Malaria in Ghana: Integrated Macroeconomic and Epidemiological-Demographic Impact Assessment

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Abstract

Aims: To develop a macroeconomic modelling framework for health policy analysis which captures the feedback effects between health, economic and demographic impacts of infectious disease.

Methods: This study presents early results from an innovative modeling methodology which, for the first time, fully integrates a dynamic macroeconomic Computable General Equilibrium (CGE) model with malaria transmission and demographic population models. The economic model is a dynamic macroeconomic simulation model with multiple sectors and multiple households. The households are distinguished by their geographical location in Ghana (ecological zones), by urban and rural location and by malaria prevalence. The malaria transmission model and demographic population model are fully integrated into the economic model such that health, demographic and economic changes feedback on each other dynamically. This modeling framework is therefore able to estimate the full macroeconomic impact of health related changes in labour supply, changes in exposure to malaria due to migration/urbanization and capture changes in the structure of the population in the short, medium and long term and to contrast non-economic (health) and macroeconomic effects.

Data: Underlying the economic model is a malaria-focused social accounting matrix for Ghana. Household and labour force survey data, together with geographical estimates of malaria from the Malaria Atlas Project (MAP) were used to disaggregate the 42 different labour and 19 geographically distinct households. Clinical outcome data from the Swiss Tropical Institute's Open Malaria model has been used in conjunction with the MAP data to parameterize the malaria transmission model and UN population statistics were used to parameterize the demographic model.

Results: We illustrate the integrated framework by demonstrating the potential economic impact of malaria elimination in Ghana. The disease malaria burden in Ghana constitutes around 1.4% of real GDP over 2011-2030 and GDP per capita effects: short term: +0.6%; long term: -0.8% were estimated together with demographic population estimates which suggest malaria elimination may increase Ghana's population by 9.3 million person years and avert 800,000 deaths between 2011-2030.

Conclusions: Our simple results illustrate the importance of our integrated methodology. CGE modelling is an important tool for determining the potential economic gains of malaria elimination in

sub-Saharan Africa, not least because of its ability to perform consistent analyses of both health and macroeconomic shocks within the same framework. This integrated framework could prove an important tool for policy analysis and enable the design of policies to reduce the health and macroeconomic disease burdens of malaria in the short, medium and long term.

Introduction

In spite of the major achievements, Malaria remains a major contributing factor to disease burdens around the world and African nations in particular. The World Health Organization's (WHO) World Malaria Report (WMR) estimates that 216 million episodes of malaria took place in 2010, and that this resulted in 655,000 malaria deaths[1]. The report also estimates that 81% of malaria episodes and 91% of malaria deaths took place in the Africa region. Malaria represents a particular problem for children under the age of five. Hence, the WMR report estimates that children under five accounted for 86% of all malaria deaths in 2010. While global malaria-specific mortality rates reportedly have been reduced by 26% between 2000 and 2010, the challenge of controlling malaria and reducing human suffering remains monumental.

International funding for the fight against Malaria have been forthcoming on an unprecedented scale over the past decade. Following the establishment of the Global Fund to Fight AIDS, Tuberculosis and Malaria (GFATM) in 2002 and the quinquinnial President's Malaria Initiative (PMI) in 2005, increased bilateral and multilateral donor funding have allowed for a massive scaling-up of Malaria interventions in developing nations. Combined with the global drive towards achieving the 2015 Millennium Development Goal of having "halted by 2015 and begun to reverse the incidence of malaria and other major diseases" (MDG 6C), 50 countries (out of 99) are on track to reduce malaria incidence rates by 75 percent in 2015[2].

Major achievements have been made for a number of developing nations, and some have already achieved or are on track to achieving eradication. Nonetheless, a large group, including a number of Sub-Saharan African nations, seem to continue to experience high (and in some cases increasing) malaria-related incidence and mortality rates in spite of major scaling-up efforts[1]. Moreover, signs of donor fatigue are starting to emerge. The combination of weak health-system capacity and problems relating to operational implementation has meant that, over recent years, major donors, including the Global Fund have been scaling-back funding for Malaria treatment and prevention interventions in developing countries such as Ghana[3]. As the deadline for the MDGs is approaches, it is important to consider whether current levels of Malaria interventions are sustainable over the longer-term.

The key issue is whether developing nations, themselves, have the resources (and political vision) to continue to maintain current intervention levels in the face of declining future international political

attention and donor funding.[i] In this context, it is important to have a clear understanding about the twin 'health' and 'macroeconomic' disease burdens. In developed countries, there is a long-standing discussion about whether health interventions should be considered a right or whether they should be conditioned by economic considerations. Among developing nations, the need for economic consideration and sustainability assessment is a basic condition. Hence, while there is a moral imperative to pursue interruption and elimination of malaria transmission out of health concerns, there is also an urgent need to understand the (current and future) macroeconomic costs and consequences of the accompanying scaling-up efforts which are required.

This study attempts to assess both health and macroeconomic malaria-related disease burdens by establishing a fully integrated epidemiological-demographic-macroeconomic (EDM) simulation model framework, which allows for assessing both clinical health outcomes and macroeconomic consequences of potential interruption and elimination of malaria transmission. "Fully integrated" means that it captures for two-way feedback between the epidemiological-demographic and macroeconomic sub-models. This model framework can therefore analyse both health and macroeconomic shocks with a focus on both health and macroeconomic policy outcomes.

Apart from the clear advantages of such a multi-disciplinary model framework, the construction of a fully integrated EDM simulation model is a unique methodological development. The existing macroeconomic simulation literature on infectious diseases (HIV/AIDS and Malaria) includes several attempts to combine epidemiological-demographic (ED) and macroeconomic models, but they have always focused on modelling one-way transmission mechanisms from clinical health outcomes to economic outcomes, with no allowance for economic feedback effects to health outcomes (HIV/AIDS (survey)[4,5]. In contrast, our integrated model framework allows for economic feedback effects to clinical outcomes through migration between regions with varying malaria transmission intensity.

