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How to Measure the Economic Impact of
Vector-Borne Diseases at a Country Level:
An Assessment

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Abstract - Vector-borne diseases (VBDs) are widespread in less developed countries and re-emerging in developed ones. Available economic studies agree that VBDs induce significant effects on countries' economic outcomes, and affirm that a systematic evaluation of such effects is crucial to the efficient allocation of resources to health priorities. This paper provides a comparative assessment of available methodologies for measuring the economic impact of VBDs at a national level. We review both macroeconometric and micro-based approaches, and examine advantages and disadvantages of currently used methods. We conclude by suggesting possible methodological advancements and new challenges for future research.

Keywords: Vector-borne diseases, economic growth, health indicators.

JEL classification: C50, I15, O44, Q57

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1 Introduction

Vector-borne diseases (VBDs) are illnesses in which the pathogenic microorganism is transmitted from an infected individual to another by an arthropod or other agent (the vector). VBDs are primarily zoonotic diseases, i.e. carried by animals. The arthropods that most commonly serve as vectors include blood sucking insects such as mosquitoes, biting flies, bugs, and blood sucking arachnids (for example, ticks). Malaria, yellow fever, and dengue, among others, are well-known and widespread VBDs. A large part of the world's population is potentially exposed to VBDs. For example, in 2007, with respect only to malaria, 2.37 billion people were at risk of contagion (WHO, 2009).

The diffusion and incidence of VBDs are of great interest for economists. Health and macroeconomics have a strong relationship, as a good health in a population sustains country economic outcomes (Bloom and Canning, 2000; Bhargava et al., 2001; Weil, 2007; Spence and Lewis, 2009; Aghion et al., 2010). The debate on which are the major channels through which VBDs influence national product and economic growth is of long standing. In one of the first papers analyzing the economic consequences of malaria eradication, Barlow (1967) indicates that the diffusion of a VBD impacts on the demographic characteristics of a population, on the quantity and quality of labour and capital inputs and on their combination. In addition, if the incidence of a VBD in a country reaches significant levels, also human mobility, trade, foreign investments, saving and land use tend to be negatively affected (Malaney, 2003).

This bundle of economic effects, however, is difficult to disentangle. The health status influences absolute and relative income levels of people, while in its turn the economic status is a determinant of health (Allanson and Petrie, 2012). As a result, the magnitude of a VBD's impact - both at an individual and country level - depends on the economic resources available to cope with illness. In this perspective, Bonds et al. (2009) discuss how the interaction between economic and disease ecology factors can give rise to poverty traps. They use a general one-disease model, where individuals can be serially reinfected over the course of their lifetime, and show formally that the initial economic and epidemiological conditions of a society shape the long-term trajectory of its economic development and future health. A number of additional conditions, including overlapping generations dynamics (Momota et al., 2005) and externality effects (Gersovitz and Hammer, 2004), further complicate the relationship between diseases and macroeconomics. In general, although the relative role played by single causality connections is still debated, there is no doubt among scholars that VBDs affect economic outcomes of countries. But how to measure this impact empirically? This paper is aimed at providing a rigorous examination of the ways in which economists answer such question.

The methods proposed by the literature can be roughly classified in two categories, macroeconomic and micro-based approaches. Macroeconomic approaches follow a traditional cross-country perspective, in which variations in economic outcome variables at a country level are explained as a function of variations in population health regressors (an example is the work by Gallup and Sachs (2001)). At the opposite, micro-based methods are bottom-up, in that they require individual or household specific measures of the economic effects of a disease, which then are aggregated at a national level (as a representative reference consider the study by Shepard et al. (1991)). Both methods present several weaknesses. In particular, on the one hand, macroeconomic analysis have their main limit in suffering from endogeneity problems, due to two-way causality between economic outcomes and VBDs' incidence; on the other, micro-based measures tend to produce under-estimates of the true economic impact of the VBDs, because they do not capture a number of macroeconomic factors and externality effects. While review articles on VBDs often discuss some crucial shortcomings of both approaches (see, e.g., Sachs and Malaney (2002)), surprisingly a systematic comparative assessment of advantages and disadvantages of the two groups of methods is still missing. With this paper we fill the gap.

Comprehensive surveys collecting estimates of VBDs' effects obtained through different methods are available for single diseases (on malaria, for instance, see Chima et al. (2003)). Therefore, we do not report here a list of numbers on the economic costs of various diseases. Rather, we focus on the methodological aspects concerning the measurement of these costs.

The motivation for our work stems from the fact that VBDs are one of the major causes of death in Africa and other less developed countries. Moreover, several studies explain that many VBDs - malaria, leishmaniasis, West Nile, dengue, and Lyme, among others - are a (re-)emerging concern in Europe and the US (Takken and Knols, 2007). Areas with both a high mobility and high density of population, like some regions in Western Europe and the South US, are increasingly at risk (Hendrickx and Lancelot, 2010). Climate change and climate variability along with certain types of land use and irrigation, urbanization, and chemical pollution are responsible for the changing geography in the risk of contagion at a global level (Sutherst, 2004; Gollin and Zimmermann, 2012). In response to this concern, virtually all governments - besides subsidizing access to health care - invest in public goods as controlling disease vectors and promoting healthy behaviors and in quasi-public goods as vaccinations. Hence, to precisely measure how important changes in VBDs' incidence are to economic outcomes of countries should be of high interest for policymakers.

We review macroeconomic approaches in section 2 and micro-based approaches in section 3. In section 4 we argue about possible lines of research for methodological advancements. Section 5 concludes.

