Assessing Economy-wide Effects of Environmental and Health Interventions in Support of Benefit-Cost Analysis

Kenneth M. Strzepek, Collins Amanya, and James E. Neumann

April 2018

Guidelines for Benefit-Cost Analysis Project
Working Paper No. 4

Prepared for the Benefit-Cost Analysis Reference Case Guidance Project
Funded by the Bill and Melinda Gates Foundation

Visit us on the web: https://sites.sph.harvard.edu/bcaguidelines/

Preface

The Bill and Melinda Gates Foundation (BMGF) is supporting the development of guidelines for the economic evaluation of investments in health and development, particularly in low- and middle-income countries ("Benefit-Cost Analysis Reference Case: Principles, Methods, and Standards," grant number OPP1160057). These guidelines will supplement the existing international Decision Support Initiative (iDSI) reference case, which provides general guidance on the overall framework for economic evaluation as well as specific guidance on the conduct of cost-effectiveness analysis. It includes 11 basic principles supported by a series of methodological specifications and reporting standards to guide their implementation.

This draft working paper is part of a series of methods papers and case studies being conducted to support the extension of the reference case to include benefit-cost analysis. This paper has been reviewed by selected experts, posted online for public comment, discussed in a November 2017 workshop at Harvard University and at special sessions at the Society for Risk Analysis (December 2017) and the Society for Benefit Cost Analysis annual meetings (March 2018), and was then finalized. Although these papers will provide the basis for the benefit-cost analysis reference case guidance, the reference case may ultimately deviate from their recommendations in some cases.

This paper, and especially the Uganda case study, reflects the work of a large team of collaborative researchers from the US and Uganda. The authors of this paper (Strzepek, Amanya, and Neumann) wish to acknowledge the contributions of: Samuel Otuba, Ugandan Ministry of Water and Environment; James Thurlow, International Food Production Research Institute; Brent Boehlert and Jacqueline Willwerth, Industrial Economics Inc.; Emmanuel Olet, Independent Consultant (Uganda); and Benjamin Ssekamuli, Independent Consultant (Uganda).

In addition, we are grateful to Channing Arndt, Anil Deolalikar, Christopher Dockins, Markus Haacker, Sandra Hoffman, Margaret Kuklinski, Carol Levin, Steve Newbold, Fran Sussman, Brad Wong, and an anonymous reviewer.

More information on the project is available at https://sites.sph.harvard.edu/bcaguidelines/.

Assessing Economy-wide Effects of Environmental and Health Interventions in Support of Benefit-Cost Analysis

Executive Summary

Economy-wide models include several distinct approaches, including input-output models, macroeconometric models, hybrid input-output-macroeconometric models, and general equilibrium models. As noted in a recent review of economy-wide modeling, a key common characteristic of these models is that they disaggregate the overall economy of a country or region into a number of smaller units, or agents, that are each represented by an appropriate sub-model, which in turn interacts with other agents (or sub-models) in an attempt to simulate the activity of markets for goods and inputs to production. The exciting prospect that this paper explores is the recent advance in methods that allows an increasing level of incorporation of non-market welfare considerations into economy-wide tools. This development in turn facilitates a much better understanding of how health and environmental interventions affects metrics of great interest to policy-makers: for example, overall GDP growth, labor productivity, sectoral patterns of output, and distribution of income and welfare among populations.

As we describe in the next section, movement in BCA away from conventional static methods (i.e., static prices, populations, and sector productivity), such as those often used in benefit-cost analyses, has the potential to capture the cumulative impact of alleviating damage to household health and welfare, and to minimize the potential for static approaches to underestimate the costs of failing to intervene. As outlined below, conditions in LMICs such as more rapid GDP growth and a smaller difference between the market and non-market consequences of poor health, not to mention the critical importance of re-allocating scarce resources to more productive uses, may make applications of economy-wide modeling in those countries even more important, simply because the cumulative effects across the economy and across time are more likely to be large. Put another way, in LMICs the opportunity cost penalty of diverting labor and health costs for "defensive" purposes from GDP formation in the immediate term has larger long-term, cumulative effects in their faster growing economies.

In general, dynamic economy-wide models, compared to partial equilibrium or static economy-wide approaches, may be less attractive when: 1) the policy or investment being considered represents a marginal change relative to the size of the economy or sector being considered; 2) when beneficial effects are largely confined to a short-term time horizon, with limited long-term/cumulative impact on human and physical capital formation which contributes to long-term economic growth potential; and 3) when the costs and/or the benefits of the intervention are largely confined to a single economic sector, with few if any spillover effects through factor or product markets.

By extension, this paper suggests that dynamic economy wide-modeling tools are best applied when the following conditions are in place:

- ***Sufficient data exist.*** A necessary requirement for any economy-wide model is that a social accounting matrix exists or can be readily developed. Yet, the barriers to developing a SAM in almost any country in the world have been considerably lessened by efforts by the World Bank and IFPRI to make these data elements more widely available. Other data are needed to characterize the population affected by the intervention, and to characterize opportunities among these populations for reallocating time, land, water, food, or economic resources elsewhere to take better advantage of productive opportunities, often at the household level, and stratified by income where possible (as effects are likely be larger among low income populations, where even smaller interventions can represent a meaningful relative impact).
- ***Effects are large.*** The exact definition of "large" varies by country context – yet some research concludes that, in fast growing economies, the ripple effects on capital accumulation are more important than in more mature, slower growing economies. This suggests that economy-wide tools may yield important insights in LMICs even for what would be considered relatively small primary impacts in other settings.
- ***Effects have a cumulative nature over time.*** Interventions that have the potential to alter resource allocations (including time resources), affect capital accumulation (including local scale human capital), or have an intergenerational effect on household prospects are much more likely to yield synergistic positive effects as a result of deploying an economy-wide modeling approach. Opportunities for such interventions are likely more prevalent in subsistence settings where even marginal decrements or improvements in productivity of health, labor, or food production can have a noticeable effect on household prospects.
- ***Inter-sectoral implications are likely.*** Effects limited to a single sector, such as for interventions that are designed to improve a single industry's productivity, can be readily analyzed without reference to general equilibrium techniques. In LMIC settings, however, the existing literature suggests that such single sector interventions may be rare – for example, virtually any intervention in the health sector improves well-being to the point that other long-term, multiple-sector, cumulative effects can result from the reallocation of time previous spent ill, or resources previously spent on treatment, provided that opportunities exist to pursue education or economic opportunity. Economy-wide tools provide a unique mechanism to explore the potential of these opportunities.

Our literature review, coupled with the details of our experience in Uganda and elsewhere applying these models in support of development policy goals, provides a strong basis to recommend the next stages of research, implementation, and capacity building needed to facilitate wider application of LMIC economy-wide modeling in support of benefit-cost evaluations. One of our goals in this paper is to make more tractable and feasible the application of these tools in LMICs, in part because the results can provide new and potentially compelling motivations to take action in the health and environmental sectors, among others. To further this goal, there are three areas where this approach can be made to be more effective and rigorous. Perhaps surprisingly, these long-term priorities are not focused on development of the major tools in the framework, so much as they relate to creating conditions to improve the operation and interpretation of these tools in low and middle income country settings:

1. Improve the sub-national collection of economic, social, public health, natural resource and civil infrastructure data to allow for modeling of economics at the scale at which these processes actually take place and where interventions have their greatest impact. These data are the critical first step to understanding the "front lines" of the interventions of interest, facilitating the quantification of mechanisms by which health and other improvements at the district, village, and household level yield meaningful economic implications that ripple beyond the granular level at which they are implemented.
2. Conduct a major effort to quantify and develop mathematical relationships for the impacts between health-based interventions/projects/programs and their outcomes on human activities (e.g. number of reduced diarrheal events per capita for increased clean water supply.) These "translational" relationships are necessary to provide the key links needed between traditional static assessments of the impact health and environmental interventions, and economy-wide modeling, thereby quantifying the potentially important cumulative, inter-sectoral, and spillover effects of these interventions. The good news is that we are in a much better position today in terms of understanding the connections between education, health, nutrition and labor productivity, thanks to the availability of hundreds of empirical studies conducted around the world on the association between social interventions and household outcomes. An important public service could be accomplished by compiling a functional and accessible (to LMIC practitioners) database of the results of these studies.
3. Develop within governments the required interdisciplinary analytical teams that can provide the support needed for decision-makers to bring economy-wide assessments to bear on crucial public policy questions – questions that are too frequently analyzed in a static or partial equilibrium framework, resulting in unintended consequences that might have been identified by using a systems or economy wide approach. While many Ministries of Economy, Planning, or Treasury already have CGE modeling units, application to health and environmental investments requires a new set of interdisciplinary skill. This may be the largest challenge in the way of greater adoption of these tools, faced equally in developed and developing country settings.

There is also a need to backcast economy-wide frameworks through data time series, perhaps tracking major shocks that may have occurred in the recent past to illustrate economy-wide benefits in a retrospective mode. There are three advantages to this backcasting approach:

1. Shine a light on the implications of past interventions
2. Improve tools and techniques, and
3. Generate greater confidence in the *ex-ante* analyses we advocate for here.

We suggest that a key next step would be the conduct of broader set of case study applications of this approach, both to further demonstrate feasibility in LMICs and to provide important practical examples for a capacity building effort among interested LMIC counterparts.

Table of Contents

Assessing Economy-wide Effects of Environmental and Health Interventions in Support of Benefit-Cost Analysis

1.0 Conceptual Framework

Economy-wide models include several distinct approaches, including input-output models, macroeconometric models, hybrid input-output-macroeconometric models, and general equilibrium models – the term "economy-wide" usually refers to a national level analysis, but could also apply to a region, or globally. As noted in a recent review of economy-wide modeling, a key common characteristic of these models is that they disaggregate the overall economy of a country or region into a number of smaller units, or agents, that are each represented by an appropriate sub-model, which in turn interacts with other agents (or sub-models) in an attempt to simulate the activity of markets for goods and inputs to production (SAB 2017). These agents include industries, service providers, households, governments, and many more. The most suitable approach for measuring social costs, as is the aim in most benefit-cost analyses, is general equilibrium modeling. Other economy-wide modeling methods should not be used if the aim is to evaluate social cost, but they may be suitable for evaluating certain economic impacts (e.g., changes in GDP or employment levels) in particular circumstances (SAB 2017). In this paper, we use examples of recent work (in Section 2) and a broad outline of available resources to LMICs necessary to conduct an economywide modeling analysis (in Section 3) to argue that conditions now exist to apply these models much more broadly in LMICs to enhance benefit-cost analyses.

