CHAPTER 16

Using Systems Thinking to Understand the Dynamics of Obesity in Low and Middle Income Countries

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Abstract: The current chapter applies a systems thinking approach to define and study the dynamics underlying increased rates of obesity in Low and Middle Income Countries (LMICs). Systems thinking and dynamics modeling belong to the rapidly evolving, interdisciplinary field of system science research. This field adds value to more traditional public health research methods by contributing to the design and testing of integrated models of change, to examine how key factors interact with each other and with health status. We frame the problem of obesity for LMICs as an aggregate, chronic energy imbalance of the population as a whole, due in large part to increased consumption of highly processed foods. To begin to explore the dynamically complex nature of global obesity, we develop a causal loop diagram, supported by the extant literature, showing a comprehensive qualitative model of the dynamics underlying increased rates of obesity in LMICs. Eighteen endogenous factors, or constructs, make up these seven distinct loops. In addition, selected exogenous factors are shown, representing the effect of policies by foreign governments, global corporate entities, and other institutions that explain obesity dynamics in LMICs. We suggest that there are two major points of intervention to curb current increasing obesity rates: the first is to sustain or grow healthy food production capacity and the second is public health education.

Keywords: Complex public health problems, exercise, fitness, global health, low and middle income countries, nutrition, obesity, overweight, processed foods, risk, systems thinking, wellness.

INTRODUCTION

In the realm of public health, one can use systems thinking to pose complex, non-linear hypotheses about how social, economic, and cultural forces impact public

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health [1-3]. The hallmark of the system dynamics approach is the study of feedback mechanisms, or cybernetics, which can be used to explain how things change over time [4-7]. Systems thinking can make explicit the interdependent relationships among these forces and how they interact over time to generate a health problem and, moreover, can identify gaps in current knowledge as well as robust policies for change [8].

Systems thinking and dynamics modeling belong to the rapidly evolving, interdisciplinary field of system science research. This field adds value to more traditional public health research methods by contributing to the design and testing of integrated models of change, to examine how key factors interact with each other and with health status. In addition to system dynamics modeling, social network analysis, agent-based modeling, micro-simulation, discrete event analysis, Markov modeling, and many operations research and engineering methods constitute systems science approaches that show great promise for public health research and policy studies [3, 9]. For example, the first author and colleagues used systems thinking to illustrate the utility of a system dynamics approach to promoting quality of life research in chronic disease, using diabetes as an example [10].

Systems thinking and system dynamics modeling has also been used to examine health care quality improvement [9, 11-16]; community-based systems of care [17-20]; epidemiology and disease surveillance [21-25]; global health care management [26-28]; behavioral health interventions in tobacco [25, 29-32], substance abuse [33-36], and mental health [37, 38]; as well as in managing chronic illness [20, 39, 40]. In addition, a system dynamics model called *HealthBound*, originally developed for the Centers for Disease Control and Prevention (CDC), is currently being used in a project called *ReThink Health*, to help people understand the critical relationship between "upstream" efforts to prevent illness and the demand for the relationships between a community's access to care, health status, and socioeconomic level [41].

OBESITY EPIDEMIOLOGY IN LMICs

Worldwide obesity has nearly doubled since 1980, with more than 1.4 billion adults overweight and approximately 200 million men and nearly 300 million women obese [42]. Prior research has show that, in low-income countries, obesity mostly affects middle-aged adults (women more than men) from wealthy, urban environments. In contrast, in high income countries (HICs) obesity affects both

sexes and all ages, but is disproportionately higher among groups with lower socio-economic status (SES) [43].

Current epidemiology shows that the fastest growth in obesity is occurring in LMICs. A recent review of the global obesity epidemiology by Popkin and Slining [44] concluded that LMICs are experiencing a rapid increase in overweight and obesity prevalence, increased body mass index (BMI) levels among overweight and obese persons, and a potential change of obesity phenotypes-*i.e.*, increasing waist circumference at each BMI level in some countries (namely China and Mexico). Similarly, using nationally representative data from 1990 through 2010 (or the most recent year available) for all Demographic Health Survey (DHS) countries, Popkin and Slining [45] also showed that over two-thirds of women in North Africa and the Middle East were overweight or obese, followed by Latin America and the Caribbean, where approximately half of the women are overweight or obese.

SYSTEMS THINKING: A TOOL FOR UNDERSTANDING OBESITY TRENDS IN LMICs

The increasing prevalence of obesity in LMICs is a complex and dynamic problem that appears to stem from steadily increasing rates of consumption of sugary beverages and processed foods containing a high volume of fat and sugar [46-50]. In addition, there is evidence that increased access to tobacco products and alcoholic beverages is associated with increased consumption of sugary beverages and processed foods [47]. Since World War II, effective corporate strategies of manufacturing and marketing these unhealthy food commodities has served to increase average childhood and adult BMIs [51, 52], resulting in both obesity and, paradoxically, under-nutrition as persons consume energy dense foods that are low in other nutrients [44, 53-58]. To provide greater insight into the drivers of this problem, we propose using systems thinking to show the dynamic links between obesity rates and increased consumption of unhealthy commodities in LMICs.

Researchers and other obesity experts [48, 56, 57] have offered a variety of theories and perspectives about the drivers of these trends in LMICs. The nutrition transition model posits that food preferences are shifting away from traditional foods in favor of high-energy, low-nutrient foods [48], driven by the problematic role of easier access to processed foods and decreased physical activity levels, which are attributed to urbanization and other factors that characterize rapidly

globalized economies [57]. Subsequently, these dynamics are ushering in a parallel increase in the global prevalence of non-communicable diseases, including diabetes, cardiovascular conditions, cancer [49, 59-64].