Background

Malaria in Ghana

Malaria is perennial and hyper-endemic in all parts of Ghana, putting the entire population of 24.4 million (2011) at risk. High transmission occurs year round, with increased transmission during the rainy seasons from April/May to July/September. The number of reported malaria cases varied from 3.1-3.5 million per year during 2001-2008[6] but has subsequently increased to 4.2 million in 2011[7]. Among hospital admissions, malaria reportedly accounts for 18% of all deaths and 30% of deaths among children under five (ibid.) The recent increase in reported malaria cases may be due to inconsistent measurement due to recent adoption of improved methods of diagnostic testing[1].

[i] The global malaria-related 2011 funding gap was $2.8bn of the estimated resource requirement of $5.1bn [2.]

Nonetheless, controlling malaria continues to represent a major challenge to Ghanaian authorities – a challenge which, if surmounted, has the potential to significantly reduce human suffering.

Malaria Control and Treatment in Ghana

The availability of unprecedented external resources has changed the strategy of the National Malaria Control Program (NMCP) in Ghana markedly over the past decade[3]. Following the establishment of the Global Fund to Fight AIDS, Tuberculosis and Malaria (GFATM) in 2002, Ghana adopted Artemisinin-based Combination Therapies (ACTs) as first-line antimalarial drugs and Sulphadoxine-Pyremethanine (SP) and Intermittent Preventive Treatment of Pregnant women (IPTp) as national policies during 2002-2004. Following the selection of Ghana as a President's Malaria Initiative (PMI) country in December 2007, NMCP adopted an aggressive 2008-2015 strategy calling for a 75% reduction in malaria morbidity and mortality by 2015 through massive scaling-up of malaria control initiatives. The instruments and targets (Table 1) included (1) universal coverage with Insecticide-Treated Nets (ITNs), (2) rapid scale-up of Indoor Residual Spraying (IRS), (3) universal coverage of pregnant women with IPTp treatment, (4) Early diagnosis of malaria using microscopy or rapid diagnostic test (RDT), and (5) prompt and effective treatment with ACT therapies.

Table 1. Malaria Indicators and Targets

	2003 DHS	2006 MICS	2008 DHS	2011 MICS	2014 Targets	2015 Targets
Proportion of households with ≥1 ITN	3%	19%	42%	49%	NA	100%
Proportion of children <5years who slept under an ITN the previous night	4%	22%	39%	39%	85%	85%
Proportion of pregnant women who slept under an ITN the previous night	3%	NA	27%	33%	85%	85%
Proportion of women who received ≥2 doses of IPTp during last pregnancy in last 2 years	0	28%	44%	65%	85%	100%
Proportion of children <5years with fever in last two weeks who received ACT treatment	NA	3%	12%	18%*	85%†	90%†

Source: USAID (2013)

More recently the original 5-year PMI program was extended for another 5-year period (2009-2014) in 2008; the Affordable Medicines Facility-malaria (AMFm) was launched in April 2009 to expand access to affordable ACTs ; Ghana secured a large 5-year grant from the Global Fund in October 2009 ($138 million) for IRS scaling-up during 2010-2014; And government legislation was liberalized in 2009 to classify ACTs as over-the-counter medicines allowing licensed chemical sellers (as well as pharmacies) to sell ACTs directly to customers.

The massive scaling-up of malaria control initiatives by NMCP has led to concomitant improvements in key indicators of coverage and up-take, including (1) increased household adoption of ITN bed nets

(2011: 49%), (2) increasing proportion of children <5 years sleeping under an ITN bed net (2011: 39%), (3) increasing proportion of pregnant women receiving ≥2 doses of IPTp during pregnancy (2011: 65%), and (4) increasing proportion of children <5 years with fever receiving ACT treatment (2011: 18%) (see Table 1). While the indicators suggest some success in terms of roll-out and uptake, the numbers are low compared to the intermediate 2014 targets (85% roll-out and uptake) and the final 2015 targets (universal coverage of ITNs and uptake of IPTp for pregnant women, 90% uptake of ACT treatment for individuals of all ages, and 85% uptake of ITNs for pregnant women and children <5 years) (see Table 1). More importantly, persistently high and increasing levels of hospital admissions indicate that the advances in roll-out and coverage have not had the desired impact and, so far, have failed to reduce malaria transmission and clinical outcomes.

Apart from the lack of measurable impacts on clinical outcomes, the ability to sustain efforts into the future is made uncertain by health-system problems including deficiencies in case management, limited access to skilled care, inconsistent supplies of ACTs, public sector procurements of ACTs that have not been WHO pre-qualified, and health workers without proper training and/or clinging to outdated or unapproved treatment regimens. These health-system challenges are likely to be compounded by emerging donor fatigue. External funding is likely to decline due to the expiration of the AMFm pilot project in December 2012 and the expiration of the Global Funds 5-year IRS grant in 2014 combined with limited scope for seeking additional Phase 2 funds due to procurement problems in implementing Phase 1[3]. PMI re-focused their attention in 2013 towards strengthening the quality of malaria case management at the Community-based Health Planning and Services level (ibid.) Nonetheless, the combination of health-system weaknesses, donor fatigue, and underperforming coverage indicators call into question the ability of NMCP to meet their broader set of 2015 targets for scaling-up of malaria control.