The starting point for assessing economy-wide effects of health and environmental interventions in support of benefit-cost analysis is well stated by Varian (1989): "We start from a simple methodological premise: there is only one correct way to do cost-benefit analysis. First, formulate an economic model that determines the entire list of prices and incomes in an economy. Next, forecast the impact of some proposed change on this list of prices and incomes. Finally, use the utility functions of the individual agents to value the pre- and post-change equilibria. The resulting list of utility changes can then be summarized in various ways and presented to decision-makers." This statement of objectives, rooted in 1989, may omit some elements of the current state of the art in BCA which reflects consideration of non-market inputs to individuals' welfare deriving from health and environmental quality improvements. Varian nonetheless provides a compelling rationale for consideration of economy-wide tools as increasingly essential for robust benefit-cost analysis.

The exciting prospect that this paper explores is the recent advance in methods that allows an increasing level of incorporation of non-market welfare considerations into economy-wide tools. This development in turn facilitates a much better understanding of how health and environmental interventions affects metrics of great interest to policy-makers: for example, overall GDP growth, labor productivity, sectoral patterns of output, and distribution of income and welfare among populations.[1] In particular, this advance facilitates, in principle, incorporation of any of a wide range of health and nutrition outcomes that cumulative impacts over time in the form of human capital erosion or accrual, though in practice the technique has been demonstrated for a more limited set of environmental health; water, sanitation, and hygiene improvements; agricultural production (with extensions to nutrition); and child and maternal time savings that can be directed toward education.

The key points that stand out as we consider applying economy-wide modeling to supplement benefit-cost analyses are "entire list of prices and incomes in an economy" and "pre- and post-change equilibria"; in part because most BCA as practiced today makes use of partial equilibrium and/or static prices and incomes. A long history of texts (Baum and Tolbert, 1985; Brent 1990; Gittinger 1984; Mishan and Quah, 2007; Harberger, Jenkins, and Kuo,2009) and handbooks on Cost-Benefit Analysis (see for example, Treasury Canada 2007; Australian Government 2006; US Dep't of Health and Human Services 1993; FEMA 2011; European Commission 2008; Transport Canada 1994, and US FAA 1999) contain hundreds of pages and many topics of how to apply a limited sequence of partial equilibrium analysis to achieve the goal of a "general equilibrium economy-wide analysis" (Robinson, 2017)

The application of these tools to the priority policies of the Gates Foundation has, until recently, been very challenging, and moreso in low and middle income country settings. In addition to the substantial burden of collecting relevant and reliable data across a national economy, applying these methods to assess health and environmental interventions (including agriculture and water resource/sanitation) necessarily involves moving beyond traditional market economics to incorporate non-market activities that, in turn, should affect both market economic indicators and household welfare. A classic example would be reducing disease, which has several beneficial outcomes for an economy: 1. It reduces spending on disease treatment expenditures; 2. It enhances labor productivity, and potentially converts time spent recuperating to leisure time, by fostering a healthier working population; 3. It improves individuals welfare by reducing pain and suffering and other implications of health that might not readily be captured but the first two categories (such as changes in lifetime savings and consumption patterns). The first effect can be readily accounted for in economy-wide models as a market effect, and the effect of reallocating that spending elsewhere can be assessed. The second effect, while not commonly addressed in economy-wide models, is nonetheless tractable for incorporating in economy-wide models – and this paper clarifies some recent examples that pave the way for wider applications. The third effect is very difficult to capture in economy-wide models – one reason that economy-wide models should be used in conjunction with BCA, rather than a full replacement.[2] We argue in this paper

---

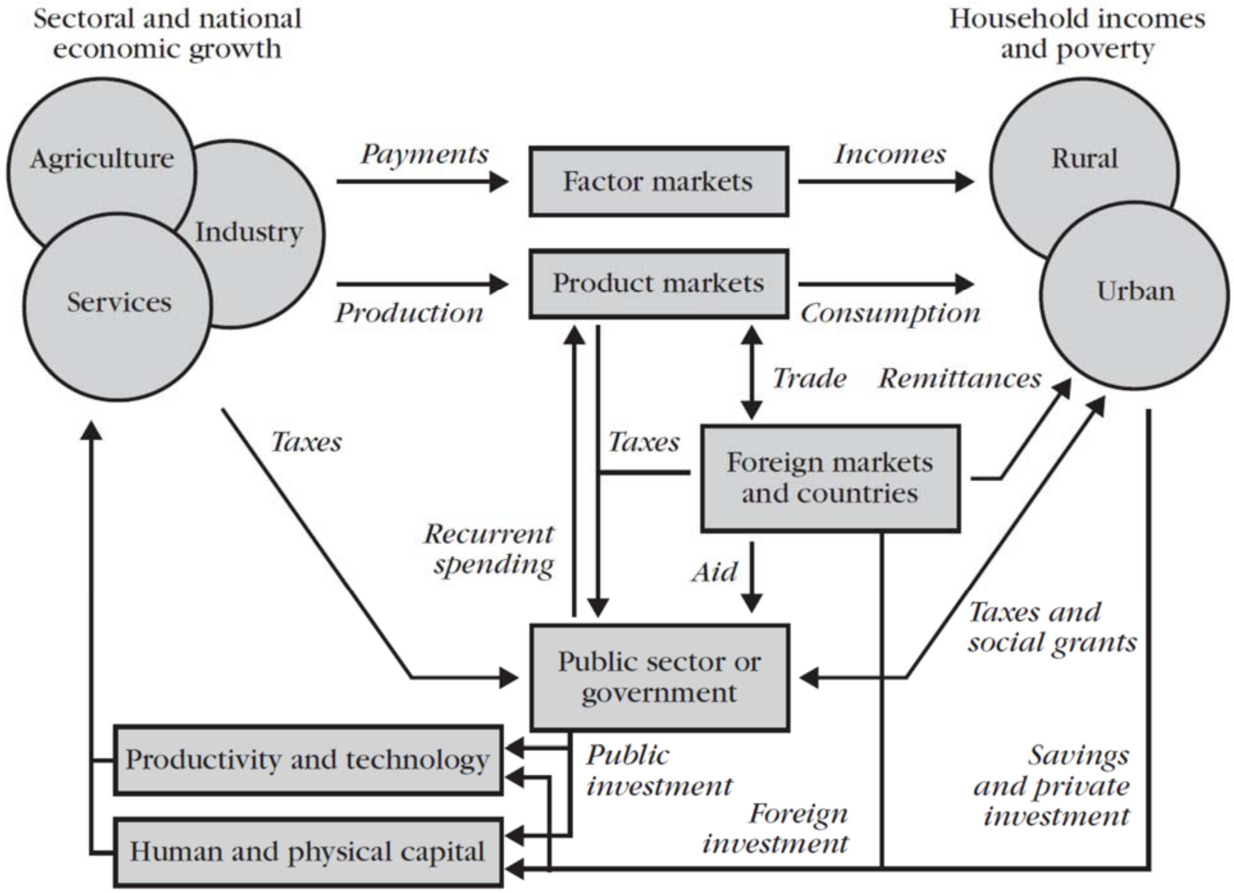
[1] Concerns about the level of sectoral and income class disaggregation in the particular CGE applied may limit these tools ability to effectively estimate distributional effects (SAB 2017), although as noted below there are examples of applications for distributional effects in data-rich environments (e.g., Saari et al. 2014) – the necessary income group-level data is more typically found in developed countries.

[2] Some recent research proposes a pathway to incorporating this third effect, at least in developed country contexts where information on trade-offs between wages and mortality risk are well-characterized, see Marten and Newbold (2017).

that conditions now exist to apply these models much more broadly in LMICs, yielding a much better understanding of how health and environmental interventions can have important “multiplier” effects over time, as resources previously used to combat disease are reallocated to productive use, and time spend recovering from disease is reallocated to education, the labor market, and even enhanced leisure.

With the dawn of digital computing came the development of economy-wide computable general-equilibrium (CGE) models (Dervis et al, 1982) with application for macro-economic policy and development planning. The economy-wide CGE model captures all income and expenditures within an economy during a given year. National production is disaggregated across detailed subsectors within agriculture, industry and services. Figure 1 is a schematic of this general structure. Economic sectors employ factors of production (land, labor and capital) to produce goods and services that are supplied to national product markets. Factor incomes are paid to households – either directly or indirectly after paying taxes – and these incomes are used to finance consumption spending and/or savings. The model is “general equilibrium” because household factor incomes come from the production process and are used to buy the outputs that sectors produce, i.e., they capture the full circular flow of goods and incomes between households and sectors. The model also includes the government sector and the rest of the world, actors that buy and sell goods within domestic markets (e.g., foreign trade or government subsidized education and health services). Finally, household, government, and foreign savings (e.g., foreign aid inflows) provide the funds needed to finance investment spending (i.e., gross capital formation). For many growth analyses, particularly in developing country contexts, a dynamic CGE model is recursive dynamic, which means that the level of investment spending in the previous period determines the amount of new capital available this year. Through the equilibrium estimation process, new capital is distributed to sectors in the model that are relatively more profitable.

Figure 1: Schematic of the structure of an economy-wide general equilibrium model



Note: Although not illustrated here, through government policy and as a source of employment, government can interact with both product and factor markets. The rest of world sector can also interact with factor markets, for example and in particular, through global capital markets. In addition, product markets can provide an important direct source of savings for private investment to enhance productivity and technology assets. (Source: Diao and Thurlow, 2012)

A Social Accounting Matrix (SAM) serves as input data for the economy-wide (CGE) model, which is in turn used to analyze and propose economic policy recommendations. A SAM is an economy-wide data set that captures flows and circulations of products, factors, and monetary flows, and reflects the process of initial income distribution and redistribution of industries and economic institutions of an economy in a certain year. The SAM effectively parameterizes the relationship among all economic actors within an economy as inputs and outputs to that actor's market economic activity, through interpretation of National Product Accounts.

