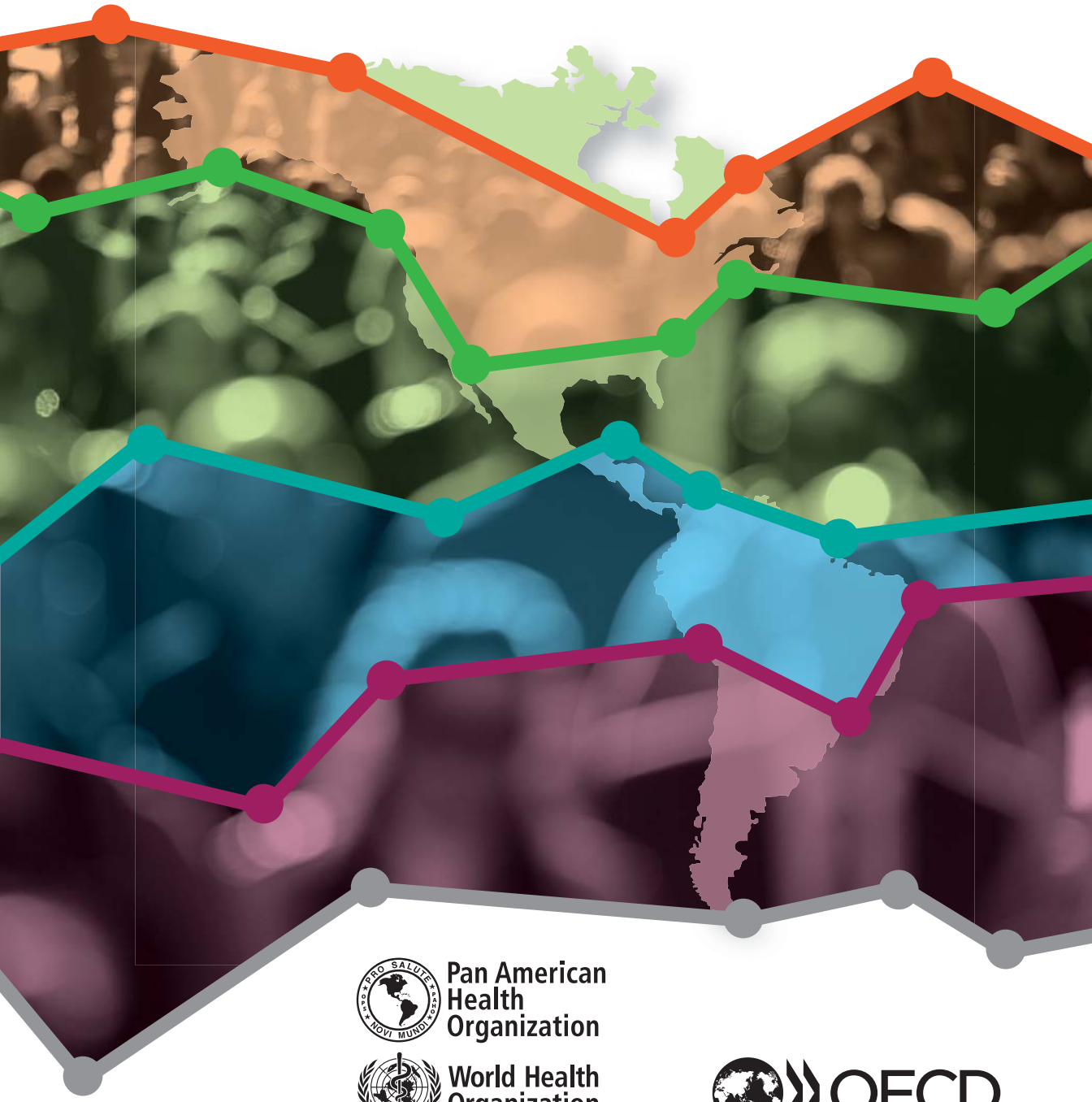
Applying Modeling to Improve Health and Economic Policy Decisions in the Americas:

The Case of Noncommunicable Diseases

Edited by Branka Legetic and Michele Cecchini



Pan American Health Organization

World Health Organization
REGIONAL OFFICE FOR THE Americas

OECD
BETTER POLICIES FOR BETTER LIVES

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FOREWORD

In the Region of the Americas, noncommunicable diseases (NCDs) are a clear threat not only to human health, but also to a country's economic development and growth. The evidence on both of these counts is compelling. In 2012, cardiovascular disease, diabetes, cancers, chronic respiratory conditions including asthma, and other NCDs were the cause of 4.5 million deaths in the Americas. Of that total number, 1.5 million of them were premature, occurring among people aged 30-69 years.

The financial impact of NCDs in the Americas is just as dismaying, with chronic diseases posing a growing threat to many nations' economic stability. According to a 2007 *Lancet* article, without intensified NCD prevention efforts, countries around the world could expect their gross domestic product (GDP) to decline by billions of dollars. Over the 2006-2015 period, from just three chronic illnesses—heart disease, stroke, and diabetes—the countries of Argentina, Brazil, Colombia, and Mexico together could face a cumulative combined GDP loss of US$ 13.5 billion.

These health and financial losses are not inevitable. Options exist today for actions that governments, civil society, and the private sector can take to substantially reduce these costs. Nevertheless, choosing the best health and economic policies can be a daunting task. Since 2011, both the Pan American Health Organization and the World Health Organization have been working with governments and such other partners as the Organisation for Economic Co-operation and Development, the Public Health Agency of Canada, and the Economic Commission for Latin America and the Caribbean to strengthen the capacities of countries to generate and use economic data in developing NCD interventions, with the aim of reducing mortality from these diseases.

This publication, *Applying Modeling to Improve Health and Economic Policy Decisions in the Americas: The Case of Noncommunicable Diseases* is the product of this collaboration. The text is the first to exclusively present different economic models and illustrate their application to NCDs in the Region of the Americas. It aims to stimulate the use of economic modeling as a tool to support the decision-making process for NCD interventions, and to encourage investment in cost-effective strategies for healthy living and NCD prevention in the Region.

The book introduces several models for assessing health and economic policies in relation to NCDs; shows how the models can be used for different diseases or risk factors; and provides case studies of those models' application in various countries in the Americas. The ultimate goal is to help policymakers find the best strategies for cost-effective and evidence-based NCD interventions.

The type of modeling presented in this publication can be a valuable supplement to the traditional work of health economists worldwide. Previous economic efforts for NCDs have mainly focused on microeconomic impact and economic evaluation, primarily through cost-effectiveness analyses done in a limited number of countries that have access to abundant data. The economic modeling presented here can complement these traditional economic analyses, by simulating the economic impact of NCD interventions over time and across a range of populations and strategies.

A healthy population is an important factor for sustainable economic growth. All the persons who share that view—including public health practitioners, researchers, students, and officials framing and implementing health policies in the private and public sectors—could benefit from this text.

Allocating existing resources and marshaling new ones are essential steps if health systems in the Region are to meet the evolving needs of their populations, particularly as it relates to NCD prevention and control. We firmly believe this book can help the nations of the Americas face that challenge.

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Director
Pan American Health Organization

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INTRODUCTION

Modeling a Better Future for the Health Sector

Michele Cecchini

Anyone who ventures a projection or who imagines how a dynamic process would unfold is running some model. But typically this is an implicit model, in which the assumptions are hidden, their internal consistency is untested, their logical consequences are not investigated, and their relation to data is unknown. It is an implicit model that has not been written down.

In its broadest sense, the term "modeling" can be taken to include anything beyond the direct application of observed data. However, in the context of economic evaluation, the term is generally understood to refer to studies that "employ an analytic methodology to account for events that occur over time" (Mandelblatt et al., 1996).

In the health sector, the purpose of modeling is to structure evidence on clinical and economic outcomes in a form that can inform decisions about clinical practices and health care resource allocations. Models synthesize evidence on health consequences and costs from many different sources, including clinical trials, observational studies, insurance claim databases, case registries, public health statistics, and preference surveys. A model's logical, mathematical framework permits the integration of facts and values and links these data to outcomes that are of interest to health care decisionmakers.

Broad, Long-Standing Use in Other Fields

For some 60 years, modeling and simulation have been applied in many sectors, ranging from pure mathematics and physical sciences to engineering, economics, and social science. Modeling represents a vital part of any planned project in the military and aerospace field and in the manufacturing arena (Robinson, 2002). Experts agree that the reason behind the broad use of modeling in these two areas is that computer models provide a significant insight into the working of a change in strategy. This feature is particularly useful when systems have a very high level of intrinsic complexity, such as in the aerospace and military spheres. It's also true for business and industry, when many possible situations are involved. And it's an advantage when empirical testing is not feasible.

Increasing budgetary pressures are another reason for greater attention to and wider use of modeling and simulation, according to many authors (see, e.g., Componation, Gholston, Hyatt, & Simmons, 2003). Gordon (2001) estimated that, compared to business as usual, the use of simulation analyses could decrease the cost of new projects by as much as a factor of 10. Utilizing such approaches is so well embedded in certain areas that, for instance, the United States Navy relies more on modeling and simulation than on actual field testing for both the acceptance and demonstration tests of new or upgraded systems (Dockery, 1998). Likewise, Rabelo and colleagues (2006) provide good evidence that modeling is an essential support to NASA managers in solving aerospace problems and making decisions about range safety and the construction of future vehicles.

Limited Utilization in Health

Health and health care systems are the resultant of complex interactions among multifaceted elements (Oderkirk, Sassi, Cecchini, & Astolfi, 2012). Health is largely determined by the interactions among social, economic, and physical environments and inherited characteristics, which together affect exposures and behaviors. In contrast, the functioning of health care systems is based on hundreds of services, each of which needs a compounded combination of input resources to work. At a higher level these services are interlinked with each other, and they have to interact with a good grade of coordination. Changes in the demographics and epidemiology of diseases as well as increasing public expectations contribute to modifying over time the way in which health services are delivered, thus keeping these structures in a state of continuous transition.

Given these circumstance, the health care sector should be an obvious candidate to use computer modeling and simulation as a valuable tool to generate sound evidence. However, modeling and simulation has had a much shorter lifespan and more limited use in the health field than in many other sectors.

Modeling in health care was first introduced about 30 years ago, but simulation has only recently started to gain acceptance as an essential planning approach (Fone et al., 2003), such as for policy development in some OECD countries (Glied & Tilipman, 2010). Moreover, when compared to other disciplines, the use of simulation in health care settings has spread much more slowly. A 1999 review by Jun and colleagues identified only 8 simulation studies done between 1973 and 1977 that looked at such health care settings as health care clinics and hospitals, and just 28 studies done between 1993 and 1997. More recent research (Royston, 2005) found that the number of citations of health simulation modeling work only showed a sizable increase beginning in the year 2000.

Major Potential for the Health Sector

In recent years there has been a growing acceptance and use of simulation models in the health care sector. At the same time, more policymakers have come to recognize the cost,

time, and ethical advantages that simulation modeling has over direct experimentation. For resource-constrained health organizations, modeling can produce good-quality evidence, especially on non-health-care interventions (e.g., population-wide prevention programs) on which health organizations are reluctant to invest without solid information on effectiveness and cost-effectiveness. Additionally, modeling can decrease the costs and the time needed to carry out large randomized clinical trials (RCTs).

More specifically, simulation modeling provides three other key benefits. First, simulation technologies make it possible to analyze and evaluate "what if" scenarios. In practical terms, this means setting up a simulated reproduction of the environment and then predicting the likely outcomes produced by changing any input parameter or by modifying the process of the system under study. In other words, modeling allows us to design, validate, and implement new ideas without disturbing production processes. That is done by manipulating an environment that is not real (it is simulated) but that imitates (represents) the real world, with real data and actual events. The simulation examples presented in this book exploit this specific characteristic of models. These simulations predict what would happen, for example, in a range of countries if these nations implemented innovative prevention policies to tackle unhealthy diet, lack of physical activity, and other key risk factors that are associated with common chronic diseases.

Another benefit is that by pooling information from various sources, simulation modeling can aid decisionmakers to evaluate and compare the outcomes of different strategies and to explore the consequences of different changes to the system. RCTs are and will remain central to the process of testing the effectiveness of a policy or an intervention. However, RCTs alone can produce misleading evidence if their results are not translated into outcomes that are valued by patients, and, more generally, by the society. For example, suppose that one RCT concludes that an intervention decreases the incidence of a relatively rare disease by 50%, while a second RCT determines that a different intervention reduces the incidence of a more common disease by 20%. Based on these two studies, a policymaker would not know which intervention is the better investment. Simulation modeling makes it possible to synthetize the evidence from the two RCTs and compare the two interventions on the same basis (e.g., increase in life expectancy at the population level, number of averted deaths, or cost-effectiveness of the intervention). In this way, policymakers will have all the relevant evidence needed to make an informed decision.

Finally, the value of a model lies not only in the results it generates, but also in its ability to reveal the logical connections between the different inputs (i.e., data and assumptions) and also between inputs and outputs (e.g., consequences and costs). For example, models simulating the functioning of a health care system could produce new insights on how the different health care services, from prevention to treatment and long-term care, interact with each other. A simulation model designed to study the effects of upscaling a country's screening strategy for a chronic disease could clarify how the screening services interact with curative services down the clinical pathway (e.g., outpatient and inpatient curative services). That model could also elucidate how

the upscaling of the screening program might affect the use and, consequently, the resources used by the other health care services.

Devising novel and affordable methodological approaches for producing high-quality evidence is a crucial challenge for the public health community. This book is an example of how PAHO and OECD have joined forces to help their member nations progress on this key issue.

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CHAPTER 1

The OECD/WHO Chronic Disease Prevention (CDP) Model: A Tool to Identify Effective and Efficient Strategies to Prevent NCDs

Michele Cecchini, Jeremy A Lauer, and Franco Sassi

The Values of Cost-effectiveness Analysis in Prevention

To determine whether preventive interventions will increase social welfare, the costs and benefits of such interventions need to be assessed against those of alternative courses of action. Increasingly, assessment of the allocative efficiency of interventions and programs is based on the framework of cost-effectiveness analysis. Cost-effectiveness analysis avoids placing monetary values on health outcomes by using quality-adjusted life years (QALYs), disability-adjusted life years (DALYs), or simply life years gained (LYGs) as common health outcome measures. However, using the cost-effectiveness analysis framework in the area of prevention poses a number of difficulties. Medical- or public-health-driven preventive interventions struggle to fit into a broad framework for allocating health care resources alongside curative, diagnostic, and palliative interventions. That is because of the somewhat uncertain and distant nature of the outcomes of preventive interventions. This places these interventions in a league of their own and often makes governments (and, indeed, health insurance organizations) uncomfortable about diverting resources away from uses that have a more immediate and certain return. This is particularly true in a health care system with tightly constrained resources, where it is not even possible to fund all the potentially available curative interventions.

When disease prevention efforts, such as improving school meals, arise in sectors other than health care, or across government departments, the cost-effectiveness analysis framework is even more problematic. That is because the outcome measures on which the framework is typically based do not allow comparisons with interventions competing for the same resources. For example, if a school meals program is funded from the education budget, it will compete with other educational interventions, whose overall effects could hardly be measured in QALYs or averted mortality. Therefore, cost-effectiveness analysis can be part of the assessment of government policies towards primary disease prevention, but it will not be the sole, or the principal, approach in the assessment process. Given tight constraints on public finances, the starting point of any assessment of prevention policies should be a thorough assessment of long-term financial implications. These implications range from estimated intervention costs (including external costs involved in raising fiscal revenues, where appropriate) to impacts in terms of changes in health care expenditure and productivity.

The OECD began a project on the economics of chronic disease prevention in 2007 (Sassi & Hurst, 2008; Sassi, Devaux, Cecchini, & Rusticelli, 2009; Sassi, Devaux, Church, Cecchini, & Borgonovi, 2009). The cost-effectiveness modeling component of the project is being carried out in collaboration with the World Health Organization (WHO). The primary aim of the modeling component is to develop an economic model of the impact of interventions to tackle overweight/obesity and associated risk factors (particularly unhealthy diets and lack of physical activity) at the population level. The economic analysis model, as well as the underlying epidemiological model, is designed to be broadly applicable to the largest possible number of countries. The model is being used to assess a range of interventions in terms of their efficiency and their distributional impact across different life-stages and socioeconomic conditions. The focus of the modeling work is on identifying efficient and equitable means of pursuing population health improvements through appropriate combinations of prevention and treatment of chronic diseases.

The WHO-CHOICE Approach

Cost-effectiveness analysis is concerned with how to make the best use of scarce health resources. The large and growing literature on the topic is dominated by the comparison of interventions aimed at a particular disease, risk factor, or health problem, which provides relevant information to program managers or practitioners with this specific disease mandate. In practice, however, different groups of policymakers and practitioners have different demands. Managers of hospital drug formularies must decide which of a vast array of pharmaceuticals they should stock, taking into account the available budget. Countries where health is funded predominantly from the public purse make decisions on what type of pharmaceuticals or technologies can be publicly funded or subsidized. All types of health insurance—social, community, or private—must select a package of services that will be provided. These types of decisions require a broader range of information, involving comparison of different types of interventions across the entire health sector. This is true whether the interventions are aimed at treating diabetes, reducing the risk of stroke, or providing kidney transplants. This type of analysis can be referred to as "sectoral cost-effectiveness analysis."

Although the number of published cost-effectiveness studies is now huge, there are a series of practical problems in using them for sectoral decision-making (Hutubessy, Chisholm, & Tann-Torres Edejer, 2003). The first is that most published studies take an incremental approach, addressing questions such as how best small changes (almost always increases) in resources should be allocated, or whether a new technology is more cost-effective than the existing one it would replace. Traditional analysis has not been used to address whether existing health resources are allocated efficiently, despite evidence that in many settings current resources do not in fact achieve as much as they could (Tengs et al., 1995). A second problem is that most studies are very context-specific. The efficiency of additional investment in an intervention aimed at a given disease depends partially on the level and quality of the existing health infrastructure (including human resources). This varies substantially across settings and is related to a third problem: that individual interventions are almost always evaluated in isolation. This is despite the fact that the effectiveness and

costs of most interventions will vary according to whether other related interventions are currently undertaken or are likely to be introduced in the future.

In response to these concerns, a more generalized approach to cost-effectiveness analysis has been developed by WHO in order to allow policymakers to evaluate the efficiency of the mix of health interventions currently available and to maximize the generalizability of results across settings. This generalized cost-effectiveness analysis (GCEA) makes it possible to explore all interventions and combinations incrementally, with respect to a counterfactual of doing nothing (Murray, Evans, Acharya, & Baltussen, 2000; Tan-Torres Edejer et al., 2003; see also www.who.int/choice). Operationally, the counterfactual that has been adopted in applied studies is defined in terms of what would happen to population health if all interventions of interest that are being provided now were stopped.

WHO has implemented GCEA via the WHO CHOosing Interventions that are Cost-Effective (CHOICE) project. Within the broader context of that project, the Chronic Disease Prevention (CDP) microsimulation model has been developed. The CDP epidemiological model is able to simulate the population dynamics of lifestyle-oriented risk factors for selected chronic diseases.

Many health interventions interact in terms of either costs or effects at the population level, and interacting interventions are undertaken in different combinations in different settings. Neither the health impact of undertaking two interventions together nor the costs of their joint production are necessarily additive. To understand whether the interventions represent efficient uses of resources independently or in combination requires assessing their costs and health effects independently and in combination. Only then is it possible to account for non-linearities in costs and effects.

GCEA seeks to maximize generalizability across settings. Most cost-effectiveness studies have been undertaken in developed countries, but not even the richest countries have been able to evaluate the full set of interventions required to undertake a sectoral analysis specific to their own setting. Thus, all countries need to borrow results of either cost or effectiveness studies from other settings, but the fact that most published studies are very specific to a particular context makes this difficult. To address this need, WHO-CHOICE reports results by 14 global subregions (i.e., sets of similar countries), and has developed tools enabling country-level analysis too.

