

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

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## Introduction

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 (WHO 2011). 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 the age of five accounted for 86% of all malaria deaths in 2010. While global malaria-specific mortality rates have been reduced by 26% between 2000 and 2010, the challenge of controlling malaria and reducing human suffering remains monumental.

Malaria is hyper-endemic in all parts of Ghana, putting the entire population of 24.4 million (2011) at risk. High transmission occurs all year round, with increased transmission during the rainy seasons from April/May to July/September. The number of reported malaria cases varied between 3.1-3.5 million per year during 2001-2008 (NMCP 2009) but has subsequently increased to 4.2 million in 2011 (GHS 2012). Among hospital admissions, malaria is also reported to account for 18% of all deaths and 30% of deaths among children under the age of five (*ibid.*) The control of malaria therefore represents a major challenge to Ghanaian authorities – a challenge which, however, also has the potential to significantly reduce human suffering.

Previous studies of malaria in Ghana indicate that malaria may have important and multidimensional economic effects. For example, macroeconomic growth regressions and malaria-specific household survey data collection have been applied to measure respectively macroeconomic and household-level effects (Asante, Asenso-Kyere and Kusi 2005).

The control of malaria is also likely to have important economic implications. The macroeconomic supply-side impact of malaria is likely to rise with the disease burden, i.e. with the malaria prevalence rate. The disease burden of malaria involves morbidity and mortality effects with implications for health system costs, labour market participation and worker productivity. Hence, the control of malaria has the potential to improve both (1) health service delivery by reducing pressures on the overburdened health system, and (2) macroeconomic outcomes by reducing private and public health care costs, and improving economic outcomes due to short- and long-term increases in the size and productivity of the Ghanaian workforce.

Over the past decade, there has been an increasing focus on measuring the macroeconomic economy-wide impact of preventing diseases and maintaining good health. Impact assessment has typically relied on applied macroeconomic models, and disease-specific applications have typically focussed on major diseases such as HIV/AIDS (Kambou, Devarajan and Over 1992; Arndt and Lewis 2000, 2001; Arndt and Wobst 2002; Arndt 2003, 2006; Jefferis et al. 2006, 2008; Gow et al. 2007; Ventelou et al. 2008; Thurlow et al. 2009) and Pandemic Flu (Smith et al. 2009; Thurlow 2011). Multiple-disease applications have been fewer and have, so far, mostly been related to macroeconomic analyses of environmental air pollution (Garbaccio, Ho and Jorgenson 2000; Li 2002; Dessus and O'Connor 2003) and climate change (Bosello, Roson and Tol 2006; Ciscar et al 2010).

The Impact assessments of health and disease have, in most cases, been based on a combination of macroeconomic and epidemiological-demographic (ED) simulation models. Applications has typically used ED models to measure a set of health-related scenario-specific demographic impacts, which has subsequently been imposed as shocks on a macroeconomic model to measure the economy-wide scenario-specific impact. In this way, ED models have typically been used as partial equilibrium (PE) satellite models to supply scenario inputs to macroeconomic general equilibrium (GE) models.

In spite of the many disease-specific satellite model applications (especially to HIV/AIDS), no macroeconomic impact assessments has yet been published on Malaria. This is, most likely, due to the lack of suitable ED models, i.e. models which accounts for Malaria and which provides demographic outputs in a format which is amenable to analysis within macroeconomic simulation models. Key issues, in this context, are 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 (). 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 (RAND 2013), the current paper aims to leapfrog the satellite model approach and produce a fully integrated ‘Epidemiological-Demographic’-‘Computable General Equilibrium’ (ED-CGE) model which allows for two-way endogenous feedback effects between the Malaria-focussed ED model and the macroeconomic CGE model. A key advantage of our ED-CGE model framework is that it allows for modelling of both (1) economic implications of health-related interventions and (2) health implications of macroeconomic policies. Hence, our proposed framework represents not only a new tool for the assessment of Malaria and Malaria-related interventions, but, more broadly, a novel methodology for integrated economic and health assessment of disease burdens and disease-specific interventions associated with specific diseases.