The SAM is a relatively straightforward concept to understand, but economywide models and, in particular, CGEs, are complex models that can be difficult to understand. At their simplest level, the models develop production functions for goods and services producing sectors, defining the relationships between factors of production and outputs; consumer demand relationships for goods; a method for tracking the stock and flow of capital; supply and demand relationships for labor; and most important, a method of "solving" for equilibrium conditions that includes assigning prices to goods in the economy. For readers who are not familiar with these models, a good primer is provided in Paltsev (2004), including a simple illustrative example of a SAM and model equilibrium estimation for static and dynamic CGEs. The distinction between static and dynamic models is described in the following passage:

> "Many CGE models are comparative-static: they model the reactions of the economy at only one point in time. For policy analysis, results from such a model are often interpreted as showing the reaction of the economy in some future period to one or a few external shocks or policy changes. That is, the results show the difference (usually reported in percent change form) between two alternative future states (with and without the policy shock). The process of adjustment to the new general, economywide equilibrium is not explicitly represented in such a model.
>
> By contrast, dynamic CGE models explicitly trace each variable through time—often at annual intervals. These models are more realistic, but more challenging to construct and solve—they require for instance that future changes are predicted for all exogenous variables, not just those affected by a possible policy change. The dynamic elements may arise from partial adjustment processes or from stock/flow accumulation relations: between capital stocks and investment, and between foreign debt and trade deficits.
>
> Recursive-dynamic CGE models are those that can be solved sequentially (one period at a time). They assume that behaviour depends only on current and past states of the economy. Alternatively, if agents' expectations depend on the future state of the economy, it becomes necessary to solve for all periods simultaneously, leading to full multi-period dynamic CGE models. Within the latter group dynamic stochastic general equilibrium models explicitly incorporate uncertainty about the future. "[3]

In the 1980 and 1990s there was a tremendous growth in both software tools for CGE and the application to policy-relevant issues, with the most common applications in the areas of trade, and food and nutrition (Thissen 1998). In the1990s analysts began to link CGE models with natural resource and environmental analyses, with some of the first applications to clarifying the role of water resources as an input factor for market activity (see Berck, et al.(1991) on the role of water for the California economy; Lofgren, et al. (1998); and Robinson et al. (2008) on the role of water in hydropower and agriculture production in Egypt).

---

[3] Wikipedia entry for Computable General Equilibrium: https://en.wikipedia.org/wiki/Computable_general_equilibrium

More recent innovations have been driven by the need to assess the impacts of climate change on market economies – while climate change is not necessarily directly relevant for the priority health and environmental interventions and investments of interest to this paper's audience, the modeling and methods innovations precipitated by climate analysis provided much greater insight about incorporating non-market activities in general (such as water resources as a factor of production) which paved the way for better applications to other non-market flows, such as health services, incorporated through household health production functions.

As we describe in the next section, movement in BCA away from conventional static methods (i.e., static prices, populations, and sector productivity), such as those often used in benefit-cost analyses, has the potential to capture the cumulative impact of alleviating damage to household health and welfare, and to minimize the potential for static approaches to underestimate the costs of failing to intervene. As outlined below, conditions in LMICs such as more rapid GDP growth and a smaller difference between the market and non-market consequences of poor health, not to mention the critical importance of re-allocating scarce resources to more productive uses, may make applications of economy-wide modeling in those countries even more important, simply because the cumulative effects across the economy and across time are more likely to be large. Put another way, in LMICs the opportunity cost penalty of diverting labor and health costs for "defensive" purposes from GDP formation in the immediate term has larger long-term, cumulative effects in their faster growing economies.

Successful interventions in the health and environment sectors in LMICs are almost tautologically macroeconomically consequential via various channels of impact relating to labor supply, productivity, capital accumulation, and vulnerability to shocks, notably those that destroy physical or human capital either in the present (e.g., flooding) or in the future (e.g., childhood malnutrition). In sum, there are several good reasons to bring these frameworks to bear due to the need to capture items such as: multi-sectoral spillover effects; resource constraints; external trade balance and exchange rate effects; and government fiscal implications.

The remainder of this paper outlines relevant literature; some pragmatic near-term recommendations; and some longer-term directions for research to enhance the potential to apply economy-wide modeling approaches to health and environmental improvements in low and middle income country settings.

2.0 Literature Review

The use of dynamic economy-wide tools, such as macroeconomic models of a national or regional economy, among Ministries of Finance and Economy has been prevalent for many years, in both developing and developed economy settings (Lofgren et al. 2002). The traditional application of these tools is focused on fiscal, tax, or monetary policy, and impacts on the productivity and relative prices within the formal market economy. The critical input data that parameterizes these models, a Social Accounting Matrix based on national income and product accounts, focuses on market transactions within an economy – and the critical recent advance is the availability of dynamic models for LMIC countries that can capture long-term cumulative effects for populations affected by health, infrastructure, and environmental investments. Within the past decade, the application of these tools has expanded to incorporate non-market applications, encompassing the implications of public health and environmental policy applications (see for example Berck and Hoffmann 2002). These policies may have both market and non-market consequences, such as reduced health expenditures (market), reduced pain and suffering (nonmarket), and increased labor productivity (indirect or secondary market).

One important public health and environmental policy application of an economy-wide tool in the context of benefit-cost analysis was the US Environmental Protection Agency's Benefits and Costs of the Clean Air Act: 1990 – 2020 (USEPA 2011).[4] The 1990 Clean Air Act Amendments (CAAA) represent a significant change in US Federal air pollution policy affecting virtually every sector of the U.S. economy, including industry as well as individual households. The EPA study first estimated direct costs and benefits of the CAAA in terms of industry's and households' direct compliance expenditures and the value of the direct human health, visibility, ecological, and other benefits associated with CAAA-related improvements in air quality – but policymakers and the public were also interested in the impact of CAAA programs on overall economic performance, as well as inter-sectoral and price implications of policy.

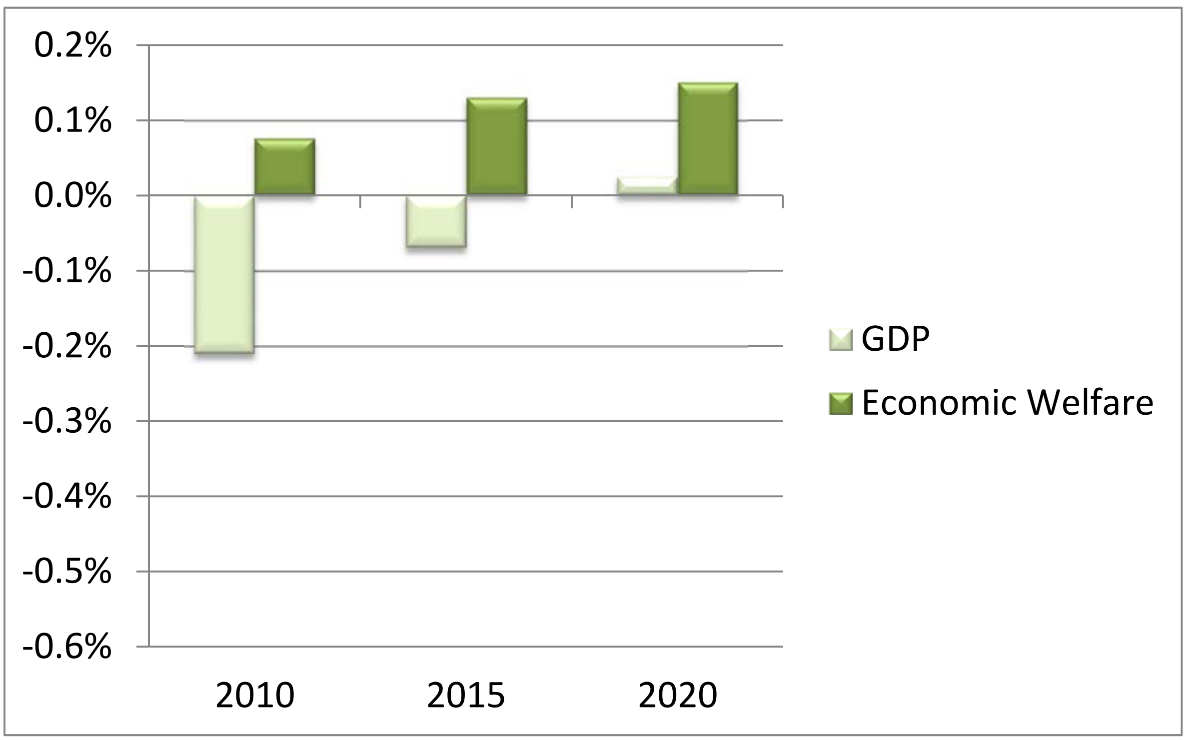
Therefore, to supplement the direct cost and benefit estimates, USEPA applied an economy-wide computable general equilibrium (CGE) analysis of the Amendments and estimated the effect of the CAAA on U.S. gross domestic product and other macroeconomic measures. Applying this dynamic CGE model required USEPA to transform some of the direct public health implications of air pollution, such as premature mortality and work time lost to illness, to measures that could be incorporated in the economy-wide CGE, such as a reduced labor force (or "endowment" in macroeconomic modeling terms) and reduced labor productivity. Other measures, such as avoided health expenditures, fit more directly into the CGE framework. Nonetheless, many of the impact measures, such as the willingness to pay to avoid premature mortality, or the pain and suffering associated with air pollution morbidity, could not be incorporated in the CGE, largely because it is unknown how these non-market effects affect the market economic activity measured in the CGE. The most important omission is individual willingness to pay to avoid mortality risk, which constituted roughly 90 percent of the overall monetized benefits in the traditional BCA results, but were incorporated in the general equilibrium analysis only to the extent that mortality reduced the overall size of the labor force.

The main benefit-cost study found that the costs of public and private efforts to meet 1990 Clean Air Act Amendment requirements would rise throughout the 1990 to 2020 period of the study, and would

[4] See https://www.epa.gov/clean-air-act-overview/benefits-and-costs-clean-air-act and https://www.epa.gov/clean-air-act-overview/benefits-and-costs-clean-air-act-1990-2020-second-prospective-study for more information.

be expected to reach an annual value of about $65 billion by 2020. The requirements were projected to yield substantial air quality improvements which in turn lead to significant reductions in air pollution-related premature death and illness, improved economic welfare of Americans, and better environmental conditions. The economic value of these improvements is estimated to reach almost $2 trillion for the year 2020, a value which vastly exceeds the cost of efforts to comply with the 1990 Clean Air Act Amendments. The economy-wide modeling found that when at least some of the beneficial economic effects of clean air programs were incorporated along with the costs of these programs, the result was a net overall improvement in economic growth and welfare. These improvements are projected to occur because cleaner air leads to better health and productivity for American workers as well as savings on medical expenses for air pollution-related health problems. The beneficial economic effects of these two improvements more than offset the economy-wide costs for air pollution control.