GCEA has now been applied to a wide range of specific diseases (including malaria, tuberculosis, cancers, and mental disorders) as well as risk factors (for example, child undernutrition; unsafe sex; unsafe water, hygiene, and sanitation; hypertension; and smoking) (see, for example, Chisholm, Rehm, et al., 2004; Chisholm, Sanderson, et al., 2004; Groot, Baltussen, Uyl-de Groot, Anderson, & Hortobágyi, 2006; Murray, Lauer, et al., 2003; Shibuya et al., 2003; and World Health Organization, 2002). Like all cost-effectiveness analyses, GCEA focuses on only one outcome: population health. There are many other possible outcomes people care about, such as inequalities in health, responsiveness, and fairness of financing (Murray & Evans, 2003). Accordingly, the results of GCEA cannot be used to set priorities by themselves but should be introduced into the policy debate to be considered along with the impact of different policy and intervention mixes on other outcomes.

The Chronic Disease Prevention (CDP) Model

This section illustrates the methods and the input data used in the CDP model to assess the efficiency and distributional impact of interventions to prevent chronic diseases linked to unhealthy diets and sedentary lifestyles. The analysis was undertaken by developing a microsimulation model of the health outcomes arising from lifestyle risk factors typically associated with obesity. The model is described in the following section, and the key assumptions upon which it rests are discussed afterward. Further details about the structure and characteristics of the epidemiological model are available elsewhere (Cecchini et al., 2010; Sassi, Cecchini, Lauer, & Chisholm, 2009)

The Epidemiological Model

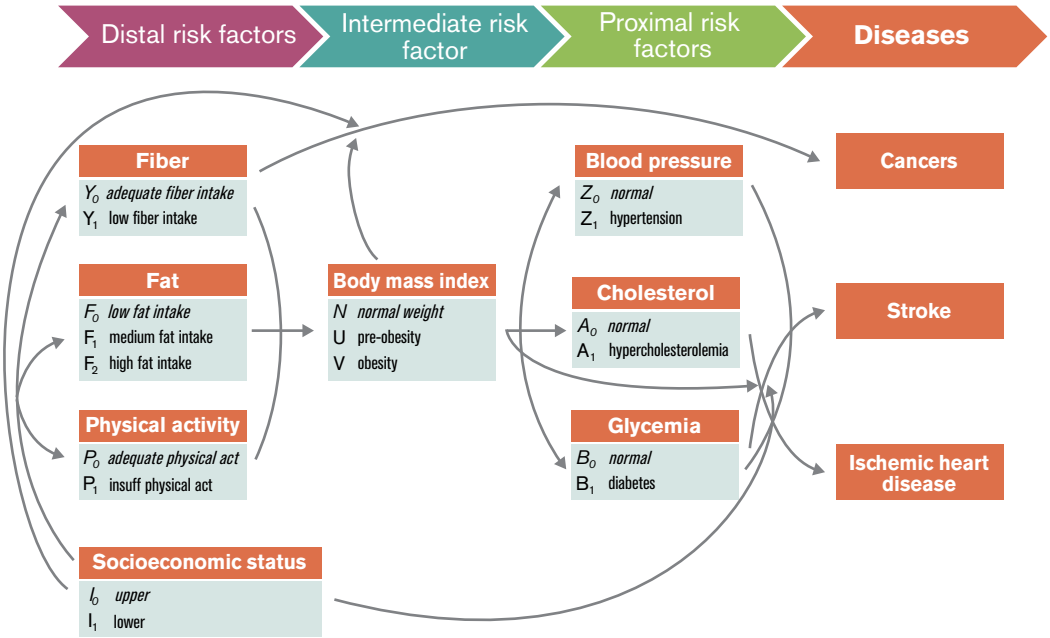
The CDP epidemiological model used in the economic analysis implements a "causal web" of lifestyle-oriented risk factors for selected adult chronic diseases. The concept of a causal web includes the idea that risk factors range in the immediacy of their effect on disease events from more distant exposures ("distal risk factors"), which are several steps away from disease events in the chain of causation, to more proximate exposures ("proximal risk factors"), which are more immediately connected to disease events. The causal web concept also typically includes the possibility, as also implemented here, that risk factors can influence other risk factors. Thus, in a causal web, disease events are influenced by risk factors both directly and indirectly. The definition of the risk factors, as well as the thresholds used to identify individuals at risk, is largely based on data provided by the WHO *Comparative Quantification of Health Risks* publication (Ezzati, Lopez, Rodgers, & Murray, 2004).

The CDP model (Figure 1) explicitly accounts for three groups of chronic diseases: stroke, ischemic heart diseases, and cancer (including lung, colorectal, and breast cancer). In the model, proximal risk factors, such as high blood pressure, high cholesterol, and high blood glucose, have a direct influence on the probability of developing such chronic diseases. This accounts for the effect of known pathophysiological mechanisms. Conversely, distal risk factors, such as low intake of fruit and vegetables, high fat intake, and insufficient physical activity, have an indirect influence on chronic diseases. The indirect effect is mediated by body mass index (BMI), which acts on proximal risk factors as well as directly on disease events. The model accounts for mortality from all causes of death. The model assumes that mortality associated with diseases that are not explicitly modeled remains stable at the rates currently observed in the relevant populations.

The CDP model is a stochastic microsimulation model. The term "microsimulation" refers to the fact that the model separately represents the lifetimes of many different individuals. Emergent properties about the population are then obtained by "adding up" across individual histories. The term "stochastic" refers to the fact that the model employs random variation. For example, individuals are randomly assigned risk factor status and are randomly assigned waiting times for disease and mortality events. The program ensures that the number of individuals with, for instance, a given risk factor status approaches the observed risk factor prevalence in the population being modeled as the number of

simulated individuals becomes large. In the same sense, the program ensures that the annual disease rates of populations simulated in the model match, on average, the disease rates in the population being modeled.

FIGURE 1. Structure of the Chronic Disease Prevention (CDP) model.



Note: states written in *italic* are considered the reference state (i.e., relative risk equal to 1) in the evaluation of the relative risks

Modgen and the CDP model

The CDP epidemiological model is a stochastic microsimulation model able to simulate population dynamics. It was written in a C++ precompiler called Modgen (http://www.statcan.gc.ca/eng/microsimulation/modgen/modgen), which is a generic "model generator" language created by Statistics Canada for developing and working with microsimulation models. The CDP model is based on an earlier child health model originally created by Statistics Canada based on a design provided by the World Health Organization. As that child health model also implemented a version of a causal web, it provided a useful starting point for developing the CDP model.

The model is dynamic in the sense that effects are measured with reference to individual life histories, with unique beginning and end points in model time. Effects are manifested through hazards (risks) to develop disease conditions or risk factor states. The structure of the model is thus inherently designed to manifest time-dependent effects. At simulation start, the initial population in the model reproduces, in cross-section, the demographic features of the population being modeled at an arbitrary point in time. Normally the model starting position is set up so as to correspond to "current time" for the population of

interest, although other scenarios are possible. The model embodies a full age, period, and cohort representation of the simulated population. Typical life table variables, such as residence time in various states, can be collected and reported for the purpose of measuring health effects or reporting on other epidemiological features of interest.

Scope of the Model, Key Assumptions, and Limitations

Existing CDP scenarios have been developed for simulating the dynamics of several world regions and of individual countries that include Brazil, Canada, China, England, India, Italy, Japan, Mexico, the Russian Federation, and South Africa. They define their common starting point as the year 2000. The population is simulated accounting for its distribution by gender, age (0 to 100), and social class (upper and lower). However, social class has been used only for the analyses of developed economies. Inclusion of additional countries or subregions is technically feasible as long as the necessary epidemiological data are available. The following section on the parameters of the model and data requirements provides guidance regarding the required parameters and some potential data sources. In addition to simulating other countries, with appropriate changes, the CDP model can be adapted to simulate, with some caveats, other sets of risk factors and chronic diseases.

As with any analytical work, results depend on a number of assumptions. Notwithstanding, essentially all the assumptions can be modified to better reflect context-specific features. The model assumptions are described below:

- There is a time perspective of 100 years, to allow all interventions to reach a "steady state" and show their full potential in terms of effectiveness.
- Interventions are assumed to influence individual behaviors in line with existing evidence while they are being delivered, but to have no effects after they are completed, with the exception of interventions aimed at children and designed to influence their long-term preferences (school-based interventions, food advertising regulation and self-regulation), which are assumed to retain 50% of their original effectiveness once completed.
- In line with current practice in most cost-effectiveness analyses, we discounted both future costs and effects at a 3% rate.
- The impact on disability for the diseases considered is expressed in disability-adjusted life years (DALYs). Age weighting is not used.
- The impact of interventions on health expenditure only accounts for the diseases and the risk factors explicitly included in the model, that is: hypertension, hypercholesterolemia, diabetes (including major complications such as chronic renal failure, retinopathy, and neuropathy), cancer, ischemic heart disease, and stroke.

A modeling approach provides the most accessible means of assessing health interventions that do not lend themselves to testing within experimental settings. However, the advantages offered by a model are inevitably associated with certain limitations. Among the drawbacks are the need to combine input data from heterogeneous sources and the need to translate all relationships among risk factors, diseases, and health outcomes into a mathematical form, with obvious simplifications. Further simplifying of assumptions was required due to the nature of the input data available. In particular, the effectiveness of the interventions evaluated in the model was assumed to be constant across individuals of

different ages, genders, and socioeconomic conditions. Due to the absence of long-term follow-up data, critical assumptions also had to be made concerning behavior changes following the completion of interventions.

Parameters of the Model and Data Requirements

As previously mentioned, the CDP model requires a series of epidemiological data by gender (males and females), by age (0 to 100), and, in some cases, by socioeconomic status (upper and lower). A first group of parameters allows the software to model the population demographic changes over time, such as mortality, fertility, and the prevalence of individuals by gender and age.

A second parameter group includes those relevant to the three kinds of risk factor (i.e., distal, intermediate, and proximal). In this group, four types of epidemiological parameters can be distinguished: prevalence, incidence of new cases, remission rates, and relative risks (RRs). The first three reflect the epidemiology of the population as a whole. For example, the incidence of pre-obesity identifies the fraction of the overall population becoming pre-obese in a given period of time. RRs, on the other hand, reflect either the probability of an individual's belonging to a risk category, given the presence of another specific risk factor, or the likelihood of someone with a risk factor moving to the next step of the web, compared to someone of the same gender and age but without that risk factor.

The last parameter group includes those relevant for modeling diseases. As before, there are prevalence, incidence rates, remission rates, and relative risks. Additionally, now, there is a further parameter called the case-fatality hazard, which corresponds to the hazard of dying due to a disease for individuals who have that disease. Disease-related relative risks can be divided into three categories: RRs of fatality, RRs of incidence, and RRs of remission from the disease. In the latter case, the value is in the range of 0 to 1 since the presence of a risk factor negatively influences the likelihood of recovering from a disease. Therefore, for instance, people with diabetes may be less likely than people without diabetes to recover from stroke.

As a final parameter group, one should specify the values to be assigned to each year of life spent in, respectively, full health, with a disease, or with multiple diseases. Assigning weighted values to years spent in less than full health allows for inclusion of the qualitative, as well as quantitative, impact of disease on life histories.

In previous analyses, we used the best available sources of information on the epidemiology of risk factors and chronic diseases to populate the microsimulation model. A reference list of the epidemiological data (and of potential sources for these parameters if no country-specific data is available) used to adapt the CDP model to a country-specific setting is given in Table 1. In general, most of the data used comes from WHO datasets, while RRs are obtained from peer-reviewed publications. When it is not possible to find inputs in this way, missing parameters are calculated using the WHO software DisMod II (Barendregt, Van Oortmarssen, Vos, & Murray, 2003) or directly from national health surveys. Selection of data should observe two main criteria: i) maximizing the representativeness of the population and ii) using data gathered in a homogeneous period.

TABLE 1. Basic epidemiological data required for adapting the CDP model to a country-specific setting.

Parameter group	Parameters	Dimensions	Potential source
Population distribution	Distribution of population by social class	By gender & age	UN Statistics Division
	Total mortality hazard	By gender & age	WHO mortality database
Distal risk factors	Prevalence of low physical activity	By gender & age	World Health Survey
	Prevalence of low fiber consumption	By gender & age	WHO Comp Quantif of Health Risks
	Prevalence of high fat consumption	By gender & age	FAOSTAT
	Prevalence of medium fat consumption	By gender & age	FAOSTAT
Intermediate risk factors	Prevalence of pre-obesity	By gender & age	WHO InfoBase
	Prevalence of obesity	By gender & age	WHO InfoBase
Proximal risk factors	Incidence of diabetes	By gender & age	DisMod II
	Prevalence of diabetes	By gender & age	IDF Diabetes Atlas
	Incidence of high systolic pressure	By gender & age	DisMod II
	Prevalence of high systolic pressure	By gender & age	WHO Comp Quantif of Health Risks
	Incidence of high cholesterol	By gender & age	DisMod II
	Prevalence of high cholesterol	By gender & age	WHO Comp Quantif of Health Risks
Diseases	Incidence of cancer	By gender & age	IARC
	Case-fatality hazard or mortality rate for cancer (either of the two)	By gender & age	WHO mortality database
	Incidence of ischemic heart disease (IHD)	By gender & age	WHO GBD
	Case-fatality hazard or mortality rate for IHD (either)	By gender & age	WHO GBD
	Incidence of stroke	By gender & age	WHO GBD
	Case-fatality hazard or mortality rate for stroke (either)	By gender & age	WHO GBD

Cost Analysis

At a conceptual level, the benefit of an intervention is the gain in welfare associated with the health improvement, while the cost is the welfare loss associated with foregone nonhealth consumption (due to resources being used to provide the intervention). Accordingly, costs should be measured from the perspective of society as a whole, in order to understand how best to use resources regardless of who pays for them or, indeed, whether they are paid for at all. In practical terms, however, there are a number of costs that are difficult to quantify due to lack of good-quality or consistent data. This is the case, for example, with the costs incurred in order to access services (e.g., travel costs) or the costs borne by informal caregivers. The impact of interventions on the time and potential earnings of patients and unpaid carers, that

is, work time lost, is a vexing question in cost-effectiveness analysis. However, it is often ignored on ethical grounds, as its inclusion would give priority to extending the life of people who earn more. Domestic taxes are also typically excluded from consideration, since they are simply transfer payments that do not use up a physical resource such as capital or labor. The conceptual foundations and practical implementation of costing within a GCEA framework are discussed in greater detail elsewhere (Evans, Edejer, Adam, & Lim, 2005; Tan-Torres Edejer et al., 2003).

In the implementation of GCEA via the WHO-CHOICE project, costs are divided into those incurred at the patient level and those incurred at the program level. Patient-level costs are incurred during the face-to-face delivery of the intervention by a health provider (broadly defined) to a recipient, for example for medicines, outpatient visits, in-patient stays, and individual health education messages. Program-level costs include all resources required to establish and maintain an intervention, such as administration, publicity, training, and delivery of supplies. Interventions like radio delivery of health education messages largely involve the latter, while treatment at health centers largely involves the former. Costs are elaborated via a standardized ingredients approach, where information on the quantities of physical inputs needed and their unit cost are catalogued (that is, total costs are the quantities of inputs multiplied by their unit costs). For program-level costs, the physical inputs (such as human resources, office space, vehicles, electricity, other services, and a variety of consumables) required to introduce and run a program are based on estimates by costing experts commissioned for this purpose, using a standard template (Johns, Adam, & Evans, 2006; Johns, Baltussen, & Hutubessy, 2003). These resource estimates represent a key building block for estimation of the costs of population-based intervention strategies, such as tobacco control or salt reduction programs.

For patient-level costs, quantities are taken from a variety of sources. Where effectiveness estimates are available from published studies, the resources necessary to ensure the observed level of effectiveness were identified. In other cases, the resources implied by the activities outlined in WHO treatment practice guidelines were estimated. Since it is not always possible to identify the exact quantities of primary inputs (human resources, consumables) necessary for patient-level costs, certain quantities and prices are estimated at an intermediate level for several inputs, such as with inpatient days at different hospital levels, outpatient visits, and health center visits (Tan-Torres Edejer et al., 2003).

Unit costs for each input were derived from an extensive search of published and unpublished literature and databases, along with consultation with costing experts. For goods that are traded internationally, the most competitive price available internationally was used. For example, estimates of drug prices were based on the median supply price published in the International Drug Price Indicator Guide, subsequently marked up to account for transportation and distribution costs. For goods available only locally (e.g., human resources, in-patient bed days) unit costs have been shown to vary substantially across countries, although international comparisons found similar cost-of-illness patterns in several OECD countries (Heijink, Noethen, Renaud, Koopmanschap, & Polder, 2008). As a result, cross-country regressions, mainly accounting for country GDP and local characteristics of the supply of health care, have been run using the collected data to estimate the average cost (with adjustments for capacity utilization) for each setting (Adam & Evans, 2006; Adam, Evans, & Murray, 2003).

Costs are reported in international dollars, or dollar purchasing power parities (US$ PPP), (rather than US dollars), with 2005 as base year. An international dollar has the same purchasing power as the US dollar has in the United States, and therefore provides a more appropriate basis for comparison of cost results across countries or world regions. Future costs are discounted using a 3% discount rate.

Modeling Interventions

The CDP model has been employed to assess a full range of single interventions and prevention packages to tackle obesity-related behaviors (e.g., physical inactivity and unhealthy diet) and associated chronic diseases. The list of prevention policies assessed includes: mass media campaigns, school-based interventions, worksite interventions, fiscal measures, regulation of food advertising to children, and compulsory food labeling. The choice, design, and quantification of the potential effects are typically based on a review of studies about the effectiveness of interventions to improve diet and physical activity.

The first step to model an intervention is to carry out a broad review of the existing evidence. This provides a sound basis for determining the characteristics and the likely effects of interventions assessed at population level in the CDP model. Earlier reviews found a noticeable number of studies in one area: school-based interventions. In contrast, substantially smaller bodies of evidence were available on such other areas as worksite interventions, interventions in the health care sector, interventions on the physical environment and transport system, and interventions on the broader social and economic environment.

From the collected body of evidence, priority is given to studies that appear particularly strong because of the size of the sample, the duration of the study and the robustness of the experimental design. When it is possible to retrieve multiple homogeneous and comparable studies for the same interventions (e.g., school-based, worksite), it is advisable to combine results using the methods of meta-analysis to arrive at a more robust quantification of intervention effectiveness.

In the CDP model, the effectiveness of interventions is modeled with respect to three dimensions: (1) coverage (i.e., share of the population covered by the intervention), (2) efficacy in changing behaviors and risk factors at the individual level, and (3) time to steady state. Data for the first two are retrieved from the literature following the approach illustrated in the previous paragraphs and discussed in further detail elsewhere (Sassi, Cecchini, et al., 2009). For instance, in the case of school-based interventions, evidence suggests there is an increased consumption of fruit and vegetables and a decrease of fat intake and of BMI. These changes are applied to all children covered by the intervention (children aged 8 or 9). The third dimension, time to steady state, is a direct reflection of the age groups covered by the intervention. During the first year of a school-based intervention (Period 1) only children aged 8 and 9 are exposed to the intervention. In the following year (Period 2), the intervention will cover children aged 8 and 9 (who were 7 and 8, respectively, in Period 1) while children aged 10 (who were 9 in Period 1) will retain half of the effectiveness of the intervention. The steady state is reached when the intervention affects the largest possible share of the population. For school-based intervention this happens when school children who were 9 years old in period 1 become 100 years old, thus 91 years after the first implementation of the intervention. Table 2 summarizes the data used to model the interventions to tackle NCDs linked to obesity and related unhealthy behaviors in the CDP model.

TABLE 2. Key input data used to model interventions in the CDP model.