(The standard calibration of the CGE model to a multi-sector multi-household Social Accounting Matrix (SAM) for Ghana – also allows for measurement of standard economic impacts on production, consumption, trade, agricultural terms-of-trade, household welfare, income distribution, poverty, and growth.)

## Background

Macroeconomic economy-wide 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. While macroeconomic economy-wide models have important advantages in terms of their ability to capture multiple economic impact channels within a single consistent model framework, the lack of macroeconomic spillover effects are typically used as an argument to preclude their application.<sup>1</sup> 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 multiple-disease macroeconomic simulation literature has had a narrow focus on environmental issues, including (a) single-country studies of air pollution, and (b) multi-country studies of climate change. Most environmental studies have employed the CGE model methodology. Single-country studies have typically focussed on health effects of changes in local air pollution due to demand-constraining carbon tax interventions (Garbaccio, Ho and Jorgenson 2000; Li 2002; Dessus and O'Connor 2003), while multi-country studies have focussed on temperature-related health effects of specific global warming scenarios (Bosello, Roson and Tol 2006; Ciscar et al 2010).

The disease-specific macroeconomic simulation literature has a narrow focus on two types of epidemics including (a) flu epidemics and (b) HIV/AIDS epidemics. Furthermore, the literature relies on three types of methodologies including (a) Computable General Equilibrium (CGE) models, (b) applied growth models, and (c) macro-econometric simulation models. The relatively narrow literature on flu epidemics has a unique focus on CGE model applications (Smith et al. 2009; Thurlow 2011), while the broader literature on HIV/AIDS epidemics includes both CGE, applied growth, and macro-econometric model applications.<sup>2</sup> A literature survey of methodologies for macroeconomic impact assessment of HIV/AIDS (Jensen and Kovsted 2012) concludes that among the three methodologies, "... the CGE model methodology provides the best starting-point for developing a proper evaluation tool" (ibid.)<sup>3</sup> Applied growth models are mainly seen as useful for illustrating

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<sup>1</sup> Macroeconomic simulation models are able to simultaneously capture the impact of health burdens on e.g. the labour market, private and public health expenditures, public unemployment and social security benefits, household-specific factor ownership and earnings potential (allowing for analyses of income distribution and poverty), distortionary public funding requirements (allowing for application of various tax instruments), private and public savings behaviour (allowing for analyses of capital accumulation and growth), etc.

<sup>2</sup> The macroeconomic impact assessment literature on HIV/AIDS epidemics includes *CGE model studies* (Kambou, Devarajan and Over 1992; Arndt and Lewis 2000, 2001; Arndt and Wobst 2002; Arndt 2003, 2006; Jefferis et al. 2006, 2008; Gow et al. 2007; Ventelou et al. 2008; Thurlow et al. 2009), *growth model studies* (Cuddington 1993a and 1993b; Cuddington and Hancock 1994, 1995; Cuddington, Hancock and Rogers 1994; Haacker 2002; Ferreira and Pessoa 2003; Bell, Devarajan and Gersbach 2003, 2004 and 2006; Corrigan, Glomm and Mendez 2005; Young 2005; Bell, Bruhns and Gersbach 2006; Johansson 2007; Roe and Smith 2008; Ventelou et al. 2008; Vasilakis 2010; Ferreira, Pessoa and Dos Santos 2011), and *macro-econometric model studies* (Laubscher 2000; Laubscher, Smit and Visagie 2001; Smit, Ellis and Laubscher 2006; Abdulsalam 2010).

<sup>3</sup> In particular, Jensen and Kovsted (2012) argues that "... the CGE model framework is specifically designed to measure policy-relevant indicators of interest to evaluation studies, including (1) detailed intervention-specific healthcare costs, (2) detailed analyses of financing options for interventions, and (3) other policy-relevant outcome measures including poverty and welfare indicators."

conceptual issues, while macro-econometric model applications, which rely on short-term Keynesian-type model specifications, is an inappropriate tool for measuring the long-term consequences of HIV/AIDS.