2 Cross-country regression analysis

2.1 Basic specification

In the standard cross-country methodology a disease variable is added to a macroeconomic equation, which is then estimated through regression techniques. In principle, a cross-country regression analysis provides an estimated parameter measuring the statistical relationship between a VBD's presence in a population and the specific economic outcome indicator used as the dependent variable in the equation (such as gross domestic product (GDP) levels or growth rates). The general form for a cross-country analysis of a disease's economic impact can be specified as follows:

$$EO_{c,t} = \beta_0 + \beta_1 DI_{c,t} + \mathbf{B}\mathbf{X}_{c,t} + \varepsilon_{c,t} \quad (1)$$

where $EO_{c,t}$ indicates an economic outcome indicator, $DI_{c,t}$ is a VBD indicator, β_1 is the parameter of interest, $\mathbf{X}_{c,t}$ is a vector of covariates, \mathbf{B} is a vector of parameters, ε denotes the residuals of the equation, and where β_0 is the constant term. Notice that the variables vary across countries c and, given data availability, over time t . If panel data are available, random or fixed effects estimation methods can be applied.

A key issue in this framework concerns the composition of the vector $\mathbf{X}_{c,t}$. All the relevant determinants of $EO_{c,t}$ have to be included in $\mathbf{X}_{c,t}$ in order to have a reliable estimate of β_1 . In traditional macro-econometric models, where $EO_{c,t}$ is a country's GDP level or its growth rates, the vector $\mathbf{X}_{c,t}$ should include indicators of human capital, life expectancy, initial income, macroeconomic policy, and geographical factors (such as tropical location). For instance, Malaney et al. (2004) suggest that environmental confounding factors as climate may drive both poverty and malaria at a country level. If relevant variables are not controlled for, the regression is spurious and one could be induced to reject a true relation or to accept a false relation between $DI_{c,t}$ and $EO_{c,t}$.

An unbiased estimate of β_1 captures both direct and indirect effects of a VBD on a country's economic outcome, including effects on schooling, demography, migration, saving, trade, tourism, and foreign direct investments (FDI). It is worth noting that some of the effects of VBDs are fully manifested only in the long-run. For example, a VBD can impact on a country's GDP through school absenteeism, and it can reduce the accumulation of human capital and the long-term learning capacity of a population. At the opposite, other economic effects (e.g., reduction of FDI and trade flows) occur in the short-run. Formal inclusion of phase displacement into statistical analysis requires an appropriate lag structure in equation (1), i.e to use suitable time-lags for the independent variables accounting for delayed effects.

2.2 Endogeneity

The estimation of the relationship between a VBD and economic outcomes is complicated by possible reverse causality. Sachs and Malaney (2002) argue that causality may run in two directions. On the one hand, VBDs may affect a country's income and economic growth, on the other also poverty may promote a VBD's diffusion because it hampers private and public expenditure in prevention, diagnosis and treatment of the disease. From an econometric point of view, the consequence of reverse causality is an endogeneity problem, i.e. $Cov(DI_{c,t}, \varepsilon_{c,t}) \neq 0$. Different strategies have been proposed in cross-country studies to tackle endogeneity in this context.

McCharty et al. (2000) perform a regression analysis of the economic impact of malaria. They study the GDP per capita growth rates of 187 countries over the 1983-1997 period. They propose to lag the VBD indicator in order to circumvent reverse causality. Although this procedure has the advantage of being easy to implement, it has also the limit of requiring to model the initial values of the VBD indicator unless they can be considered exogenously determined in t_0 . McCharty et al. (2000), however, do not include in their model an initial conditions equation, while initial VBD values are unlikely to be exogenous.

Gallup and Sachs (2001) focus on the effects of malaria diffusion in 149 countries on the growth of the log GDP per capita in 1995. They control for the possible endogeneity of the VBD indicator using an instrumental variable (IV) technique. The IV method is based on the possibility of employing an instrumental variable $z_{c,t}$ correlated with $DI_{c,t}$ but not with $\varepsilon_{c,t}$. A $z_{c,t}$ variable of such type is employed to obtain exogenous values of the $DI_{c,t}$ indicator, to be used then in the second-stage outcome regression. Gallup and Sachs use the prevalence of Anopheles mosquito vectors in each country in 1952 as an instrument. The distribution of Anopheles vectors, indeed, is strongly correlated with malaria intensity and its change over time (precisely, Gallup and Sachs observe in their sample that the first-stage regression of the change in the malaria index on Anopheles vectors gives an R^2 of 0.51). The two authors argue that the only way the distribution of malaria mosquito vectors affects economic growth is through its effect on malaria diffusion, and that this makes vector prevalence an appropriate instrument for malaria change. Nevertheless, they do not check statistically if causality runs also from economic growth to the IV's values. Gallup and Sachs do not furnish elements for ruling out the possibility that their instrument is endogenous to a country's economic outcome, but this could well be the case. For example, Acemoglu and Johnson (2007) discuss about the importance of the use of DDT against mosquito vectors, being the implementation and extension of DDT campaigns conditional to available economic resources. Gallup and Sachs only provide results from the Hausman (1978) test, that unfortunately are likely to be misleading when the instrument is weak (Wooldridge, 2005).

A more convincing IV choice has been recently proposed by Barreca (2010). Barreca studies poverty rates of cohorts of people in the US conditional on exposure to malaria. He instruments a $DI_{c,t}$ indicator (the malaria death rate in State c and year t) by the fraction of year t that State c had a certain mean daily temperature. On the one side, VBDs are strongly associated to specific ranges of temperature and humidity; mosquito-born diseases, in particular, such as malaria, dengue fever, and yellow fever, require warm weather to survive. On the other side, a climate index can be reasonably considered an exogenous variable with respect to economic outcomes, at least in the short-run. The instrumenting strategy of Barreca (2010) recalls a previous study by Lorentzen et al. (2008) in which mortality rates, used as a regressor in an economic growth model, are instrumented by means of a set of climate variables and of a country's geographic features (the distance of a country's centroid from the equator, the mean distance to the nearest coastline, the average elevation, and the log of land area). The study of Lorentzen et al. (2008), however, does not focus specifically on mortality due to VBDs.