A Hypothesis of the Causal Structure of the Obesity Problem

The hallmark of the system dynamics approach is the study of feedback structures, or cybernetics [5-7, 65]. What we present below is a generic conceptualization of the hypothesized underlying cybernetic 'structure' of the obesity problem in LMICs, expressed in terms of multiple causal loops. Causal loop diagramming is a useful technique for illustrating how specified constructs are linked together and how they change over time, with respect to a given problem. Causal loop diagrams capture the qualitative nature of relationships among key constructs.

The objective was to design causal loops that illustrate general observations about the causes of overweight and obesity in LMICs based on the published reviews, empirical reports [44, 46, 50, 66, 67], and white papers [42, 59, 68] examined in this chapter. Collectively, these loops form a comprehensive qualitative model of the dynamics underlying increased rates of obesity in LMICs (see Fig. **1**). In total, eighteen endogenous factors, or constructs, make up these seven loops, which have been labeled A-G. In addition, four exogenous factors are shown. By definition, they are theoretically controlled (or specified) by external forces, such as a foreign government, a global corporate entity, or some other institution independent of the LMIC itself. Note that one could argue a way to make one or more of these exogenous factors part of the endogenous structure. However, for our purposes, that would move beyond the scope of the current chapter. The two exogenous factors shown in red (*Direct Foreign Investment in LMIC* and *LMIC population growth rate*) are hypothesized to have direct impact on 'Per capita productivity' within the LMIC. The two shown in green (*Healthy food production capacity* and *Public health education*) are policy levers, or intervention points that are hypothesized to be a means through which constructive impact on population obesity rates in LMICs could be achieved.

Interpreting Causal Loops

Table **1** provides a glossary of these key terms, to assist with interpretation of the loop diagrams. Note that linking arrows between variables infer causality, not correlation. Every causal link has a polarity, either positive (+) or negative (-). A

positive (+) link indicates that an incremental increase in the input (antecedent) variable causes the output (dependent) variable to also increase (by some specified amount over each increment of time). Similarly, an incremental decrease in the input variable would cause the output variable to decrease (by some specified amount over each increment of time). A negative (-) link indicates the opposite relationship between two variables, such that an incremental increase in the input variable causes the output variable to decrease (by some specified amount over each increment of time) and *vice versa*.

Each feedback loop has postulated polarity that is either reinforcing (+) or balancing (-). Reinforcing loops tend to promote or accelerate the growth, often generating instability in the system. In contrast, balancing loops are stabilizing, or goal-seeking, creating a homeostatic (steady-state) condition. Depending on the postulated purpose of the loop, the resultant dynamics could generate a policy trend that either promote/fuels obesity or that slows/curbs its, over time. Keep in mind that the overall dynamics of the problem are the outcome of the interactive effects of the loops over time. For example, two reinforcing loops may interact to bring a particular construct into a steady state, or, alternatively, may generate an oscillating pattern over time, with one loop dominating the other in an alternating manner.

Table 1. A glossary of systems thinking terms.

Term	Definition
Dynamics	The behavior over time of a system or any of its components.
Systems Thinking	A non-linear approach to studying the dynamics of social problems in terms of causally linked, closed chains of variables.
Causal Loop Diagram	A visual representation of problem of interest expressed in terms of causally linked, closed chains of variables; a hypothesis of the dynamics underlying a given problem of interest.
Balancing Loop	A closed chain of variables that serves to stablize a system, over time, by forcing a correction, or a reversal, of whatever direction of change is imposed; a negative feedback structure.
Reinforcing Loop	A closed chain of variables that serves to destabilize a system over time, by amplification of whatever direction of change is imposed; a positive feedback structure.
Exogenous Factors	Any variable that changes due to conditions external to the looped (endogenous) dynamics of a social problem of interest; any contextual characteristic or environmental condition that is not influenced by the system dynamics of focus.

In Table **2** we have listed each of the seven loops shown in our model (Fig. **1**) by its corresponding letter (A-G) and a brief label. In addition, each loop is