We argue that, by the same token, the CGE model methodology provides the best starting point for developing a proper impact assessment tool for Malaria disease burdens and Malaria-related interventions. 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) epidemiological-demographic models – something which is difficult to integrate within e.g. Overlapping Generations (OLG) growth models with their focus on long generational periods (20-30 years).<sup>4</sup>

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<sup>4</sup> Other types of applied growth models such as the neo-classical Solow and Ramsey growth models

## Model framework

The current model framework consists of three separate epidemiological, demographic, and macroeconomic models, which are integrated into one unified Epidemiological-Demographic-Computable General Equilibrium (ED-CGE) 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 (CGE). Each of the three sub-model specifications is set out, 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 (Anderson and May 1992), 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).

A key feature of our epidemiological model specification is that we rely on so-called ‘reversible catalytic’ specifications of disease transmission. This is a standard epidemiological specification which (crucially) allows for closed-form solutions, and thereby allows us to re-specify standard continuous time epidemiological specifications into discrete time specifications. In this way, we ensure that the epidemiological model specification is numerically compatible with the discrete time (annual) demographic and macroeconomic models.

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 adopts the same approach and specifies clinical outcomes, i.e. morbidity and mortality effects, as a function of the EIR rate. 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 (). These prior simulations allowed for the derivation age- and gender-specific relationships between central EIR values and a number of clinical outcomes (including the two types of clinical outcomes which have been included here).

A key goal in our epidemiological model specification was to capture the heterogeneity of transmission across different geographical regions of Ghana. Malaria transmission is typically considered to vary with ecological characteristics and rural-urban location. Ghana is typically subdivided into three ecological zones: Coastal, Forest, and Savannah. A subdivision between rural and urban areas in the three ecological zones would therefore seem to be the obvious choice. This

would, however, not 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 therefore decided to introduce a further geographical subdivision between low, medium, and high prevalence areas within each ecological zone. With rural-urban subdivisions and one separate epidemiological model for the Greater Accra Metropolitan Area (GAMA), this meant that we had to calibrate distinct epidemiological transmission models for 19 separate geographical areas.

Model calibration relied on parameter values from the literature (Filipe et al. 2007). Specifically, exogenous values were imposed on the following parameters: 1. clearance rate for super infections ( $\mu_{\text{super}}$ ), 2. human biting rate ( $a$ ), 3. infectiousness of humans to mosquitoes ( $c$ ), 4. mortality rate for mosquitoes ( $\mu$ ), 5. incubation period for mosquitoes ( $\text{incub}$ ), 6. infectiousness of mosquito bites on humans with immunity ( $b_{\text{Imm}}$ ), 7. infectiousness of mosquito bites on humans without immunity ( $b_{\text{NonImm}}$ ), and 8. reversion rate for immunity ( $\mu_{\text{Imm}}$ ). The 8 parameters with exogenously imposed values mostly relate to zoological, parasitological and human physiological characteristics and were therefore considered to be relatively uniform across geographical sub-regions. As a consequence, the chosen set of values (Table ?) was imposed uniformly across the 19 geographically distinct epidemiological transmission models.

In order to model differences in transmission between geographical areas, two sets of location-specific parameter values were calibrated based on location-specific information about human prevalence rates ( $\text{PrevH}$ ) and entomological inoculation rates ( $\text{EIR}$ ): 1. mosquito population ( $m$ ), and 2. the ratio between acquired immunity and force of infection ( $k$ ). The choice of calibrated parameters was made based on model-specific and ecological considerations. Hence, both of these parameters are central to the current transmission specification, and both are considered to be locally specific and vary with local ecological conditions.

The parameter calibration was based on data which were obtained from the Malaria Atlas Project (MAP). Worldwide malaria maps are available for 2007 (Hay et al. 2009) and 2010 (Gething et al. 2011) with a 1x1km pixel resolution size, and, for our purposes, relevant information was available on human prevalence ( $\text{PrevH}$ ) and entomological inoculation rates ( $\text{EIR}$ ). In our model calibration, we relied on the most recently available MAP data set for 2010.