In conclusion, it is worth mentioning the work by Acemoglu and Johnson (2007). The two authors empirically investigate the effect of life expectancy at birth on various outcome variables, namely the log GDP, log GDP per capita, and log GDP per working age population. The sample covers 59 countries over the 1940-1980 period. Acemoglu and Johnson treat the endogeneity of life expectancy by using an instrument of predicted mortality due to a set of 15 diseases (not all of them are VBDs). They find that there is no evidence of a significant impact of exogenous life expectancy changes to a country's economic growth. Notice that the study by Acemoglu and Johnson (2007) has stimulated some discussion on the assumptions regarding the statistical relevance of initial conditions of health and income and concerning the correct modelling of conditional convergence (Bloom et al. 2009; Acemoglu and Johnson, 2009). A simple way to incorporate convergence effects is including initial per capita income and initial life expectancy in the model specification. Nevertheless, as Acemoglu and Johnson (2009) observe, issues related to convergence or other types of mean reversion dynamics in income per capita do not necessarily influence final results in a statistically significant manner.

2.3 Measures of disease

Apart from possible endogeneity, a limit of the cross-country approach in evaluating the economic impact of VBDs concerns the measures of the incidence of illnesses used (the $DI_{c,t}$ variable in equation (1)). Indicators commonly employed include crude and age-adjusted death rates, infant mortality rates, or the expectation of life calculated in the presence of a certain disease. For example, Swaroop and Uemura (1957) suggest to use a propor-

tional mortality indicator (PMI), defined as deaths at age 50 and above as percentage of all deaths at all ages, i.e. formally:

$$\text{PMI} = \frac{n}{n + m} \cdot 100 \quad (2)$$

where n is the number of deaths at an age equal to or higher than 50 years, and m is the number of deaths at an age lower than 50 years. Similarly, Katsunuma and Koizumi (1968) propose an age-corrected version of the PMI, where the age distribution in the observed population is explicitly taken into account.

Empirical papers often show even simpler choices. McCharty et al. (2000) use the total population morbidity in t due to a given VBD per 100,000 population. Gallup and Sachs (2001) use an index calculated as the fraction of the population living in areas with high VBD risk in t times the fraction of the given VBD's cases in $t + k$. Barreca (2010), analogously, employs a VBD death rate for each t .

These types of statistics have the advantage of being available in most countries and easily comparable across economies. However, they are notoriously troublesome, because deaths due to VBDs often are not accurately identified. In some areas of Africa many cases of death occur at home and are not officially registered, as a result formal reporting systems may be unreliable (Snow, 1999). Moreover, death statistics focus on mortality due to illness and do not include information on non-fatal health outcomes which have a strong impact on economic dimensions. A non-fatal ill status affects the individual's consumption and saving (Kochar, 2004), absenteeism at school and drop-out rates (Brooker et al., 2000), acquisition of human capital by weakening cognitive development and learning abilities (Holding and Snow, 2001), and mobility decisions (Sawyer, 1993). In addition, VBDs are a determinant of anaemia, which has been shown to curb labour productivity (Scholz et al., 1997). The effects of illness due to VBDs, moreover, are likely to differ across individuals and often change intensity also for the same individual at different ages. Typically, households face different private costs and expenditure choices for care of the disease (Russell, 2004). For these reasons, death rates calculated at a national level tend to be too rough and do not provide a precise measure of disease's incidence. Micro-based indicators, reviewed in the next section, are conceived to work at a higher detail.

3 Micro-based methods

Micro-based methods follow a bottom-up approach, in which a VBD's impact is first calculated at an individual or household level and in which then national amounts are obtained by aggregating case level numbers (as

in Leighton and Foster (1993)). The most common micro-based methods are cost-of-illness (COI), disability-adjusted life years (DALYs), healthy life-years (HeaLYs), and willingness to pay (WTP).

3.1 Standard COI

The cost-of-illness (COI) is a traditional method for the evaluation of the economic burden of a disease, introduced by Rice (1967). The COI can be considered a micro-based approach as it accounts for both private and non-private medical costs. Private costs include the private expenditures for prevention, diagnosis and treatment by the individual or the household. Non-private costs refer to public expenditures for vector control, health facilities and research. Both private and non-private medical costs are direct costs of a disease. In addition, the COI includes the indirect (private) costs of forgone income and the non-economic personal burden, such as pain and suffering. The standard formula of COI is:

$$\begin{aligned} \text{COI} = & \textit{private medical costs} + \textit{non-private medical costs} + \\ & + \textit{forgone income} + \textit{non-economic costs} \end{aligned} \quad (3)$$

Notice that the VBD’s non-economic burden due to pain and suffering is difficult to measure, unless very strong simplifications are made, and generally it is excluded from the calculation.

While medical costs often can be measured to an acceptable degree of approximation, the calculation of the indirect costs requires an estimate under a set of assumptions. Foregone income can be estimated by calculating the capitalized value of the lost future earnings of sick individuals and of those who died prematurely because of a VBD. The value of lost workdays is calculated as the time lost multiplied by some value of a day of work. To this purpose, commonly the time lost is measured through basic longevity estimates based on age specific mortality rates, and the value of a working day is approximated by the average wage given the sex and age class of individuals. Often demographic characteristics of ill individuals are not available, and empirical studies using the COI method employ some arbitrary strategies. For instance, Cropper et al. (2000) - in a study on the economic burden of malaria in Ethiopia - assume that the wage of an ill worker is equal to the full (or to one-half) of the average wage of a healthy worker under a “high” (or a “low”) productivity assumption. In the same study, Cropper et al. assume that the wage of teenagers is one-half of an adult’s average wage. To the extent that such empirical strategies are not supported by reliable data, a bias may be introduced. In the COI measure, moreover, seasonal variations of economic activity and the time lost by adults caring for sick children or other household’s members should be included, but rarely this is the case (Chima et al., 2003).