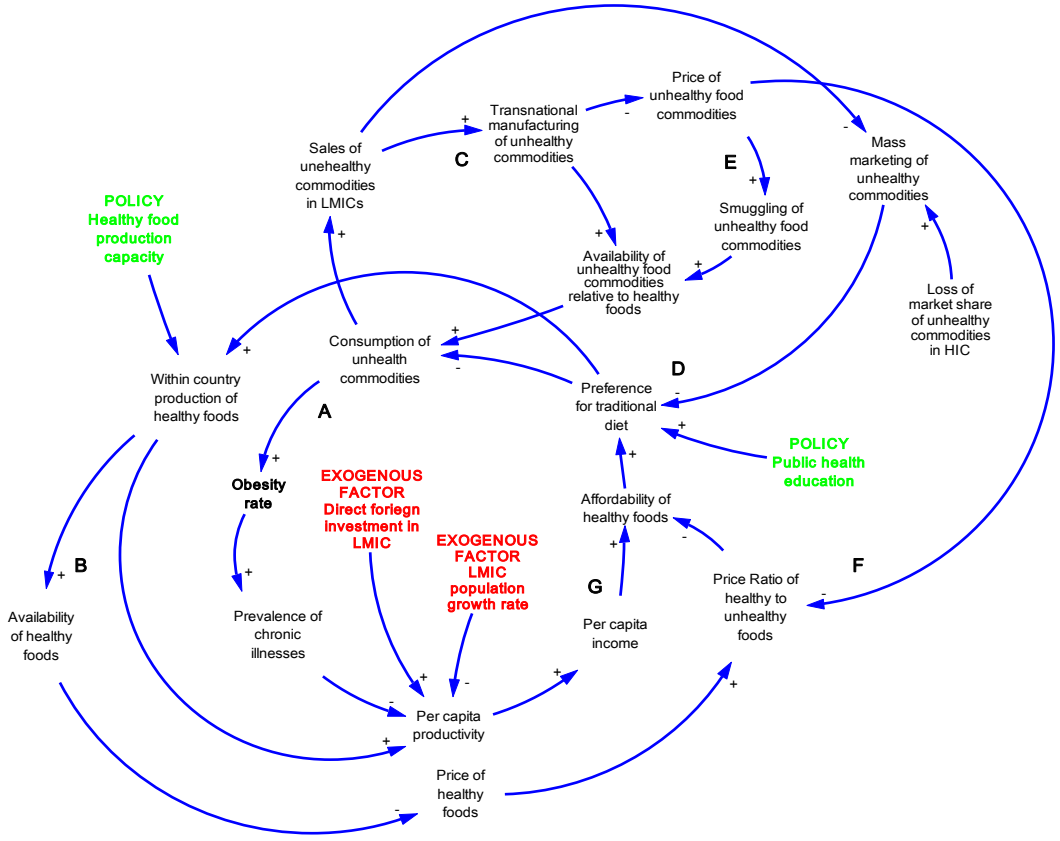

Fig. (1). Postulated model of the dynamics of obesity in low and middle income countries.

categorized by type (*i.e.*, Reinforcing or Balancing) and by predicted effect (*i.e.*, Fuels obesity or Curbs obesity). This assessment of the loop's effect is a value judgment based on whether the loop is expected to further exasperate or serve to mitigate the problem of overweight and obesity at the population level in a LMIC.

Loop A-Consumption of Unhealthy Commodities (Reinforcing, Fuels Obesity)

This loop is arguably the heart of our model, as it includes obesity rate, representing the pace at which the problem of overweight and obesity grows in LMICs. Estimates of current overweight and obesity rates range from 0.31% per year to 0.92% per year for Latin America and the Caribbean and for the Middle East and North Africa, respectively [44]. Results are similar for rural and urban settings, except for South Asia and sub-Saharan Africa, where higher underweight status was associated with rural communities [44].

Table 2. Index to the model's causal loops.

Loop ID	Descriptive Label	Dynamics	
		Type of Loop	Trend
A	Consumption of Unhealthy Commodities	Reinforcing	Fuels obesity
B	Within Country Production of Healthy Foods	Reinforcing	Curbs obesity
C	Transnational Manufacturing of Unhealthy Commodities	Reinforcing	Fuels obesity
D	Preference for Traditional Diet	Balancing	Curbs obesity
E	Smuggling Unhealthy Commodities	Balancing	Fuels obesity
F	Price Ratio of Healthy to Unhealthy Commodities	Reinforcing	Fuels obesity
G	Per Capita Productivity	Reinforcing	Curbs obesity

Tracing through Loop A, one can determine that it is a reinforcing loop comprised of seven variables. Consistent with the literature summarized here, this loop hypothesizes that increases in consumption of unhealthy commodities, defined as soft drinks, and processed foods that are high in salt, fat, and sugar, as well as tobacco and alcohol [47], will contribute to the obesity rate, the rate at which persons in a given LIMC meet objective criteria of obesity. Assuming that current trends will persist, this loop's dynamics serve to fuel, or increase the obesity rate in these countries.

Loop A represents the hypothesis that a higher obesity rates will eventually add to the prevalence of chronic illnesses, mainly non-communicable diseases such as diabetes, cardiovascular diseases, and cancers. Although the burden of chronic illness is still ramping up in LMICs, the level of compromised quality of life, reduced per capita productivity-both in terms of lost family income (per capita income) and social costs of delivering care to the sick-it has been described as a "a slow-motion disaster," as noted by Dr. Margaret Chan, Director-General of the World Health Organization [53].

Loop B-Within Country Production of Healthy Foods (Reinforcing, Curbs Obesity)

This loop taps the LMIC's potential to make more or to sustain levels of production of healthy foods. This is a reinforcing process with a potentially favorable impact on overweight and obesity prevalence. Loop B shares two variables with Loop A, namely affordability of healthy foods and preference for traditional diet. To the extent that the LMIC's preference for traditional diet is

sustained or, ideally, expanded, we hypothesize that farmers and producers will be motivated to increase their production of these healthy foods, such as whole grains, vegetables, fresh poultry, fish and meats, and other natural products. Greater production means greater availability to healthy foods. Additionally, per commonly accepted economic theory, greater supply of these healthy foods should push their price lower. At the market then, the price ratio of healthy to unhealthy foods would favor the purchase of cheaper, healthy foods. Over time, within country production of healthy foods would be expected to expand to meet this demand, which is a good outcome, though not one that is hypothesized to directly impacting a LMIC's obesity rate.

However, Loop B could also reinforce an undesirable scenario, where the availability of health foods is decreased over time, driven by a shrinking level of within country production of health foods. Under these circumstances, we would expect the price of healthy foods to rise. This would, in turn, dampen preference for traditional diet, as it would require procurement of healthy foods, which are comparatively expensive [43, 47, 56, 57]. Then, a dampened preference for traditional diet would likely promote consumption of unhealthy commodities, which further increases the obesity rate [43, 47].

