy Analysis.” In Dixon, P.B. and D.W. Jorgenson, eds., *Handbook of Computable General Equilibrium Modeling.* North Holland, Elsevier B.V., pp. 159-276.

Lofgren, Hans and Sherman Robinson. 2002. “A standard computable general equilibrium (CGE) model in GAMS. Microcomputers in Research 5. International Food Policy Research Institute (IFPRI), Washington DC.

McDonald, S., K. Thierfelder, and S. Robinson. 2007. “GLOBE: A SAM-based global CGE model using GTAP data,” Economics Working Paper, US Naval Academy, Annapolis, USA.

McDonald, S., K. Thierfelder, and T. Walmsley. 2013. “GLOBE2_DYN: Technical document and user guide.” Processed.

McKibbin, W.J. and A.A. Sidorenko (2006), “Global Macroeconomic Consequences of Pandemic Influenza,” Lowy Institute for International Policy, Sydney Australia.

Narayanan, B., Aguiar, A. & McDougall, R., 2012. *Global Trade, Assistance, and Production: The GTAP 8 Data Base,* Center for Global Trade Analysis: Purdue University, West Lafayette IN.

O’Neill, J., 2016. “The Review on Antimicrobial Resistance, Tackling Drug-Resistant Infections Globally: Final Report and Recommendations.” Independent review, commissioned by UK Prime Minister David Cameron in 2014.

Rudholm, Niklas. 2001. “Economic implications of antibiotic resistance in a global economy,” *Journal of Health Economics*, 21: 1071–1083.

Smith, Richard D. Milton Yagoa, Michael Millarb, Jo Coastc . 2005.” Assessing the macroeconomic impact of a healthcare problem: The application of computable general equilibrium analysis to antimicrobial resistance, *Journal of Health Economics*, 24: 1055–1075.

Taylor, J., M. Hafner, E. Yerushalmi, R. Smith, J. Bellasio, R. Vardavas, T. Bienkowska-Gibbs, and J. Rubin. 2014. *Estimating the economic costs of antimicrobial resistance – model and results.* Cambridge, UK: RAND Europe.

Timmer, M.P. (Ed.). 2012. "The world input-output database (WIOD): Contents, sources and methods." WIOD Working Paper Number 10.

United Nations, 2013. *World Population Prospects: The 2012 Revision, DVD Edition.,* New York: United Nations, Department of Economic and Social Affairs, Population Division.

World Bank, 2016. *Global Economic Prospects 2016,* Washington DC: World Bank.

World Bank, 2014. *The Economic Impact of the 2014 Ebola Epidemic – Short and Medium Term Estimates for West Africa.* A World Bank Report.

World Bank, 2006. *Global Development Finance: Review, Analysis and Outlook* (vol 1). Washington DC: World Bank.

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