Ghana is currently at an important juncture in the battle against malaria. Whilst progress has been made, the availability to fund and implement the necessary control initiatives to continue towards malaria elimination is in question. At such a time, policy analysis tools which can analyse the health and macroeconomic consequences of sustained interventions and disease burdens, could be of vital importance to inform domestic policy makers and external donors about the need to increase domestic resource allocation and sustain external funding.

Economic Implications of Malaria

Over the past decade, there has been an increasing focus on measuring the macroeconomic economy-wide impact of preventing disease and maintaining good health. Macroeconomic impact assessments of infectious diseases have mainly employed growth regressions and applied

macroeconomic simulation models. The seminal studies in the health-focussed empirical growth literature[8,9] argued for including health as a complement to education in order to account more broadly for human capital. Two separate types of empirical health variables have subsequently been employed: (1) general measures of health conditions such as life expectancy at birth[8,9,10,11,12,1314,15,16,17,18,19,20,21], and (2) disease-specific measures of disease burden and transmission intensity for individual epidemics such as Malaria[16,22,23,24,18,25,26,27,28].

Malaria-related growth-regression studies , pioneered by Jeffrey Sachs and co-authors , has generally found that the most affected countries experience reduced growth rates of between -1/4% p.a.[23] and -1.3% p.a.[18]. Based on more recent studies, a one standard deviation decline in malaria risk has been found to have the following macroeconomic effects: (1) *GDP per capita* increases 1.6-1.9 fold in global samples[25,27] and 3.6 fold based in an African sample[28]; (2) *GDP growth* increases by 1.5% p.a. over a 40 year period (1960-2000) = 2-fold increase in GDP per capita in 2000 in an African sample (Bhattacharyya 2009).[ii] These macroeconomic impacts are generally much higher than what is found in other types of macroeconomic impact assessments e.g. using macroeconomic simulation models (see below). The Malaria-related growth literature has generally be criticized on two accounts: (1) it employs poor empirical proxies for the underlying theoretical Malaria transmission intensity variables, and (2) the empirical Malaria variables are highly correlated with a Sub-Saharan African dummy, and may proxy for other tropical diseases or health-related control variables[16,26]. Hence, the very large impact estimates of Malaria disease burden, derived from the health-focussed growth regression literature, are not to be trusted.

Macroeconomic Simulation Models of Infectious Disease/Malaria

Macroeconomic economy-wide simulation-based assessments of health burdens and health-related interventions have gained momentum over the past decade. Two types of macroeconomic simulation models have been employed: applied growth models and Computable General Equilibrium (CGE) models. Health burdens associated with individual diseases and illnesses are oftentimes considered too small to generate important macroeconomic spillover effects. As a consequence, macroeconomic economy-wide models have mainly been applied to assess either (1) disease-specific epidemics, or (2) large-scale environmental problems with multiple-disease impacts. The latter multiple-disease applications are generally relatively crude with little attention to modelling of individual diseases. They typically employ an Integrated Assessment Model (or similar) to study the interaction between climate change and disease-transmission (including Malaria) based on simplistic reduced form econometric relationships with rainfall and temperature[30,31,32].

[ii] Macroeconomic growth regressions and malaria-specific household survey data collection have also been applied to measure Ghana-specific macroeconomic and household-level effects[29].

The disease-specific macroeconomic simulation literature typically pays more attention to the modelling of health. The literature focuses on three types of epidemics: (a) flu, (b) HIV/AIDS, and (c) Malaria; and it relies on three types of macroeconomic simulation methodologies: (a) Computable General Equilibrium (CGE) models, (b) applied growth models, and (c) macro-econometric simulation models. The relatively narrow literatures on flu epidemics[33] and Malaria epidemics[5] has a unique focus on CGE model applications, while the much broader literature on HIV/AIDS epidemics include both CGE model, applied growth model, and macro-econometric model applications (for a survey, see[4]). Epidemiological-demographic (EPI-DEM) models have been used for measuring morbidity- and mortality-effects in most simulation-based macroeconomic assessment studies of *disease burdens* associated with HIV/AIDS epidemics. More recently, increasing knowledge about HIV/AIDS transmission mechanisms and infection thresholds in concert with the availability of effective treatment options has prompted the development of more sophisticated EPI-DEM models, and allowed for EPI-DEM based macroeconomic assessment studies of *treatment interventions* based on a growth model framework for six Sub-Saharan African countries[34], and a CGE model framework for Botswana[35,36].

Only one non-standard macroeconomic simulation-based impact assessment of Malaria disease burdens and regular Malaria interventions have been published so far, and this study did not rely on proper epidemiological modelling[37] but employed cross-sectional reduced-form econometric relations between disease burden and socio-economic outcomes (based on Global Burden of Disease data). They found that Malaria elimination in Zambia only has level effects on GDP per capita: -1.5% in the short term and +2.0% in the long term. While such simulation results underpins the suggestion that previous point estimates of macroeconomic disease burdens, derived from health-focussed growth regressions, are likely to be misleading, the lack of a proper epidemiological foundation means that these simulation results are, themselves, likely to be suspect. The lack of proper modelling is, most likely, due to the lack of suitable ED models, i.e. models which account for Malaria transmission and which provides demographic outputs in a format which is amenable to analysis within macroeconomic simulation models. A key issue in this context is that available Malaria-specific ED models are specified as continuous time models and with a focus on 'vector cycles' (i.e. mosquito life times) of 14 days or less[38]. As a consequence, these models do not communicate well with applied macroeconomic models, which are typically specified as discrete time models with annual or generational time intervals.

In spite of the apparent incompatibility of ED and macroeconomic models, there has recently been an increased focus on measuring the macroeconomic consequences of Malaria and Malaria-related interventions. To the knowledge of the authors, no articles have yet been published in this area.