Loop C-Transnational Manufacturing of Unhealthy Commodities (Reinforcing, Fuels Obesity)

Another problematic, reinforcing dynamic concerns global corporations that profitably market unhealthy commodities to LMICs. Increasingly easier access to processed foods and out-of-home fast-food franchises are facilitating unhealthy dietary patterns, a direct result of the role of global corporate producers in the manufacturing, marketing, sale, and distribution of unhealthy commodities in these settings [51, 52, 69, 70]. From the perspective of these global corporations, sales of unhealthy commodities in these markets are profitable to the investing entity, as they can be produced at low cost, have a long shelf-life (minimizing waste), and support a high retail value [56-58]. Some of the largest multi-national producers include major soft drink and candy companies [52]. Arguably, they can exert substantial market control over the global supply of many of these unhealthy commodities [50, 51, 69].

Thus, Loop C represents the hypothesis that increasing consumption of unhealthy commodities will drive up sales of unhealthy commodities in LMICs. In turn, as sales increase, transnational manufacturing of unhealthy commodities rises to

meet the demand, which increases the availability of unhealthy food commodities relative to healthy foods. Stuckler *et al*. [47] have performed analyses that showed growth in sales of unhealthy commodities has increased in many LMICs and has decreased in HICs. Moreover, they project that the pace of consumption of unhealthy commodities is expected to occur faster in LMICs than in HICs, and that transnational companies have as strong a presence in middle-income countries as they do in HICs.

Researchers have observed that higher intake of unhealthy foods correlates strongly with higher tobacco and alcohol consumption, suggesting use of common strategies in marketing and distribution across these industries [50-52, 69]. Higher levels of direct foreign investment and the implementation of free-trade agreements have been associated with rising income in some LMICs, but these economic policies have also been correlated with higher consumption of unhealthy commodities [56, 57]. However, economic growth is not always associated with higher unhealthy commodity consumption, which suggests that growth-oriented policies that are grounded in public health goals can promote healthy food choices and curb obesity trends.

Loop D-Preference for Traditional Diet (Balancing, Curbs Obesity)

Sales of unhealthy commodities in LMICs also drives *mass marketing of unhealthy commodities*. As hypothesized in Loop D, to the extent that demand for transnational processed food commodities is flat or dropping in HICs, they would invest more in the mass marketing of unhealthy commodities. Marketing of these unhealthy commodities, by billboard, radio, TV or internet, or by direct marketing in the form of free samples, would serve to decrease preference for traditional diet [43, 51, 57, 71]. Note that the causal influences of ‘good’ Loops B and G, and bad Loop C will also serve to affect preference for traditional diet. Yet, to the extent that preference for traditional diet is sustained or even enhanced, made possible through policies that limit unhealthy commodity marketing and keep healthy food relatively cheap (affordability of health foods), consumption of unhealthy commodities would drop, which would help slow, or ideally even reverse obesity rates. For example, this effect is evident in the rapidly declining consumption of tobacco in the United States, where the national adult smoking prevalence, estimated by the National Health Interview Survey, has reached a record low of 18.0% in 2013 [72]. In turn, this type of loss of market share has encouraged major investment in the marketing of tobacco to Africa and Latin American [69].

Loop E-Smuggling Unhealthy Commodities (Balancing, Fuels Obesity)

Another dynamic to take note of is the potential impact of smuggling unhealthy food commodities. Here we hypothesize that, to the extent that the price of unhealthy food commodities remains high and preference for traditional diet is dampened by suppressed effects of 'good' Loops B, D and G), smuggling will be more lucrative [47]. In turn, this contributes directly to the availability of unhealthy food commodities relative to healthy foods, and would drive up consumption of unhealthy commodities, over time. However, while the distinct possibility of smuggling exists, there are limited data to gauge such an effect on commodity availability in a given LMIC, and the effect may result in higher priced contraband products, which would likely include tobacco and alcohol.

Loop F-Price Ratio of Healthy to Unhealthy Commodities (Reinforcing, Fuels Obesity)

The matter of changes in the price ratio of healthy to unhealthy goods is of great concern. We believe that price will influence day-to-day food purchase decisions. There is a need for further study of price elasticity in LMICs, to explain, for example, how a consumer would change purchasing patterns given a price hike in fresh fruits and vegetables relative to processed fruits and vegetables, of how a fast food meal would be preferred over a home cooked one, if the fast food meal is perceived to be as cheap, or cheaper.

It has been relatively well established that global change in overweight status of a population is correlated with SES, using indices for educational level, income, or both. For example, using cross-sectional data, Subramanium *et al*. found a robust positive correlation between SES and overweight status [73]. Monteiro *et al*. [74] found that a lower SES was a protective factor against obesity, although countries with GNP per capita above $2,500 had a greater risk of obesity among lower SES women.

Jones-Smith *et al*. [75] studied national trends in overweight burden using both indices of wealth and education, and found that 27 of 37 countries showed a positive association between SES and overweight prevalence, but that higher per capita GNP and narrower income inequity were both linked to a higher proportion of overweight in lower SES subpopulations. The work of Monteiro *et al*. [74] and Jones-Smith *et al*. [75] also found that increased national wealth drives the burden of overweight and obesity to lower SES subpopulations. These results provide

some context for understanding the effect of changes in price ratio of healthy goods to unhealthy goods.