	School-based interventions	Worksite interventions	Mass media campaigns	Fiscal measures	Physician counseling	Food advertising regulation	Food labeling
Coverage							
Age range (yr)	8-9	18-65	18+	0+	22-65	2-18	0+
Restrictions	only schoolchildren	large employers	none	none	BMI≥25 or high chol/blood pressure or diabetes	none	only label users
Effectiveness at the individual level							
Fruit/vegetables (g/day)	+37.6	+45.6	+18.4	+8.6	-	-	+9.87
Fat (% of total energy from fat)	-1.64	-2.2	-	-0.77	-1.6	0.39	-0.36
Share of population physically active	-	+11.9	+2.4	-	-	-	-
BMI (kg/m2)	-0.2	-0.5	-	-	-0.83	-0.12 to -0.18	-0.02
Cholesterol (mmol/l)	-	-	-	-	-0.12	-	-
Systolic blood pressure (mmHg)	-	-	-	-	- 2.3	-	-
Time to steady state							
Timeframe of intervention (years)	91	35	0	0	35	82	0

Costs of interventions are evaluated using the standard WHO-CHOICE "ingredients" approach described in the earlier section on cost analysis. The total cost of an intervention is calculated as the sum of three components: (1) cost at the target level (e.g., working hours of health personnel, equipment), (2) program costs (e.g., planning and enforcing at the central level), and (3) training costs (i.e., education of personnel involved in the intervention). Data on consumption of resources is directly retrieved from the source papers, while the cost of each standard component is provided by WHO in a series of tables reporting prices for local (i.e., national) goods and services, to allow for cross-country comparisons. Costs are expressed in 2005 international dollars.

Outputs Produced by the CDP Model

Using the methods and data illustrated in the previous sections, the CDP model is run to compute the health outcomes and the health care costs associated with a baseline scenario reflecting the epidemiology of the relevant risk factors and chronic diseases in the absence of any of the preventive interventions that the researcher wants to assess. Intervention scenarios are then developed, and their health outcomes and health care costs are compared to those of the baseline scenario. The results of such comparisons (that is, the difference between the health outcomes and health expenditure of the baseline scenario and those of the intervention scenario) indicate the net effect of the new prevention policy.

The CDP model is able to assess prevention policies on the following aspects: i) changes in the prevalence and the incidence of the considered risk factors and chronic diseases; ii) health outcomes, expressed both in terms of life years gained and years of life adjusted for the quality of life; iii) interventions costs and impact of interventions on the health expenditure; and iv) cost-effectiveness of the interventions both in terms of cost per life year gained and cost per years of life adjusted for the quality of life. Each of these outcomes can be evaluated for the modeled population as a whole or for specific subgroups. In particular, the present version of the CDP model is able to handle any combination of the following dimensions: age, age groups, and socioeconomic status (if the corresponding data have been provided). Therefore, the CDP model is able to assess the distributional impact of a considered prevention policy, including whether the policy would decrease or increase the inequalities in health across the different population subgroups.

As with other epidemiological and economic analysis models, the estimates produced by CDP are subject to uncertainty in relation to a number of factors. These include input parameters' variability and heterogeneity; limited follow-up in assessing the effectiveness of the prevention policies; the disability weights based on expert judgment from the Global Burden of Disease (Murray & Lopez, 1996); and costs based on standard schedules of resource inputs derived from treatment protocols and experimental studies. In addition, the CDP model generates estimates based on a stochastic process involving the simulation of large numbers of individual lives. As the latter numbers become larger, model estimates tend to converge towards central values. To properly address these and other potential concerns the CDP model has been explicitly built so to allow single- or multiple-dimension sensitivity analysis. In addition to simple variation of the parameters, analyses are integrated with probability sensitivity analysis employing the WHO MCLeague software.

Case Study: The Effectiveness and Cost-Effectiveness of Prevention Policies in Brazil, Canada, and Mexico

This section will present the potential effects that single interventions and a combination of interventions to tackle unhealthy risk factors (e.g., unhealthy diet and physical inactivity, obesity and related risk factors) could have for Brazil and Mexico, according to the CDP model. Following the procedures described in the first part of this article, modeling those results began with developing a microsimulation model (i.e., the CDP model) that replicates the epidemiological characteristics of a given country. The model reproduces both major risk factors associated with obesity (i.e., diet and levels of physical activity) as well as key NCDs (e.g., cancer, diabetes, and cardiovascular diseases) caused by such risk factors. The simulated population is then used to evaluate the effects at the population level of the set of prevention interventions listed in Table 2. Table 2 also reports the main characteristics of each intervention and its effect at the individual level (e.g., the expected decrease in fat consumption). This section also present results for Canada, in order to draw attention to similarities and differences among settings with dissimilarities in income levels, risk factors distribution, health-system characteristics, and costs.

Effects of the Interventions on Obesity, Health, and Life Expectancy

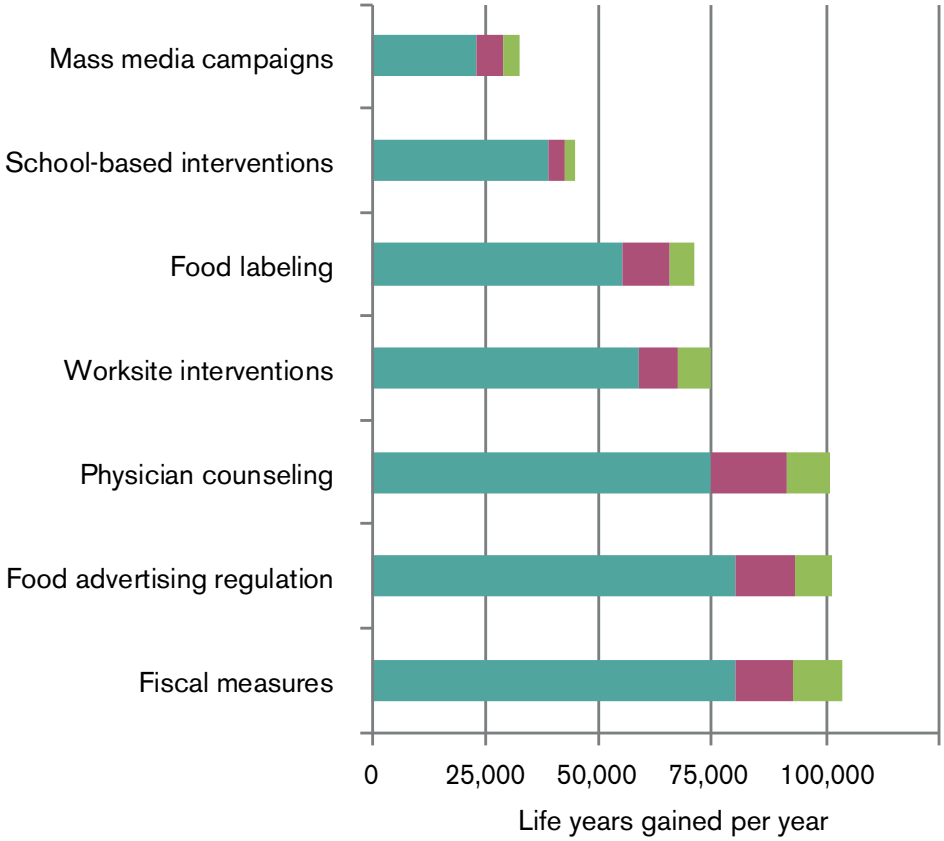
Interventions to improve diets and increase physical activity have the potential to reduce obesity rates as well as to decrease the incidence of ischemic heart disease, of stroke, and, to a lesser extent, of at least three forms of cancer. The impact of interventions on the morbidity associated with these chronic diseases is generally larger than their impact on mortality. Prevention in many cases delays the onset of chronic diseases, rather than preventing them altogether.

If implemented in isolation, the average intervention would generate a reduction in the number of people who are obese on the order of 3% to 4% in Canada and 6% to 7% in Brazil, although the majority of interventions (e.g., mass media campaigns, worksite interventions, and school-based interventions) would have substantially smaller impacts. This may seem a modest achievement, but in fact measuring changes in obesity rates is a rather inadequate way of assessing the value of such interventions. Many more people benefit from prevention than those who actually make it across the line that formally separates obesity from non-obesity thanks to those interventions. Improving one's own lifestyle and losing weight will generate beneficial effects on health regardless of the BMI category in which someone is classified.

The outcomes that matter the most when assessing the impacts of prevention are mortality and the occurrence of chronic diseases, or morbidity. Accordingly, health outcomes are measured in this analysis in terms of life years gained (LYGs) through prevention (reflecting improvements in mortality) and disability-adjusted life years (DALYs). These outcomes capture comprehensively the ultimate impacts of prevention on health and longevity, although they fall short of reflecting some of the more subtle effects of improved lifestyles on quality of life, particularly in terms of psychological well-being and social functioning.

The average yearly increase in health outcomes for all interventions relative to the baseline scenario is shown in Figure 2 (life years gained) and in Figure 3 (disability-adjusted life years). Results are presented for the whole population of each of the three countries.

FIGURE 2. Health outcomes at the population level (average effects per year, in life years gained), for interventions in Brazil, Mexico, and Canada.



For all the interventions, the increase in disability-adjusted life years is higher than the gain in life years. In practical terms, this means that interventions are more effective in reducing morbidity (by delaying the onset of chronic diseases) than in reducing mortality. Across the three countries, primary care counseling is the intervention providing the highest gain in terms of disability-adjusted life years, and fiscal measures show the highest gain in terms of life years. On the other hand, mass media campaigns rank lowest, with a total gain across the three studied countries of about 26,000 life years and of about 37,000 disability-adjusted life years. Brazil consistently shows higher gains compared to the other two countries. For example, in the case of mass media campaigns, the Brazilian population would gain a total of 18,200 LYGs, Mexico 4,800 LYGs, and Canada 2,900 LYGs. Of course, part of this effect is attributable to the different population size of the three countries.

FIGURE 3. Health outcomes at the population level (average effects per year, in disability-adjusted life years) for interventions in Brazil, Mexico, and Canada.

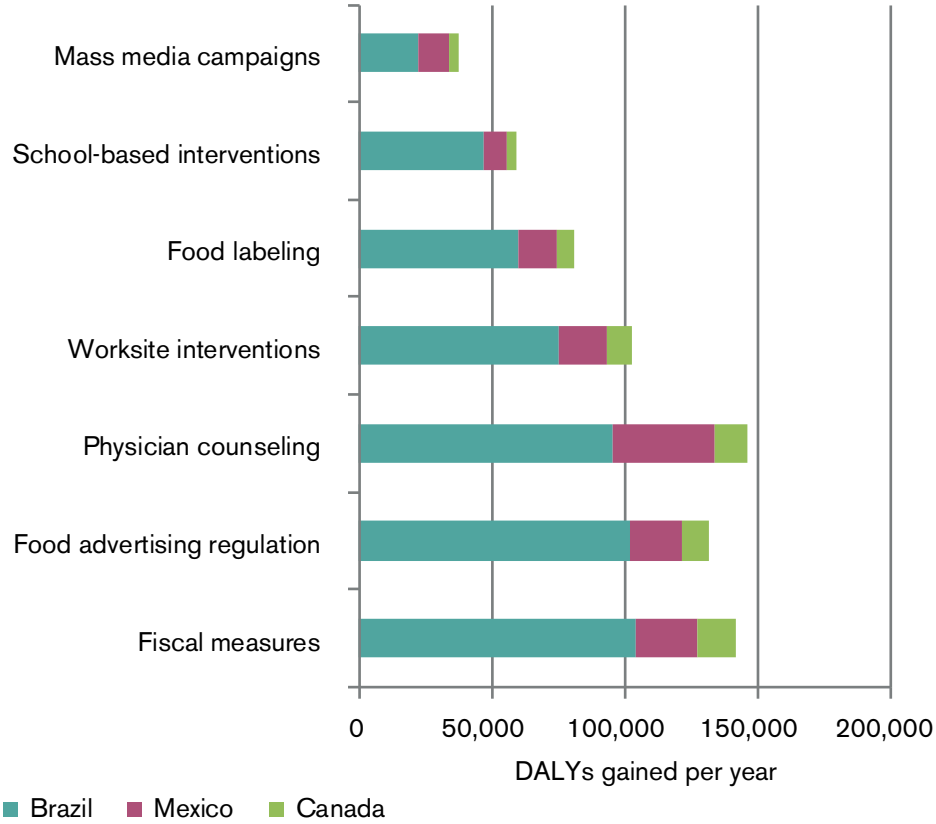


Figure 4 and Figure 5 report the gain in life years and disability-adjusted life years by class of age, for, respectively, school-based interventions in Brazil and physician counseling in Canada. Although they have different orders of magnitude, the patterns are reasonably similar for the two countries. As expected, these interventions in Brazil and Canada show almost no effect on people less than 40 years old. Our model incorporates chronic diseases typically affecting middle-age or elderly individuals. Therefore, even if some interventions do decrease the prevalence of intermediate (i.e., BMI) and proximal (e.g., high blood pressure) risk factors in young people, the effects on diseases are not immediately visible. That is because the risk factors need time to cause the disease and, in any case, the incidence of the diseases is so low that the effect is not appreciable.

Figure 4 and Figure 5 are two examples of very similar patterns, with higher gains in DALYs in the age group 41-80 and with higher gains in life years in the age group 81-100, These patterns can be consistently found across all the studied interventions and countries (results not shown). This is due to the nature of chronic diseases, generally entailing a slow course of the disease before death, and to the effects of preventive interventions that delay the onset of diseases. As a consequence, in the age group 41 to 80, the decrease of new cases produces a higher gain in disability-adjusted life years (i.e., with no chronic diseases). As the population gets older, the incidence of the diseases increases and consequently the impact on disability-adjusted life years weakens. At the same time, in the scenario without interventions, people who are now 80

FIGURE 4. Health outcomes for school-based interventions in Brazil (life years gained and disability-adjusted life years, average effects per year) at the population level by age groups.

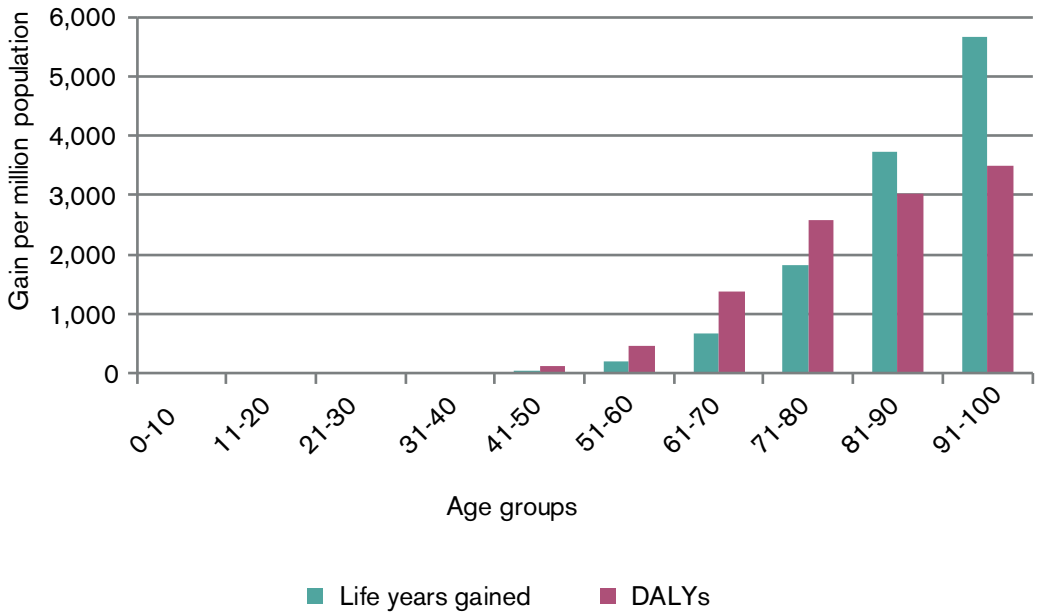
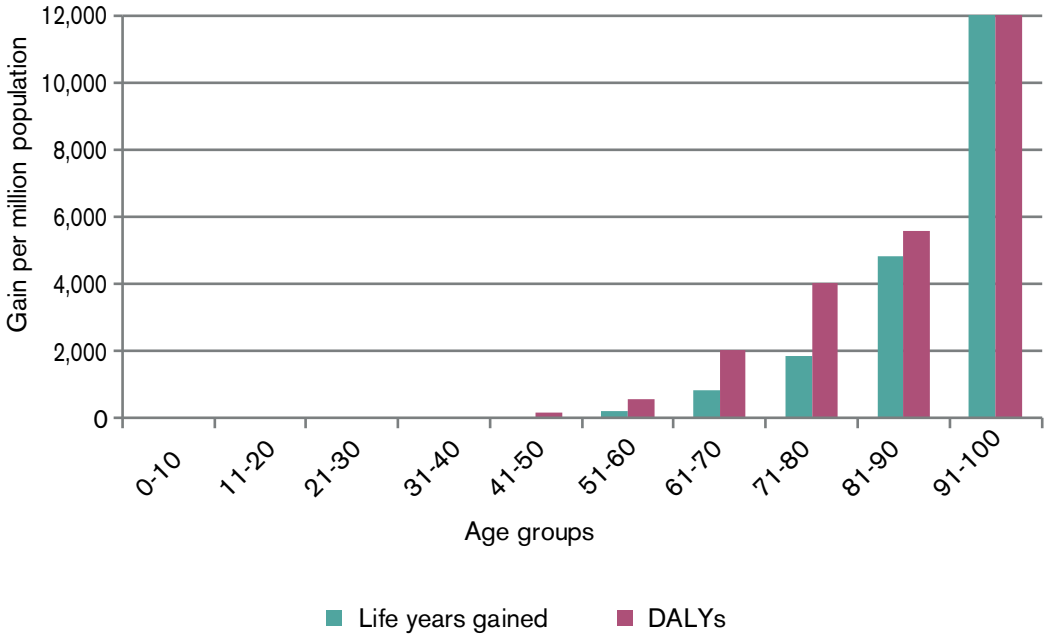


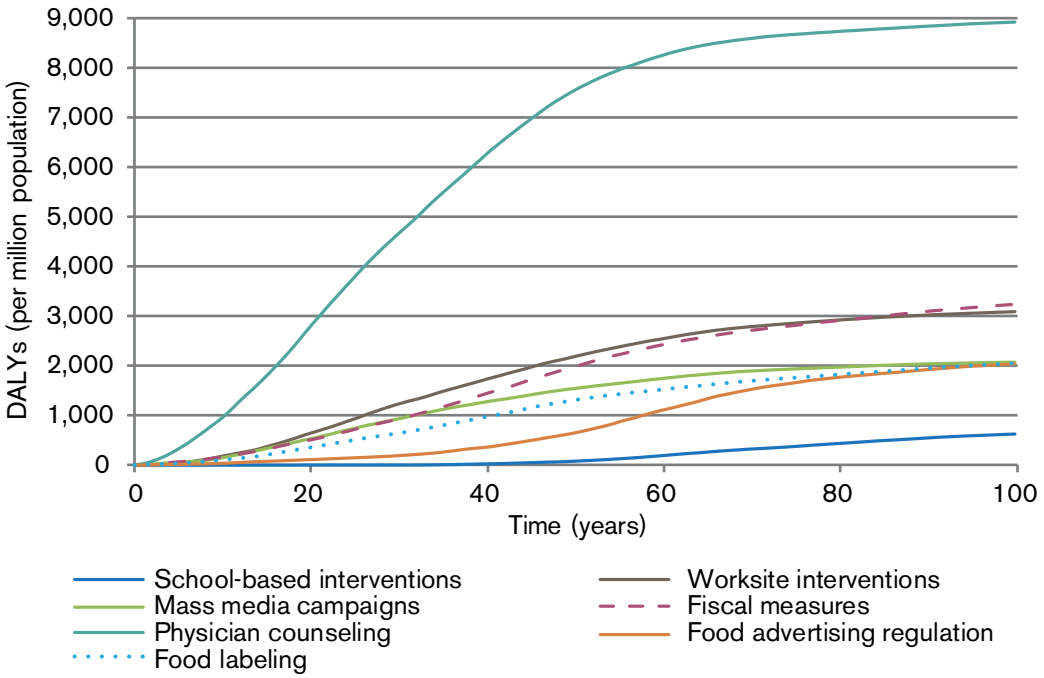
FIGURE 5. Health outcomes for physician counseling in Canada (life years gained and disability-adjusted life years, average effects per year) at the population level by age groups.



years old and who had developed diseases when they were younger start dying, but under the intervention scenario they only start developing the disease. Consequently there is an increase in life years gained and a relative decrease in disability-adjusted life years.