Figure 2. Differences in model projections of GDP and economic welfare between the *With-CAAA* and *Without-CAAA* scenarios – omitting non-market benefits.



Notes: Economic growth as depicted by the light shaded bars is initially lower but by the end of the study period the 1990 Clean Air Act Amendment programs lead to higher overall growth in the economy. The dark shaded bars indicate growing improvement in the measure of household economic welfare, a result which occurs because of beneficial effects of cleaner air and the fact that welfare is not determined by economic growth alone. Including more of the beneficial effects of cleaner air, as proposed in Marten and Newbold (2017), would result in even greater improvements in economic growth and household economic welfare.

Since the USEPA study, other groups have linked biophysical and macroeconomic tools to extend analysis of economy-wide effects of air pollution, and human health more generally, to other economies. In particular, Matus et al. (2012) assessed the impact of high ozone and particulate matter concentrations to the Chinese economy, using a variant of MIT's Emissions Prediction and Policy Analysis model. A key finding resulted when the authors compared their estimated particulate-matter impact on gross domestic product (a loss of US$64 billion in 1995) to a World Bank estimate drawn from a static approach (a loss of US$34 billion) – they conclude that conventional static methods (i.e., static prices, populations, and sector productivity), such as those often used in benefit-cost analyses, neglect the cumulative impact of health and welfare damage and so are likely to underestimate the costs of these damages.[5]

It is interesting to consider some key differences between the results and methods of the USEPA CAAA analysis and the Matus et al. (2012) study of China, because it highlights the importance of applying economy-wide tools in low and middle income country settings. It is striking that USEPA's conventional BCA showed a much higher benefit-cost ratio than the general equilibrium analysis, while Matus et al. (2012) found the opposite result. As noted above, a key limitation of the USEPA analysis was the inability to incorporate the full willingness to pay for mortality risk reduction in the economy-wide tool, which accounted for a very large portion of overall benefits. The same limitation appears to have applied in the Matus application (some details of their application are not clear)[6], but the valuation per avoided mortality appears to have been much lower compared to morbidity valuation estimates, and the overall share of mortality reduction benefits in the "static" approach was therefore much lower – in other words, with a lower VSL, the omission of the full willingness to pay in the dynamic analysis was less important. The other factor that Matus et al. point to is the impact of considering cumulative effects of labor productivity and health expenditures in a fast growing economy are larger than in a more moderately growing economy – effectively, the CGE estimates that the opportunity cost penalty of diverting labor and health costs for "defensive" purposes from GDP formation in the immediate term has larger long-term, cumulative effects in fast growing economies.

---

[5] A similar macroeconomic tool was also used to assess the distributional effects of ozone air pollution in the US (Saari et al. 2014).

[6] Matus et al. (2012) use the fourth version of the MIT Emissions Prediction Policy Analysis (EPPA) model (Paltsev et al., 2005), which is a multi-region, multi-sector computable general equilibrium (CGE) model of the world economy built on the Global Trade Analysis Project 5 (GTAP5) dataset. EPPA version 4 (EPPA4) was modified to include valuation of health impacts. In particular, the following modifications were made to EPPA4 to estimate historic health impacts of air pollution in China. First, the data and analysis includes household healthcare production and leisure in the social accounting matrix. Introduction of a household healthcare production sector that provides ''pollution health services'' allows the authors to capture the health effects related to both morbidity and mortality. Their model also calculates the incidence and overall costs of each health outcome, such as restricted activity days, respiratory hospital admissions, asthma attacks, and other morbidity and mortality outcomes from acute and chronic exposure (as do static benefit-cost analyses). The model calculates the service, labor and leisure costs of all impact categories (often referred to as ''health endpoints'' in epidemiological literature).

In a follow-on study to the USEPA air pollution work, however, Marten and Newbold (2017) propose a new way to incorporate a broader measure of the welfare effect of avoided premature mortality than the restricted labor endowment approach that is typically applied in applications to health risks. Their method takes advantage of the fact that most US VSL studies are based on risk-income trade-offs in the labor market that can also be used to adjust household behavior regarding savings and labor market choices within a life-cycle mortality risk model. Marten and Newbold show that, with this new approach, benefit-cost analyses conducted with economy-wide models yield similar benefit-cost results as partial equilibrium analyses. Marten and Newbold's work is a potentially important counter-point to analysts who have argued that the "side-by-side" USEPA Clean Air Act study suggests that traditional VSL approaches must overestimate benefits, presumably because budget constraints are imposed on all agents in the general equilibrium approach. As a result, their work has important implications for developed country applications of the economy-wide approach. For developing countries, a lack of data and hedonic labor market results to parameterize a life-cycle model may make it more difficult to demonstrate a similar effect, but the Matus et al. (2012) work also suggests that in developing country settings the partial equilibrium and general equilibrium results are more similar.

Applications of these principles to developing countries have, until very recently, been limited to attempts to capture economy-wide effects through carefully executed partial equilibrium approaches, or hybrid applications of macroeconomic results in a static framework – essentially, as multipliers on traditional benefits estimates. Patrinos and Psacharopoulos (2011) provides both a good review of these applications in the education sector, and also their own global application of both long term human capital accumulation and broader economy wide benefits using the results of macroeconomic models. Two metrics apply in this context: 1. Private returns to education relate income to direct costs and opportunity costs (foregone wage income) for the marginal year of schooling; 2. Macroeconomic tools estimate the effect of additional schooling on economy-wide income growth rates. The results, while generally inconsistent in their estimates of returns to the marginal year of schooling, illustrate that there is an important and often omitted component of education policy benefits that constitutes an economy-wide component external to the private perspective.[7]

The inability to access or apply, in a cost-effective way, an economy-wide tool in developing country settings was a major impediment to implementing the type of general equilibrium applications noted

---

[7] In the health arena, important steps have been taken in partial equilibrium contexts to better clarify both long-term and indirect benefits of public health interventions by incorporating some elements of the dynamics that make most economy-wide approaches attractive. A key innovation in this literature is the extended cost-effectiveness analysis (ECEA) method. ECEA was developed to evaluate the health and financial consequences of public health policies in four domains: (1) the health gains (part of a traditional benefits analysis); (2) the financial risk protection benefits; (3) the total costs to the policy makers; and (4) the distributional benefits. The technique can also capture the synergistic effects of multiple interventions. Examples include Verguet et al (2016) for review of applications and a general explanation of the method; Verguet et al. (2012) for application in South Africa; and Pecenka et al. (2015) and Verguet et al. (2015) for applications in Ethiopia. The ECEA method can capture some elements of dynamic policy impacts, but dynamism is largely limited to the health sector (hence the partial equilibrium categorization).

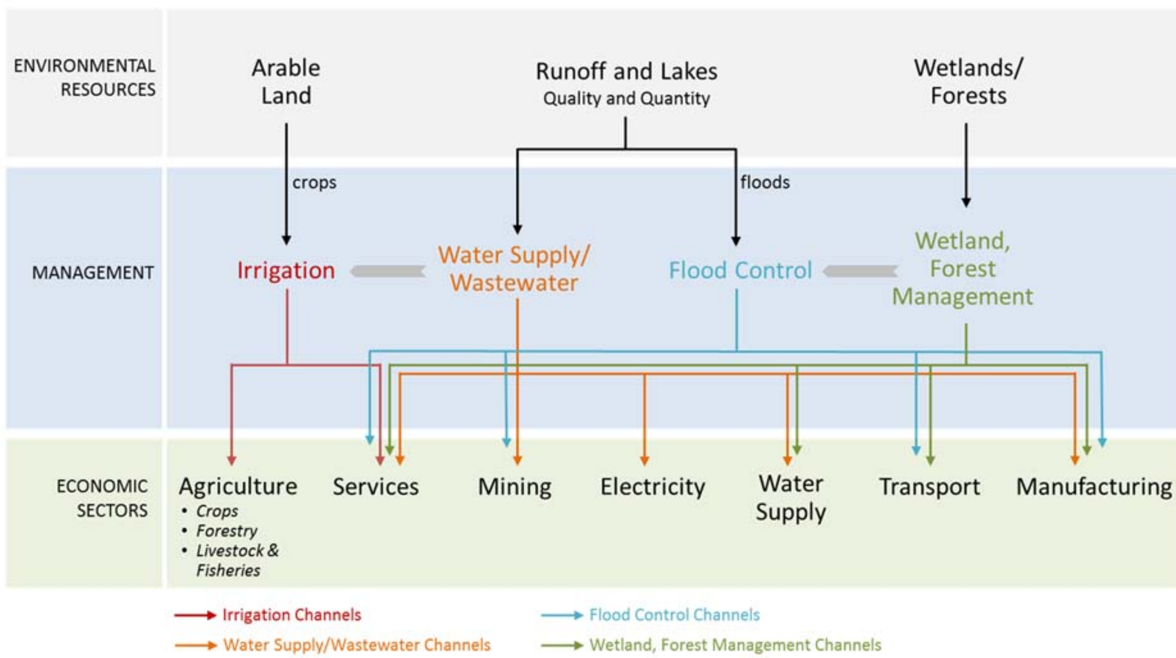
above for US air quality policy. As a result, there is a broad development economics literature focused on partial equilibrium applications within the labor, education, and public health sectors. The aim of this literature is to clarify the secondary and long-term impacts for human capital accumulation and its private (individual) and social (economywide) implications as a result of policy interventions. These applications tend to be good approximations of first order spillover and in some case, cumulative effects, often with the goal of developing insights about "multiplier effects" to characterize both individual and economywide effects beyond the immediate direct effect of policies.

A major step forward was made possible when economy-wide models began to be standardized and made broadly accessible for developing country economies through efforts at the International Food Policy Research Institute (IFPRI). As noted above, these CGEs were then applied in a new framework, the Systematic Analysis of Climate Resilient Development (or SaCRED – see Appendix A) to better understand how natural resource stocks and flows affected not just physical environmental metrics but also economic productivity, capital accumulation pathways, and GDP growth over time. In addition to the many country-level applications of SaCRED noted in the appendix of this paper, Alton et al. (2014) used the approach to assess the implications of carbon taxes in South Africa, taking advantage of the framework's explicit modeling of water resources for various market uses for energy production (hydropower, mining, and thermal power plant cooling), as well as for other productive uses (agriculture, domestic water supply, food processing, etc.). Hassan and Thurlow (2011) used a similar approach, combining both macro- and micro-economic modeling approaches, to assess agricultural policies and nutrition in South Africa. Pauw et al. (2011) assessed the macroeconomic implications, and in particular the dynamic effects on capital accumulation pathways, by modeling impacts of extreme weather events in Malawi. In all cases, the macroeconomic tool was a critical component necessary to fully understand the economy-wide effects of policy, but also the impact on economic development goals in these Southern African contexts.