Loop G-Per Capita Productivity (Reinforcing, Curbs Obesity)

Our final feedback structure, or loop, examines the impact of per capita productivity on per capita income. We hypothesize that new capacity for within country production of healthy foods will directly translate to increased per capita productivity. New jobs and wage increases will be generated, and this will make healthy foods more affordable, which is hypothesized to support a preference for traditional diet [47].

Moreover, higher prevalence of chronic illnesses will have profound impacts on per capita productivity, affecting population health and health economics in the long run [49, 76-78]. However, where external policies pump up direct foreign investment in an LMIC, per capita income will be buffered, which we hypothesize to increase consumption of unhealthy commodities [56]. Notably, careful data analyses suggest that rising income levels are a significant correlate of increasing exposure to unhealthy foods in LMICs [47, 56].

Note, here, that two exogenous effects, both shown to directly impact per capita productivity. The first is direct foreign investment in LMIC. More investment from overseas is welcomed, as it typically fosters growth in government institutions and business enterprises, which creates jobs and contributes to per capita productivity. The second is the country's population growth rate. The majority of LMICs are experiencing high population growth rates [42, 58, 74, 79]. Rapidly rising population growth rates tend to increase unemployment, which directly diminishes per capita productivity.

PUBLIC HEALTH POLICIES

Curb Consumption of Unhealthy Commodities and Obesity Rates in LMICs

Our model of obesity dynamics in LMICs identifies postulated feedback structures about the main drivers of the obesity epidemic in LMICs (Fig. **1**, Loops A-G). Given the complexity and the scale of the problem, what can be done to address it? The prevalence of obesity has been increasing worldwide for more than 30 years, in countries rich and poor [78, 80]. Our model helps identify multiple points of leverage, places where empowered stakeholders can intervene, to begin to stem the rate of obesity and all of the undesirable externalities that

come with it, including increased prevalence of chronic illnesses and the resultant decrease in per capita productivity and income.

While governments and responsible public health institutions have the potential power and knowledge to curb obesity rates in LMICs, which policies and programs can be developed, effectively implemented, and sustained, is less clear. Government strategies to control tobacco and alcohol provide a potentially useful model, but arguably curbing obesity poses a more complex challenge. In short, management of the overweight and obesity problem requires multiple types of interventions that are staged at multiple levels. An ecological framework to guide effective interventions is necessary [81], to understand and effectively promote health-positive attitudes and behaviors at the individual level, as well as to organize and change social and built environments, such that choosing to eating healthfully and to exercise regularly are embedded in a dominant, continually reinforced feedback loop.

Having framed the problem for LMICs as a chronic energy imbalance of the population as a whole, due in large part to increased consumption of highly processed foods, we suggest that there are two major points of intervention. The first is to sustain or grow healthy food production capacity and the second is public health education.

Healthy Food Production Capacity

It is evident that, over time, the globalization of the world economy is changing systems of food production and distribution. In traditional societies, individuals managed the production of most of their food through family-based, community-level husbandry, which in market-based economies is being replaced by mass production methods, using vast networks of corporate farms and processing facilities. The result of this shift has been a reduction in the "time price" of food, making it cheaper and more accessible to simply purchase what was once grown, harvested, and prepared by individuals or families [66].

Promoting sustainable agriculture for healthy food production and distribution is a potentially robust policy for addressing overweight and obesity rates in LMICs. Sustainable agriculture systems in LMICs have the potential to produce whole foods conveniently and affordably. The major goal of sustainable agriculture is to develop technologies and practices that protect the environment while fostering improvements in food productivity. Arguably, there is a balance to be struck, as progress in agricultural productivity in the past 50 to 60 years has come *via*

increased use of fertilizers, irrigation water, agricultural machinery, pesticides, and land. What is called for is a resumption of old (traditional) approaches that integrate biologically and ecologically sustainable processes into food production, and that promote healthier food consumption.

Our CLD model suggests that investment in policies that build healthy food capacity would support Loops A, B and G, all of which impact LMIC obesity rates. *Via* Loop A, to the extent that sustainable agriculture translates into jobs and more affordable healthy foods, we hypothesize that a preference for traditional diet (which is, in most instances, a working definition of healthy eating), would drive down consumption of unhealthy commodities. This dynamic would, over time, serve to decrease importation and sales of unhealthy commodities to the LMIC. Over time, these dynamics would help to build important assets in the form of well managed natural resources and an infrastructure for farming, processing and distribution of healthy foods that generate both financial capital and 'natural' capital [82].

For example, drawing on recent scientific literature, the United Nations General Assembly highlighted the utility of 'agroecology' as a mode of agricultural development that can effectively support the human right to healthy food, particularly for vulnerable communities within LMICs. Well implemented agroecology is complementary to better known conventional farming approaches in many LMICs and strongly contributes to community-level economic development [68, 83]. In fact, there is growing support by the international community [68] for interventions that are consistent with 'agroecology' [83], a form of action-research that can enhance existing traditional LMIC agricultural systems and develop capacity to grow, process, and distribute healthy foods in a manner that generates achieves these goals.

Most efforts to foster greater agricultural production in LMICs have focused on improving seeds and ensuring that farmers are provided with a set of inputs that can increase yields, replicating the model of most industrialized countries. Alternatively, an agroecological approach can simultaneously increase farm productivity and food security, improve incomes and rural livelihoods, and reverse the trend towards species loss and genetic erosion [68, 82, 84].