Figure 6 shows the cumulative effectiveness of various interventions over time in the specific context of Mexico. The vertical axis shows the number of disability-adjusted life years, and the horizontal axis shows the time frame of our analysis. Disability-adjusted life years are discounted at a 3% rate. Primary care counseling is, by far, the most effective intervention. The second best performing interventions, fiscal measures and worksite interventions, together yield a total effect that is about a third less than that of physician counseling. Food labeling schemes, mass media campaigns, and food advertising regulation all show a similar cumulative effectiveness in the long run, but, during the first years of the simulation, mass media campaigns and food labeling schemes have a larger impact. As noted in relation to previous figures, interventions targeting children (i.e., school-based interventions and food advertising regulation) yield significant results only after about 40-50 years.

FIGURE 6. Cumulative health gains (DALYs) over time in Mexico with various interventions.



Intervention Costs and Impact on Health Expenditure

Prevention produces multiple and sometimes interacting effects, which are difficult to predict. For instance, certain forms of prevention may substantially reduce future health care costs, but often this will not be the case. Prevention may reduce fatality rates associated with certain chronic diseases and extend life with those diseases, which may

increase overall health care costs in the long run. Individuals who live longer as a result of prevention will also develop diseases other than those targeted by prevention, which may require treatment and increase health expenditure.

The preventive interventions assessed in this analysis reflect a wide variety of approaches and are based in diverse settings. The costs associated with those interventions may arise in different domains. Some of the costs are typically paid through public expenditure (e.g., the costs associated with regulatory measures), and others are typically not (e.g., most of the costs associated with worksite interventions). Some of the costs arise within the health sector (e.g., health care costs), and others occur within other sectors of government intervention (e.g., most of the costs associated with school-based interventions).

Figures 7, 8, and 9 present the average yearly per capita economic impact of the interventions in Canada, Mexico, and Brazil, respectively. The average is calculated over a time horizon of 100 years. The figures show both the costs of the interventions and their impacts on health expenditure. All the interventions, with the exception of food advertising regulation in Mexico and Canada, decrease health expenditures for the conditions explicitly included in the model (cancer, IHD, stroke, diabetes, high cholesterol, and high systolic blood pressure), with the effects on expenditure being indicated with a negative sign at the bottom of each of the figures. Costs reported in Figures 7, 8, and 9 are expressed in US$ PPP.

FIGURE 7. Economic impacts (US$ PPP) at the population level (average effects per year per capita over a 100-year period) for interventions in Canada.

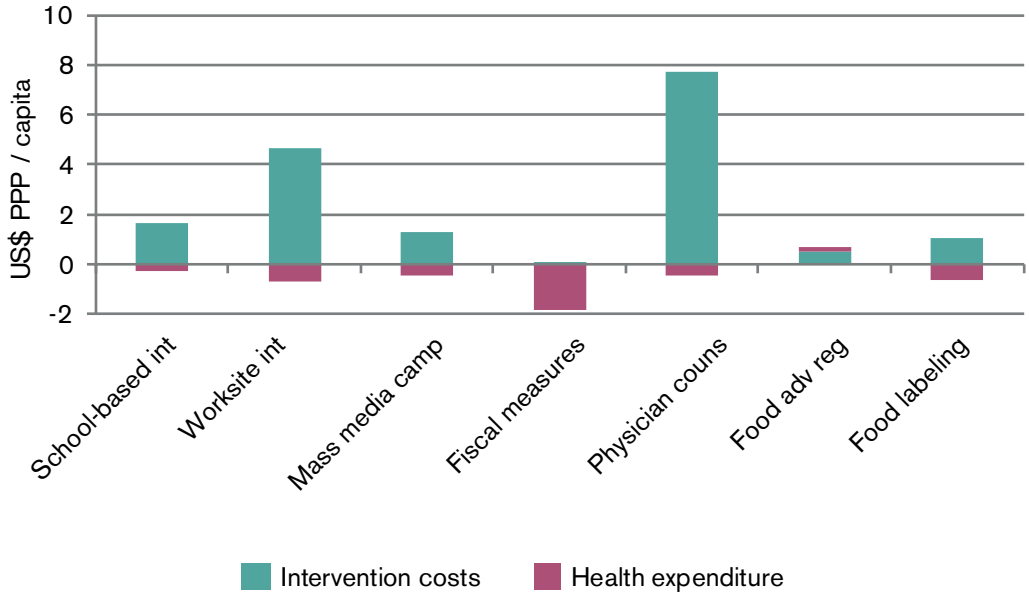


FIGURE 8. Economic impacts (US$ PPP) at the population level (average effects per year per capita over a 100-year period) for interventions in Mexico.

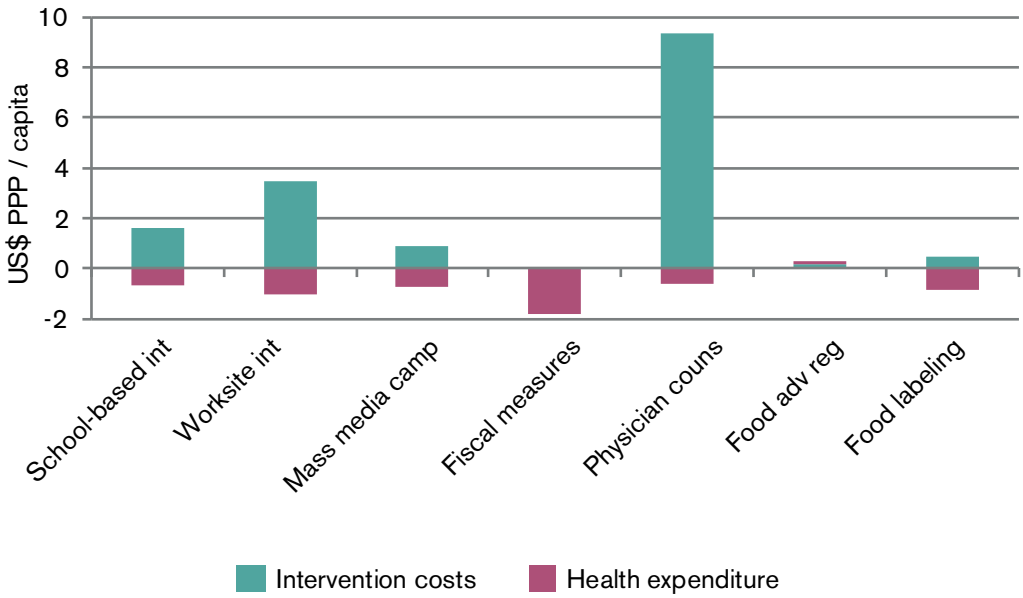
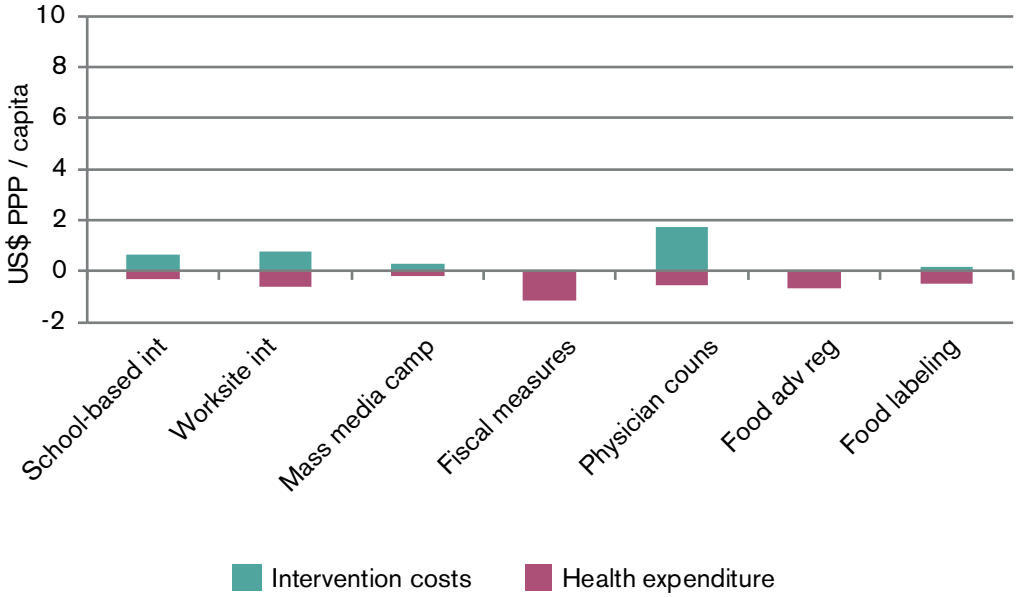


FIGURE 9. Economic impacts (US$ PPP) at the population level (average effects per year per capita over a 100-year period) for interventions in Brazil.



Physician counseling is, consistently across countries, the most expensive intervention, with expected per capita per year costs of about US$ PPP 7.73 in Canada, 9.32 in Mexico, and 1.70 in Brazil. Conversely, regulation of advertisement is the least expensive intervention, costing about US$ PPP 0.51 in Canada, 0.19 in Mexico, and 0.04 in Brazil per person every year. Fiscal measures consistently generate reductions in health expenditure that more than offset intervention costs. At the population level, fiscal measures can be expected to produce total per year savings of about US$ PPP 54.1 million in Canada, 189 million in Mexico, and 211 million in Brazil). In addition, in Brazil and Mexico, but not in Canada, the implementation of a food labeling scheme would also produce net savings.

Figure 10 and Figure 11 depict the potential cost savings due to the interventions by class of age. As with Figure 4 and Figure 5, respectively, school-based interventions in Brazil and physician counseling in Canada were selected as examples. In general, interventions generate savings in most age groups, as indicated by the negative values in the lower portion of each figure. However, the interventions become consistently more expensive in the oldest age groups than in the baseline. The main cause of this is the increased life expectancy of the population. The number of individuals and, accordingly, the number of individuals with a disease is higher in the intervention scenario. Consequently, the costs for treating those with diseases increase as well. It is important to emphasize that the costs illustrated in Figure 10 and Figure 11 reflect health care resources devoted to the treatment of the diseases and risk factors explicitly included in the model. If a broader definition of health care costs had been assumed, encompassing the treatment of all diseases, it is plausible that overall savings would have been smaller.

FIGURE 10. Effects of school-based interventions in Brazil on health care costs by age group (average effects per year per capita, in US$ PPP).

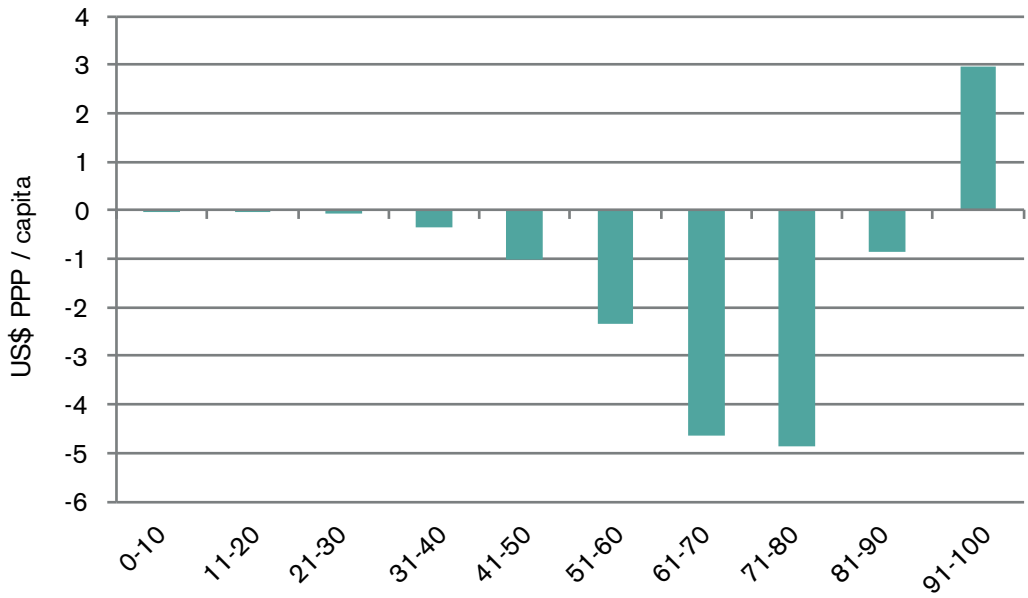
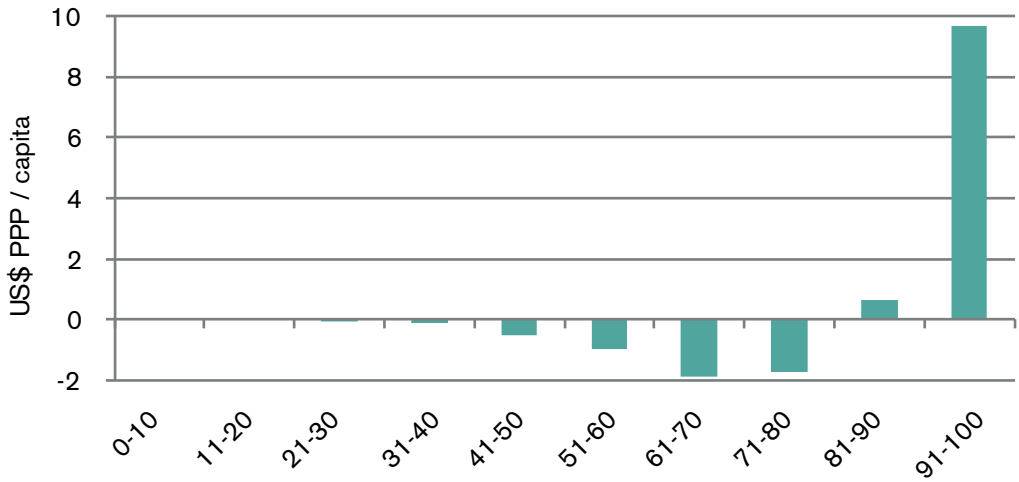


FIGURE 11. Effects of physician counseling in Canada on health care costs by age group (average effects per year per capita, in US$ PPP).



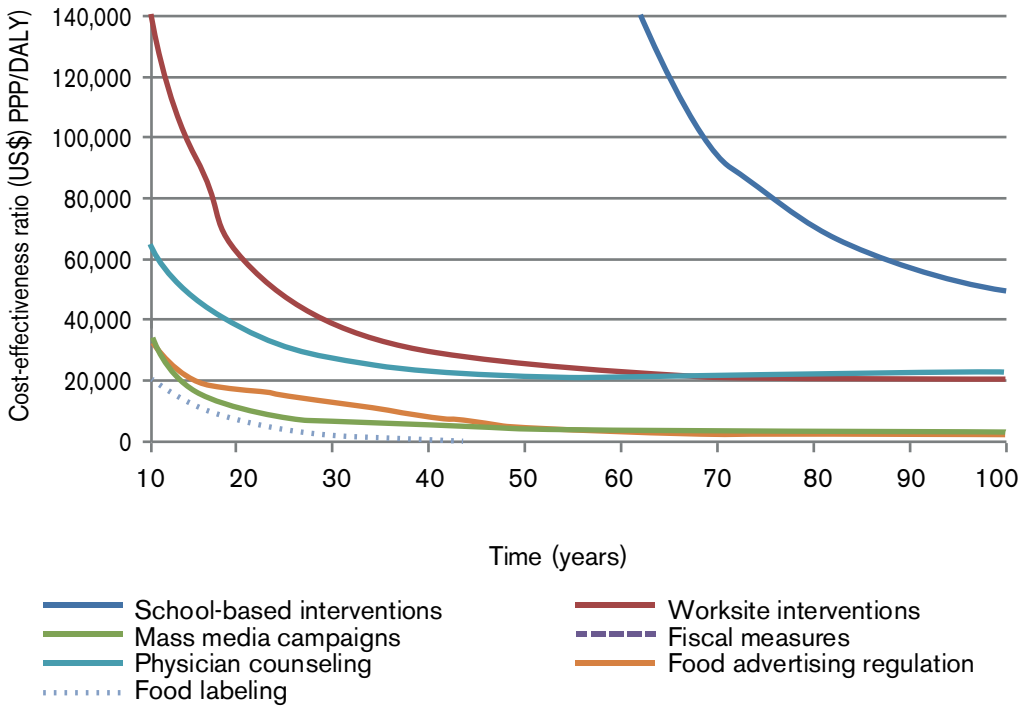
Assessment of the Cost-Effectiveness of Interventions

In the first 20-30 years of their implementation the cost-effectiveness ratios of some of the interventions examined are extremely high. In general, the scale of the impact of individual interventions is limited by the difficulties involved in reaching a large proportion of the national population. This is either because only certain age groups are targeted by the intervention (in which case it may take many years before a large share of the population receives some exposure to the intervention) or because compliance rates are low (as is typically the case for several of the interventions examined, based on existing evidence).

Figure 12 and Figure 13 show, respectively, for Brazil and Mexico, the cost-effectiveness ratios for each of the preventive interventions at different points in time over the 100 years of the simulation. Figure 12 and Figure 13 only show interventions that have a positive cost-effectiveness ratio (i.e., interventions that are not cost-saving). That is, the shown interventions increase the quality of life (i.e., DALYs) of the population for a net cost per DALY equal to what is shown in Figure 12 and Figure 13. Interventions that are cost-saving have a negative cost-effectiveness ratio, and their cost-effectiveness ratio falls below the horizontal axis. Both costs and effectiveness are discounted at a 3% rate.

Food labeling, mass media campaigns, and food advertising regulations appear to have favorable cost-effectiveness ratios from the early years after their implementation. Food labeling schemes in particular become cost-saving in the medium term. All three of these interventions are characterized by a relatively small cost of implementation, along with

FIGURE 12. Cost-effectiveness of interventions over time in Brazil, in US$ PPP per disability-adjusted life year.

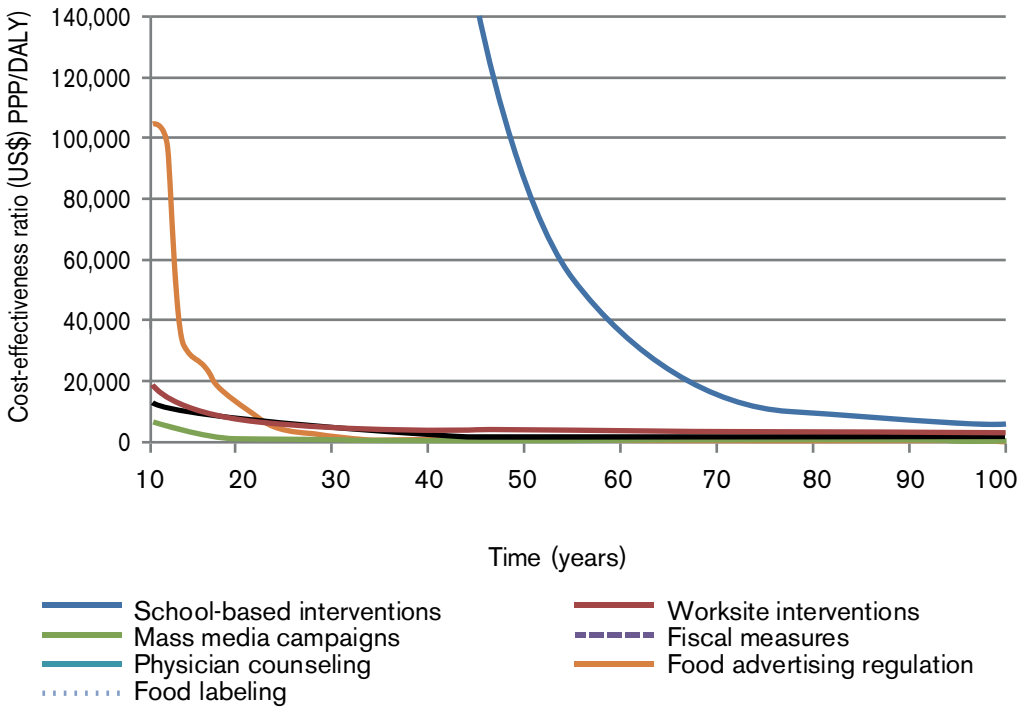


effects that influence a large share of the population. A second group of interventions, including physician counseling and worksite interventions, reaches a cost-effectiveness of US$ PPP 20,000 after about, respectively, 50 years in Mexico and 10 years in Brazil from their initial implementation. School-based interventions need about 60 years in Brazil to reach similar values. Fiscal measures generate net savings shortly after their implementation.