The most recent key innovation has been combining analyses of health and environmental interventions in an economy-wide modeling context for a developing country economy – the case study that we argue represents the current state-of-the-art is an effort funded by the Uganda Ministry of Water and Environment, with World Bank support (Strzepek et al. 2016). The Uganda MWE study evaluates a broad set of planned interventions, separately and together, over 25 years and considers impacts of each GDP and overall income. The addition of public health "channels" to a modified version of the SaCRED framework provides an important illustrative application that encompasses effects on urban and rural water supply; industrial and agricultural water supply; sanitation/handwashing with concomitant gains in household time (which can be applied to human capital development) as well as reduced health effects (which enhances labor productivity); and forest resource protection, with concomitant gains in individual air pollution exposure reduction because of beneficial changes in cookstove fuels (enhancing health and labor productivity) and reduced wood gathering time (which can be applied to human capital development).

This analysis employed a detailed-sector national CGE macro model of Uganda's economy, coupled with biophysical models of irrigation water demand, crop yield, rainfall-runoff, along with municipal and industrial water demand models to produce inputs to a detailed 84 sub-basin water balance model of Uganda. Additional wetland, water quality, flood risk, and land-use models simulate the impacts of water development and environmental management investment on land, labor, and capital productivity in the economic model. The water and environmental investments impact the economy via a complex interconnection of the economic production factors of labor, capital, and natural resources – the interconnections are summarized in Figure 3 below, with the center panel labeled "Management" representing the "levers" of investment that can be used to enhance economic productivity.

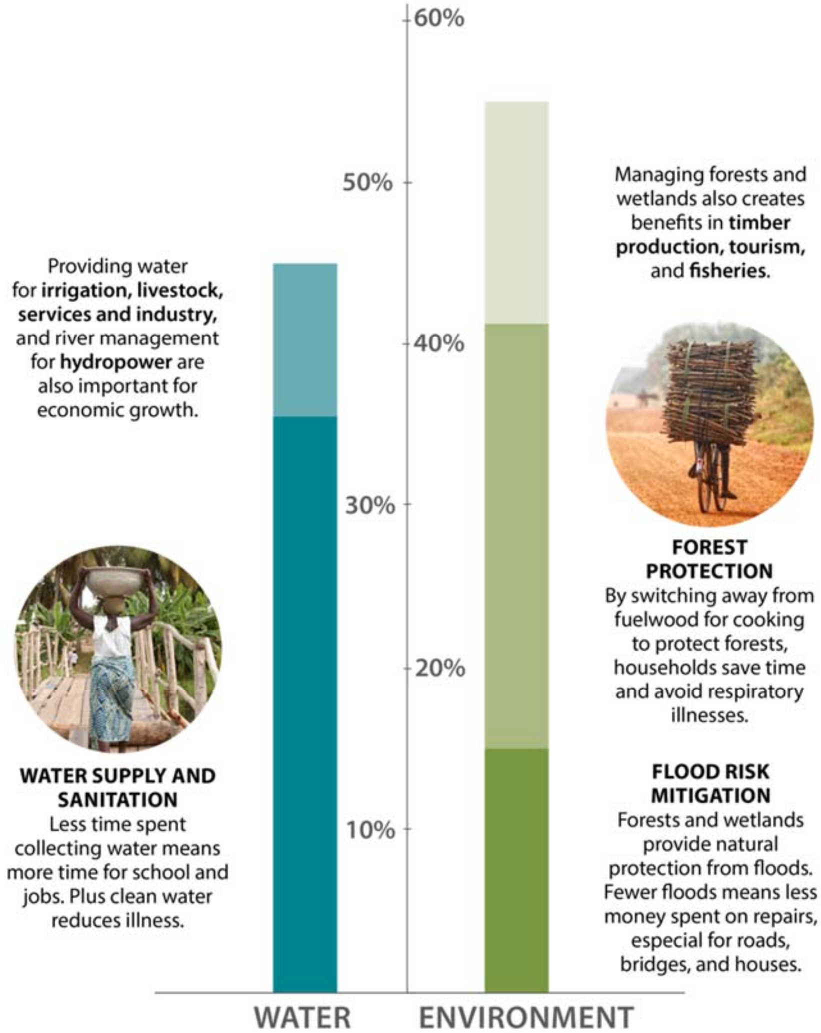
Figure 3: General Framework Applied in Modeling the Economy-wide Impact of Water and Environmental Investments in Uganda



Investments that enhance factors of production ripple throughout all sectors of the economy. For example, investments in urban and rural water supply and sanitation increase the supply and quality of labor which is the major productive factor of the commercial and manufacturing sectors. Investments in environmental management improve ecosystem services such as reduced flooding, improved water quality and improved public health. These services reduce government expenditures for infrastructure repairs and health care, enhancing GDP.

The study found that the overall increase in GDP per capita for all the investments considered is 9 percent through 2040, equivalent to an extra $111 per person in 2040 in this very fast growing population. Figure 4 below illustrates the results of the method as applied to MWE investments, and denominated in terms of contributions to GDP growth over the 2015 to 2040 period, allocated to individual components of the investment package. The reader should be immediately struck not just by the large shares associated with environmental and water investments, but by the inter-relatedness of a multi-sector economy, water availability and quality, environmental/ecological productivity enhancements, labor productivity, and critical health outcomes, particularly among disadvantaged rural households.

Figure 4: Estimated contribution of Ugandan Ministry of Water and Environment Investments to the Total 9% Increase In GDP in 2040.



The key conclusion of this broad literature review is that economy-wide tools provide a new and compelling tool (to policymakers, particularly in Ministries of Finance) for assessing the benefits and costs of a wide range of interventions. Some decision makers may care more about GDP than economic welfare, or may simply better understand the terminology and implications of the GDP metric. The literature points to the importance of careful scenario construction and proper evaluation of the results. Tools can be highly sensitive to assumptions such as how the project is financed, and the ordering of investments, assumptions that are further evaluated in the last section of this paper.

3.0 Steps to Developing an Economy-Wide Modeling Framework

The undertaking of a benefit-cost analysis of a health or environmental project program policy is a significant undertaking in any setting. Performing a cost benefit analysis that includes assessment of economy-wide effects requires all of the data gathering that would be necessary for a static or partial equilibrium accounting of benefits and costs in a cost-benefit analysis. What this approach provides, provided the framework is a dynamic economy-wide model, is a mechanism to more effectively estimate second and third and fourth order impacts across the economy in addition to including nonmarket and ecosystem services to the analysis.

The economy-wide modeling approach is not a substitute for classical cost-benefit analysis but in fact is an extension that enhances the information being provided by the analysis. Taking an economy wide approach for cost-benefit analysis requires additional time and effort, but it is the authors' opinion that the costs are often less than the benefits, provided certain circumstances are evident. With that in mind, it is important to understand both the conditions under which a dynamic, economy-wide modeling approach is likely to provide compelling new insights, compared to a conventional BCA welfare analysis (i.e., what are the marginal benefits of an economy-wide approach), as well as what is involved, step-by-step, in completing the economy-wide variant (i.e., what are the marginal costs of an economy-wide approach).

3.1 Conditions Where An Economy-Wide Model May Make Sense

In general, dynamic economy-wide models, compared to partial equilibrium or static economy-wide approaches, may be less attractive when: 1) the policy or investment being considered represents a marginal change relative to the size of the economy or sector being considered; 2) when beneficial effects are largely confined to a short-term time horizon, with limited long-term/cumulative impact on human and physical capital formation which contributes to long-term economic growth potential; and 3) when the costs and/or the benefits of the intervention are largely confined to a single economic sector, with few if any spillover effects through factor or product markets.

By extension, the literature summarized in section 2 above suggests that dynamic economy wide-modeling tools are best applied when the following conditions are in place:

- ***Sufficient data exist.*** A necessary requirement for any economy-wide model is that a social accounting matrix exists or can be readily developed. As noted below, the barriers to developing a SAM in almost any country in the world have been considerably lessened by efforts by the World Bank and IFPRI to make these data elements more widely available. Other data are needed to characterize the population affected by the intervention, and to characterize opportunities among these populations for reallocating time, land, water, food, or economic resources elsewhere to take better advantage of productive opportunities, often at the household level, and stratified by income where possible (as effects are likely be larger among low income populations, where even smaller interventions can represent a meaningful relative impact).

- ***Effects are large.*** The exact definition of "large" varies by country context – for example, Berck and Hoffmann (2002) suggest that in an economy as large as that of the U.S., effects smaller than $100 million annually are not likely to yield meaningful results in an economy-wide tool. The Matus et al. (2012) example cites meaningful results for effects of $30 to 60 billion in the large Chinese economy, which more than meets the $100 million threshold, but the Matus work also concludes that, in fast growing economies, the ripple effects on capital accumulation are more important than in more mature, slower growing economies. This suggests that economy-wide tools may yield important insights in LMICs even for what would be considered relatively small primary impacts in other settings.
- ***Effects have a cumulative nature over time.*** Interventions that have the potential to alter resource allocations (including time resources), affect capital accumulation (including local scale human capital), or have an intergenerational effect on household prospects are much more likely to yield synergistic positive effects as a result of deploying an economy-wide modeling approach. Opportunities for such interventions are likely more prevalent in subsistence settings where even marginal decrements or improvements in productivity of health, labor, or food production can have a noticeable effect on household prospects.
- ***Inter-sectoral implications are likely.*** Effects limited to a single sector, such as for interventions that are designed to improve a single industry's productivity, can be readily analyzed without reference to general equilibrium techniques. In LMIC settings, however, the existing literature suggests that such single sector interventions may be rare – for example, virtually any intervention in the health sector improves well-being to the point that other long-term, multiple-sector, cumulative effects can result from the reallocation of time previous spent ill, or resources previously spent on treatment, provided that opportunities exist to pursue education or economic opportunity. Economy-wide tools provide a unique mechanism to explore the potential of these opportunities.