In order to derive location-specific data for each epidemiological model, we had to compute average MAP values for each of our 19 geographical regions. In this context, a specific problem arose: Our basic source of regional household characteristics was the 2005/06 Ghana Living Standards Survey (GLSS5), but this survey relied on a 2005 district classification with 110 districts (which is different from the current 175 district classification). In order to maintain consistency with the demographic and CGE models (which rely on information from GLSS5, see below), we therefore had to construct specific shape files which allowed for calculation of district-specific values, and allowed for subsequent aggregation to our 19 distinct geographical areas. The district-specific values were calculated using the ArcGIS software. MAP shapefile data were converted to one 1km<sup>2</sup> point datasets. The Ghana regions and districts were selected by location using region/district boundary shapefiles and urban/rural locations were determined using an adaptation of the AFRIPOP geographical database (also supplied from the MAP). Population density at 1km<sup>2</sup> resolution was used to select urban/rural populations such that the Ghana Census regional urban/rural population

totals were matched, before calculating the required weighted prevalence and EIR values by district and urban/rural location.

## 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 2013). The model is very detailed and distinguishes between one-year age groups between the ages 0-100, i.e. 101 separate age groups. Furthermore, the demographic model distinguishes 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 patterns relied on a combination of (1) UN assumptions about net international migration patterns over 2010-2100, and (2) region-specific immigration and emigration patterns from the 2000 Ghana Census (GSS 2003).

The UN population projections do not account for domestic regional migration patterns. Hence, the calibration of domestic migration patterns between our 19 distinct geographical areas had to rely on reasonable assumptions about future domestic migration patterns. Based on numbers from the 2000 and 2010 Census Reports (GSS 2003, 2012), 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 of the past 25 years, it is therefore clear that future urbanization rates (within our time horizon 2010-2100) will have to be smaller. Instead of assuming unchanged domestic migration patterns, 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. This assumption implies that urbanization levels will stabilize beyond 2100 at around 82.6%. Based on this assumed counterfactual domestic migration pattern, we proceeded to calibrate domestic rural-urban migration patterns for each of our 19 distinct geographical areas based on regional domestic migration patterns from the 2000 Ghana Census (GSS 2003). (Currently, our model only captures rural-urban migration. Hence, migration between two distinct rural areas or two distinct urban areas is not captured. This is considered to be a minor shortcoming in the current context, since major changes in exposure and transmission intensity mainly stem from migration between rural and urban areas.)

## CGE Model

### CGE Model Specification

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 (corresponding to the geographical areas

in the demographic model) – and the household-specific 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 static CGE model for Ghana is based on the so-called ‘IFPRI standard model’ which is fully documented in Löfgren, Harris and Robinson (2002). The standard model 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.

Firms seek to combine resource inputs to maximize profits, while consumers allocate their disposable income in order to maximize welfare. Production technologies are assumed to consist of nested Leontief functions (intermediate inputs) and Constant Elasticity of Substitution (CES) functions (primary factor inputs) with a CES function top-nest, while consumer welfare are based on a Stone-Geary utility function which gives rise to a so-called Linear Expenditure System (LES). The specification of nested Leontief/CES production technologies and LES demand systems is standard in the CGE model literature.

Governments levy taxes, distribute benefits, and purchase goods directly, while foreign agents interact with domestic agents through goods trade (imports/exports), international factor income flows, foreign unrequited transfers and foreign borrowing and lending. Imperfect substitution is assumed in goods trade through an Armington (CES) specification on the import side and a Constant Elasticity of Transformation (CET) specification on the export side. Imperfect substitution between traded goods and domestic commodities is a standard assumption in the CGE model literature, since it allows for cross-hauling (simultaneous imports and exports) of goods.<sup>5</sup> Cost minimization (imports) and revenue maximization (exports) means that international trade flows are determined by relative international price incentives (the real exchange rate).

### **CGE Model Calibration**

The static CGE model for Ghana was calibrated on the basis of a 2004 Malaria-focussed Social Accounting Matrix (SAM) data set (Jensen, Keogh-Brown et al. 2012). The new Malaria-focussed 2004 Ghana SAM was constructed on the basis of the original 2004 Ghana SAM (Jensen, Duncan and van den Anel 2008). The crucial difference is that the new Malaria-focussed SAM includes a new household breakdown with 19 household types which are categorised according to 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).

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<sup>5</sup> Cross-hauling is observed for most product accounts at most aggregation levels (in conventional national accounts classification schemes). The specification of perfectly tradable goods is therefore, typically, avoided on empirical grounds.