Strategies Involving Multiple Interventions

If evidence of the effectiveness of individual interventions is not abundant, evidence of the combined effectiveness of multiple interventions implemented simultaneously is virtually nonexistent. It is difficult to predict whether combinations of interventions would create synergies that translate into an overall effect larger than the sum of individual interventions. The opposite could be true, with adding interventions to a prevention strategy generating decreasing incremental returns. However, a microsimulation model like CDP can be used to assess at least some of the effects to be expected from combining multiple interventions into a prevention strategy that targets different population groups. For groups exposed to more than one intervention at the same time, an assumption is required as to what the combined effect of the interventions will be. The assumption made in this analysis is a conservative one, estimating that the overall effect of interventions is less than additive, relative to the effects of individual interventions.

FIGURE 13. Cost-effectiveness of interventions over time in Mexico in US$ PPP per disability-adjusted life year.



In the case of Mexico and Canada, we explored the potential impact of a combination of five measures: the regulatory interventions of compulsory food labeling and industry self-regulation of food advertising to children; worksite and school-based health promotion programs; and intensive counseling of individuals at risk in primary care. This combination of interventions provides a balanced coverage of different age groups (children and adults), and it uses both regulation and health promotion approaches. In addition, it targets high-risk individuals with a more focused intervention that has been shown to be particularly effective in previous analyses.

In the case of Brazil the proposed prevention package is composed of interventions at the population level, with mass media campaigns, fiscal measures, regulation of food advertising, and an enforcement of food labeling schemes. The package has a cost of 0.40 US$ PPP per capita per year.

Figure 14 shows the average annual health outcomes for the multiple-intervention strategies in the three countries.

Figure 15 shows the projected impact of the multiple-intervention prevention package in Brazil, in terms of the cumulative net expenditures for the package over a 30-year period, with future costs and savings being discounted at a 3% rate. The prevention package

FIGURE 14. Health outcomes for multiple-intervention strategies in Canada, Mexico, and Brazil (average effect per year, in DALYs and life years gained).

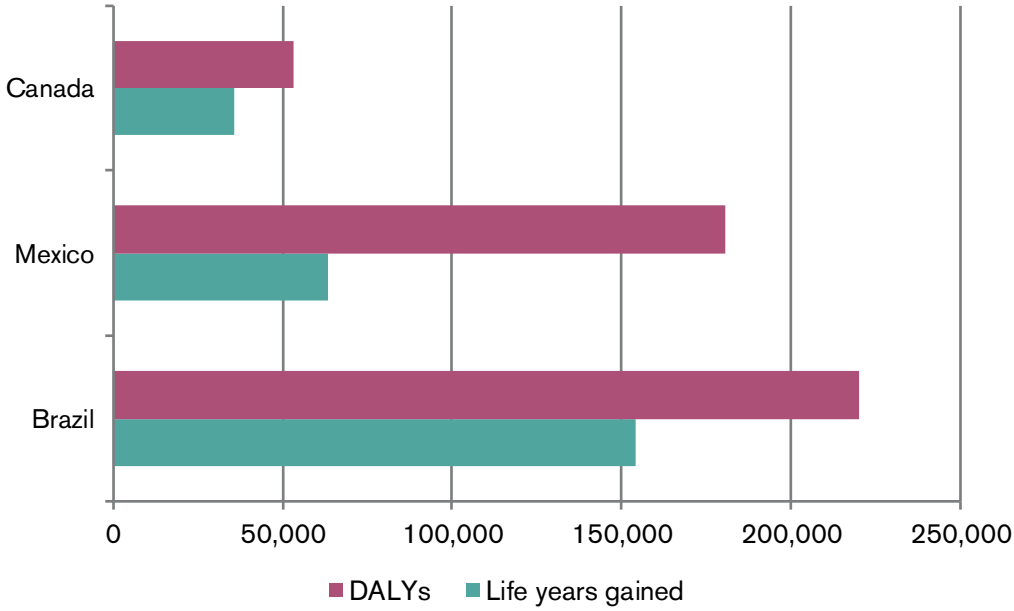
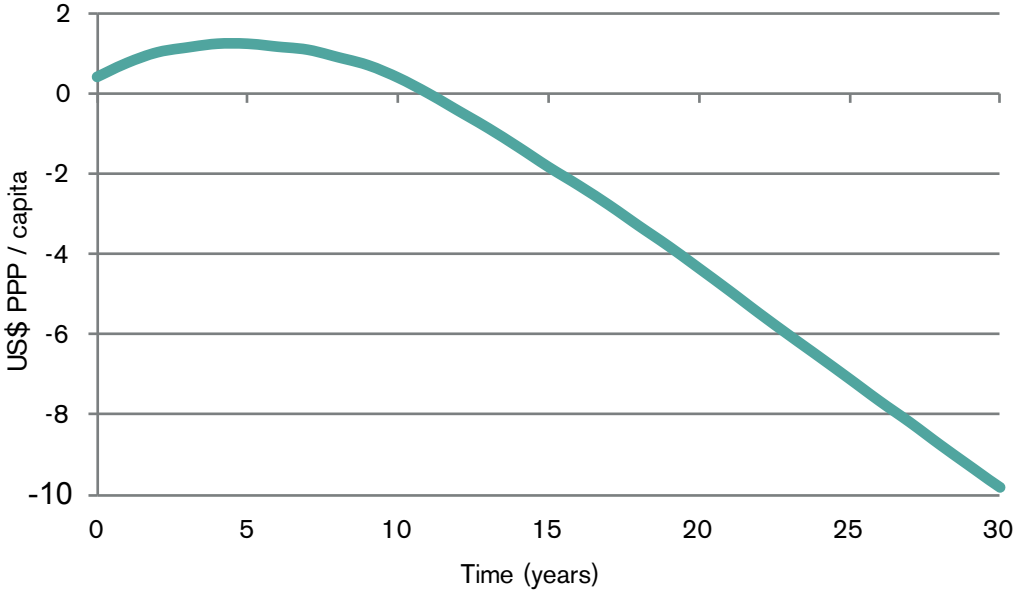


FIGURE 15. Cumulative health expenditures (US$ PPP per capita) for a multiple-intervention prevention package in Brazil over a 30-year period.



requires a first phase of five years in which implementation costs are higher than the savings produced in health expenditures. However, afterwards, the savings become larger than the implementation costs. Over a 10-year period, the prevention package completely pays for itself, and the reduced total health care expenditure continues thereafter.

The findings presented in this chapter are the result of a major analytical effort, aimed at bringing together the best existing evidence on the epidemiology of risk factors and chronic diseases in the three countries concerned along with the best evidence on the effectiveness of preventive interventions. Analyses were carried out through a dynamic microsimulation model, the CDP model, that simulates the population dynamics of lifestyle-oriented risk factors (such as unhealthy diet and levels of physical inactivity) for selected key chronic diseases. The health and economic impact of individual interventions are sizable but, overall, relatively limited compared to the total burden caused by NCDs in Brazil, Canada, and Mexico. However, when single interventions are bundled together into multiple-intervention strategies, the overall impact is noticeably enhanced. For example, in the case of Brazil, a multiple-intervention strategy would completely pay for itself over a 10-year period, and with reduced total health care expenditure continuing thereafter. Interventions with the most favorable cost-effectiveness profiles (e.g., fiscal measures and food labeling) are outside the health care sector and can provide a substantial contribution to the population health without putting additional loads on health care systems.

DISCLAIMER: This chapter is based on the OECD Health Working Paper "Improving Lifestyles, Tackling Obesity: The Health and Economic Impact of Prevention Strategies", the OECD publication: "Obesity and the Economics of Prevention - Fit not Fat" and the Lancet paper (Cecchini et al, 2010) "Tackling of unhealthy diets, physical inactivity, and obesity: health effects and cost-effectiveness". Any additional opinions expressed or arguments employed herein are solely those of the authors and do not necessarily reflect the official views of the OECD or its member countries.

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CHAPTER 2

Estimating Macroeconomic Impacts with Computational General Equilibrium Modeling

Kakali Mukhopadhyay and Paul J. Thomassin

There are multiple approaches to projecting the effects that health and economic policies might have, and there are also many ways to classify and sort those various modeling methodologies. One way to categorize policy models is to consider the unit of analysis on which they focus: individuals ("micro models"), groups ("component-based models"), or the community as a whole ("macro-level models"). Within the group of macroeconomic models, a category called computable general equilibrium (CGE) models project future expenditure trends within the context of the entire economy (Oderkirk, Sassi, Cecchini, & Astolfi, 2012).

In the past two decades, CGE modelling has become an accepted tool of empirical economic analysis. Recently, advances in model calibration, data availability, and computer technology have reduced the cost of CGE-based policy analysis. The CGE model is of widespread use because it combines economic theory and applied policy research (Lofgren, Harris, & Robinson, 2002).

CGE models have been developed that are Walrasian and multisectoral, but that also incorporate macro variables and mechanisms for achieving balance among aggregates. CGE models rely on the social accounts framework and the social accounting matrix (SAM) to capture national income and product information as well as input-output information. The advent of these models has intensified the study of the reconciliation of macroeconomic and multisectoral perspectives.

One widely used CGE model is the Global Trade Analysis Project (GTAP) model. GTAP is a multi-country, multi-commodity model. It is designed to facilitate economy-wide analyses. The GTAP model works in conjunction with the GTAP Data Base, which is a high-quality, internally consistent, peer-reviewed global database. The GTAP model draws on a set of economic accounts for each country/region, with detailed inter-industry links. Using a global CGE model such as GTAP enables interactions between regions and sectors to be captured within a fully consistent framework.

While GTAP modeling has been used most often to study bilateral international trade, the tool has also been applied in many other fields (see Box 1), including health. For example, GTAP can estimate the macroeconomic effects that noncommunicable diseases (NCDs) have on a particular economy and on other economies of the world (Mukhopadhyay &

Thomassin, 2015). The two case studies that appear later in this chapter look at Canada and consider the macroeconomic impact of a healthy diet and the effect of nutrition-related NCDs on worker absenteeism and labor productivity.

Box 1. GTAP Model Used in Multiple Fields

Studies using the GTAP method are numerous. Many of the areas in which the model has been used, along with cites of example research, are listed below.

Regional economic integration and trade agreements: Fukase & Martin, 1999; Nakajima, 2002; Japan External Trade Organization, 2003; Cheong, 2003; Cheong, 2005; Lee & Park 2005; Igawa & Kim, 2005; Park, 2006; Jensen, Baltzer, Babula, & Frandsen, 2007; Thierfelder, Robinson, & McDonald, 2007; Strutt & Rae, 2007; Kinnman & Lodefalk, 2008; Antimiani, Mitaritonna, Salvatici, & Santuccio, 2008; Lochindaratn, 2008; Mukhopadhyay & Thomassin, 2008; Mukhopadhyay & Thomassin, 2010; Gumilang, Mukhopadhyay, & Thomassin, 2011.
Poverty issues: Evans, 2001; Gilbert, 2007; Gerard & Piketty, 2007; Go & Quijada, 2012.
Migration: Walmsley, 2002; Winters, Walmsley, Wang, & Grynberg, 2003; Walmsley & Winters, 2005; Walmsley, Winters, Ahmed, & Parsons, 2007; Walmsley, Ahmed, & Parsons, 2009; Aguiar & Walmsley, 2010.
Technological changes: Meiji & Tongeren, 1999; Burniaux & Lee, 2003; Kloverpris, 2008; Schmitz, Dietrich, Lotze-Campen, Muller, & Popp, 2010; Viloria, 2012.
Labor markets: Ahmed, 2007; Valin & Mitaritonna, 2007; Stone & Bottini, 2012.
Population aging: Oyamada, Someya, & Itakura, 2012; McDonald, 2012.
Climate change: Roson, 2003; Calzadilla, Rehdanz, Betts, Falloon, Wiltshire, & Tol, 2010; Truong, 2010; Rose, Golub, Hertel, & Sohngen, 2012; Henderson, Golub, Pambudi, Hertel, & Gerber, 2012.
Carbon leakages: Kuik & Gerlagh, 2003; Gerlagh & Kuik, 2007; Rutherford, 2010; Antimiani, Costantini, Martini, Salvatici, & Tommasino, 2011.
Nonrenewable energy: Burniaux & Truong, 2002; Golub, Hertel, & Rose, 2012.
Renewable energy and biofuels: Taheripour, Birur, Hertel, & Tyner, 2007; Hertel, Tyner, & Birur, 2008; Tyner, Hertel, Taheripour, & Birur, 2009; Calzadilla & Ruth, 2012; Pavel, Kancs, & Rajcaniova, 2012; Taheripour & Tyner, 2012.
Food security: Food and Agriculture Organization, 2003; Ford, Aquila, & Conforti, 2007; Ferreira, Bento, & Horridge, 2012; Steinbuks & Hertel, 2012.

History of GTAP

The origin of the GTAP model can be traced to the ORANI model (Dixon, Parmenter, Sutton, & Vincent, 1982), a single-country general equilibrium model first developed for the Australian economy by Peter Dixon and others. Dixon was the leader of the applied general equilibrium model-building team at the IMPACT Project at the University of Melbourne. Dixon designed the ORANI models of Australia in the 1970s and 1980s, the MONASH model of Australia in the1990s, and the MONASH-style USAGE model of the United States of America, beginning in the year 2000 (Powell, 2007).

The theory of the ORANI model (Plummer, Cheong, & Hamanaka, 2010) has been extended to allow international trade to take place between the different countries in the global economy through the global transport sector and savings (Mukhopadhyay & Thomassin, 2010).

Since the mid-1990s, the analytical landscape has changed dramatically with the advent of the GTAP model (Hertel, 1997). The GTAP model has been developed by the Center for Global Trade Analysis, which was established in 1992 by a group at Purdue University, in the United States, in order to evaluate the impact of international trade on world economies. Now, almost all of the individuals and agencies analyzing the global implications of trade liberalization make use of the GTAP database as well as the GTAP global applied general equilibrium model.

The basic structure of the GTAP model includes various industrial sectors, households, governments, and global sectors across countries. Countries and regions in the world economy are linked together through trade. The GTAP model incorporates both the demand and supply in its specifications (Hertel 1997).

The demand side of the model is based on a Cobb-Douglas aggregate utility function. That function allocates regional household expenditures among private expenditures, government expenditures, and savings, along with a constant budget share to provide an indicator of economic welfare for the regional household. A representative household in each region maximizes a constant difference of elasticity (CDE) expenditure function that is calibrated to an income level and elasticity of demand that vary according to the level of development and the consumption patterns of the region. Current government expenditures go into the regional household utility function as a proxy for government provision of public goods and services (Gumilang et al., 2011).

On the supply side, firms minimize costs of inputs given their level of output and fixed technology. This means that the relationship between intermediate inputs is fixed. Similarly, the relationship between the amount of intermediate inputs and outputs is also fixed. Firms combine primary factors and intermediate goods, using the Leontief production structure and a constant return to scale technology to produce final goods in a perfectly competitive environment. The final goods produced are then sold to both private households and the government. Prices and quantities are simultaneously determined in both factor markets and commodity markets. Five main factors of production are included in the model: skilled labor, unskilled labor, capital, natural resources, and land. It is assumed that the total amount of labor and land available is fixed.

The GTAP model uses constant returns to scale technology and nested constant elasticity of substitution (CES) functions to estimate the firms' demand for primary and intermediate inputs (Mukhopadhyay & Thomassin, 2009). The GTAP model utilizes the Armington approach to goods and services. With this approach, goods and services are differentiated by region of origin and are imperfect substitutes. Using this method, an optimal combination of imported and domestic goods can be calculated to be used in production. All sectors in the model produce a single output, and firms face a zero profit assumption. Firms can purchase intermediate inputs locally or import them from other countries. It is also assumed that domestically produced goods and imports are imperfect substitutes.

The model includes two global sectors. They are: (1) the global banking sector, which deals with global savings and investments, and (2) the global transportation sector, which takes into account the difference between FOB and CIF values. The global banking sector brings into equilibrium the savings and investment in the model. The transportation sector considers the difference in the price of a commodity as a result of transporting the good between countries. In addition, domestic support and trade barriers (tariff and non-tariff) are measured in ad valorem equivalents (Mukhopadhyay & Thomassin, 2009).

The GTAP database and the model follow the basic accounting identity. The GTAP model by itself does not take into consideration macroeconomic policies or monetary phenomena. Due to the static nature of the model, the impact of investment on production and trade is captured through its effects on final demand (Gumilang et al., 2011).

Macroeconomic closure can be achieved in two ways. The first way is to adjust national savings or investments by fixing the trade balance to zero. The second way is through the use of the global banking sector, which adjusts its purchases of shares in regional investment goods to account for changes in global savings. This second way allows modelers to indigenize both sides of the identity above. Both of the methods above are neoclassical in nature (Gumilang et al., 2011).

The macro closure is very important in GTAP modeling. Variables in the model are classified as being either endogenous or exogenous. The classification of the variables can be identified by closure. Endogenous variables are solved within the model, while exogenous variables are predetermined outside the model. Therefore, the exogenous variables can be shocked. Closure can be used to capture policy regimes and structural rigidities (Mukhopadhyay & Thomassin, 2009).

The closure elements of GTAP can include population growth, capital accumulation (including foreign direct investment), industrial capacity, technical change, and policy variables (e.g., taxes and subsidies). Under GTAP's default closure, the supply of labor, capital, land, and resources is fixed; factor prices (i.e., wages, and return on capital and land) adjust to restore full employment of the factors of production in the post-shock equilibrium.

For the closure to work, the number of endogenous variables considered has to be equal to the number of equations used. This is a necessary condition, but not a sufficient one. The choice of exogenous variables will help determine whether the model is in a general or partial equilibrium. Finally, in equilibrium, all firms have zero real profit, all households are on their budget constraint, and global investment is equal to global savings. Changing the model's parameters allows one to estimate the impact from a country's or region's moving from its original equilibrium position to a new equilibrium position.

The economics of the welfare effects of tariff eliminations are modeled as allocative efficiency gains stemming from reallocation of productive resources across sectors. In contrast, modeling of regulatory barriers such as barriers to trade in services is less straightforward. Regulatory barriers require the use of real resources to meet regulatory requirements. This is not a necessary part of the production and delivery process, but rather are an additional or discretionary burden of costs added by government. A reduction of regulatory barriers

represents a saving of real resources. In general, decreasing non-tariff barriers would result in greater gains than would reducing tariffs on the price of traded products. Tariffs represent a transfer of income to the collecting country/region, thus shifting welfare commensurately from the paying country/region to the recipient country/region (Federal Affairs, Trade and Development Canada, 2013).

The dynamic GTAP model (GTAP-Dyn) is the result of continuing research aimed at extending GTAP's standard modeling framework to incorporate dynamic behavior. GTAP-Dyn is a recursively dynamic applied general equilibrium (AGE) model of the world economy. It broadens the standard GTAP model (Hertel, 1997) to include international capital mobility, capital accumulation, and an adaptive expectations theory of investment.

Standard GTAP (Hertel & Tsigas, 1997) is a comparative-static AGE model of the world economy, developed as a vehicle for teaching multi-country AGE modeling and to complement the GTAP multi-country AGE database (Gehlhar et al., 1997). It provides basic AGE modeling techniques that include some special features, notably an extensive decomposition of welfare results. On the other hand, GTAP-Dyn captures the long-run behavior within the GTAP framework. In standard GTAP, capital can move between industries within a region, but not between regions. This impedes analysis of policy shocks and other developments affecting incentives to invest in different regions (Ianchovichina & McDougall, 2000). For a good long-run treatment, then, we need international capital mobility.

GTAP Databases

At the heart of the Global Trade Analysis Project is the GTAP Data Base. That is a fully documented, publicly available global database that includes extensive bilateral trade information, transport, and protection linkages. The protection dataset in the GTAP dataset covers such items as import tariff rates, anti-dumping duties, export subsidy rates, rates of total domestic support, percentage shares of output subsidies, and intermediate input subsidies (Dimaranan, 2006). The GTAP Data Base is widely used and is a key input into contemporary applied general equilibrium analysis of global economic issues (http://www.gtap.agecon.purdue.edu/databases/default.asp).

The GTAP model and databases of Version 7 include 57 commodities (sectors) and 113 countries/regions, with a base year of 2004. The 57 sectors in the model provide a broad disaggregation of the sectors in each country and region. The GTAP 7 Data Base consists of regional input-output data, macroeconomic data, bilateral trade flows, protection data, and energy data for the reference year 2004. The current release, the GTAP 9 Data Base, contributes three reference years (2004, 2007, and 2011) as well as 140 regions for all 57 GTAP commodities (Narayanan, Aguiar, & McDougall 2015).