This last point about the potential for inter-sectoral implications as a key rationale in expanding a partial equilibrium to a multi-sectoral general equilibrium approach is also emphasized in SAB (2017), where they expand on this point to further note that a strong rationale exists when *both* of the following are present [emphasis in original]:

- Significant cross-price effects, where a costly policy in one market drives consumers to buy more of a substitute or less of a complement good from another industry, and
- Significant distortions in those other markets (e.g. market power, taxes, or regulation). Distortions arising from externalities could also be captured in models where environmental quality [or in this case, health] is not separable from market goods.

SAB (2017) also notes that an economy-wide CGE model can provide a consistent and comprehensive accounting framework to analyze and combine effects of a policy change on both the cost side and the benefit side in a way that satisfies all budget and resource constraints simultaneously – that is, the key motivating point that begins Section 1 of this paper.[8]

A separate point can be made about whether a sectorally resolved economy-wide model is needed, rather than a simpler aggregate macroeconomic model that is capable of capturing cumulative effects that relate primarily to overall population health. In general, we advocate for the application of the simplest models or tool capable of fully characterizing the economy-wide effects. For example, Jefferis and Matovu (2008), in evaluating the macroeconomic impact of HIV/AIDS in Uganda, apply both an aggregate growth model and a sectorally rich CGE – as they note, the aggregate growth model is well-accepted in the literature, particularly for HIV/AIDS analyses, and is simpler, but the CGE provides a broader and richer range of outputs and can more thoroughly trace impacts through the economy. Interesting, both estimate a similar magnitude of GDP impact. In another example, Hellmuth et al. (2006) applies an aggregate macroeconomic tool to assess economy-wide and long-term implications of water quality improvements on prospects for the HIV infected population of Botswana. These simpler aggregate growth modeling tools are not adequate to capture the effects of policies or interventions with multiple and complex multi-sectoral implications, however, as noted above. The simpler tools do form the basis for the “multipliers” on health improvements estimated in the extended cost-effectiveness analysis (ECEA) method (see Verguet et al. 2016). Four key distinguishing factors in deciding whether to apply an aggregate or multi-sector macroeconomic model could be: 1) the nature of the shock to the economy – in particular, whether the shock is focused on a relatively narrow demographic or sectoral component[9]; 2) The shock or intervention has broad multi-sectoral impacts such as a broad labor impact on the national economy; 3) whether there is a desire to estimate distributional impact across income classes, or distinguish the impact on urban or rural poor; and 4) whether a sectorally disaggregated set of outputs is desired, as in the Uganda case study.

3.2 Biophysical, Biochemical, and Chemical Models

Once all the data has been gathered for the particular health or environmental program to be evaluated then a series of biophysical models must be prepared that link the proposed program to the elements of the economy. For example, for a wetlands restoration project, hydro climatic data is needed and a model of the flood mitigating properties of the wetland needs to be developed. The physical outputs of this model can then be mapped to various ecosystem services which can then be linked to the economy wide model using "channels" described above for the Uganda study. In the wetlands example, the

---

[8] In Section 3 of their report, which was focused on air pollution applications, SAB (2017) further notes that “Inclusion of resource and budget constraints in a CGE model allows it to provide a useful reality check in the analysis of policy. A CGE model specifies a labor endowment, for example, so any additional use of labor in one industry must come from somewhere else and may therefore bid up the economy-wide wage rate, whereas non-GE models often assume an infinitely elastic supply of labor. Another example is that total willingness to pay (WTP) for separable non-market goods must consistent with household budgets. Treating PE measures of marginal WTP as constants when measuring the benefits of non-marginal changes in environmental quality ignores the effects of the budget constraint on the marginal willingness to pay.”

[9] We are grateful to Markus Haacker for expression of this point.

reduction in flood peaks will lead to reduced damages of transportation infrastructure and other public and private capital. The channel in the CGE is a reduction in the depreciation of capital in the appropriate sectors.

Similarly, a cookstove intervention requires a biophysical model of health improvements for reductions in indoor air exposure; a nutritional intervention requires a model of how health improvements, which in turn can yield enhancements to labor or educational endowment, may result; and water and sanitation improvements, as illustrated in the Uganda study, must include models of the health benefits of clean water provision relative to the existing baseline conditions.

For effects that are mediated by biophysical processes, these models of natural environmental systems and civil infrastructure systems may be available in developing nations as they are used directly in classic benefit cost analysis for infrastructure investments . A good source for these models and expertise would be local universities and national ministries of water resources or environment. In addition, the UN water related agencies as well as the World Bank and many bilateral aid agencies have expertise and in archives of modeling efforts. Some NGOs such as the Stockholm Environment Institute provide modeling tools available free of cost for developing countries.

3.3 Health Models

Cost-benefit analyses that are examining public health aspects (including vaccines, prenatal and maternal health, as well as indirect effects on health mediated through food, water, or environmental pathways) will need to add additional channels that are developed from and informed by similar models that are in practice in the public health sector. For example, reduced flood damage to water supply and wastewater/sanitation facilities will decrease the need for health expenditures (cholera outbreaks) which can go directly into the CGE through a channel of reduced health sector spending.

In the recent Uganda study (Strzepek et al. 2016) three channels were identified from the literature on how clean water supply would reduce the number of diarrheal cases among children and adults. The first channel was to reduce the health costs associated with each case of diarrhea prevented, increase the labor productivity of adults due to reduced sick days and increase the effectiveness of education as children would have fewer absences. The conceptual and mathematical models as well as the data for developing health related channels was all found in the published literature and vetted with local Ugandan experts for their veracity in the Ugandan urban and rural settings. Local universities and ministries of public health as well as UN agencies, development banks and NGOs all have data expertise and modeling studies for most regions of the world.

To this point the development of channels would appear to be well within the sphere of classic cost-benefit analysis but requiring some deeper digging and conceptual framing to cast the problem into channels. The difficulty becomes when one seeks to link these channels with an economy wide model - in this case a computable general equilibrium model, CGE. Many feel that a framework using a CGE would be prohibitively expensive in terms of data gathering, model building, and accessing CGE expertise. However due to a number of global and regional efforts the data and software needed for building CGE models has become much more widely available, as described in the next section.

3.4 Social Accounting Matrices

As mentioned above the first thing needed to develop a CGE model is to have a social accounting matrix (SAM). There are many national level and sub-national level SAMs that have been developed by Ministries of Planning, Economic, or Finance for macro policy assessments. Additionally, many development banks and universities have developed SAMs for most countries. Additionally, there is the Global Trade Analysis Project (GTAP). GTAP is coordinated by the Center for Global Trade Analysis in Purdue University's Department of Agricultural Economics. The GTAP 9 Data Base features 2004, 2007 and 2011 reference years as well as 140 regions for a list of 57 GTAP commodities. A user may extract country SAMs or I-O tables from the GTAP Data Base for single country models.

International Food Policy Research Institute (IFPRI) and the World Bank have developed many national SAMS as part of their economy-wide modeling efforts. Contacting them as well as searching their archives is a great starting point.

3.5 CGE Modeling Software

Once a SAM has been developed or acquired one needs to have software to run a CGE Model.[10] It is possible to program a CGE model from scratch in any programming language but it highly discouraged. There are three popular CGE modeling software systems:

- GEMPACK (General Equilibrium Modelling Package) requires a GEMPACK license to modify the standard GTAP Model. The Centre of Policy Studies (CoPS), Australia develops and supports GEMPACK. GEMPACK licenses must be obtained from CoPS.[11]
- MPSGE is a mathematical programming system for general equilibrium analysis which operates as a subsystem within GAMS (see Paltsev 2004 for a primer on its use). The system can be obtained through GAMS, which requires a license.[12]
- IFPRI Standard Model is a “standard” CGE model written in GAMS with an EXCEL interface. The analyst is not forced to make “one-size-fits-all” assumptions. The GAMS code is written to give

[10] Note that these tools and the software referenced here do not require supercomputers but they do require modern multi-core CPUs with large RAM memory and ample disk storage for model outputs from the many scenarios that will be run.
[11] GEMPACK https://www.copsmodels.com/gempack.htm
[12] MPSGE https://www.gams.com/solvers/mpsge/index.htm. Note that a GAMS license can be obtained for as little as $500, so it represents a relatively modest investment in most contexts.

the analyst considerable flexibility in model specification. Obtained through IFPRI.[13] Notably, the IFPRI standard model was originally developed as a static model (Lofgren et al. 2002), but relatively recent investments have improved it to the recursive-dynamic format used in the Uganda case study featured in this paper (Diao and Thurlow, 2012).

3.6 Developing A Fully Integrated Framework

Once you have the models that represent the health or environmental project or program to be analyzed, the SAM: at national or subnational level, and the CGE software one must develop the linked framework. This requires bringing the disciplinary experts together to work on the development of the channels and their linkage to the appropriate parameters/functions in the CGE. It is not required but extremely beneficial to have someone on the team who is "bilingual" in economics and health or environmental systems who can facilitate the dialogue among the team.

A key factor is that one of the more important aspects of modeling environmental and/or health systems is the variability of the inputs to the system. Most frequently it is the climatic or weather variability usually manifested as floods and droughts that have major impacts on human systems: public health, water supply, agriculture, transportation, and economic systems. It is very important that the modeling framework model the variability explicitly and not model average parameters as these in many cases lead to the "flaw of averages", as illustrated for agricultural planning in Ethiopia by Block et al. (2010).

Cost-benefit analysis will take place by running the system with and without the proposed investments. It is therefore very important that the team carefully designed what is the baseline without the investment given autonomous behavior of an economy and the scenarios with the investments in place. This includes dimensions of the baseline and intervention scenarios that relate to population and changes in population growth determinants, energy and food prices (including world market prices), and other exogenous drivers to the system.

One very important aspect when dealing with economy wide models is identifying by whom and how investments are to be financed: grants from donors, loans from development banks, domestic tax based investments, or public-private partnership projects. How these are accounted for in the model, as lump-sum investments or annual payments to bondholders, or banks, can critically affect the results. In developing country settings in particular, it is important to have a complete accounting of the government budget within the economy-wide model.

---

[13] IFPRI http://www.ifpri.org/publication/standard-computable-general-equilibrium-cge-model-gams. See for example Lofgren et al. (2002) for a description of how to address the issue based on existing research and data, which can be potentially incorporated into the reference case principles, methodological specifications, and reporting standards.

Finally, the value in using these tools is only realized when there is thoughtful analysis by a team of multidisciplinary analysts who following the wisdom of Keynes - that models offer insights and not answers.