An example of 'agroecological' policy intervention is evidenced in Uganda, where experiments in organic farming have been stimulated by farmers and consumers working in collaboration with private, foreign companies. In Uganda, organic farming has focused more on the crop sector than livestock sector and has

primarily involved the private sector, such as organic products exported by companies and non-governmental organizations. Agriculture in Uganda and many African countries is 'traditional' in that it is less mechanized, uses a minimum of chemical fertilizers, pesticides, and drugs, thus the essential characteristics of an organic approach. Traditional farming, however, does not always meet principles of organic farming (*i.e.,* ecology, fairness, health, and care) [85]. These efforts, however, have met challenges of implementation, including problems of managing disease, organic feed insufficiency, and limited education of farmers. While promising, there is a need for more scientific research in Uganda and other LMICs, research that supports their local farming communities and institutions.

Public Health Education

Education at multiple levels is also a recommended policy for addressing the obesity problem in LMICs. Programs that foster education of the general population about healthy nutrition and providing information about health problems caused by overweight and obesity are important [84, 86]. Such programs can be mounted in communities *via* local organizations and institutions, such as public schools. They can also be mounted in mass media campaigns, using print, television, or radio, as well as the internet and social media sites [87].

In addition, national programs to ensure that all packaged food is labeled with clear, accessible nutrition information and calorie counts per serving will help educate the populous about energy intake. Similarly, restaurants could be directed to provide calorie counts for dishes served on menus, and advertisements of unhealthy foods could be taxed, while those promoting healthy food making among parents could come with tax break or other incentive [88]. Education for health care professionals who can advise their patients about healthy nutrition, exercise, smoking cessation, and moderating alcohol use, is also effective [89]. Notably, health professionals typically have greater access to women who are often mothers, so for these patients they can impart education about how to better ensure the healthy weight of their children, for instance by teaching about the benefits of breast feeding among newborn children to prevent weight gain.

Notably, an agroecological approach is knowledge-intensive, requiring the development of both ecological literacy and decision-making skills in farmer communities and, more broadly, in the population at-large. To address the educational needs of farmers, investments in agricultural extension and agricultural research would be essential. Investing in extension programs would

likely serve to reduce poverty and agricultural productivity in developing countries. According to the International Food Policy Research Institute, agricultural extension research generates large dividends and has had "the largest impact on agricultural production and second-largest impact on poverty reduction (after rural education) in China, and the second-largest impact on poverty reduction in rural India (after investment in roads)" [90].

In addition, there is a need to further educate and foster critical policy analyses among multi-sectoral, multi-disciplinary experts in nutrition, medicine, economics, sociology, anthropology and other health-related fields. Here, international 'working groups,' like the *Global Forum on Agricultural Research* (GFAR; http://www.egfar.org/) and *Global System Dynamics and Policy* (GSDP; http://www.gsdp.eu/), are building new platforms for global exchange of ideas and perspectives on complex topics, including the global problem of overweight and obesity. Both of these groups seek to inform and shape better policy making to help solve complex and interrelated issues impacting health of diverse societies and the world today.

CONCLUSION

Using systems thinking, the qualitative model that has been presented shows the complex dynamics associated with the growing obesity epidemic in LMICs. Systems thinking is a precursory step toward the development of formal system dynamics models, which are formally defined sets of differential and algebraic equations. These mathematical models are used to conduct virtual experiments, *via* simulation analyses, to quantify the short and long term impact of alternative policies. Effective systems thinking informs a sort of 'blueprint' for the subsequent design and development of a quantitative system dynamics model or models [5, 10]; models that could be calibrated to examine a particular LMIC, integrating country-specific environmental, cultural, social, and economic factors. However, the quality of this 'blueprint' is a function of how well extant theory and evidence are used to articulate the 'structure' of the problem. The choice of constructs to be included in key constructs by extant sources of evidence and research and becomes the basis for simulation analyses that compare and contrast alternative strategies to find feasible, sustainable ways to address the problem of concern [2, 4, 7, 91-94].

In this model, we have generated a host of interdependent causal hypotheses, calling attention to two general recommended policy domains: grow *healthy food*

production capacity and promote *public health education*. An agroecological approach, strongly endorsed by the United Nations and its affiliated partners in addressing global health, would likely foster gains in both of our recommended policy domains. However, for such an approach to have recognizable impact, the need for collaborative, multi-sector partnerships is evident. At this juncture in the global obesity epidemic, public authorities, experts and local organizations need to come together in long-term, constructive relationships that invest in ambitious programs and policies to scale up agroecological models in diverse settings. Although today no population is unaffected or unthreatened by the global forces currently driving the obesity epidemic, our model suggests that change is possible and that obesity rates in all countries can be slowed or reversed over time, with effective leadership and support for effective policies.

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CONFLICT OF INTEREST

The authors confirm that this chapter contents have no conflict of interest.

REFERENCES

[1] Homer JB, Hirsch G. System dynamics modeling for public health: Background and opportunities. Am J Public Health 2006; 96(3): 452-8.

[2] Maani KE, Cavana RY. Systems Thinking and Modeling: Understanding Change and Complexity. Auckland, New Zealand: Pearson Education New Zealand Limited; 2000.

[3] Mabry P, Olster D, Morgan G, Abrams D. Interdisciplinarity and systems science to improve population health: A view from the NIH Office of Behavioral and Social Sciences Research. Am J Prev Med 2008; 35(S2): S211-S24.

[4] Forrester JW. The model *versus* a modeling process. System Dynamics Review 1987; 1(1): 133-4.

[5] Repenning NA. A simulation-based approach to understanding the dynamics of innovation implementation. Organization Science 2002; 13(109-127).