The GTAP Satellite Data Base and Utilities are available for purchase for use with the GTAP 8 Data Base. The Satellite Data Base covers the Global Bilateral Migration Data Base (GMig2) (Walmsley, Aguiar, & Ahmed, 2013) and the Land Use and Land Cover Data Base (Baldos &

Hertel, 2013). Further, the GMig2 Data Base includes skilled labor, wages, and remittances. These materials allow users to easily use and adapt the full suite of GTAP models for analysis of global trade and environmental issues.

Advantages and Disadvantages of GTAP

Advantages

CGE modeling is a very powerful tool, allowing economists to explore a wide range of issues numerically. These issues could not be analyzed with econometric estimation. CGE modeling is particularly useful in forecasting the effects of future policy changes.

CGE modeling has facilitated our understanding of global trade. The GTAP framework has improved data quality on which to base models and has provided a set of tools for modeling and analysis. In addition, the GTAP framework has facilitated widespread replication of results. Largely nonexistent in the global modeling area prior to GTAP, that feature has assisted in the evaluation of scenarios and in the promotion of dialogue among researchers. Thierfelder and colleagues (2007) have emphasized the importance of having a model that is based on theory but is estimated with actual data: "The strength of the multicountry CGE model is that it elegantly incorporates the features of neoclassical general equilibrium and real international trade models in an empirical framework."

The global coverage of the database is the central part of GTAP. The model is based on an individual country input-output database together with economic linkages among regions through bilateral trade, transport, and protection data. The input-output database accounts for inter-industry linkages. It illustrates the flows between sales and purchases of industry outputs or product outputs.

A great variety of issues can be addressed, including trade policy reform, regional integration, energy policy, global climate change, technological progress, and links between economic growth and trade (Hertel, 1997).

With regard to trade in particular, the shift towards general equilibrium modeling has had many advantages. One advantage is greater theoretical consistency. GTAP models are a stylized simplification of reality, in which behavior is represented by variables and by assumptions about how they are determined and interact. The model identifies the complex issues, to work out how changes in an economic system matter, and (sometimes) to make predictions about economic performance (Hertel, 1997).

Another advantage is improved welfare analysis. Welfare in a GTAP model is computed directly in terms of household utility and not by some abstract summation of producer, consumer, and taxpayer surpluses. The welfare decomposition in GTAP includes allocative efficiency, terms of trade effect, endowment tax effect, technical change effect, and explanatory factors like investment-savings (I-S) effects.

Associated factor returns can also be estimated endogenously from the model. The role of prices in the allocation of resources is also considered. Factor return covers finite resources

and accounting consistency by relying on social accounting matrices (SAM). This allows the capture of inter-industry linkages between agricultural and non-agricultural sectors of the economy, and it provides an economy-wide perspective for any type of analysis.

Another GTAP advantage is user-friendly software. The software makes it possible to carry out simulations of the standard model, including macro variables (such as population, GDP, skilled labor, unskilled labor, and capital) and policy variables (such as technological change, tariff barriers, and non-tariff barriers). The user can identify the exogenous and endogenous variables using model closure.

Behavioral parameters may also be altered. Outputs include a complete matrix of bilateral trade and activity flows (and percentage changes) by sector and region, private and government consumption, regional welfare, and a variety of summary variables. Users with access to GEMPACK software can also modify the theory of the model (Hertel 1997).

GTAP has substantially lowered the costs associated with database construction, database maintenance, and model development. Additional advantages of using GTAP software packages such as GAMS, GEMPACK, or GAUSS are the transferability, reproducibility (and therefore cross-checking) of models, and ease of maintenance (Hertel, 1997).

The GTAP framework captures the linkages between all sectors and agents of the economy and worldwide bilateral trade flows. These characteristics are inherent in global multicountry CGE models, and they are sufficiently modeled to enable sophisticated analysis of global issues.

The advantage of using a general equilibrium framework includes the possibility of simulating intersectoral factor flows (mainly labor and capital) and also the possibility of incorporating and estimating income effects. The existing GTAP applications have covered a wide range of economic analysis of the consequences of integrating various economies internationally. The strengths of the GTAP modeling framework are undoubtedly the strong focus on both the agricultural sector as well as non-agricultural sectors, and the interrelationships among sectors.

A major reason for GTAP's success is that the model generates useful and reliable results on policy-relevant issues. The GTAP model can predict the economic implications of changes in economic policies. The information generated is especially suitable for considering the future direction of regional policies. Therefore, this information is helpful to policymakers seeking guidance on policy changes (Nielsen, Stæhr, Frandsen, Jensen, Ratinger, & Thomson, 2000).

In connection with the above advantages, the representation of policies is an important feature of GTAP. An adequate representation of policy instruments is essential in applied trade models. Tariffs and quantitative restrictions such as quotas are important trade policy instruments. Tariffs can be introduced in a straightforward manner and are most of the time expressed as ad valorem tariff rates. Also, specific (per unit) tariffs are then translated into ad valorem rates.

GTAP is a useful tool for analyzing issues related to the World Trade Organization (WTO). However, the GTAP framework has some important limitations, as it is still rather stylized in certain aspects.

Disadvantages

Despite their power, CGE simulations also have their shortcomings.

First, CGE simulations are not always appropriate predictions but rather ex ante policy experiments in the assumed circumstances and year. The probability of tentative results is always a vulnerability with this model (Hertel et al., 2008).

Second, while CGE models are quantitative, they are not empirical in the sense of econometric modeling. Instead, they are basically theoretical, with limited possibilities for rigorous testing against experience.

Third, conclusions about trade policy are very sensitive to the levels assumed for trade restrictions in the base data. One can readily do sensitivity analysis on the parameter values assumed for economic behavior, although less so on the data. That is because altering one element of the base data requires compensating changes elsewhere in order to keep the national accounts and social accounting matrix in balance.

Of course, many of these criticisms also apply to other types of economic modeling. Therefore, while imperfect, CGE models remain the preferred tool for analysis of global trade policy issues.

With GTAP models, it has been argued that they do not capture many important characteristics of the economy, and that solid econometric foundations are needed for GTAP parameters (Keeney & Hertel, 2005). Further, the possibility of instability or uncertainty in this type of economic model cannot be ignored (Palatnik & Roson, 2009). Another limitation is the technical problem of the software. For smooth running of the model and better results, the software demands more aggregated regions and sectors.

Box 2. Output from the Model

The GTAP static and dynamic models can generate numerous results, with both the time and spatial dimensions associated with them. These variables include: GDP; sectoral output; sectoral exports and imports; welfare decomposition; regional household income; regional private and government consumption expenditures; normal rate of growth in capital; rate of factor returns; equity effect; household income earned on capital abroad; price of investment goods; index of prices for tradable goods; actual, targeted, and expected gross rate of return; normal rate of growth in capital; rate of return to equity owned by foreigners in a region; rate of return to foreign equity owned by a region; equity held by the regional household in domestic firms; and regional household income from equity.

Implications for Policy

GTAP modeling can be used for various policy analyses. For example, by treating trade liberalization, a policy change with global impacts, as an exogenous shock, GTAP can be used to quantitatively evaluate its impact on such things as industrial structure, allocation of resources, and income distribution. GTAP does this by taking into account the relative price fluctuations and how economic entities change their actions based on such fluctuations. The GTAP model can be used to estimate price changes and the time dimension of the analysis. Several policies can be applied individually and/or in combination to estimate the impact on the macro economy.

GTAP can derive various simulation exercises to address the macroeconomic benefit of decreasing the prevalence of chronic disease in a country. Various scenarios related to NCDs can be attempted using GTAP, including such ones as: i) impact of increase or decrease in direct costs of health care to the economy; ii) impact of increase or decrease in household expenditures in the economy as a result of lower or higher expenses for health care services and products; iii) impact of decrease in absenteeism at work; and iv) impact of increase or decrease in the productivity of the industrial sectors. Multiple scenarios could also be run on various combinations of the impacts.

Background to Case Studies

A global diet transition is causing public health apprehensions because the pattern of food consumption is a major modifiable risk factor for the most common global noncommunicable diseases (NCDs). What to do is a central concern for policymakers worldwide. Healthy eating, following the World Health Organization (WHO) guidelines, is one approach to addressing this challenge. The prevalence of nutrition-related chronic disease would decrease by adopting "healthier diets." This would have an impact on the health and well-being of individuals and households, would decrease the financial burden on the health system, and would increase productivity through increased labor efficiency. However, these changes in the demand for food and related commodities will have much wider, and more profound, effects on the global economy. The adoption of a "healthier diet" would impact agricultural production patterns and the balance of trade in these commodities, with spillover effects on associated industries and sectors and productivity of labor. Understanding the impacts and tradeoffs across sectors and countries is a central challenge for academic and decision-making communities in a globalizing world. Toward that direction, the following two case studies were conducted for Canada.

Case Study 1: The Impact of Adopting a Healthier Diet in Canada

Using a global computable general equilibrium (CGE) approach, this case study aimed at estimating the macroeconomic impacts of adopting a healthier diet in Canada.

Since the WHO published its guidelines on diet, physical activity, and health (2003), a number of researchers have estimated the impacts that adhering to the dietary guidelines would have on consumption in OECD countries (Shankar, Srinivasan, & Irz, 2008; Srinivasan, 2007; Srinivasan, Irz, & Shankar, 2006). Several countries have their own guidelines (Murphy, 2007), including the United Kingdom (NHS, 2015), the United States (U.S. Department of Health and Human Services and U.S. Department of Agriculture, 2005), Australia (NHMRC 2015), and Japan ((Yoshiike, Hayashi, Takemi, Mizoguchi, & Seino, 2007). Canada's food guide was announced in 2004 by Health Canada and documented for the public in 2007 (Health Canada 2007). That guide covers the essential food groups, including vegetables and fruits, grain products, milk and alternatives, and meat and alternatives. The recommended servings are based on meeting the estimated requirements for vitamins, minerals, and other nutrients in order to reduce the risk of NCDs and to contribute to overall health and vitality.

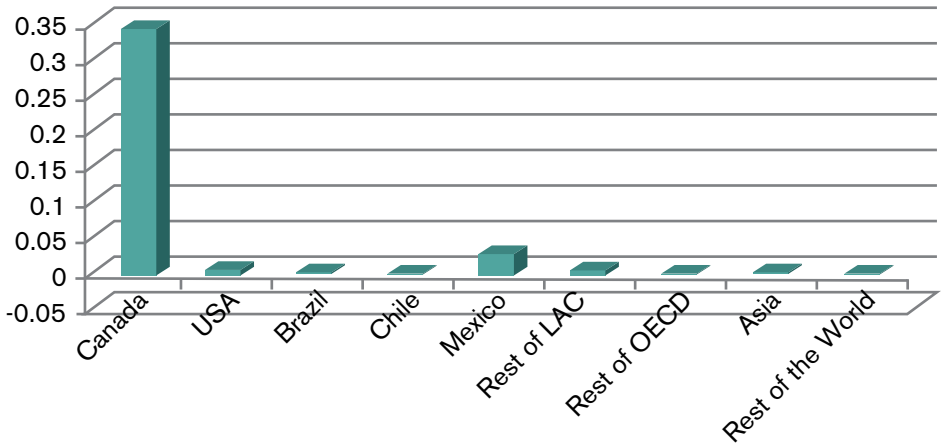
This case study used a combined diet strategy, with three food categories (fruits and vegetables, milk and alternatives, and meat and alternatives), to analyze the healthy diet's impact. The analysis took into account the effect on the agriculture and agri-food sectors of this change in demand for these commodities. These impacts will affect the Canadian economy and also the economies of trading partners of Canada, including the United States, Mexico, Brazil, and Chile.

Versions 7 of the GTAP model and database were used for this analysis. The database was constructed for the base year 2004. This dataset included 57 commodities (sectors) and 113 countries/regions. The 57 sectors in the model provided a broad disaggregation of the industrial sectors in each country and region. To emphasize the agriculture and agri-food and health sectors, we aggregated 57 sectors into 32 sectors. The 113 countries were aggregated into five individual countries and four regions. These were the countries of Canada, United States, Brazil, Chile, and Mexico, and the regions of Rest of Latin America and the Caribbean, Asia, Rest of the OECD, and Rest of the World (ROW). Thus, the model ultimately calculated for five countries and four regions, along with 32 sectors.

The gap between actual household consumption of food and the recommended consumption was estimated using data sources provided by Statistics Canada (2010) and the Canadian food guide of 2007. Under the Canadian healthy diet strategy, the consumption of fruits and vegetables and dairy products would increase while the consumption of meat and meat products would decrease. The study estimated that household consumption of fruits and vegetables and of milk and milk products would increase by 50% and 41%, respectively. In contrast, consumption of meat and meat products would decrease by 20%.

The results from our analysis indicate that if Canadian households were to adopt the healthy diet, this would result in an increase in GDP for Canada and also, but to a much smaller degree, for the other countries of the world included in the study (Figure 1). This suggests that the adoption of the healthy diet by Canadian households is not only good for the health of individuals in Canada, it is also good for the Canadian economy.

FIGURE 1. Change in GDP (%) due to the adoption of a healthy diet in Canada.



Changes in the food consumption patterns of Canadian households to a healthier diet had an impact on the industrial sectors in Canada. As might be expected, the sectors with the largest increase in industrial output were dairy products, fruits and vegetables and nuts, raw milk, and wool. The sectors that had the largest decrease in industrial output were livestock and meat products, cattle and sheep, and animal products not elsewhere classified.

Changes in Canadian household consumption to a healthier diet would be expected to affect the exports and imports among the various countries and regions (Figure 2). The trade patterns suggest that the United States and several Latin American countries (but not Mexico[1]) would have increases in their exports. By far, Canada's imports increase more than for any other country or region. This could be due to the growth in the consumption of fruits and vegetables. Since Canada imports approximately 57% of its fruits and vegetables, the increased demand for fruits and vegetables would be satisfied partially by importing these commodities from other countries and regions.

Among the agricultural sectors in Canada that have a decrease in their exports are wheat, cereal grains not elsewhere classified, oilseeds, crops not elsewhere classified, meat, and other related commodities. Sectors in Canada that have increases in exports include fruits and vegetables, sugar (cane and beet), dairy products, light manufacturing, and heavy manufacturing. An increase in output of fruits and vegetables tends to also result in increases in exports for those sectors.[2] The adoption of a healthy diet by Canadian households not only impacts output, GDP, exports, and imports, it also affects welfare. We noticed a positive welfare impact for almost all countries, including Canada (Figure 3).

1 We found some reduction of total exports and imports for Mexico. This reduction might be due to various reasons. Mexico has a number of other trading partners besides Canada. Due to the increase in demand for fruits and vegetables in Canada, Mexico is likely to divert its exports from other trading nations to Canada, which might have a negative impact on total exports from Mexico.

2 An increase in output of fruits and vegetables is anticipated to produce a certain rise in exports. Canada's main fruit exports are blueberries, cranberries, and apples, while its main fruit imports are grapes, bananas, strawberries, and citrus fruit. The United States is the number-one export destination, absorbing 75% of Canada's fruit exports, followed by Germany (4%), Japan (3%), the Netherlands (3%), and the United Kingdom (2%) (Agriculture and Agri-Food Canada, 2010).

FIGURE 2. Changes in total exports and imports (%) due to the adoption of a healthy diet in Canada.

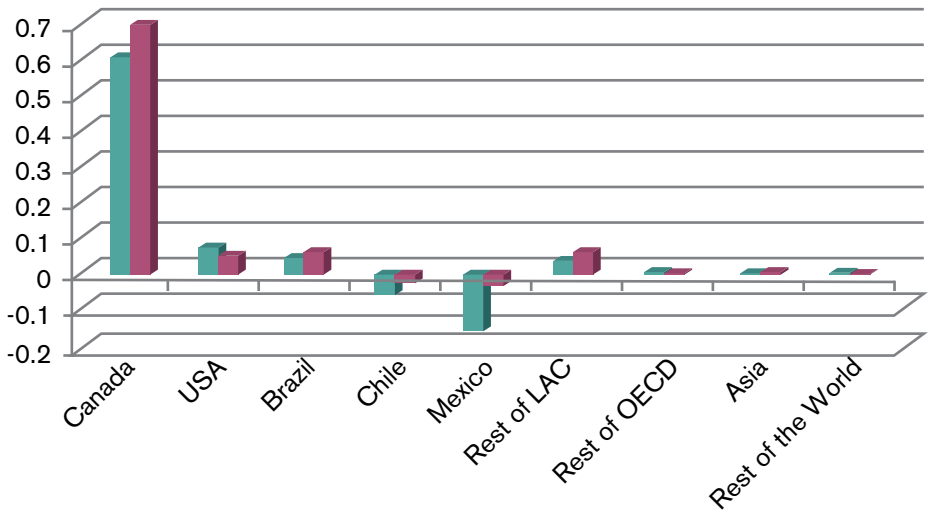
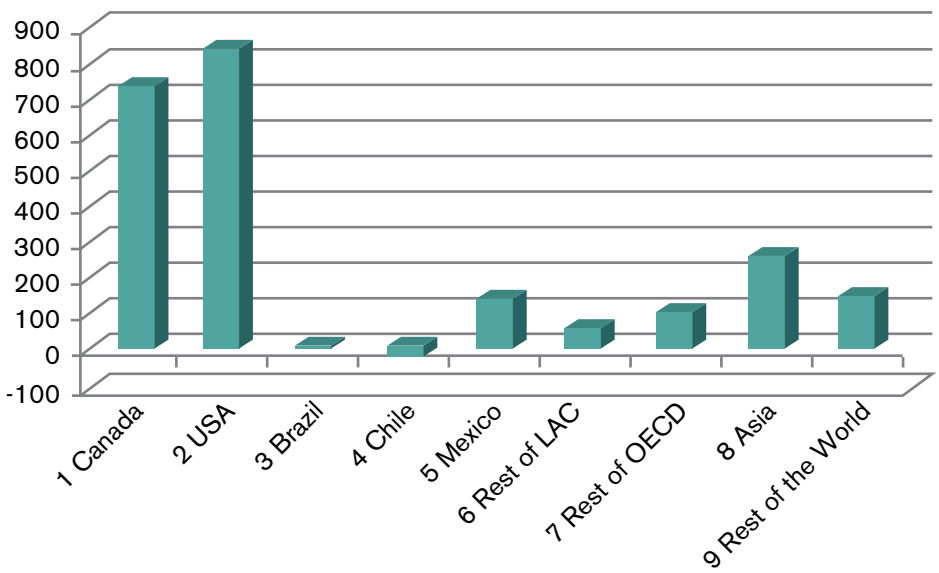


FIGURE 3. Welfare implications due to the adoption of a healthy diet in Canada (US$ million).



To adopt a healthy diet, Canadians would need to increase their consumption of fruits and vegetables and milk and milk alternatives, and decrease their consumption of meat and meat alternatives. Overall, the study shows that adoption of a healthier diet would increase GDP in Canada by 0.34%, industrial output by 0.11%, and welfare by US$ 748 million. Making those diet changes has some impact on agricultural production patterns and the balance of trade, with spillover effects on associated industries in Canada.

Case Study 2: The Effect of Nutrition-Related NCDs on Worker Absenteeism and Labor Productivity in Canada

A healthy work force is one of the most important economic assets of a nation. It is well known that eating a wholesome diet, engaging in physical activity, and following other healthy lifestyle practices reduce NCDs and therefore mortality and morbidity. That, in turn, leads to an increase in the productivity of the work force in a country.

Using a global computable general equilibrium model, this second case study estimates the macroeconomic impacts of a healthier labor force due to a reduction in nutrition-related NCDs in Canada. The data set from the Canadian Community Health Survey (CCHS 2010) was used in the analysis of this study. The 2010 CCHS survey had 49,897 households respond to the survey. The survey interviewed one person from each representative household.