4.0 Recommendations

Our literature review, coupled with our joint experience in Uganda and elsewhere, provides a strong basis to recommend the next stages of research, implementation, and capacity building needed to facilitate wider application of LMIC economy-wide modeling in support of benefit-cost evaluations. The components described in the SACReD framework, as applied in Uganda, and an extension of that framework to public health and environmental management, as well as the example of the use of CGE's and air pollution policy in United States and China have all shown that it is the linkage and the systems thinking that provides for the added value of economy wide modeling in benefit-cost analysis. The Uganda application described here uses economy wide modeling to estimate metrics not usually addressed in a traditional benefit-cost analysis, namely the contributions of investments and interventions to GDP and overall country-level development objectives. Demonstrated here only for the US air pollution policy application, these tools can also be used to estimate benefits and costs in a welfare economic framework, and these estimates are an important supplement and enhancement to a traditional partial equilibrium benefit-cost analysis.

One of our goals in this paper is to make more tractable and feasible the application of these tools in LMICs, in part because the results can provide new and potentially compelling motivations to take action in the health and environmental sectors, among others. To further this goal, there are three areas where this approach can be made to be more effective and rigorous. Perhaps surprisingly, these long-term priorities are not focused on development of the major tools in the framework, so much as they relate to creating conditions to improve the operation and interpretation of these tools in low and middle income country settings:

1. Improve the sub-national collection of economic, social, public health, natural resource and civil infrastructure data to allow for modeling of economics at the scale at which these processes actually take place and where interventions have their greatest impact. These data are the critical first step to understanding the "front lines" of the interventions of interest, facilitating the quantification of mechanisms by which health and other improvements at the district, village, and household level yield meaningful economic implications that ripple beyond the granular level at which they are implemented.
2. Conduct a major effort to quantify and develop mathematical relationships for the impacts between health-based interventions/projects/programs and their outcomes on human activities (e.g. number of reduced diarrheal events per capita for increased clean water supply.) These "translational" relationships are necessary to provide the key links needed between traditional static assessments of the impact health and environmental interventions, and economy-wide modeling, thereby quantifying the potentially important

cumulative, inter-sectoral, and spillover effects of these interventions. The good news is that we are in a much better position today in terms of understanding the connections between education, health, nutrition and labor productivity, thanks to the availability of hundreds of empirical studies conducted around the world on the association between social interventions and household outcomes. An important public service could be accomplished by compiling a functional and accessible (to LMIC practitioners) database of the results of these studies.[14]

3. Develop within governments the required interdisciplinary analytical teams that can provide the support needed for decision-makers to bring economy-wide assessments to bear on crucial public policy questions – questions that are too frequently analyzed in a static or partial equilibrium framework, resulting in unintended consequences that might have been identified by using a systems or economy wide approach. While many Ministries of Economy, Planning, or Treasury already have CGE modeling units, application to health and environmental investments requires a new set of interdisciplinary skill. This may be the largest challenge in the way of greater adoption of these tools, faced equally in developed and developing country settings.

While analyses such as the Uganda water analysis presented are valuable, there is also a need to backcast economy-wide frameworks through data time series, perhaps tracking major shocks that may have occurred in the recent past to illustrate economy-wide benefits in a retrospective mode. There is a growing literature that does exactly this (see for example, Dyer and Taylor 2011; Horridge et al. 2005; and Arndt et al. 2012). There are three advantages to this backcasting approach:

1. Shine a light on the implications of past interventions
2. Improve tools/techniques, and
3. Generate greater confidence in the *ex-ante* analyses we advocate for here.

We suggest that a worthwhile area for the Gates Foundation to conduct a backcasting approach using economy-wide tools would be examination of interventions taken against the HIV/AIDS pandemic.[15] If such an approach is considered, it should be guided by the substantial work already completed in assessing the macroeconomic impact of HIV throughout Africa (e.g., Jefferis and Matovu 2008; Haacker 2016). Most important, though, we suggest that a key next step would be the conduct of broader set of case study applications of this approach, both to further demonstrate feasibility in LMICs and to provide important practical examples for a capacity building effort among interested LMIC counterparts.

---

[14] We are grateful to Anil Deolalikar for expansion of this point.
[15] We are grateful to Channing Arndt, Lawrence Summers, and participants in the November 2017 project workshop for this suggestion.

5.0 References

Arndt, C., M.A. Hussain, E.S. Jones, V. Nhate, F. Tarp, and J. Thurlow. 2012. "Explaining the Evolution of Poverty: The Case of Mozambique." American Journal of Agricultural Economics 94(4):854-872.

Australian Government, 2006. Introduction to Cost–Benefit Analysis and Alternative Evaluation Methodologies and Handbook of Cost–Benefit Analysis, Finance Circular 2006/01. http://www.finance.gov.au/publications/finance-circulars/2006/01.html

Baum, W.C. and S.M. Tolbert. 1985. Investing in Development: Lessons of World Bank Experience. London and New York: Oxford University Press for the World Bank.

Berck, Peter, George Goldman, and Sherman Robinson. (1991). "The Use of Computable General Equilibrium Models to Assess Water Policies." In *The Economics and Management of Water and Drainage in Agriculture*. A. Dinar and D. Zilberman (eds.). Amsterdam: Kluwer Publishing Co.

Berck, Peter & Sandra Hoffmann (2002), Assessing the Employment Impacts of Environmental and Natural Resource Policy, Env't & Res. Econ. 140: 133-36 (2002)

Block, Paul, and Kenneth Strzepek (2012). Power Ahead: Meeting Ethiopia's Energy Needs Under a Changing Climate. Review of Development Economics. 16 (3): 476–488

Brent, Robert J. 1990. Project Appraisal for Developing Countries. Hertfordshire, UK: Harvester Wheatsheaf.

Dervis, Kemal; de Melo, Jaime and Robinson, Sherman. (1982) *General Equilibrium Models for Development Policy.* New York : Cambridge University Press.

Diao, Xinshen and James Thurlow. (2012). "A Recursive Dynamic Computable General Equilibrium Model" In Diao X., J. Thurlow, S. Benin and S. Fan (eds*.), Strategies and Priorities for African Agriculture: Economywide Perspectives from Country Studies.* Washington DC, USA: IFPRI. ISBN: 978-0-89629-195-9

Dyer, G.A. and J.E. Taylor. 2011. "The Corn Price Surge: Impacts on Rural Mexico." World Development 39(10):1878–1887.

European Commission (2008). Guide to Cost-Benefit Analysis of Major Projects. Evaluation Unit, DG Regional Policy.

Federal Emergency Management Administration, (2011). Guide to Benefit Cost Analysis.

Gittinger, J.P. (1984). Economic Analysis of Agricultural Projects. Baltimore: Johns Hopkins University Press.

Haacker, Markus (2016). *The Economics of the Global Response to HIV/AIDS*. Oxford, UK: Oxford University Press.

Haacker, Markus, editor (2004). *The Macroeconomics of HIV/AIDS*. Washington, DC: International Monetary Fund.

Hassan and Thurlow. (2011). Macro-Micro Feedback Links of Water Management in South Africa: CGE Analyses of Selected Policy Regimes. Agricultural Economics 42(2) : 235-247.

Harberger, Arnold, Glenn Jenkins and CY Kuo, (2009). Cost-Benefit Analysis for Investment Decisions (Kingston: Queen's University, December 2009

Hellmuth, Molly, David Yates, Kenneth Strzepek & Warren Sanderson. (2011). "An integrated population, economic, and water resource model to address sustainable development questions for Botswana." Water International, 31:2, 183-197, DOI: 10.1080/02508060.2006.9709669

Horridge, M., J. Maddan and G. Wittwer (2005), "The impact of the 2002–2003 drought on Australia." Journal of Policy Modeling 27: 285–308.

Jefferis, Keith and John Matovu (2008), Assessing the Macroeconomic Impact of HIV/AIDS in Uganda: Phase III – Analysis of Macroeconomic Impact. Report commissioned by the Ministry of Finance, Planning and Economic Development (MoFPED) and the United Nations Development Programme (UNDP) in Uganda. October 2008. Available at: http://www.econsult.co.bw/tempex/Phase%20III%20Final%20Report%20October%202008.pdf

Lofgren, H.; Robinson, S.; El-Said, M. A Standard Computable General Equilibrium (CGE) Model in GAMS; TMD Discussion Paper No. 75., International Food Policy Research Institute: Washington, DC, USA, 2002.

Lofgren, H., S. Robinson, and D. Nygaard. (1998) " Tiger or Turtle? Exploring Alternative Futures for Egypt to 2020" in Raed Safadi, ed. *Opening doors to the world: a new trade agenda for the Middle East*. pp. 167-197 (Chapter 5). The American University in Cairo Press

Marten, Alex L. and Stephen C. Newbold. (2017). "Economy-Wide Effects of Mortality Risk Reductions from Environmental Policies" US Environmental Protection Agency National Center for Environmental Economics Working Paper 17-03. July 2017.

Matus, K., K.-M. Nam, N.E. Selin, L.N. Lamsal, J.M. Reilly and S. Paltsev (2012): Health damages from air pollution in China. Global Environmental Change, 22(1): 55-66 (http://dx.doi.org/10.1016/j.gloenvcha.2011.08.006)

Mishan, E.J. and Euston Quah. (2007). *Cost-Benefit Analysis.* Fifth Edition. Routledge Publishing.

Paltsev, Sergey (2004). Moving from Static to Dynamic General Equilibrium Economic Models: Notes for a beginner in MPSGE. Technical Note No. 4, MIT Joint Program on the Science and Policy of Global Change. Note available at https://globalchange.mit.edu/publication/14238 or http://web.mit.edu/paltsev/www/docs/move04.pdf

Patrinos, Harry Anthony and George Psacharopoulos (2011). Education: Past, Present and Future Global Challenges. The World Bank, Human Development Network (Washington, DC). Education Team Policy Research Working Paper 5616, March 2011.

Pauw et al. 2011. The Economic Costs of Extreme Weather Events: A Hydro-Meteorological CGE Analysis for Malawi. Environment and Development Economics 16(2) : 177-198.

Pecenka CJ, Johansson KA, Memirie ST, et al. (2015). Health gains and financial risk protection: an extended cost-effectiveness analysis of treatment and prevention of diarrhoea in Ethiopia. BMJ Open 2015;5:e006402. doi:10.1136/bmjopen-2014-006402.

Robinson, Sherman, IFPRI (Personal Communication 2017)

Robinson, Sherman, Ken Strzepek, Moataz El-Said and Hans Lofgren. (2008). "The High Dam at Aswan." In Ramesh Bhatia, Rita Cestti, Monica Scatasta, and R. P. S. Malik, eds., *Indirect Impact of Dams:*

Case Studies from India, Egypt, and Brazil. Washington, DC, and New Delhi, India: World Bank and Academic Foundation, pp.227-273.