[6] Richardson GP. Feedback Thought in Social Science and Systems Theory. Waltham, MA: Pegasus Communications, Inc.; 1991.

[7] Richardson GP, Pugh III AL. Introduction to System Dynamics Modeling. Portland, Oregon: Productivity Press 1981.

[8] Luke DA, Stamatakis KA. Systems science methods in public health: dynamics, networks, and agents. Annu Rev Public Health 2012; 33: 357-76.

[9] Hirsch G, Immediato CS. Microworlds and generic structures as resources for integrating care and improving health. System Dynamics Review 1999; 15(3): 315-30.

[10] Lounsbury DW, Hirsch GB, Vega C, Schwartz CE. Understanding social forces involved in diabetes outcomes: a systems science approach to quality-of-life research. Qual Life Res 2013.

[11] Arboleda CA, Abraham DM, Lubitz R. Simulation as a tool to assess the vulnerability of the operation of a health care facility. Journal of Performance of Constructed Facilities 2007; 21(4): 302-12.

[12] Cavana RY, Davies PK, Robson RM, Wilson KJ. Drivers of quality in health services: Different worldviews of clinicians and policy managers revealed. System Dynamics Review 1999; 15(3): 331-40.
[13] Hirsch G, Miller S. Evaluating HMO Policies with a Computer Simulation Model. Medical Care 1974; 12(8): 668-81.
[14] Hovmand PS, Gillespie DF. Implementation of Evidence-Based Practice and Organizational Performance. Journal of Behavioral Health Services & Research 2010; 37(1): 79-94.
[15] Royston G, Dost A, Townshend J, Turner H. Using system dynamics to help develop and implement policies and programmes in health care in England. System Dynamics Review 1999; 15(3): 293-313.
[16] Wolstenholme E, Monk D, McKelvie D, Arnold S. Coping but not coping in health and social care: masking the reality of running organisations beyond safe design capacity. System Dynamics Review 2007; 23(4): 371-89.
[17] Braithwaite J, Westbrook JI, Ranmuthugala G, Cunningham F, Plumb J, Wiley J, *et al*. The development, design, testing, refinement, simulation and application of an evaluation framework for communities of practice and social-professional networks. BMC Health Services Research 2009; 9.
[18] Elf M, Poutilova M, Ohrn K. A dynamic conceptual model of care planning. Scandinavian Journal of Caring Sciences 2007; 21(4): 530-8.
[19] Taylor K, Dangerfield B. Modelling the feedback effects of reconfiguring health services. Journal of the Operational Research Society 2005; 56(6): 659-75.
[20] Homer J, Hirsch G, Minniti M, Pierson M. Models for collaboration: How system dynamics helped a community organize cost-effective care for chronic illness. System Dynamics Review 2004; 20(3): 199-222.
[21] Dangerfield BC, Fang YX, Roberts CA. Model-based scenarios for the epidemiology of HIV/AIDS: the consequences of highly active antiretroviral therapy. System Dynamics Review 2001; 17(2): 119-50.
[22] Flessa S. Decision support for AIDS control programmes in eastern Africa. OR Spectrum 2003; 25(2): 265-91.
[23] Lebcir RM, Atun RA, Coker RJ. System Dynamic simulation of treatment policies to address colliding epidemics of tuberculosis, drug resistant tuberculosis and injecting drug users driven HIV in Russia. Journal of the Operational Research Society 2010; 61(8): 1238-48.
[24] Roberts C, Dangerfield B. Modeling the epidemiologic consequences of HIV infection and AIDS: A contribution from operational research. Journal of the Operational Research Society 1990; 41(4): 273-89.
[25] Roberts EB, Homer J, Kasabian A, Varrell M. A systems view of the smoking problem: Perspective and limitations of the role of science in decision-making. International Journal of Bio-Medical Computing 1982; 13(1): 69-86.
[26] Chick SE, Mamani H, Simchi-Levi D. Supply Chain Coordination and Influenza Vaccination. Operations Research 2008; 56(6): 1493-506.
[27] Homer J, Ritchie-Dunham J, Rabbino H, Puente LM, Jorgensen J, Hendricks K. Toward a dynamic theory of antibiotic resistance. System Dynamics Review 2000; 16(4): 287-319.
[28] Thompson KM, Tebbens RJD. Using system dynamics to develop policies that matter: global management of poliomyelitis and beyond. System Dynamics Review 2008; 24(4): 433-49.
[29] Ahmad S. The cost-effectiveness of raising the legal smoking age in California. Medical Decision Making 2005; 25(3): 330-40.
[30] Ahmad S. Closing the youth access gap: The projected health benefits and cost savings of a national policy to raise the legal smoking age to 21 in the United States. Health Policy 2005; 75(1): 74-84.
[31] Cavana RY, Clifford LV. Demonstrating the utility of system dynamics for public policy analysis in New Zealand: the case of excise tax policy on tobacco. System Dynamics Review 2006; 22(4): 321-48.
[32] Tengs TO, Osgood ND, Chen LL. The cost-effectiveness of intensive national school-based anti-tobacco education: Results from the Tobacco Policy Model. Preventive Medicine 2001; 33(6): 558-70.
[33] Homer JB. A system dynamics model of national cocaine prevalence. System Dynamics Review 1993; 9(1): 49-78.