The households in the CCHS were divided into three income groups. The high-income group (more than CAD 70,000 per year) accounted for the largest proportion, with 40.2% of the total households. The number of households in the low-income group (less than CAD 40,000) was the second largest, with 33.1% of the households in the sample. The middle-income group (income between CAD 40,000 and CAD 70,000) had the lowest number of households, only 27%. The sample of households in the CCHS survey does not provide an equal distribution of households in each income category. Among the households surveyed, 30,220 people had been employed during the last 12 months. In the 3 months prior to the survey, the number of employed persons was 27,297. The survey data included: (1) daily consumption of total fruits and vegetables among households in the different income levels, (2) number of people who missed days from work because of different types of NCDs in the preceding 3 months (Table 1), and (3) employment status of the household (Mukhopadhyay & Thomassin, 2015). Individuals were divided into full-time and part-time employment. The number of people employed full time was nearly five times greater than those who had part-time employment. The high-income group had the largest proportion of people who worked full-time, while the low-income group had the largest proportion of people who worked part-time. The largest proportion of individuals (58%) consumed fewer than 5 servings of fruits and vegetables per day. The high-income group had the largest proportion of individuals who consumed more than 10 servings of fruits and vegetables per day (5%), followed by the middle-income group (4%). Only 3% of the low-income group consumed more than 10 servings of fruits and vegetables per day.

The CCHS reports the frequency of people having health problems that reduce their days at work. This data set was used to estimate the percentage of people across the three income groups who were absent from work due to NCDs.

The number of people who lost workdays because of chronic disease in the preceding three months was 3,352, or 12.27% of the total number of employed people in that time period (Table 1). This suggests that chronic disease is a noteworthy reason for people's absence from work—and for a decline in the country's production.

Table 1. Number of persons, by income group, who missed days from work because of chronic disease in the preceding three months.

	High-income group	Middle-income group	Low-income group	Total/ Overall
Total number of persons employed	14,502	7,574	5,221	27,297
Number of persons who missed days of work	904	708	1,740	3,352
Percentage of persons who missed days of work	6.24	9.34	33.32	12.27

Calculated by the author from CCHS survey.

Decreasing the prevalence of NCDs could lessen the financial burden on society and boost the productivity of the economy through an increased labor supply, that is, with people missing fewer days of work.

On the basis of that three-month estimate, we extrapolated the number of persons across the different income levels who missed workdays over a 12- month period. We used the GTAP 8 database for our analysis. That database covers 57 sectors and 129 regions. Given that the main focus of the study is on Canada and its main trading partners, the 129 countries and regions in the original database were aggregated into 10 countries and regions, with an emphasis on country trade with Canada. The 10 were: Canada, United States, Mexico, Brazil, 27 European Union member countries (EU-27), China, India, Japan, Rest of OECD, and Rest of the World (ROW). The 57 sectors were aggregated into 23 sectors.

The percentage reduction in the labor force due to NCDs (CCHS data set) was applied to the global CGE model. The macroeconomic impact on the Canadian economy from a reduction in NCDs was estimated by increasing the labor force by the amount of absenteeism that occurred from the various types of NCDs. Table 2 provides the labor force reductions in the Canadian economy from the various NCD scenarios.

Table 2. Number of persons in the CCHS sample away from work due to different types of NCDs, over a 12-month period.

Types of NCDs	Number of persons away from work	Percentage of persons away from work
Food-related NCDs[a]	952	3.11
Food-related NCDs plus mental illness	1,383	4.52
All NCDs except "others"[b]	2,386	7.79

Source: CCHS 2010

a Food-related NCDs: cardiovascular disease, kidney disease, asthma, chronic bronchitis plus emphysema or chronic obstructive pulmonary disease, diabetes, migraine, cancer, digestive diseases, fibromyalgia and chronic fatigue syndrome, and multiple chemical sensitivities.

b Others: back problems, arthritis, osteoporosis, neurological disease.

These labor force reductions were then allocated to skilled and unskilled labor within the economy (Table 3). The estimates for the shares of the skilled and unskilled labor force were taken from the GTAP data set (Mukhopadhyay & Thomassin, 2015).

Table 3. Skilled and unskilled labor force absenteeism in Canada from different types of NCDs.

Types of NCDs	Percentage of skilled labor force away from work due to different types of NCDs	Percentage of unskilled labor force away from work due to different types of NCDs
Food-related NCDsa	2.18	0.93
Food-related NCDs plus mental illness	3.16	1.36
All NCDs except "others"b	5.46	2.34

Source: CCHS 2010 and GTAP version 8 database.

a Food-related NCDs: cardiovascular disease, kidney disease, asthma, chronic bronchitis plus emphysema or chronic obstructive pulmonary disease, diabetes, migraine, cancer, digestive diseases, fibromyalgia and chronic fatigue syndrome, and multiple chemical sensitivities.

b Others: back problems, arthritis, osteoporosis, neurological disease.

In order to estimate the macroeconomic impact, this percentage share of the skilled and unskilled labor force that was absent due to NCDs was used to shock in the GTAP model (that is, assume that the sick labor force became healthy due to a reduction in NCDs).

Our analysis indicates that the impact of a reduction in nutrition-related NCDs and the resulting reduction in absenteeism has a positive impact on Canada's GDP. The increase in GDP is due to an increase in the labor force. A reduction in NCDs that resulted primarily from a healthy lifestyle resulted in a 0.83% increase in Canada's GDP. Regional household income grew by 0.71%. Industrial output rose due to the improvement of the health of the labor force. Total industrial output increased by US$ 17.45 billion (0.68%).

Further analysis on a sectoral basis shows that a reduction in NCDs has a larger effect on the service sectors. This is due to the fact that service sectors employ more skilled labor

compared to unskilled labor.[3] Another positive impact occurs in the "heavy industries" sector, with an output increase of US$ 2.22 billion (Mukhopadhyay & Thomassin, 2015).

There is a positive impact on household income in Canada due to the reduction in NCDs and the resulting increase in the labor force. Household income in the United States also has a marginal increase. The impact on other countries is minimal.

With the increase in regional household income in Canada, it is expected that private consumption expenditures will also increase. Not all sectors in the economy are affected equally with the increase in consumer expenditures. The largest increases in output come in the service sectors and the industrial sectors. Among the services sector, "financial services" and "other utilities" are important. Within the industrial sectors, private household demand increases the most for the "heavy industry" sector, rising by 0.80%. This is followed by the "energy-intensive" sector (0.78%) and the "light manufacturing" sector (0.77%) (Mukhopadhyay & Thomassin, 2015).

The increase in labor supply due to a reduction in NCDs resulted in an increase in both exports and imports for Canada. Total Canadian exports rose by around US$ 1.16 billion (0.28%). Sectoral analysis of exports shows that the services and industrial sectors are the ones most affected. This can be attributed to the fact that a large share of Canadian exports are from various services and industrial sectors. Thus, they are likely to see greater value changes. Among industrial sectors, the "heavy industry" sector saw the largest growth, with exports increasing by 0.61%. In the services category, "other services" gained 0.94% and "financial services" gained 0.57% (Mukhopadhyay & Thomassin, 2015).

We also conducted a welfare analysis of the impact of a reduction in NCDs in Canada, with respect to allocative efficiency, terms of trade, and investment-saving impact. Reducing NCDs increased the labor supply and resulted in a significant gain in welfare in Canada. The larger the increase in the labor supply as a result of a healthier workforce, the greater the gain there is in welfare for the country. The total welfare gain in Canada amounted to US$ 12.03 billion. These estimates suggest that Canada could obtain substantial welfare benefits if the country implemented policies to reduce NCDs (Mukhopadhyay & Thomassin, 2015).

In summary, it is probable that the increase in labor supply that would result from a decrease in nutrition-related NCDs would have a positive impact on the Canadian economy. This increase in the labor supply is expected to boost GDP in Canada, along with such other economic variables as household income, private household consumption, industrial output, exports, imports, and welfare. The sectoral impact in terms of industrial output, exports, and imports varies by sector. The largest impacts are expected in the service sector and the heavy industry sector. This is a win-win situation for Canada. The impact of NCD reductions in Canada also has some positive consequences for the United States. The effect for other countries with respect to GDP, income, and welfare is very marginal (Mukhopadhyay & Thomassin, 2015).

3 The CCHS survey indicates that there is a 15.43% reduction in the labor force due to various types of NCDs. Out of this, the skilled and unskilled labor contribution is 10.8% and 4.63%, respectively. It is a well-known fact that three-quarters of Canadians are engaged in the services sector. Thus, the reduction in NCDs is most likely to have a large impact on services.

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CHAPTER 3

The Cardiovascular Disease Policy Model: Using a National Cardiovascular Disease Simulation Model to Project the Impact of National Programs to Lower Dietary Salt

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Introduction: The Role of Simulation Models in Cardiovascular Disease Health and Economic Policy Analysis

In cardiovascular disease research, randomized, controlled clinical trials are placed at the top of the evidence hierarchy. However, traditional clinical trials study a selected cohort, while national and subnational food, pharmaceuticals, and tobacco policies and clinical practice guidelines are meant for the whole population. "Pragmatic" clinical trials that study a more "real world" cohort embedded in clinical practice have recently emerged, but even these are usually short-term and small scale and provide limited information for policymakers seeking information on the potential long-term effects of an intervention or on a program's large-scale financial costs.

Additionally, population-wide interventions are very difficult to test using a standard experimental design. It is logistically challenging to compare intervention and control groups at the population level (for instance, comparing states or provinces within a country), and such studies are especially prone to biases. In two large-scale diet and lifestyle interventions, the Stanford Five-City Project in the United States of America and the North Karelia Study in Finland, problems with "contamination" (for example, intervention measures were adopted in control areas) and background secular trends complicated interpretation of the results (Ebrahim & Smith, 2001).

Computer simulation of cardiovascular disease prevention policies can bridge some of these knowledge gaps for policymakers and the public (Garnett, Cousens, Hallett, Steketee, & Walker, 2011).

Among the ways that policy simulation can help are to:

- translate existing clinical trial evidence into practice, e.g., would medication treatment benefit a population older than the age range represented in the trial?

- extend the results in time, e.g., what if the intervention effects could be sustained for an additional 15 years?
- scale up the results to a larger population, e.g., what benefits and costs to payers would be expected on the national scale? And, how might the intervention work in various geographic regions and population subgroups?
- compare the same intervention in different populations
- once a policy intervention is applied to an entire population, estimate the benefits by comparing to a simulated counterfactual of no intervention

"What if?" results from simulation models are justifiably viewed with caution. However detailed it is, every model is only one version of the world, and model results are only as accurate and precise as the inputs assumed. Uncertainty about model inputs should be propagated forward into results in the form of sensitivity analyses and uncertainty intervals. Confidence in simulation model results also builds when simulated effects (predictions) approximate observed effects (real data). This sort of model validation may be performed by comparing simulated results with historic secular trends or events recorded in observational cohort studies or clinical trials. Ideally, a simulation model's validity is tested using a pre- and post-intervention comparison.

In this chapter, we illustrate the how the Cardiovascular Disease Policy Model, a computer simulation model developed and validated for the United States, was used to project the potential health and economic impact of population-wide dietary salt reduction in the United States. We also describe how the same model was adapted and the policy approach refocused in order to project the impact of a specific dietary salt reduction policy in Argentina. In addition, the chapter includes a description of how the CVD Policy Model's software and methods have been shared among researchers from Chile, Mexico, and other countries in order to project the impact of dietary-salt-lowering policies in their countries.

Dietary Salt, Blood Pressure, and Cardiovascular Disease

Sodium is necessary for human life, but for thousands of years humans consumed less than a gram of salt daily. Most contemporary societies consume an average of 4-5 grams of sodium daily. Though the public health community has debated the best target for individual daily intake, the fact is that most of the population in many countries consumes a sodium level higher than targets proposed by different guidelines, which range between 1.5 and 2.3 g/day (Yaktine, Oria, & Strom, 2013). Lower dietary salt intake is associated with a higher likelihood of having a normal range blood pressure in observational studies, and randomized, controlled clinical trials have demonstrated that lowering dietary salt lowers blood pressure, in both individuals with normal blood pressure and those with hypertension (He, Li, & MacGregor, 2013).

The association between high blood pressure and risk for cardiovascular diseases has been established for over a century. It follows logically that lowering dietary salt should lower cardiovascular disease risk (via a reduction in blood pressure), but the randomized trial evidence of the cardiovascular disease prevention benefits is sparse. Some researchers and policy advocates argue that policy action to lower dietary salt should wait until better trial evidence emerges (O'Donnell, Mente, & Yusuf, 2014). However, others argue that

the logistical challenge of mounting such a trial is daunting, the level of contemporary salt ingestion is relatively high relative to historical levels, and the need for low-cost, effective prevention programs is so urgent that dietary-salt-lowering programs should be implemented, particularly given the high burden of hypertension and hypertension-related diseases worldwide.

Policies to Lower Dietary Salt in Populations: The Importance of Context

Simulation studies provided early evidence supporting the potential health benefits of population-wide dietary salt-lowering (Murray et al., 2003; Asaria, Chisholm, Mathers, Ezzati, & Beaglehole, 2007). Economic analyses for the United Nations High Level Meeting on Non-Communicable Diseases in 2012 identified population dietary salt-lowering among the "best buys" available for noncommunicable disease prevention (Hayward, 2014). The epidemiologic and economic evidence in support of dietary salt-lowering convinced a critical mass of health policymakers to act. As of 2010, at least 32 countries had adopted salt-lowering programs, using varied approaches (Webster, Dunford, Hawkes, & Neal, 2011). Five of these countries have demonstrated an impact of their salt-lowering programs on individual salt intake (measured using urine sodium collections) and on food industry behavior.

Some of the most impressive evidence for program effectiveness comes from the United Kingdom. There, a policy implemented in 2003 improved labeling of salt content in processed foods, increased public awareness of the risks of consuming a high-salt diet, and produced agreements with the food industry to develop salt-lowering formulations. An analysis of the Health Survey for England suggested that mean sodium consumption in England's overall population fell by about five grams daily between 2003 and 2007, though consumption changed little in subgroups with highest intake (Millett, Laverty, Stylianou, Bibbins-Domingo, & Pape, 2012).

The early results from national salt-lowering policy experiments are encouraging, but no single policy approach fits the need of each nation considering sodium reduction. One reason is that salt consumption patterns differ among countries and communities within countries because of different culinary traditions, different eating habits, and differences in food production and distribution. In the United States over three-quarters of dietary salt comes from processed foods purchased by consumers (Mattes & Donnelly 2012). These processed foods are often produced by companies distributing to broad geographic areas and across multiple local political jurisdictions. In Argentina, close to two-thirds of dietary salt comes from processed foods, and a quarter of the total comes from salt in bread produced primarily by local companies (Ferrante et al., 2011). In other countries, most of the dietary salt is added during cooking or at the table, as either table salt or such other sodium-containing condiments as soy sauce. Dietary salt-lowering policies are more likely to succeed when these differences are accounted for.

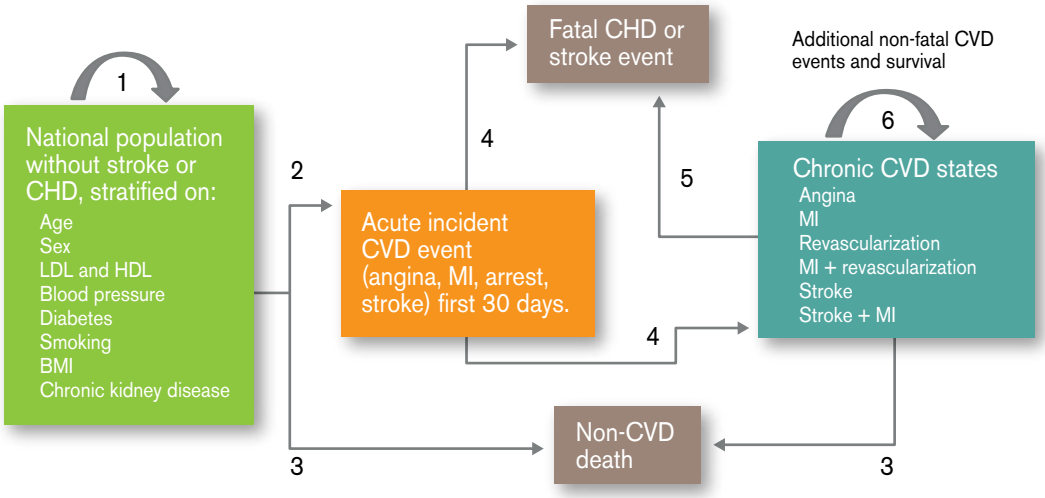
Additionally, the overall population impact of sodium reduction policies on cardiovascular outcomes is likely to depend on other aspects of cardiovascular disease epidemiology that are context-specific. For example, hypertension rates vary among countries. Sodium

reduction interventions have greater impact on individuals with hypertension than those without, so the overall population benefit of sodium reduction depends on the prevalence of hypertension in each national context. Although most countries consume on average far more than what is recommended, the actual level of sodium consumption varies considerably. The relationship of sodium reduction to blood pressure reduction appears to be linear across high levels of sodium consumption. However, it is possible that blood pressure reduction may be less when sodium consumption levels start closer to the recommended values. This phenomenon would lead to variable results when the same intervention is carried out in different nations. Finally, the overall impact of sodium reduction interventions depends strongly on the prevalence of other cardiovascular risk factors that are known to vary across countries (such as tobacco use, obesity, and diabetes) and on the relative importance of certain types of cardiovascular outcomes that are hypertension-sensitive (such as stroke) in that country.

The Cardiovascular Disease Policy Model

The Cardiovascular Disease (CVD) Policy Model is a computer-simulation, state-transition (Markov cohort) mathematical model of coronary heart disease and stroke incidence, prevalence, mortality, and costs in the United States population over age 35 years (Bibbins-Domingo, Coxson, Pletcher, Lightwood, & Goldman, 2007; Hunink et al., 1997; Weinstein et al., 1987). The model simulates CVD on an annual basis, and the demographic characteristics of the simulated population change over time according to

FIGURE 1. Cardiovascular Disease (CVD) Policy Model structure.*



*The CVD Policy Model is a state-transition simulation model of CVD in adults. State transitions are numbered in the diagram: Transition 1 = remain in CVD-free state; Transition 2 = incident CVD; Transition 3 = non-CVD death; Transitions 4 and 5 = survival or case fatality; Transition 6 = survival with or without repeat CVD event in chronic CVD patients. LDL = low density lipoprotein cholesterol; HDL = high density lipoprotein cholesterol; BMI = body mass index; MI = myocardial infarction.

census projections. Every adult alive in a given simulation year must be in a healthy or diseased state (Figure 1). The CVD Policy Model can be adapted for policy analyses in any country with sufficient input data.

The United States version of the CVD Policy Model predicts coronary heart disease and stroke incidence and non-CVD mortality among adults without CVD, stratified by age, sex, blood pressure, and up to seven additional categorized risk factors. The risk factors are estimated from data from pooled, survey-design-weighted United States National Health and Nutrition Examination Surveys from the years 2007 through 2010. Risk function betas risk factors were estimated separately for the risk of incident coronary heart disease events, incident stroke events, and non-CVD deaths, using examinations 1-8 of the Framingham Offspring cohort (Feinleib, Kannel, Garrison, McNamara, & Castelli, 1975). The Framingham coefficients have been useful across many populations (Brindle et al., 2003; D'Agostino Sr, Grundy, Sullivan, & Wilson, 2001; Liu et al., 2004; Wilson et al., 1998). CVD events, coronary revascularization procedures, and CVD and non-CVD mortality are also predicted in adults living with chronic CVD, based on natural history studies. The general chronic CVD categories are coronary heart disease only, stroke only, and combined past coronary heart disease and past stroke. Each state and event has an annual cost and quality-of-life adjustment and an annual probability of repeat event and/or transition to a different CVD state. All population distributions, risk factor levels, coefficients, event rates, case-fatality rates, costs, and quality-of-life adjustments can be modified for forecasting simulations. Model input assumptions for the United States are listed in Table 1 (along with the assumptions for the Argentina CVD Policy Model; see the next paragraph).