In principle, the COI methodology can be applied to illness due to any cause. In particular, studies implementing the COI method to the evaluation of the economic impact of VBDs are numerous. Among others, Shepard et al. (1991), Ettlting and Shepard (1991), Cropper et al. (2000), and Asante and Asenso-Okyere (2003) use a cost-of-illness approach for measuring the burden of malaria.¹ Examples of analysis of other VBDs based on the COI approach are the works by Maes et al. (1998) on Lyme disease, by Zohrabian et al. (2004) on West Nile disease, by Rijal et al. (2006) on leishmaniasis, and by Suaya et al. (2009) on dengue.

Shepard et al. (1991) examine data on malaria costs for four sites in Rwanda, Burkina Faso, Chad and Congo. They measure direct and indirect costs by multiplying, respectively, the average estimated health system's costs per case times the number of cases and the adult's output per day times the estimated productive time lost. They find that, in 1987, the average cost for a case of malaria is equal to 9.84 US dollars. In a similar way, Ettlting and Shepard (1991) estimate the costs of malaria in Rwanda. Ettlting and Shepard measure that in 1989 the total cost of malaria is \$2.88 per capita (in 1987 US dollars). Specifically, 21.87% of the total cost is due to direct costs, while the remaining 78.13% is due to indirect costs. Given the average output per day of the Rwandan economy, the two authors estimate that the per capita malaria cost equals 3.5 days of production or, in the aggregate, 1% of GDP. Cropper et al. (2000) distinguish a high and a low productivity assumption for the estimation of indirect malaria costs in Ethiopia. An adult's productivity equals the daily wage under the high productivity assumption and half of the daily wage under the low productivity assumption. Under these assumptions, the total COI per malaria episode is estimated to range from \$7 to \$24 for adults, from \$7 to \$23 for teenagers, and from \$4 to \$12 for children, while the average annual household COI ranges from \$9 to \$31. How the costs of treating malaria illness vary due to the combination of malaria and other illness episodes is provided by Onwujekwe et al. (2000). Asante and Asenso-Okyere (2003) report a detailed measure of the various components of the COI for malaria in Ghana. They include households' costs for prevention, drugs, laboratory tests and transportation of the ill person, and institutional costs for prevention and research, health education, treatments and salaries of health personnel in the direct costs component. Where the costs are not malaria specific, the proportion of costs due to malaria is calculated through an incidence based costing approach. In the indirect costs component, Asante and Asenso-Okyere include time spent travelling to obtain health care, waiting time for treatment at the facility, time spent caring for the sick and time lost due to incapacitation. So doing, the authors obtain an average total (household) cost of a malaria

¹On the economic costs of malaria, a comprehensive review of studies measuring both direct and indirect private costs is provided by Chima et al. (2003).

episode equal to \$15.79, which is composed for 43.52% by direct costs and for 56.48% by indirect costs. Direct costs are found relatively higher (53% of the total cost) for leishmaniasis by Rijal et al. (2006), which analyse a case study in eastern Nepal. In particular, Rijal et al. measure that 75% of the direct costs are borne by the household before patients actually receive any treatment for the disease. Maes et al. (1998) include direct and indirect costs in a decision analysis model to estimate the total cost of Lyme disease in the US. Using an annual mean incidence of 4.73 cases per 100,000 population, they obtain an expected national expenditure of \$2.5 billion (in 1996 US dollars) over 5 years. Zohrabian et al. (2004) study the impact of West Nile disease in Louisiana in 2002. They estimate a \$10.9 million cost of illness (of which \$4.4 million are medical costs and \$6.5 millions are non-medical costs). Finally, the more recent study by Suaya et al. (2009) proposes an extensive multicountry measuring of the economic impact of dengue in 2005. They examine five countries in the Americas (Brazil, El Salvador, Guatemala, Panama, and Venezuela) and three countries in Asia (Cambodia, Malaysia, and Thailand). With an annual average of 574,000 cases reported, Suaya et al. estimate that the aggregate annual economic cost of dengue for the eight countries considered ranges from \$587 million to \$1.8 billion.

Despite its large use, the COI methodology presents some important weaknesses. First, as Shiell et al. (1987) point out, since the COI includes a measure of medical costs, if past resources allocation to health services has been made in an inefficient or even irrational manner, then the COI formula may result in a misleading evaluation of the impact of a disease. Second, an additional bias in the COI measure may be introduced when there is discrepancy between the true and the estimated forgone income, if wrong assumptions on the lost future wages are made, as we have discussed above. Third, it has been noted that ill individuals may return to work before they have fully recovered from a VBD episode (this is common when a worker is the only one earner in the household); in this case, the COI approach fails to account for lost productivity (Malaney, 2004). More in general, fourth, the COI formula does not take into account the “coping strategies” that households develop in response to a VBD affecting one or more of their members. Typical coping strategies include intra-household labour substitution, which may imply a positive bias of the estimated VBD costs, and selling household’s assets, which on the contrary may imply an under-estimate of the true costs (Sauerborn et al., 1996). Fifth, finally, in the standard COI formula the forgone income is calculated as the capitalized value of lost wages, where wages are assumed constant across different levels of employment. However, a VBD’s diffusion in a population of workers may imply an inward shift of the labour supply curve, that in its turn should cause an increase in wages. The final wage level, therefore, depends itself on the incidence of the disease (Malaney, 2003).