Nevertheless, while other current projects maintain a singular focus on specifying one-way transmission mechanisms (from Malaria to economic outcomes) and measuring standard economic impacts on production, income distribution and growth[5], the current paper aims to leapfrog the satellite model approach and produce a fully integrated Epidemiological-Demographic-Macroeconomic (EDM) model which allows for two-way endogenous feedback effects between the Malaria-focussed ED model and the macroeconomic CGE model. The frequency mismatch which is mentioned above, is solved by (1) employing an epidemiological sub-model specification with closed form solutions, and by (2) applying a semi-equilibrium epidemiological sub-model methodology with bi-weekly time intervals which reduces the number of discrete time intervals to 26 per year.

A literature survey of methodologies for macroeconomic impact assessment of HIV/AIDS[4] concludes that among the different types of macroeconomic simulation models, "… the CGE model methodology provides the best starting-point for developing a proper evaluation tool" (ibid.) Applied growth models are mainly seen as useful for illustrating conceptual issues, while macro-econometric model applications, which typically rely on short-term Keynesian-type model specifications, is an inappropriate tool for measuring the long-term consequences of HIV/AIDS. The same argument applies to Malaria: Malarial infections have long-term consequences, especially for young individuals, which precludes the use of short-term macro-econometric models (economy-wide macro-econometric models are also typically precluded due to a lack of long-term time series data in developing countries.) Moreover, proper assessment of Malaria disease burdens and Malaria-related interventions requires the use of (annual and regional) epidemiological-demographic models – something which is difficult to integrate within aggregate neo-classical growth models and Overlapping Generations (OLG) models with their focus on long generational periods (20-30 years). The CGE model methodology therefore provides the best starting point for developing a proper impact assessment tool for Malaria disease burdens and Malaria-related interventions.

Model framework

The current model framework consists of three separate epidemiological, demographic, and macroeconomic models, which are integrated into one unified Epidemiological-Demographic-Macroeconomic (EDM) simulation model framework. The model is dynamically recursive, with separate state variables for each of the three sub-models: (1) multiplicity of infection and prevalence of immunity (Epidemiology); (2) population composition (Demography); (3) primary factor stocks (Macroeconomic). Each of the three sub-model specifications is discussed, below.

Epidemiological Model

Our epidemiological model for malaria transmission is a compartmental model with two compartments: A human compartment and a vector (mosquito) compartment. The model structure resembles the classical Ross-MacDonald malaria transmission model[38], but has been expanded to include a MacDonald-Dietz type specification of malaria transmission which accounts for superinfections, i.e. multiple infections with different types of parasites. Furthermore, the model has been extended to account for epidemic risks from non-immune individuals entering into the population (mostly migrants from low-prevalence areas and children below the age of 10).

The epidemiological model methodology is specified to model prevalence rates (e.g. for human and mosquito populations). Hence, actual measurement of the number of infected individuals is only achieved when the epidemiological human prevalence measures are applied to the demographic population projections. In addition to prevalence rates, the epidemiological model allows for the measurement of clinical outcomes for infected individuals. Currently, the epidemiological model accounts for simple morbidity effects (expected number of uncomplicated spells of malaria/person/year) and mortality effects (expected rate of malaria-related mortality/person/year).

Epidemiological malaria models typically use the entomological inoculation rate (EIR) as the key indicator for transmission intensity and clinical outcomes. Our model is no exception and specifies clinical outcomes, i.e. morbidity and mortality effects, as a function of the EIR. Our measurement of clinical outcomes is age- and gender-specific, and their measurement is based on data derived from prior simulations with the Swiss Tropical Institute (STI) model which allowed for the derivation of age- and gender-specific relationships between central EIR values and clinical outcomes (including the two types of clinical outcomes which are accounted for in our current model specification).

A key goal in our epidemiological model specification was to capture the heterogeneity of transmission across different geographical regions of Ghana. Our basic sub-division was based on ecological characteristics (Coastal, Forest, and Savannah) and rural-urban location. However to account for transmission heterogeneity within the ecological zones, e.g. between the western swamps and other parts of Coastal areas where transmission intensity is much lower, we introduced a further geographical subdivision between low, medium, and high prevalence. Adding an epidemiological model for the Greater Accra Metropolitan Area (GAMA) required us to calibrate distinct epidemiological transmission models for 19 geographical areas. Model calibration relied on parameter values from the literature[39]. Specifically, we imposed uniform exogenous values on eight parameters across the 19 regions: 1. clearance rate for super infections, 2. human biting rate, 3. infectiousness of humans to mosquitoes, 4. mortality rate for mosquitoes, 5. incubation period for

mosquitoes, 6. infectiousness of mosquito bites on humans with immunity, 7. infectiousness of mosquito bites on humans without immunity, and 8. reversion rate for immunity.

In order to model differences in transmission between our 19 geographical areas, two sets of parameter values were calibrated based on location-specific information about human prevalence rates (PrevH) and entomological inoculation rates (EIR): 1. mosquito population, and 2. the ratio between acquired immunity and force of infection. The parameter calibration was based on ArcGIS data which were obtained from the Malaria Atlas Project (MAP). For model calibration, the most recent 2010 data on human prevalence (PrevH) and entomological inoculation rates (EIR) was used.

Demographic Model

Our demographic model is a fully-specified dynamically-recursive model with fertility, mortality, and (domestic and international) migration specifications. The model is specified with annual time intervals and calibrated to quinquennial UN population projections for Ghana (UN 2013b). The detailed model distinguishes between one-year age groups between the ages 0-100, between gender types and keeps track of population groups in our 19 distinct geographical areas.