The new household breakdown was achieved by deriving new household income and expenditure patterns from the 2005/06 Ghana Living Standards Survey (GLSS5). As mentioned above, the GLSS5 survey was stratified according to the 2005 district classification of 110 districts. Hence, the construction of different household types according to location in low, medium and high transmission intensity areas had to rely on the classification of the 110 districts according to these transmission intensity categories (after review of the district-level human prevalence levels, it was decided to use 33% and 47% human prevalence levels as cut-off points between low, medium, and high prevalence areas. This classification was solely based on the desire to have an equal distribution of districts in the three categories 36/37/37).

The final 2004 Malaria-focussed SAM included 388 accounts: 175 production activities, 139 retail commodities, one trade margin account, 43 factor types, one enterprise account, 19 household accounts, seven government accounts (including six tax accounts), one savings-investment account, one stock changes accounts, and one 'rest of the world' account. Subsequently, the number of activities and commodities were reduced to 10 each, in order to reduce the complexity of the model and facilitate numerical computation: agriculture, industry, utilities, housing and infrastructure, transportation, trade, public administration, health, education, other services. (This breakdown of activities and commodities were considered to be a reasonable trade-off between reducing computational complexity and maintaining sufficient sector detail in order to allow for modelling of domestic trade as well as health- and skill-consequences of malaria).

### Counterfactual Growth Path

Following the calibration of the static model to the 2004 SAM data set, factor stock accumulation equations were added, including labour growth and capital accumulation equations, to turn the static model into an enhanced dynamically-recursive CGE model framework. In order to measure the future economic impact of the policy scenarios (see appendix B), it was necessary to run a pre-simulation to target historical Ghana growth patterns over the period 2004-2010. Focus was on targeting of nominal and real GDP. In this way, the pre-simulation established 2010 as the base year for undertaking meaningful simulations of the Ghana malaria epidemic and malaria interventions over the period 2011-30.

In order to measure the impact of the policy scenarios, it was, furthermore, necessary to establish 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 (WDI 2012). 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. Hence, the purpose of the analyses, below, is to measure the economic loss which Ghana is suffering from not addressing the health burden imposed by current malaria transmission levels. A set of three scenarios are analysed including: (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 section, below.

## Results

### GDP

The following section outlines the results from our morbidity, mortality and combined morbidity and mortality simulations. We begin by presenting aggregate macroeconomic indicators before elaborating on the impact on the disaggregate household and labour types.

Table 1 shows the cumulative net present value impact on aggregate macroeconomic indicators over the 20 year period of the simulation (2010-2030). Nominal GDP impacts for the morbidity (GHC 9.27m) and mortality (GHC 8.97m) scenario are similar and constitute an overall GDP gain of around 0.45%. The combined morbidity and mortality impact is approximately double this (GHC18.29m, 0.92%).

Figure 1 shows the trajectory of annual GDP impact for the three scenarios over the 20 year simulation. The plot shows that in the short term, the reduction in morbidity makes the most substantial impact on the GDP gains (between 2m and 4m Cedis per annum for the first 10 years), but since mortality effects are cumulative<sup>6</sup>, the mortality effect makes a more substantial contribution than morbidity from around year 15 (2025) and yields annual gains of 14m Cedis by 2030. This reflects the relative impacts on the effective labour force: morbidity effects are approximately constant yielding a 1% increase in the effective labour force for each year of the simulation, the mortality effects in contrast are less than 0.1% for the first year (2011) but rise to 0.94% by 2021 and reach 2.29% by the end of the simulation (2030). This implies that in a longer term simulation, mortality effects would be expected to dominate the results whereas for short to medium term economic gains, morbidity effects show the most immediate benefits.

Table 2 presents the GDP per capita impacts in the short, medium and long term of the simulation. Since the mortality scenario does not assume any increased survival, the economic gains are positive throughout and increase from GHC8.5 per capita in 2011 through GHC 67.0 in 2020 to GHC 633 per capita in 2030. Conversely, the morbidity scenario shows a small negative GDP per capita impact in the short term (GHC -2.7) which further decreases in the medium term (GHC -152) and becomes a large loss in 2030 (GHC -2135) which shows the impact of the increased denominator in the GDP per capita calculations. The combined effects are approximately equivalent to adding the morbidity and mortality effects.