3.2 WTP

Even if the total economic costs of a disease turn out null, people could still assign a positive intrinsic value on preventing death, i.e. health can be considered as an argument of a welfare function. Phrased differently, people assign a value (possibly quantifiable) to the incidence of a given disease, which goes beyond the monetary direct and indirect costs borne in the case of illness. This idea is at the basis of the approach focusing on the willingness to pay (WTP) people express for avoiding a disease. WTP measures can be viewed as a variant of the standard COI method.

The WTP approach is a micro-based method in which the analysis focuses on the individual's preferences for his personal outcome. Following Pratt and Zeckhauser (1996), let us consider a situation in which there are no externalities of valuation and in which the risk of death for an individual is independent from the risk faced by other individuals. Suppose that the individual has an utility function $U(s, w)$, where s is a variable that takes the value 0 in the case of death and 1 if the individual survives, and where w is the individual's wealth. We can reasonably assume that $U(0, w) < U(1, w)$. Given a certain probability of death p , the initial utility of the individual is:

$$U_\alpha = p \cdot U(0, w) + (1 - p) \cdot U(1, w) \quad (4)$$

The maximum amount m that the individual is willing to pay for a reduction q in death probability (i.e. an increment q in survival probability) can be determined comparing U_α with the utility (U_β) of the individual after he makes the choice to pay for the risk reduction, i.e.:

$$U_\beta = (p - q) \cdot U(0, w - m) + (1 - p + q) \cdot U(1, w - m) \quad (5)$$

Notice that the marginal utility of money, affecting the amount m the individual is willing to pay, in its turn is likely to be affected by both the individual's health status and wealth. Under the assumptions made, the sum of the individuals' WTP gives the monetary equivalent of the aggregate value a population assigns to the reduction of a disease's incidence. WTP can be also analyzed with reference to health insurance policies (see, e.g., Asenso-Okyere et al. (1997)).

An example of empirical analysis based on the WTP approach is given by Weaver et al. (1996). The authors present the results of a survey conducted in Central African Republic to determine the population's WTP for a national program concerning malaria, among other issues. Weaver et al. report an individual's median willingness to pay for drugs to treat malaria equal to \$7.98. They also find that the WTP is greater in rural areas than in urban areas. Other examples include Cropper et al. (2000) and Onwujekwe et al. (2002). Cropper et al. (2000) examine the WTP of households in

Ethiopia for a hypothetical malaria vaccine granting total protection against malaria for one year. They find an average annual household's WTP equal to \$36, with a median value of \$25. Onwujekwe et al. (2002) present an interesting study of the altruistic WTP for insecticide-treated nets in Nigeria. The study is conducted in malaria holoendemic communities where some community members are indigent and some others are asked to pay for those who cannot afford the nets. The authors find a median altruistic WTP ranging from \$0.11 to \$0.21.

The WTP method has come under criticism because it requires surveys for data gathering, and this exposes WTP measures to a number of limitations. In particular, the value respondents assign to avoiding a VBD may be subject to personal interpretation of the questionnaire. Moreover, interviewed individuals may try to engage in strategic behavior (Malaney, 2003). Generally, contingent valuation type methods (like WTP) suffer from being conditional to the way in which questions and alternatives are specified in the survey (Frew et al., 2004). This makes WTP numbers often not credible and rarely comparable across different surveys (Diamond and Hausman, 1994). A way to circumvent the lack of credibility of valuations expressed by survey respondents might be to look at prices actually paid for vaccines. However, VBDs vaccines may be unaffordable for low income households (consequently, in fact, vaccines are often distributed within national health programs without costs for individuals), so that vaccines' prices cannot be used as a reliable measure of WTP.

3.3 DALYs and HeaLYs

A more recent - but already extensively used - measure of a disease's incidence is given by disability-adjusted life years (DALYs). The DALYs, conceived by Murray (1994), are a health gap indicator that measures the lost years of health due to a set of disease or injury causes. DALYs include a measure of time lived in states other than full health, without focusing exclusively on mortality. This indicator originally was introduced as a unit for measuring the magnitude of the fatal and non-fatal incidence of a disease, and does not provide *per se* a number for the monetary costs of illness. In order to be converted in monetary terms, DALYs must be multiplied for some value of a year of production.

Following Murray and Acharya (1997), the incidence of a disease j for an individual i can be expressed as:

$$\int_{a_i}^{a_i+L} \mathcal{W}_j \cdot C \cdot x \cdot e^{-\beta x} e^{-r(x-a_i)} dx \quad (6)$$

where x is time, a_i is the age of onset, L is the duration of disability or time lost due to premature mortality, \mathcal{W} is the disability weight (death

implies $\mathcal{W} = 1$), $Cxe^{-\beta x}$ is the age weighting function (with C being an age weighting correction constant and β an age weighting parameter), and $e^{-r(x-a_i)}$ is a continuous discounting function (with r being the discount rate). The solution of the integral (6) gives the DALY formula for the individual i :

$$\mathcal{W}_j \frac{C \cdot e^{-\beta a}}{(\beta + r)^2} \{e^{-(\beta+r) \cdot L} [-1 - (\beta + r) \cdot (L + a)] + [1 + (\beta + r) \cdot a]\} \quad (7)$$

At an aggregate level, thus, DALYs are an indicator of the time lived with a disability and of the time lost due to premature mortality of a population. Consequently, from a normative perspective, DALYs are a quantity of ill-health to be minimized.