The calibration of the demographic model involved the exogenous imposition of (interpolated) quinquennial UN parameter values for fertility rates, while age- and gender-specific mortality rates were calibrated to ensure consistency with the quinquennial UN population projections for 2000-2100. The calibration of international migration was based on (1) UN assumptions about net international migration patterns over 2010-2100, and (2) region-specific immigration and emigration patterns from the 2000 Ghana Census[40].

The UN population projections do not account for domestic regional migration patterns. Hence, our calibration of domestic migration patterns between our 19 distinct geographical areas had to rely on reasonable assumptions about future domestic migration patterns. Based on the 2000 and 2010 Census Reports[40,41], it was clear the urban population share had grown from 32.0% in 1984, to 43.8% in 2000, and to 50.9% in 2010. This amounts to growth rates of 0.73%-points p.a. during 1984-2000, and 0.71 %-points p.a. during 2000-2010. Given the very high levels of urbanization over the past 25 years, it is clear that future urbanization rates (within our time horizon 2010-2100) will be smaller. We therefore assumed that rural-urban migration rates will decline linearly from 0.71 %-points p.a. in 2010 to 0.0%-points p.a. in 2100, implying stable urbanization levels of 82.6% beyond 2100. We calibrated our geographical domestic rural-urban migration patterns using regional domestic migration data from the 2000 Ghana Census[40] and this assumed counterfactual migration pattern.

CGE Model

The dynamically-recursive CGE model for Ghana is based on a static CGE model, which was extended to include a set of factor accumulation equations. Primary factors of production include labour and capital, and separate factor accumulation equations were added for the 42 different types of labour (distinguished by two gender types, rural-urban location, three ecological zones + GAMA, and three skill levels) and one type of capital. The labour factor accumulation equations are linked to the labour factor ownership of 19 individual household types – and the labour factor ownership is in turn linked to the household-specific demographic projections for the 19 distinct geographical areas (where the effective labour force is measured by the working age population (15-64 years) corrected for gender-specific participation rates and absenteeism due to malaria-related episodes – currently, a rough estimate of 4 lost workdays/episode is employed).

The CGE model for Ghana is based on the 'IFPRI standard model' which is fully documented elsewhere[Error! Bookmark not defined.] and is a static multi-sector simulation model with multiple production activities and goods markets for individual sectors such as agriculture, manufacturing, and services. There are four main forms of economic 'agents' in the model: firms, consumers, government, and foreign agents.

CGE Model Calibration

The static CGE model for Ghana was calibrated from a 2004 Malaria-focussed Social Accounting Matrix (SAM) data set[42]. The new Malaria-focussed 2004 Ghana SAM was based on another 2004 Ghana SAM[43], but with a new household breakdown based on the 19 geographical areas from the Demographic model: one GAMA household + 18 household types categorised according to rural-urban location, three ecological zones (Coastal, Forest, Savannah), and three malaria transmission intensity levels (low, medium, high human prevalence – human prevalence is closely correlated with location-specific EIR values, and is therefore a good proxy for transmission intensity).

The new household breakdown was achieved by deriving income and expenditure patterns from the 2005/06 Ghana Living Standards Survey (GLSS5). The construction of different household types according to location in different transmission intensity areas had to rely on the classification of the 110 districts of the GLSS5 survey. After review of the district-level information, it was decided to use 33% and 47% human prevalence rates as cut-off points between low, medium, and high prevalence areas (to ensure an equal distribution of districts in the three categories- 36/37/37). To facilitate numerical computation, the 2004 Malaria-focussed SAM was aggregated to calibrate a CGE model with 10 production activities and 10 retail commodities (agriculture, industry, utilities, housing and infrastructure, transportation, trade, public administration, health, education, other services).

Counterfactual Growth Path

Following the calibration of the static CGE model to the 2004 SAM data set, factor accumulation equations were added, including labour growth and capital accumulation equations, to turn the static model into an enhanced dynamically-recursive CGE model framework. Then a pre-simulation targetting historical Ghana growth patterns over the period 2004-2010 was run. Focus was on targeting of nominal and real GDP and the pre-simulation established 2010 as the base year for undertaking simulations of the Ghana malaria epidemic over the period 2011-30.

In order to measure the impact of the policy scenarios we established a counterfactual growth path over the period 2011-30. The expected future growth path was modelled on the basis of the historical Ghana growth performance during 2006-2010, which included an average 25.4% nominal GDP growth rate and an average 6.6% real GDP growth rate[44]. The targeting of nominal and real GDP growth rates were achieved by letting the GDP deflator act as price numeraire, and by allowing the model to determine the underlying expected change in Total Factor Productivity (TFP) in the Ghanaian economy over the projection horizon.

Scenarios

This paper analyses the macroeconomic implications of having an unchanged malaria burden over the coming 20 year period (2011-30) in Ghana compared with the economic impact of successful malaria elimination in Ghana. The purpose of the analyses is to measure the economic loss which Ghana is suffering from the health burden imposed by current malaria transmission levels. A set of three scenarios are analysed: (1) elimination of malaria-related morbidity (episodes of uncomplicated malaria), (2) elimination of malaria-related mortality, and (3) the combined elimination of malaria-related morbidity (uncomplicated malaria episodes) and mortality. The results of these scenarios are analysed and discussed in the next section.

Results

The following section outlines the measurement of disease burdens in Ghana (macroeconomic and health). The first sub-section discusses the macroeconomic impacts of our malaria elimination simulations, while the second sub-sequent sets forth the health and demographic implications.