Saari, R., N.E. Selin, S. Rausch and T.M. Thompson (2014): A Self-Consistent Method to Assess Air Quality Co-Benefits from US Climate Policies. Joint Program Report Series Report 259, 25 p. (http://globalchange.mit.edu/publication/15577)

SAB (USEPA Science Advisory Board) 2017. SAB Advice on the Use of Economy-Wide Models in Evaluating the Social Costs, Benefits, and Economic Impacts of Air Regulations. Report number EPA-SAB-17-012. September 29, 2017. Available at: https://yosemite.epa.gov/sab/sabproduct.nsf/WebBOARD/4B3BAF6C9EA6F503852581AA0057D565/$File/EPA-SAB-17-012.pdf

Strzepek, Kenneth; Brent Boehlert; Jacqueline Willwerth, and James Neumann (2016). The Contribution of Water Resources Development and Environmental Management to Uganda's Economy. Prepared for the Uganda Ministry of Water and Environment, 12 October 2016.

Thissen, M.J.P.M. 1999. Two Decades of CGE Modelling; Lessons From Models for Egypt. SOM Research Memorandum 99C01, University of Groningen, Groningen.

Transport Canada (1994). Guide to Benefit-Cost Analysis in Transport Canada. Transport Canada. Economic Evaluation Branch, Transport Canada, Ottawa, 1994

Treasury Canada (2007). Canadian Cost–Benefit Guide: Regulatory Proposals, Treasury Canada, 2007.

US Department of Health and Human Services (1993). Feasibility, Alternatives, and Cost/Benefit Analysis Guide, Administration for Children and Families, and Health Care Finance Administration. http://www.acf.hhs.gov/programs/cb/systems/sacwis/cbaguide/index.htm

US Environmental Protection Agency (2011). Benefits and Costs of the Clean Air Act 1990-2020, the Second Prospective Study. Washington, DC.

US Federal Aviation Administration (1999). Airport Benefit-Cost Analysis Guidance, 1999

Varian, H. R., 1989. Measuring the Deadweight Costs of DUP and Rent Seeking Activities, *Economics and Politics*, 1(1), pp. 81–95.

Verguet, Stéphane, Jane J. Kim, and Dean T. Jamison (2016). Extended Cost-Effectiveness Analysis for Health Policy Assessment: A Tutorial. PharmacoEconomics (2016) 34:913–923. DOI 10.1007/s40273-016-0414-z

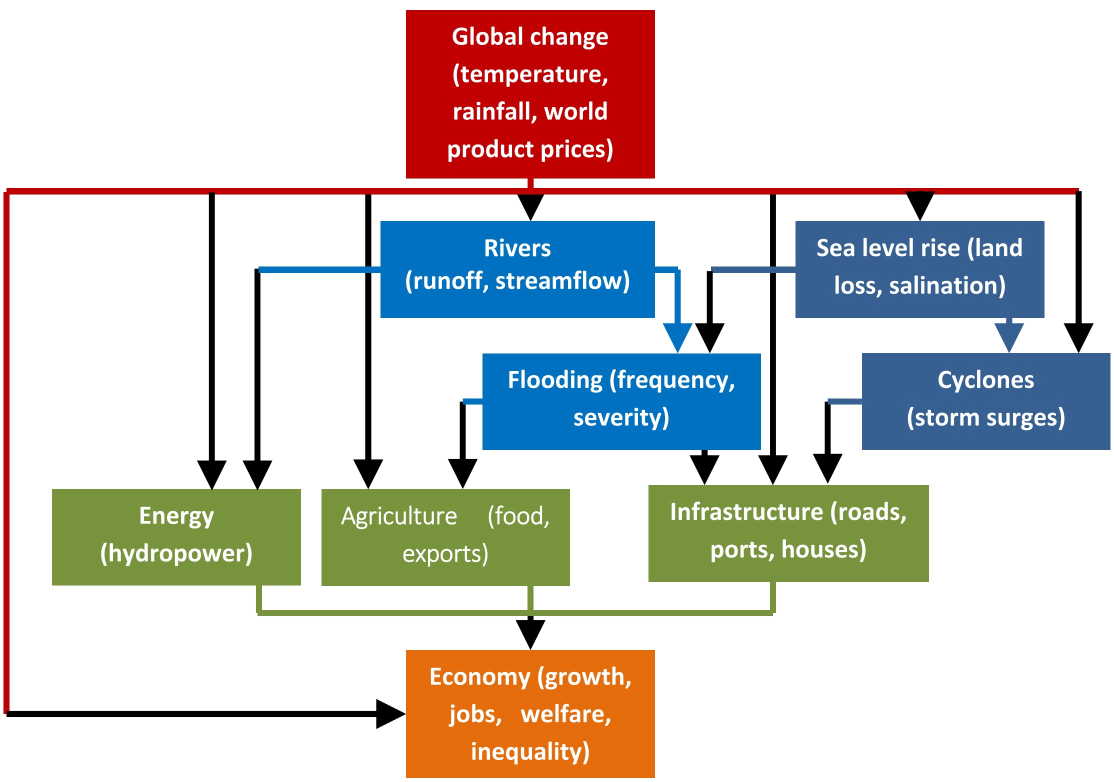
Verguet, Stéphane, Zachary D Olson, Joseph B Babigumira, Dawit Desalegn, Kjell Arne Johansson, Margaret E Kruk, Carol E Levin, Rachel A Nugent, Clint Pecenka, Mark G Shrime, Solomon Tessema Memirie, David A Watkins, Dean T Jamison. Health gains and financial risk protection afforded by public financing of selected interventions in Ethiopia: an extended cost-effectiveness analysis. Lancet Glob Health 2015;3: e288–96.

Verguet, Stéphane, Waasila Jassat, Melanie Y. Bertram, Stephen M. Tollman, Christopher J. L. Murray, Dean T. Jamison, and Karen J. Hofman. Supplementary immunization activities (SIAs) in South Africa: comprehensive economic evaluation of an integrated child health delivery platform. Glob Health Action 2013, 6: 20056 - http://dx.doi.org/10.3402/gha.v6i0.20056

Appendix A: The Systematic Analysis of Climate Resilient Development Analytical Framework

Responding to the need highlighted by the EACC case studies and to assist policy makers in evaluating the potential economic impacts of climate change, as well as to identify specific regional and sector vulnerabilities, the United Nations University – World Institute for Development Economic Research (UNU-WIDER), in collaboration with external partners, has progressively developed an analytical framework, called Systematic Analysis of Climate Resilient Development (SACReD). The SACReD approach is novel in that it integrates comprehensive biophysical modeling with economy-wide economic analysis. The climate impacts and adaptations component of the SACReD framework is illustrated in Figure A-1.

Figure A-1: Systematic Analysis for Climate Resilient Development (SACReD) framework



The framework begins with climate change scenarios for a particular country. Climate change manifests itself as changes in projected levels for temperature, precipitation, barometric pressure, humidity and other weather outcomes. However, with this information alone, it is difficult to assess the potential impacts of climate change on many variables of interest such as economic growth, development prospects, and the material wellbeing of the population. As such, the SACReD framework traces the implications of changes in climate outcomes through a series of important impact channels—including the production of hydropower, agricultural yield, water supply/demand balance, and costs of maintaining and repairing damaged infrastructure and other installed capital.

These climate change impacts then serve as inputs into an economy-wide model of the country in question. The economy-wide models employed respect macroeconomic identities, meaning that all futures are economically coherent and account for multiple simultaneous impacts. For example, higher levels of rainfall may be favorable for hydropower generation, water supply, and agricultural production, but unfavorable for road infrastructure due to washouts or widespread flooding – both effects are accounted for in the framework. Yet, in addition, the SACReD framework respects biophysical limitations and opportunities for the use of natural resources as factors of production across a wide range of sectors – for example, the use of constructed wetlands to reduce flood risks and, in the process, effectively reduce depreciation rates of capital vulnerable to floods. Variants of the SACRED framework have been applied to Ethiopia (Robinson, et al 2013), Ghana (Arndt et al 2015), Malawi (Arndt et al. 2014), Mozambique (Arndt et al 2011a), Tanzania (Arndt et al 2011b), Vietnam (Arndt et al 2015b), Zambia (Schlosser and Strzepek 2013), and South Africa (Cullis et al, 2015).

The most recent applications of economy-wide tools extend the SACReD framework from a climate change focus to include the economy-wide implications of investment in public health, which in many instances, especially in developing economies, are linked to environmental health (see, for example, Strzepek et al. 2016 for an application in Uganda, as summarized in the main text).

References

Arndt, C., Asante, F. & Thurlow, J., 2015a. Implications of Climate Change for Ghana's Economy. Sustainability, 7(6), pp.7214–7231.. Available at: http://dx.doi.org/10.3390/su7067214

Arndt, C., Farmer, W., Strzepek, K. and Thurlow, J. 2011. Climate Change, Agriculture, and Food Security in Tanzania. UNU-WIDER

Arndt, C., Pauw, K. and Thurlow, J. 2014. The Economywide Impacts and Risks of Malawi's Farm Input Subsidy Programme. UNU-WIDER

Arndt, C., Tarp, F., and Thurlow, J. 2015b. The economic costs of climate change: A multi-sector impact assessment for Vietnam. Sustainability, 7, pp. 4131-4145. DOI: 10.3390/su7044131

Cullis, James, Theresa Alton, Channing Arndt, Anton Cartwright, Alice Chang, Sherwin Gabriel, Yohannes Gebretsadik, Faaiqa Hartley, Gerald de Jager, Konstantin Makrelov, Gordon Robertson, C. Adam Schlosser, Kenneth Strzepek, and James Thurlow, 2015. An uncertainty approach to modelling climate change risk in South Africa. WIDER Working Paper 2015/045. World Institute for Development Economics Research. Available at: https://www.wider.unu.edu/sites/default/files/WP2015-045-.pdf

Robinson S, Strzepek K and Cervigni , R. 2013. The Cost of Adapting to Climate Change in Ethiopia: SectorWise and Macro-Economic Estimates. ESSP working paper 53. 1-23

Schlosser, C.A., and K. Strzepek (2013): 'Regional climate change of the greater Zambezi river basin: A hybrid assessment'. Working Paper 2013/040. Helsinki: UNU-WIDER.