The DALYs indicator has been the subject of a number of criticisms (see, e.g., Anand and Hanson (1997, 1998) and Williams (1999)). In particular, Anand and Hanson (1997) question two assumptions underlying the construction of DALYs. First, Anand and Hanson challenge the principle of valuating time lived at different ages differently. The two authors argue that, even if it might be justified in a human capital framework, age weighting is hard to defend ethically. Second, Anand and Hanson affirm that critical characteristics such as wealth and access to publicly-provided services should be taken into account in addition to sex, age and disability status (i.e. the DALY information set), especially when DALYs are used for resource allocation purposes. Phrased differently, a greater importance should be accorded to a disadvantaged individual with respect to an advantaged one showing the same health outcome.

Murray and Acharya (1997) have replied to both criticisms. As for the age weighting argument, they sustain that, if the well-being of a certain age group is instrumental for a society's growth, then the health status of this age group should be valued more. Population preferences seem to corroborate this proposition. Busschbach et al. (1993), for example, asked people to compare the utility of health at different periods of life. Respondents find health in the early periods of life to be twice as important as in the last decade of life. Similarly, Cropper et al. (1994) estimate in a study conducted in the United States that a saved life has its highest value for people around the age of 30. More recently, Johannesson and Johannesson (1997) report that, in a random sample of 1000 interviewed individuals in Sweden, saving 50-year olds is valued more highly than saving 70-year olds. Nonetheless, it is worth noting that a researcher employing DALYs can make the choice of not using age weights when computing the DALY formula (see, e.g., Mathers et al. (1999)). As for the restricted information set argument, Murray and Acharya (1997) affirm that using a restricted information set can be justified from an egalitarian approach, i.e. to avoid discrimination between different

people’s lives. On the one hand, some economists might argue that a greater weight should be accorded to the health of higher income individuals, because their contribution to the economy is higher. On the other hand, some others might find according greater importance to low income individuals more desirable, because resource allocation to the poorest is at the basis of a plausible treatment of equity. Murray and Acharya propose that excluding information on income, wealth and other socio-economic aspects from the DALY formula is an acceptable compromise solution between these two opposite views.

DALY statistics have been implemented with regard to many types of diseases. A comprehensive report of DALY measures for a large set of diseases and VBDs for all world’s regions is provided by Lopez et al. (2006). Examples of VBD specific studies using DALYs include Clark et al. (2005) and Seyler et al. (2010). In particular, Clark et al. (2005) measure the DALYs lost for fatal and non-fatal cases of dengue in Thailand in 2001. They estimate 427 DALYs/million population lost. Similarly, Seyler et al. (2010) present a measure of DALYs lost due to chikungunya fever in village in India between 2005 and 2006.

It is worth mentioning also the healthy life-years (HeaLYs) indicator proposed by Hyder et al. (1998). The HeaLY is a composite index that conflates a measure of the amount of healthy life lost due to morbidity and that due to premature mortality. As its proponents argue, the HeaLY can be applied at an individual or at a population level to determine the impact of a particular disease. The HeaLY (per 1000 individuals per year) can be formulated as follows:

$$I \cdot \{[CFR \cdot (Ea - (Ed - Ea))] + (CDR \cdot De \cdot Dt)\} \quad (8)$$

where I is the incidence rate per 1000 individual per year, CFR is the case fatality ratio (i.e. the proportion of those affected by a certain disease who die because of the given disease), Ea is the expectation of life at the age of onset, Ed is the expectation of life at the age of death, CDR is the case disability ratio (i.e. the proportion of those affected by a certain disease who have disability because of the given disease), De is the extent of disability, and where Dt is the average duration of disability for those affected by the given disease. To the best of our knowledge, there are no empirical studies employing the HeaLY indicator.

3.4 General limits of micro-based methods

Besides the specific weaknesses that single micro-based approaches show, such methods also share some general limits.

The first limit concerns the fact that micro-based methods do not measure all the externalities produced by VBDs. The presence of a VBD at

an household level casues negative spillovers on the community (the first of which is an increased risk of contagion), that are not included in the traditional cathogory of public medical costs and that are not taken into account in standard micro-based formulas. Given the epidemiological characteristics of VBDs, the magnitude of the risk of an increase in disease diffusion varies with the present level of diffusion, climate factors and population distribution (Snow et al., 1999; Wen et al., 2012). Consequently, to assign a value to negative externalities which is valid across different households and regions of a country is virtually impossible. Moreover, these negative spillovers may also influence the behavior of third parties not affected yet by the disease. In WTP measures, in particular, the private evaluation of a VBD' costs may differ substantially from social costs. The presence of externalities, to conclude, makes aggregation of household level numbers difficult, and total estimated costs obtained through micro-based formulas are likely to be under-estimates of the actual economic burden at the national level.

Second, there is evidence that single VBDs are linked with a number of other illnesses (see, for instance, Hedberg et al. (1993) and Shiff et al. (1996)). Hence, the presence of a VBD implies an increased risk of being affected by other diseases and therefore additional costs, which, again, micro-based measures fail to capture.

A third (and probably the main) limit of using micro-based methods for evaluating the national level economic impact of VBDs is that these measures do not account for a number of macroeconomic effects. The most intuitive way through which VBDs affect the macroeconomic dimension of a country is the demographic channel. On the one hand, VBDs impact positively on mortality rates, and therefore have a negative effect on population growth. On the other, however, VBDs also may induce higher fertility, if a so called "child-replacement" strategy is adopted by people in response to the high risk of loosing children (Galloway, 1988). Although the final effect of VBDs on the age-structure of a population is difficult to predict *a priori*, it reasonable to expect that VBDs change dependency ratios and that this influences macroeconomic dynamics. VBDs should also negatively affect both saving and investment levels, beacuse households may need to recur to past savings in order to compensate for days lost due to illness. Tourism, trade and foreign direct investments may decline as well (see, e.g., Thurow (2001)). The negative effects on schooling, educational attainment and, more in general, human capital accumulation are another important channel thorough which VBDs curb national economic outcomes (Bleakley, 2003; Lucas, 2010). Finally, to the extent that the risk of contracting a VBD for rural workers depends on the type of agricultural activities where they are employed, the presence of VBDs may affect land use decisions. For example, farmers in high risk areas may choose types of plant that require less labour inputs, in order to reduce workers' exposure to vectors (Conly, 1972). This, in its turn, may imply lower economic productivity from agri-

cultural activity. Similarly, a high incidence of VBDs in certain areas may affect human mobility, if settlement of new lands is conditional on the risk of contracting a disease (Malaney, 2003).