Macroeconomic impact

Indicators for the macroeconomic disease burden (Table 3) indicate that the malaria disease burden in Ghana is likely to be around 1.4% of real GDP over the period 2011-2030. The dynamic impact on real per capita GDP varies from +0.6% in the short term (2011) to -0.8% in the long term (2030). The negative long-term per capita impact reflects that malaria affects disadvantaged regions

disproportionally, and that the surviving population is likely to earn below-average wages. In addition, their survival is likely to reduce average productivity in the broader workforce due to slowly accumulating capital equipment and declining returns to scale of labour inputs. This argument is akin to the 'gift of the dying' argument in the HIV/AIDS growth regression literature, although it does not account for potentially increasing fertility which may further reduce long term per capita incomes[45].

While the signs and dynamic evolution of per capita impacts differ, our measured orders of magnitude are similar to the short-/long-term impacts (-1.5%/+2.0% of GDP level) found in the previous macroeconomic simulation study for Zambia (Ashraf, Lester and Weil 2009). In contrast, orders of magnitude differ strongly from the long-term impacts (1.6-3.6 fold increase in GDP level from one std. dev. reduction) found in growth regression studies on global and African sub-samples[25,46,28]. While malaria transmission intensities differ globally and this study limits attention to core long term transmission mechanisms to labour market outcomes (without specific attention to other mechanisms such as educational attainment, fertility decisions, etc.), the difference suggests that the growth regression literature overstates the macroeconomic disease burden of Malaria.

While the smaller macroeconomic health burden does not affect the moral imperative to intervene based on health concerns, it does suggest that macroeconomic rewards from interruption of malaria transmission may not be able to cover the required intervention costs. This suggests that long-term continuation of current levels of malaria control (without health-system improvements and measurable reductions in clinical outcomes) is likely to be costly to the wider Ghanaian society. Given that the Ghanaian government is faced with a multitude of development challenges – and given that donor support seems to be waning – this indicates that the Ghanaian government may be faced with some tough choices over the coming years: Either re-direct domestic funding to ensure sustainability of the current malaria control roll-out strategy, or scale back the malaria control efforts.

Returning to the measurement of macroeconomic disease burden, our indicators suggest that, overall, morbidity effects account for about two-thirds (0.9%-points) while mortality effects account for one-third (0.45%-points) of the long-term GDP impact over 2011-2030 (Table 3). The Morbidity-related disease burden is equally split between people being unwell and not attending work (0.47%-points) and family caring for unwell children (0.44%-points). Nevertheless, the dynamic evolution of per capita GDP indicates that long-term illness-related morbidity (2030: 0.55%-points) is more important than long-term caretaker morbidity (2030: 0.48%-points). Ghana is currently undergoing a demographic transition with declining fertility rates and declining shares of younger age cohorts. This is reflected in the long-term demographic composition of the population. Hence, while population expansion implies that more children are born and in need of care (leading to an absolute increase in

caretaker morbidity), the declining share of the younger age cohorts means that caretaker morbidity declines relative to disease-related morbidity. In spite of the declining long-term importance of caretaker morbidity, the numbers indicate that caretaker morbidity continues to account for a major share of the overall macroeconomic disease burden.

Table 3: Malaria Disease Burden in Ghana

	Morbidity (sick)	Morbidity (caretaker)	Mortality	Total
NPV of GDP				
2011-2030	0.90%	0.47%	0.44%	0.45% 1.36%
GDP per capita				
2011	0.73%	0.37%	0.37%	-0.12% 0.62%
2020	0.90%	0.46%	0.44%	-1.04% -0.15%
2030	1.02%	0.55%	0.48%	-1.83% -0.82%

Source: Own calculations

Figure 1 presents the trajectory of the absolute annual GDP impact measured in millions of Ghana Cedis (GHC) in Net Present Value (NPV) terms. The results indicate that the mortality disease burden accumulates faster than the morbidity disease burden over our 20 year simulation. Initially, mortality effects are minute, but since the absolute impact of mortality effects accumulate over time (in contrast to morbidity effects), mortality effects grow rapidly and are therefore likely to dominate over the very long term (beyond our 20 year time horizon). More specifically, mortality effects accumulate since, in addition to the removal of malaria-related workforce mortality in the current period, the survivors from previous periods continue to contribute to the workforce over future periods (unless they die from other causes). This implies that in a longer term simulation, mortality effects are expected to dominate morbidity effects in absolute terms. Overall, the results indicate that the increased labour supply from reduced morbidity effects and an increased labour force may raise Ghana's real GDP in 2030 by around 3.5 million GHC in NPV terms.

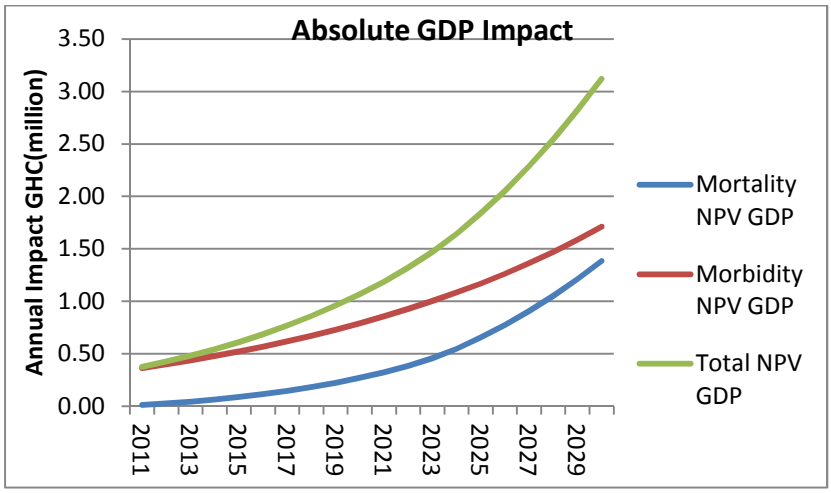

Figure 1 Macroeconomic Disease Burden (absolute impacts million GHC in NPV terms)

We now turn to the distributional implications of the macroeconomic disease burden. Figure 2 presents the intra-regional breakdown of malaria disease burden between morbidity and mortality

effects. The breakdown is presented for each of our regional classification types: rural/urban location, low/medium/high malaria prevalence area, and coastal/forest/savannah ecological zone. The breakdown for urban households is remarkable (Panel A): morbidity effects account for almost 100% of the total disease burden in urban areas (including the GAMA region). Malaria transmission intensity levels are relatively low in urban areas, and this means that clinical outcomes are mostly limited to uncomplicated episodes with low mortality risk. In contrast, the results indicate that mortality effects account for >50% of the macroeconomic disease burden in disadvantaged rural areas due to high transmission intensity levels and high associated levels of mortality.