The Argentina version of the CVD Policy Model was built in collaboration with researchers in Argentina's National Ministry of Health and at the University of Buenos Aires. Argentine national risk factor surveys did not perform physical examinations or blood testing to inform risk factor exposure information for Argentina in 2010. Therefore, laboratory and physical examination measurements from the Cardiovascular Risk Factor Multiple Evaluation in Latin America (CARMELA) Study (Schargrodsky et al., 2008) supplemented self-reported data from the Argentine National Risk Factor Survey (*Encuesta Nacional de Factores de Riesgo*) (Ferrante & Virgolini, 2007). Because no local cardiovascular disease cohort study data were available, the Argentina version of the CVD Policy Model used risk factor relative risk estimates from the Framingham Heart Study in the United States. The Framingham-based coronary heart disease and stroke prediction functions were recalibrated for Argentina by entering age- and sex-specific coronary heart disease and stroke incidence as the intercept for the prediction function. The Argentina version of the model was calibrated to ensure that simulated coronary heart disease and stroke mortality fit with mortality observed by Argentina's national statistics reported by the National Statistics and Census Institute (*Instituto Nacional de Estadística y Censos*) (Moran et al., 2011).

CVD Policy Model versions for the United States and Argentina were used to project the potential impact of dietary-salt-lowering policies in each country. Information on that work is given later in this chapter, in the case study section.

TABLE 1. Model inputs sources for the CVD Policy Model versions for the United States and Argentina.

Variable	Source	
	Argentina	United States
Population, adults aged 35-94 years in 2010 and projected incoming 35-year-olds, 2010-2050*	Argentina's Census: www.indec.gov.ar	U.S. Census Bureau
Incidence		
CHD	Incidence of hospitalized AMI (Caccavo et al., 2007)	Framingham Heart Study and National Hospital Discharge Survey
Total stroke	Incidence of stroke: national vital statistics and hospital admission registry, Ministry of Health, Argentina (personal communication, Dr. Daniel Ferrante)	
Prevalence of CHD in 2005	Calibrated from age-specific incidence, case-fatality, and mortality rates using the CHD Policy Model; stroke prevalence used a 1991-1992 population-based household survey of prevalent stroke as a guide(personal communication, Dr. Daniel Ferrante)	National Health Interview Survey
Total and cause-specific mortality, 2010		
Total	National vital statistics, www.indec.gov.ar, all deaths in adults age 35-84 years	National vital statistics, http://wonder.cdc.gov/, all deaths in adults age 35-84 years
CHD	Vital statistics; using CHD ICD-10 codes I20-25 and 2000 Global Burden of Disease "garbage code" definitions for a proportion of CHD deaths	Vital statistics; using CHD ICD-10 codes I20-25 and two-thirds of I49, I50, and I51
Stroke	Vital statistics; using stroke ICD-10 codes I60-69	Vital statistics; using stroke ICD-10 codes I60-69
CHD risk factor means and joint distributions, 2005	Cardiovascular Risk Factor Multiple Evaluation in Latin America (CARMELA) Study (Schargrodsky et al., 2008) and *Encuesta Nacional de Factores de Riesgo* (Argentine National Risk Factor Survey) (Ferrante & Virgolini, 2007)	Pooled, survey design-weighted United States National Health and Nutrition Examination Surveys 2007-2010
Risk factor hazards for CHD and stroke	Framingham Heart Study (USA) (Muntwyler, Abetel, Gruner, & Follath, 2002; (Wolf, D'Agostino, Belanger, & Kannel, 1991)	Framingham Heart Study (USA) (Muntwyler et al., 2002; Wolf et al., 1991)
One-day and 28-day CHD case-fatality		
CHD		
In-hospital	*Encuestas SAC* [SAC Surveys] (Blanco et al., 2007)	National Hospital Discharge Survey
Stroke		
In-hospital	Argentinian National Stroke Registry (ReNACer) (Sposato et al., 2008)	National Hospital Discharge Survey
28-day case fatality	Proyecto Investigación de Stroke en Chile: Iquique Stroke Study (PISCIS) (Lavados et al., 2005)	Atherosclerosis Risk in Communities Study (Rosamond et al., 1999)

Disseminating and Adapting CVD Policy Model Methods as Part of the PAHO Dietary Salt Reduction Initiative: Notes from a University of California and National Institute of Public Health of Mexico Workshop

The Pan American Health Organization (PAHO) launched the Cardiovascular Disease Prevention through Dietary Salt Reduction initiative in 2009. A regional expert group was formed, including 18 leaders in nutrition and chronic diseases from universities, government agencies, and research institutions in North America, South America, Central America, the Caribbean, and Europe. CVD simulation modeling and economic analysis of dietary salt reduction policies were seen as essential components of the initiative. Policy experts from Argentina, Chile, Mexico, and the United States began to collaborate on research using the common framework of the CVD Policy Model. Shared methods and model structure meant that participants would be able to compare the impact of different approaches to dietary salt reduction in different epidemiological, societal, and cultural contexts.

The CVD Policy Model investigators at the University of California at San Francisco (UCSF) and at Columbia University have worked closely with researchers from Argentina, Chile, China, Mexico, and New Zealand to develop country-specific models and to train local researchers to design and implement model simulations relevant to each country's context. Visiting researchers assembled national data necessary for populating the simulation model prior to visiting these two universities in the United States. Over a total of about three to four months on average, junior investigators with competence in data analysis and health research have been trained to adapt and run computer simulations with a new national CVD Policy Model version. The CVD Policy Model investigator team continues to support the software and research work of collaborating investigators whom they trained.

In an effort to extend the reach of the CVD Policy Model in Latin America and to enhance the region's capacity for health policy research, investigators at UCSF and Columbia University, in collaboration with researchers from Argentina and Mexico, developed a curriculum to train graduate-level students and junior investigators in the fundamentals of policy-oriented research in cardiovascular disease. The week-long course, entitled "Policy-oriented Research in Obesity, Diabetes, and CVD Prevention and Treatment," was supported by a grant from the U.S. National Institute of Health's Fogarty International Center. The course took place at Mexico's National Institute of Public Health (*Instituto Nacional de Salud Pública*, INSP) in August 2014, and was attended by 30 students from Mexico and other countries of Latin America. Through didactic sessions as well as hands-on exercises using the CVD Policy Model, students learned about the role of research in policy formation, how to develop policy-relevant questions, and the use of simulation modeling to address these questions. Additional sessions covered topics relating to professional skills such as accessing and using national data, writing manuscripts, identifying stakeholders, and working with the media to disseminate research findings. In addition to formal lectures, the course included panel discussions on topics of particular relevance to CVD prevention efforts within the Latin American region and globally,

including policies around dietary salt and the consumption of sugar-sweetened beverages. The primary goal of the course was to increase the capacity of young researchers to develop and carry out policy research projects in their own areas of interest. To this end, students developed individual research proposals through small group discussions and one-on-one meetings with faculty throughout the week. The majority of students plan to continue work on their proposals beyond the course, including a subset of researchers who are implementing projects using the CVD Policy Model.

Simulation Models in Cardiovascular Disease Health and Economic Policy Analysis: Future Directions

The experience of computer simulation modeling of cardiovascular disease using the CVD Policy Model across different national contexts has highlighted several important features that hold promise for future work:

1. **Using a common modeling platform to address cardiovascular disease prevention and treatment questions specific to each national context:** The goal of the collaborative work using the CVD Policy Model is to create simulation specific to each national context that investigators can then use to address questions of relevance in their own countries. Within the Americas, models are being developed for Argentina, Canada, Chile, and Mexico, and more are planned. All of the investigators become part of the CVD Policy Model "Commons" in order to share information and technical updates to the model, but each investigative group seeks to address questions of relevance to their country. In Argentina, for example, current work is examining the impact of changes in national policies regarding purchase of and indications for high- versus low-potency statin medications. In Mexico, the high rate of diabetes has led to plans to evaluate prevention and treatment policies related to this condition. The computer simulation models allow for comparisons of one intervention relative to other hypothetical or planned interventions (e.g., tobacco control, obesity prevention). Therefore, modeling may become an important tool for policymakers, academics, and health advocates to examine and compare the population health impact of proposed interventions in their countries.

2. **Using a common modeling platform to address cardiovascular disease prevention regionally:** A major potential for this collaborative work is in examining similar cardiovascular disease prevention policies across the Americas. Sodium reduction policy is an important example, and the case study at the end of this chapter highlights both country-specific differences (approaches targeting regulation of the food industry in the United States versus focusing on local bakeries in Argentina) as well as similarities (the need to engage large multinational food manufacturers through voluntary or regulatory means). Control of the high consumption of sugary beverages through taxation and regulation is another such intervention that is being considered by many countries in the Western Hemisphere, and is currently being modeled by investigators using the CVD Policy Model. Comparative modeling supports ongoing timely policy discussion for such issues and may be an additional vehicle to encourage sharing

of information in these contexts. Additionally, since many of these public health interventions and policies target multinational industries that operate in more than one country, the collaborative comparative modeling approach may encourage and support regional solutions to such issues.

3. **Using a common modeling platform to promote continued capacity-building for cardiovascular disease research and policy evaluation across the Americas.** Our experience with the course at Mexico's National Institute of Public Health focused on cardiovascular disease prevention through policy initiatives. Using examples from the CVD Policy Model research highlighted the potential for rich discussion and collaboration across the Americas on these topics, as well as the importance of continuing to train students and fellows to pursue this research. The course fostered discussions of cardiovascular disease prevention solutions within national contexts and across the Hemisphere, and it stimulated interest in continuing such regional training opportunities at other sites in the future.

Continued Innovation and Adaptation of Simulation Modeling

In this chapter we have highlighted the potential for a common platform, adapted to each national context, for evaluating and addressing important cardiovascular-health-related topics in the Americas. However, several technical challenges must continually be addressed in order for such modeling to remain relevant. These issues include the need to address subgroups within each country, as well as smaller geographic areas that are also subject to variation in the context of cardiovascular disease risk factors and outcome. Risk factor, dietary intake, disease incidence and prevalence, and even good-quality mortality data are sparse or missing for many countries in the Americas, necessitating methods for imputing or modeling estimates using data available from similar countries. Additionally, there is growing awareness of the need to examine the larger social determinants of the health context when modeling specific disease conditions, as well as to consider the life-course perspective in this work. Finally, although additional complexity is often good, this cannot come at the expense of adaptability and ease of use. Overly complex and technically daunting models cannot easily be put in the hands of multiple local users across a range of contexts.

Case Study: Projecting the Health and Economic Impact of Dietary Salt-Lowering in the United States and Argentina

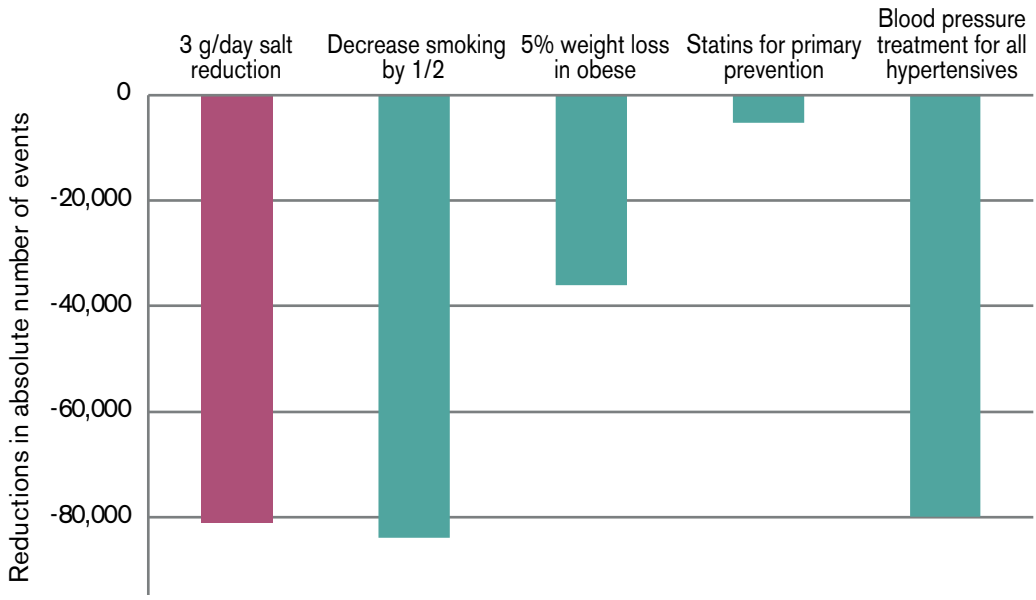
CVD Policy Model versions for the United States and Argentina were used to project the potential impact of dietary-salt-lowering policies in each country. Both studies assumed that the effect of salt reduction on blood pressure reduction was linear over the range of zero to three grams of salt (sodium chloride) daily. Meta-analyses of observational studies and clinical trials provided estimates of the magnitude of blood pressure reduction. It was assumed that the magnitude of coronary heart disease and stroke risk reduction with blood pressure reduced by salt restriction corresponded to the positive association between higher blood pressure and higher CVD risk observed in cohort studies.

United States Dietary Salt Reduction Policy Simulations

The United States dietary salt policy analysis was initiated because of public debate concerning national efforts by the U.S. Food and Drug Administration and the National Salt Reduction Initiative to regulate sodium in processed foods. The United States study simulated the potential impact of reducing dietary salt by 1.0, 3.0, or 6.0 grams daily, based on what was considered feasible starting from an average consumption of 10.4 g/day in men and 7.3 g/day in women. Based on evidence from clinical trials of blood pressure response to salt reduction, an accentuated response was assumed for African-Americans, people with hypertension, and persons aged 65 and older. In order to place the projected benefits of dietary salt reduction in context, such other public health interventions as reduced smoking, weight reduction, and cardiovascular risk factor reduction with statin treatment were compared with the projected benefits of dietary salt reduction.

The United States analysis projected that dietary salt reductions would lead to avoided CVD and all-cause deaths (thereby avoiding premature deaths and adding life years) and financial cost savings due to avoided acute and chronic CVD health care costs. According to the model, over a 10-year period more than 800,000 life years could be gained for every one gram of dietary salt reduction in the population, while also producing a net cost savings. African-Americans, women, and young adults would benefit the most from a national dietary-salt-lowering policy. Though spread across the entire population, regardless of CVD risk, the benefits of a 3 g/day dietary salt reduction were comparable to the potential public health gains of other public health interventions studied (Figure 2) (Bibbins-Domingo et al., 2010).

FIGURE 2. Projected annual reductions in all-cause deaths with a 3 gram per day reduction in mean dietary salt consumption compared with other hypothetical public health and clinical interventions in the United States, 2010-2019, according to the CVD Policy Model (Bibbins-Domingo et al., 2010).



Argentina Dietary Salt Reduction Policy Simulations

The CVD Policy Model-Argentina was used to project the health benefits of a 10% reduction in sodium reduction in processed foods that are part of the national government's "Less Salt, More Life" (Menos Sal Más Vida) initiative, simulating a short-term effect (8% reduction over two years) and the impact of a cumulative 40% reduction if the policy was sustained for 10 years. The Argentina analysis started with dietary sodium consumption measured using spot urine sodium in the La Pampa Pilot Study. The analysis projected that even a two-year intervention would prevent about 19,000 total deaths (Table 2). If sustained over 10 years, the policy could prevent about 55,000 deaths. Argentina investigators (Ferrante et al., 2011) have also published the results of their interventions working directly with local bakeries to reduce salt added to bread and other baked goods, a primary interventions point appropriate to Argentina and the patterns of sodium consumption there.

TABLE 2. Projected potential impact of short-term dietary salt reductions (2-year policy) and longer-term dietary salt reductions (10-year policy) on reductions in cardiovascular events and total deaths in Argentina, 2013-2023, according to the CVD Policy Model (Konfino, Mekonnen, Coxson, Ferrante, & Bibbins-Domingo, 2013).

	Total deaths		CHD deaths		MI		Stroke	
	Baseline	Avoided events	Baseline	Avoided events	Baseline	Avoided events	Baseline	Avoided events
Two-year policy effect (8% reduction overall, 4% of this reduction in years 1 and 2)								
Men	1,555,000	-12,000	318,000	-4,500	488,000	-8,000	515,000	-5,500
Women	1,550,000	-7,000	275,000	-1,500	376,000	-5,000	495,000	-4,500
Total	3,100,000	-19,000	593,000	-6,000	864,000	-13,000	1,010,000	-10,000
Ten-year policy effect (initiative maintained for 10 years, progressively reducing sodium 40%, 4% each year)								
Men	1,555,000	-35,000	318,000	-11,500	488,000	-25,500	515,000	-15,000
Women	1,550,000	-20,000	275,000	-4,500	376,000	-12,500	495,000	-12,000
Total	3,100,000	-55,000	593,000	-16,000	864,000	-38,000	1,010,000	-27,000

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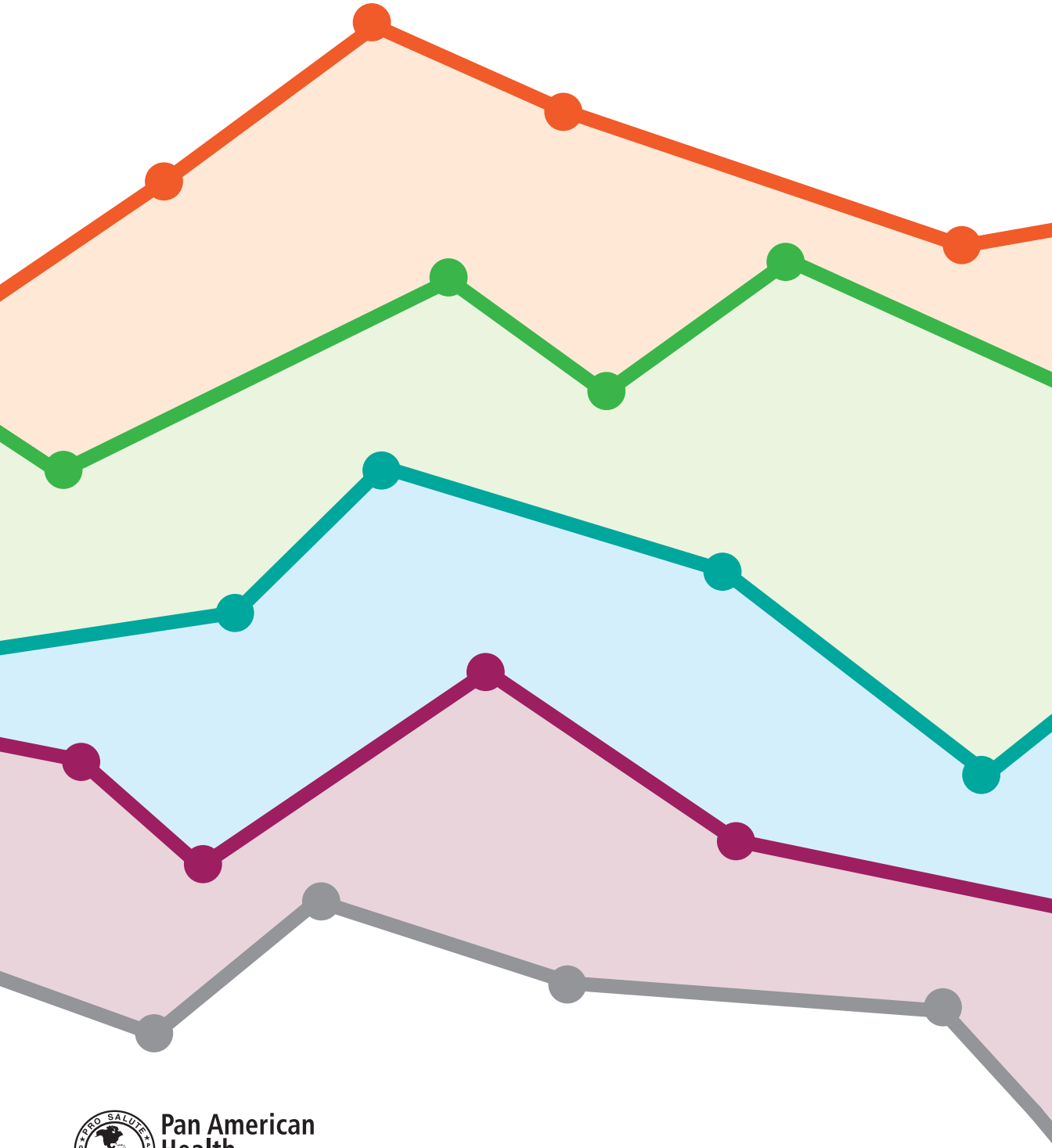

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