Fourth, micro-based measures are generally calculated with reference to a specific year and refer to short-run costs of VBDs. Nevertheless, many of the economic implications of VBDs manifest their effects only in the long-run. This is the case, in particular, of the effects on macroeconomic dimensions. Thus, the calculation of a disease's economic impact in a given year, on the one side, should include the effects of the disease that will appear only in the future, on the other it should exclude the costs that are due to the levels of the disease showed in the past. While a measure of short-run costs may be of some interest, estimating the national level economic impact of a disease necessarily requires to account for long-term dynamics, which often are the most relevant to a country's economic growth rates.

These limits are responsible for the acknowledged divergence in the VBDs' economic effects estimated by macro and micro-based studies. In particular, microeconomic studies commonly report a smaller impact of VBDs than macroeconomic ones. The gap between measures is likely to suggest that micro-based methods provide under-estimated values.

4 Discussion

The systematic examination of both macroeconomic and micro-based methods reveals the importance of identifying a compromise solution between the two approaches. In our opinion, available techniques allow some methodological improvements with respect to what existing studies offer. On the one hand, micro-based measures provide numbers for quantifying diffusion and incidence of VBDs, including both fatal and non-fatal ill outcomes. On the other, the aggregation of micro-based numbers across individuals or households at a national level results in country indicators that can be included in cross-country regression analysis, in order to account for macroeconomic and externality effects. For instance, the DALYs indicator, which measures the lost years of health due to a disease, can be calculated at an aggregate level and then can be used as an explanatory variable in macroeconomic models. A combination of macroeconomic and micro-based methods has been recently indicated as a point of departure for future research by Bonds et al. (2009). In their study of twoway effects of income and infectious diseases on each other, Bonds et al. propose a cross-section empirical investigation in which the natural log of per capita income and per capita DALYs are included in a two-stage least-square linear regression. They use data at a country level, for 65 countries in a single given year, and find negative and statistically significant effects between income and diseases.

Future research should consider improving the approach traced by Bond et. (2009) in several directions. Firstly, the baseline econometric model to be used should follow the specification type of Barro (1991). This requires building a growth econometric panel model in which GDP growth rates are used as the dependent variable. Moreover, a comprehensive set of covariates should include human capital indicators, investment levels, public expenditures and other State intervention indicators, measures for possibly relevant macroeconomic and institutional characteristics, demographic and geographical variables. Initial levels of country income should also be taken into account through appropriate regressors. Secondly, given the panel nature of the model, the health index must cover a sufficiently long period of time. Data availability is probably the main limit in this context. Official and exhaustive databases containing aggregate micro-based health indicators, like DALYs, are rare. In particular, measures comparable across countries along a sufficient time period are still missing. Available studies either provide DALY numbers for a large sample of countries with reference to a single year (Lopez et al., 2006), or offer country-specific case studies for single diseases which do not allow international comparisons (e.g. Clark et al. (2005)). Production of panel DALY statistics for econometric purposes would be of great help to applied research in this area.

The contribution of estimating growth models with the use of DALYs as a measure of a VBD's incidence is twofold. It provides indeed an estimated impact of VBDs which includes, first, the economic implications of non-fatal health outcomes of individuals (in addition to deaths) and, second, externalities due to a disease. It is worth recalling that the magnitude of these externalities is conditional to the dynamics of disease transmission (Kremer and Miguel, 2007), which in its turn is affected by the economic, social and natural environment and by human mobility (Montalvo and Reynal-Querol, 2007). Once appropriate control regressors are introduced in the equation, an estimated parameter for a DALYs variable in a macroeconomic model should encompass this complex system of causality channels connecting VBDs and economic growth.

Avoiding under-estimates of a VBD's impact is extremely important for improving resource allocation. Unreliable estimates of the economic costs of diseases undermine, for instance, cost-effectiveness analyses of vaccination programs. The economic benefits of vaccination are often calculated without using appropriate macroeconomic models (Meltzer et al., 1999; Shadick et al., 2001; Hsia et al., 2002), and so they fail to assess cost-effectiveness validly. This is crucial, more in general, to the specification of national priorities concerning health interventions and investments.

In conclusion, it is worth mentioning what is the main challenge for future research examining the economic impact of VBDs: the role played by climate and biodiversity changes. Global climate change modifies the diffusion dynamics of tropical diseases (Gollin and Zimmermann, 2012) and is

responsible of the re-emergence of some VBDs in Europe (Hendrickx and Lancelot, 2010). VBDs are strongly sensitive to climate variability as the various species of vectors live in specific ecosystems and under specific climate conditions. Climate change (whether it is induced by humans or not) also impacts on biodiversity, which is an important - and so far neglected - determinant of VBDs incidence. Biodiversity, or biological diversity, refers to the variety and variability of biological organisms (Wilson and Peter, 1988). As such, it refers to diversity both within and between species and ecosystems. A change in biodiversity influences VBDs' incidence in two ways. First, it alters vectors' habitats (i.e. their structure, biological characteristics and size) and consequently induces variations in the population of organisms (included vectors) in single habitats. Second, it influences the relation between pathogens and humans. If changes in biodiversity imply a reduction of the number of species in a habitat, this could determine a reduction in competition and predation among organisms and an increase in the likelihood that a vector gets in contact with pathogen hosts, i.e. a reduced "dilution" (Zaghi et al., 2010). A reason why the interlinkages between climate change, biodiversity and VBDs still remain remarkably underexplored is that biodiversity variations are often caused by cyclically occurring or stochastic natural conditions, which give rise to complex environmental and reproductive externalities in the population of both humans and vectors (Barrett et al., 2011). Moreover, the relationship between biodiversity and climate change is not necessarily linear, as particular habitats can support only a limited number of species before becoming saturated (Boyero et al., 2011).