The intra-regional breakdown of disease burden across low, medium and high prevalence areas shows an interesting pattern (Panel B): Mortality effects account for the largest share of macroeconomic disease burden (≈40%) in medium prevalence areas (33%-47% prevalence rates), while smaller shares are found in low prevalence areas (≈one-third) and high prevalence areas (≈20%). This remarkable result arises because high transmission intensity in high prevalence areas leads to increased immunity and reduced mortality. This result is important since it highlights that there is a potentially very important trade-off associated with interruption of malaria transmission (without elimination): Reduced transmission lowers infant mortality, but it also lowers immunity in the broader population and may thereby increase mortality in older generations (if interruption fails to lead to sufficient reductions in transmission intensity). Hence, the distributional analysis points to the need for further analyses of strategies with partial interruption (such as the current NMCP strategy), since it indicates that doing nothing may, under certain circumstances, be favourable to pursuing intermediate control strategies where interventions are not sustained over the long term.

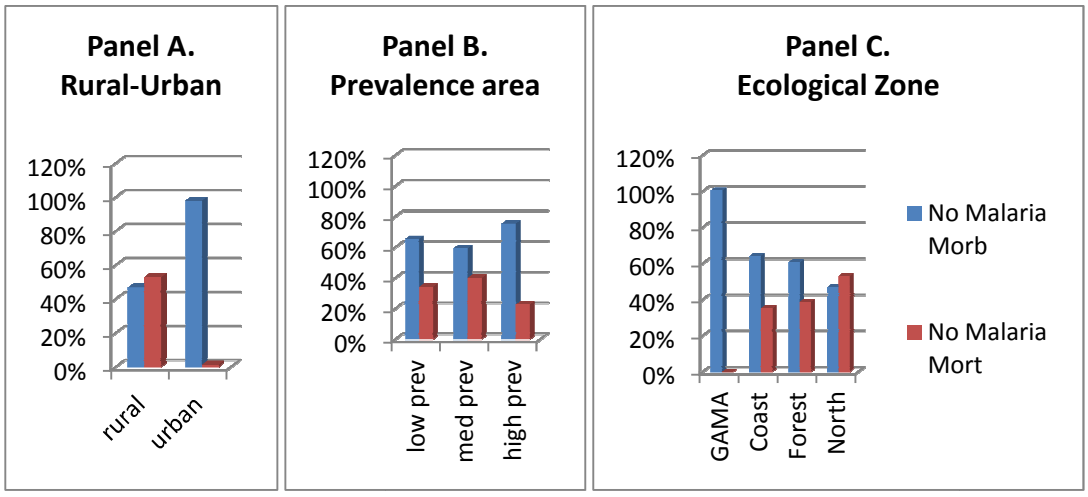

Figure 2 Macroeconomic Disease Burden (Intra-regional distributional impacts)

In contrast to figure 2, which presented *intra-regional* distributional impacts, figure 3 presents results on the *inter-regional* distributional composition of malaria disease burdens for each of our regional

classification types: rural/urban location (Panel A), low/medium/high malaria prevalence area (Panel B), and coastal/forest/savannah ecological zone (Panel C). The rural-urban results underline that malaria is overwhelmingly a disease which affects the most disadvantaged population groups in the Ghanaian society (Panel A): Rural areas account for >60% of the overall macroeconomic disease burden. Moreover, since the ever-increasing urban population has accounted for >50% of the Ghanaian population since 2010, rural areas also bear a disproportionally large per capita share of the macroeconomic disease burden.

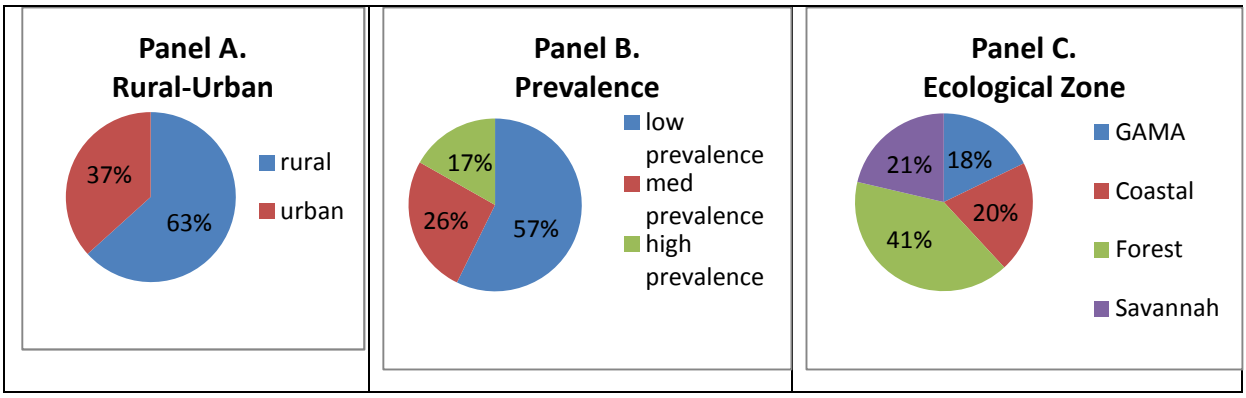

Figure 3 Macroeconomic Disease Burden (inter-regional impacts)