### Household Specific Effects

Figure 2 shows the GDP impact by household location. A comparison of the rural and urban household effects reveals that the morbidity effect is similar whilst the mortality effect is almost double the morbidity effect in rural households and almost zero for urban households. The similarity in the morbidity effects is attributable to the difference in wages between rural and urban households. Whilst malaria incidence tends to be lower in urban areas, the higher wages of the

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<sup>6</sup> Workers who survive in one year are able to contribute to the workforce every additional year they survive. Also, those who survive to/during fertile age contribute to future population and workforce increases

urban workforce yields a proportionately larger economic effect per worker, highlighting the difference between health gains to the population and economic effects. The very low mortality rate amongst those of working or fertile age in urban areas means that the mortality effect on GDP is very small.

Turning to the households categorisation by prevalence, the GDP effects are disproportionately related to prevalence, which seems counter-intuitive. Low prevalence households exhibit larger GDP effects whilst high prevalence households exhibit low GDP gains from the reductions in illness and death.

## Conclusion

The results presented above are very preliminary and are intended to demonstrate the functionality of our integrated framework rather than present definitive results for policy analysis. However, some of the model outputs provide helpful illustrations of the potential macroeconomic implications of malaria elimination in Ghana. Perhaps it is not surprising that interventions to reduce morbidity in the short term are likely to see the most immediate economic gains and may therefore be more attractive from the political perspective, but it is the long term effects of reductions in mortality which are likely to dominate the positive economic effects in two or three generations time. A study of the mortality effects suggests that, because of low mortality in urban areas, many of the long term economic gains from reduced mortality are likely to come from rural households.

Our scenarios highlight the direct workforce impacts (since we do not include the effects on workers caring for sick children) and show that there is a potential disconnect between the value and the quantity of health gains. When viewing the aggregate GDP impacts, our results suggest that morbidity effects in rural and urban areas are approximately equal. However, further investigation reveals that whilst the value of those morbidity effects are equal, the higher wages in urban areas disguise the smaller quantity of health gains.

Whilst further work is required to refine many elements of our modelling framework and scenario design, these simple results illustrate the importance of the 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 (potential) ability to capture the effect of non-health interventions on malaria. However, the demographic and epidemiological elements of our framework are essential to the effective analysis of results from the population health and economic perspectives. We hope that, with further development, our integrated framework will prove an important tool for policy analysis and will enable the design of policies to effectively reduce the population health and economic burden of malaria in the short, medium and long term.

Table 1 Macroeconomic Indicators (Million GHC, NPV)

|          | Morbidity | Mortality | Total |
|----------|-----------|-----------|-------|
| GDP_R    | 0.79      | 0.45      | 1.25  |
| ABSORP_R | 0.81      | 0.46      | 1.27  |
| CP_R     | 0.58      | 0.31      | 0.90  |
| CG_R     | 0.14      | 0.11      | 0.25  |
| IV_R     | 0.09      | 0.05      | 0.13  |
| EXP_R    | 0.36      | 0.20      | 0.56  |
| IMP_R    | 0.36      | 0.20      | 0.56  |
| GDP_N    | 9.27      | 8.97      | 18.29 |
| ABSORP_N | 9.31      | 9.09      | 18.44 |
| CP_N     | 7.38      | 7.19      | 14.61 |
| CG_N     | 0.79      | 0.77      | 1.57  |
| IV_N     | 1.14      | 1.12      | 2.27  |
| EXP_N    | 3.67      | 4.04      | 7.72  |
| IMP_N    | 3.71      | 4.15      | 7.88  |

Table 2 GDP Per Capita

|      | GDP Per Capita (GHC) |           |         |
|------|----------------------|-----------|---------|
|      | Morbidity            | Mortality | Total   |
| 2011 | 8.5                  | -2.7      | 5.8     |
| 2020 | 67.0                 | -151.7    | -85.4   |
| 2030 | 632.8                | -2134.7   | -1512.8 |