The role played by biodiversity variations is further complicated by the fact that biodiversity is affected not only by climate changes but also by human activity and, in particular, economic activity (industrialization, land use, urbanization, and human mobility). For example, Conn et al. (2002) show that the emergence of new neotropical malaria vectors can be facilitated by human migration and changes in land use. This should stimulate the analysis of an additional causal relationship, which runs from economic outcomes to VBDs' diffusion indirectly through biodiversity and environmental developments. Human-caused deforestation, in particular, alters substantially the ecological link between disease hosts and vectors (Pattanayak et al., 2006). Deforestation changes the ecology of a disease vector and its options for hosts. It affects climate at a local, regional and - when it is made extensively - even at global level. This implies changes in temperature and moisture, that in their turn influence the pace at which vectors develop and come into contact with hosts. In addition, deforestation may favor migration and other behavioral changes that enhance the spread of VBDs. Finally, it can cause mutation and tighter selection of vectors, so stimulating their greater resistance. While some empirical studies examine how deforestation affects VBDs' incidence (see, e.g., Pattanayak et al. (2005), Ginwalla et

al. (2005), Vittor et al. (2006), Afrane et al. (2006), Yasuoka and Levins (2007)), literature investigating the link between deforestation and the economic impact of VBDs is still missing. This could be a productive area for future research. Specifically, future investigations on the relationships between VBDs, economics and ecology should employ appropriate instrumental variable strategies and multiple-stage equations in econometric models, in order to rigorously address these empirical issues. More in general, it is worth emphasizing that economic analysis would greatly benefit from natural science and medical studies focusing on multicausality in VBDs' diffusion.

5 Conclusions

In this paper we have developed a comparative assessment of various macroeconomic and micro-based methods for measuring the economic impact of VBDs at a country level. A summary of available methodologies is provided in Table 1. Column 1 of Table 1 lists the type of approach (i.e., macroeconomic or micro-based), column 2 lists the methods, columns 3 and 4 outline, respectively, advantages and limits of each method, and column 5 reports the main empirical references in the literature.

[Insert Table 1 around here]

The heterogeneity across existing methodologies and their results suggests that there is no unique and reliable method for estimating the relation between VBDs and income or wealth. This is due to several reasons, including the presence of externality effects, heterogeneity in individuals' and households' behavior (which often makes the assumptions in the model setting unrealistic), the various ways in which methodologies account for countervailing dynamics exerted by public institutions and social factors, and data limitation issues. Besides, from an empirical point of view, the main problem in estimating the impact of illness on economic variables relates to two-way causality. Health, indeed, can be considered as a normal good to the extent that individuals increase their demand for good health when - being prices equal - their income increases, and viceversa. The evaluation of the aggregate economic burden of VBDs, therefore, also requires taking account of the various economic variables (such as direct and indirect costs, levels of productivity, national income, economic development and growth) on which (and by which) VBDs can impact (and be affected). Finally, environmental changes - induced by climate dynamics and variations in biodiversity - introduce additional complexity that future empirical studies will need to tackle. We believe that much further theoretical and empirical multidisciplinary research on this topic is needed.

Tabella 1: Summary table.

<i>Approach</i>	<i>Measure</i>	<i>Advantages</i>	<i>Limits</i>	<i>Main empirical references</i>
Macroeconometric	Estimated parameter in cross-country regression	It captures macroeconomic effects and externalities	Endogeneity issues; (often) too simplified indicators of disease's diffusion are employed	McCarthy et al. (2000) [malaria]; Gallup and Sachs (2001) [malaria]; Barreca (2010) [malaria]
Micro-based	Standard COI	It includes both private and non-private medical costs and forgone income at an individual level	It requires strong assumptions on people behavior and labour supply; it does not capture macroeconomic effects and externalities	Shepard et al. (1991) [malaria]; Ettling and Shepard (1991) [malaria]; Maes et al. (1998) [Lyme]; Cropper et al. (2000) [malaria]; Asante and Asenso-Okyere (2003) [malaria]; Zohrabian et al. (2004) [West Nile]; Rijal et al. (2006) [leishmaniasis]; Suaya et al. (2009) [dengue]
Micro-based	WTP	It quantifies both monetary and non-monetary costs of illness	It is conditional to the survey's format; difficult comparability across surveys; it does not capture macroeconomic effects and externalities	Weaver et al. (1996) [malaria]; Onwujekwe et al. (2002) [malaria]; Cropper et al. (2000) [malaria]
Micro-based	DALY	It allows valid cross-country comparisons; it requires relatively easier data gathering	It needs assumptions on weighting age and economic status of people; it does not capture macroeconomic effects and externalities	Lopez et al. (2006) [various VBDs]; Clark et al. (2005) [dengue]; Seyler et al. (2010) [chikungunya fever]
Micro-based	HeaLYs	Easy to compute; in principle it should allow valid cross-country comparisons	It employs average values of the extent and duration of disability across different individuals; it does not capture macroeconomic effects and externalities	None

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