The results also indicate that nearly 60% of the macroeconomic burden of malaria falls on households in low prevalence areas (Panel B). Given that around 40% of the population live in low prevalence areas, this suggests that the macroeconomic malaria burden falls disproportionally on low prevalence areas both in absolute and relative terms. This seemingly counterintuitive result is mainly due to the relatively high average wage levels which characterize low prevalence areas (including GAMA). This result, which seems to suggest that interventions focussed at the least disadvantaged areas would be economically most effective, provides a crucial example of the need to employ integrated modelling tools which can provide both macroeconomic and health-focussed indicators. The health indicators below reverse economic suggestion and strongly indicate that interventions should be focussed at the least advantaged areas to provide maximum (health) impact.

Health and demographic impact

One of the strengths of the integrative approach is the ability to measure non-economic health and demographic effects. Table 4 illustrates some such impacts which add to the health disease burden.

Table 4: Malaria Disease Burden in Ghana (Population Effects)

	Δ Population (1000' person years)	Mortality (1000' persons)	Morbidity (1000' person years)	Δ Workforce Morbidity (sick)	Δ Workforce Morbidity (care)	Δ Workforce (1000' person years)
Cumulative impact						
2011-2030	9,267	-799	9,325	3,526	4,650	11,809
Annual impact						
2011	36	-35	397	139	211	358
2020	412	-40	463	173	233	542
2030	985	-44	533	217	248	932

Source: own calculations

The simulation results indicate that malaria elimination will increase Ghana population numbers by 9.3 million person years over our 20 year time horizon (due to 800,000 deaths averted). The annual numbers indicate gradual population gains: 36,000 person years saved in the short-term (2011); ≈1 million person years saved in the long-term (2030). Combined with morbidity effects (another 9.3 million persons years of illness and caretaking averted), this expands the Ghana work force by 11.8 million person years over 20 years (population corrected for labour market participation).

Crucially, the positive health impact on population numbers is the key reason for the adverse macroeconomic disease burden (since increased population numbers lower GDP per capita). The strong opposition of these key health and macroeconomic indicators illustrate the crucial need for integrated modelling tools which allow for juxtaposition of health and macroeconomic indicators, and thereby allow for informing policy makers properly before crucial decisions have to be made about e.g. commitment of domestic resources to maintain a large-scale roll-out malaria control strategy in the face of important domestic resource constraints.

Conclusion

In this paper, we presented a novel methodology which allows for full integration of macroeconomic and epidemiological-demographic simulation models. Our integrated framework allows for two-way feedback mechanisms between the epidemiological-demographic and macroeconomic sub-models. Crucially, this enables us to perform consistent analyses of both health and macroeconomic shocks within the same framework with a focus on both health and macroeconomic policy outcomes. As illustrated in our analyses, the juxtaposition of consistent health and macroeconomic indicators is likely to be especially important for policy makers in developing nations, who have to make important decisions regarding sustainable strategies to fight multiple infectious diseases in the face of hard budget constraints, multiple development challenges, and potentially waning donor support.

We applied our novel methodology to measure health and macroeconomic disease burdens of the malaria epidemic in Ghana. We have purposefully kept our current model application simple with a focus on labour market outcomes (but excluding important transmission mechanisms such as

educational attainment, fertility decisions, etc.). Our results should therefore be considered as preliminary and intended to demonstrate the functionality of our integrated framework. Nonetheless, our analyses do give rise to a number of important conclusions.

First, the order of magnitude of our macroeconomic disease burden measure for Ghana (GDP per capita: short term: +0.6%; long term: -0.8%) is consistent with the order of magnitude of effects measured in the only previous macroeconomic simulation study of malaria elimination (GDP per capita in Zambia: short-term: -1.5%; long-term: +2.0%), but disagrees strongly with the orders of magnitude found in the growth regressions literature (long-term impacts: 1.6-3.6 fold increase in GDP from one std. dev. reduction in malaria prevalence). This difference in orders of magnitude strongly suggests that the growth regression literature may be overstating the true macroeconomic disease burdens of Malaria.

Second, we find that health and macroeconomic indicators provide strongly diverging policy conclusions regarding the attractiveness of committing resources to maintain a large-scale roll-out malaria control strategy in the face of important domestic resource constraints. Health indicators suggest that malaria elimination may increase Ghana's population by 9.3 million person years and avert 800,000 deaths over our 20 year time horizon, while macroeconomic indicators suggest that per capita GDP may decline by 0.8% over the long-term. While the moral imperative for intervention based on health considerations remains unchallenged, it is vital for Ghanaian policy makers to take due notice of the potentially negative economic repercussions which may ensue, since this may complicate Ghana's ability to maintain a sustainable malaria control strategy over the long term. This analysis further underlines the crucial importance for policy makers in developing nations to have access to modelling tools which allows for juxtaposition of consistent health and macroeconomic indicators for making important decisions regarding sustainable strategies to fight infectious disease.

Whilst further work is required to refine many elements of our modelling framework and scenario design, our simple results illustrate the importance of our integrated methodology. CGE modelling is an important tool for determining the potential economic gains of malaria elimination in sub-Saharan Africa, not least because of its ability to perform consistent analyses of both health and macroeconomic shocks within the same framework, and with a focus on both health and macroeconomic policy outcomes. We hope that, with further development, our integrated framework will prove an important tool for policy analysis and enable the design of policies to reduce the health and macroeconomic disease burdens of malaria in the short, medium and long term.

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