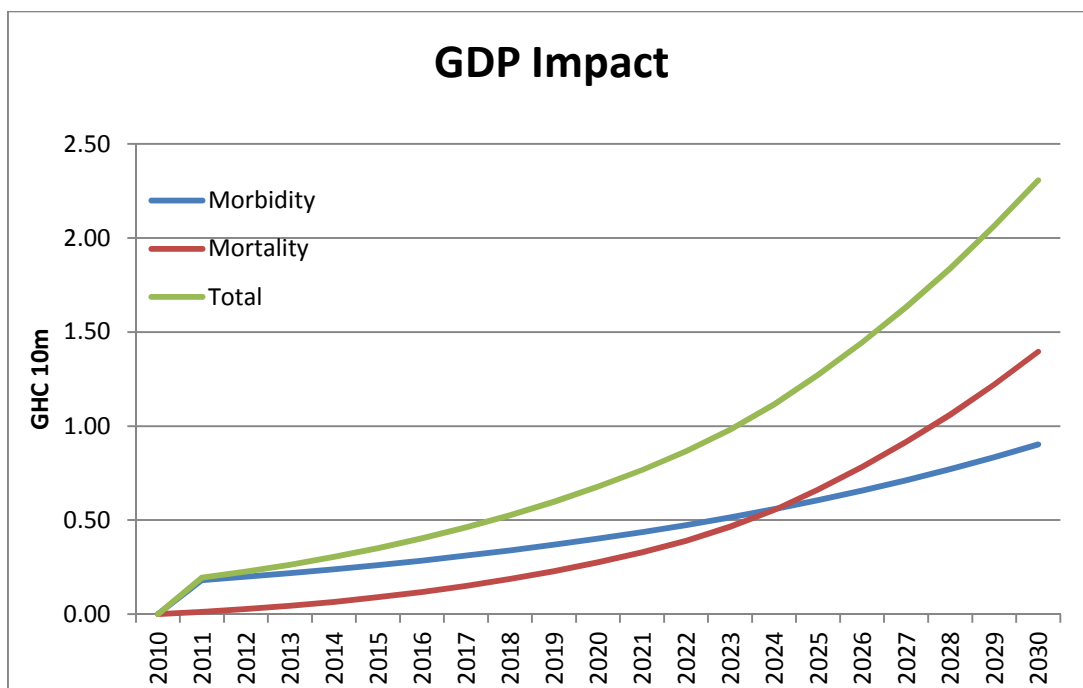


Figure 1NPV GDP By Year (10m GHC)

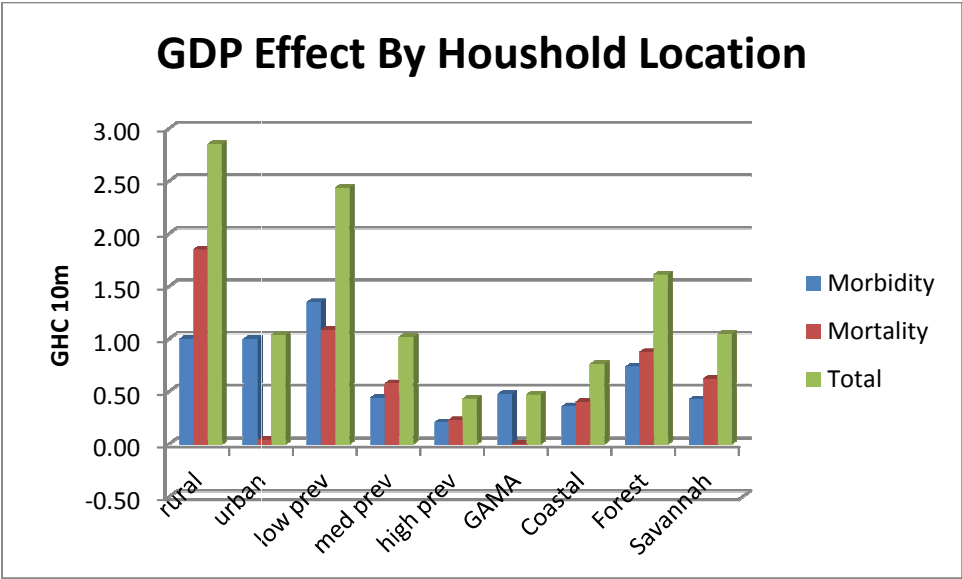


Figure 2 GDP By Household

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