[34] Homer JB, StClair CL. A model of HIV transmission through needle sharing. Interfaces 1991; 21(3): 26-49.
[35] Smith PC, van Ackere A. A note on the integration of system dynamics and economic models. Journal of Economic Dynamics & Control 2002; 26(1): 1-10.
[36] Wakeland W, Schmidt T, Gilson AM, Haddox JD, Webster LR. System Dynamics Modeling as a Potentially Useful Tool in Analyzing Mitigation Strategies to Reduce Overdose Deaths Associated with Pharmaceutical Opioid Treatment of Chronic Pain. Pain Medicine 2011; 12: S49-S58.
[37] Huz S, Andersen DF, Richardson GP, Boothroyd R. A framework for evaluating systems thinking interventions: An experimental approach to mental health system change. System Dynamics Review 1997; 13(2): 149-69.
[38] Smits M. Impact of policy and process design on the performance of intake and treatment processes in mental health care: a system dynamics case study. Journal of the Operational Research Society 2010; 61(10): 1437-45.
[39] Homer J, Hirsch G, Milstein B. Chronic illness in a complex health economy: the perils and promises of downstream and upstream reforms. System Dynamics Review 2007; 23(2-3): 313-43.
[40] Siegel CA, Siegel LS, Hyams JS, Kugathasan S, Markowitz J, Rosh JR, *et al*. Real-time Tool to Display the Predicted Disease Course and Treatment Response for Children with Crohn's Disease. Inflammatory Bowel Diseases 2011; 17(1): 30-8.
[41] Milstein B, Homer J, Hirsch GB. Analyzing natinal health reform strategies with a dynamic simulation model. Am J Public Health 2010; 100(5): 811-9.
[42] World Health Organization. Obseity and Overweight Fact Sheet2013. [Cited March 3 2014] Available at: http://www.who.int/mediacentre/factsheets/fs311/en/.
[43] Swinburn BA, Sacks G, Hall KD, McPherson K, Finegood DT, Moodie ML, *et al*. The global obesity pandemic: Shaped by global drivers and local environments. Lancet 2011; 378(9793): 804-14.
[44] Popkin BM, Slining MM. New dynamics in global obesity facing low- and middle-income countries. Obes Rev 2013; 14 Suppl 2: 11-20.
[45] USAID. Demographic and Health Surveys. US Agency for International Development, 2013. [Cited March 3 2014] Available at: http://www.dhsprogram.com/
[46] Vandevijvere S, Monteiro C, Krebs-Smith SM, Lee A, Swinburn B, Kelly B, *et al*. Monitoring and benchmarking population diet quality globally: a step-wise approach. Obes Rev 2013; 14 Suppl 1: 135-49.
[47] Struckler D, McKee M, Ebrahim S, Basu S. Manufacturing epidemics: The role of global producers in increased consumption of unhealthy commodities, including processed foods, alcohol, and tobacco. PLOS Medicine 2012; 9(6): 1-8.
[48] Popkin BM, Adair LS, Ng SW. Global nutrition transition and the pandemic of obesity in developing countries. Nutr Rev 2012; 70(1): 3-21.
[49] Owen J, Reisin E. Non-Communicable Disease: A Welcome and Long Needed Addition to the WHO's 2012 World Heath Statistics. Curr Hypertens Rep 2012; 14(6): 475-7.
[50] Monteiro CA, Moubarac JC, Cannon G, Ng SW, Popkin B. Ultra-processed products are becoming dominant in the global food system. Obes Rev 2013; 14 Suppl 2: 21-8.
[51] Brezis M, Wiist WH. Vulnerability of health to market forces. Med Care 2011; 49(3): 232-9.
[52] Wiist WH. Public health and the anticorporate movement: rationale and recommendations. Am J Public Health 2006; 96(8): 1370-5.
[53] Chan M, editor Noncommunicable diseases damage health, including economic health. High-level meeting on noncommunicable diseases, United Nations General Assembly; 2011 September 19, 2011; New York, NY: WHO.
[54] Wells JC. Obesity as malnutrition: the dimensions beyond energy balance. Eur J Clin Nutr 2013; 67(5): 507-12.
[55] Doak C, Adair L, Monterio C, Popkin B. Overweight and underweight coexist within households in Brazil, China and Russia. Journal of Nutrition 2000; 130: 2965-71.
[56] Hawkes C. The role of foreign direct investment in the nutrition transition. Public Health Nutr 2005; 8(4): 357-65.
[57] Hawkes C. Uneven dietary development: linking the policies and processes of globalization with the nutrition transition, obesity and diet-related chronic diseases. Global Health 2006; 2: 4.

[58] Rigby NJ, Kumanyika S, James WP. Confronting the epidemic: the need for global solutions. J Public Health Policy 2004; 25(3-4): 418-34.
[59] Nishida C, Uauy R, Kumanyika S, Shetty P. The Joint WHO/FAO Expert Consultation on diet, nutrition and the prevention of chronic diseases: Process, product and policy implications. Public Health Nutrition 2004; 7(1A): 245-50.
[60] Glasgow R, Wagner E, Kaplan R, Vinicor F, Smith L, Norman J. If diabetes is a public health problem, why not treat it as one? A population-based approach to chronic illness. Annals of Behavioral Medicine 1999; 21(2): 159-70.
[61] Mittal S, El-Serag HB. Epidemiology of hepatocellular carcinoma: consider the population. J Clin Gastroenterol 2013; 47 Suppl: S2-6.
[62] Norrving B, Kissela B. The global burden of stroke and need for a continuum of care. Neurology 2013; 80(3 Suppl 2): S5-12.
[63] Subramanian S, Chait A. Hypertriglyceridemia secondary to obesity and diabetes. Biochim Biophys Acta 2012; 1821(5): 819-25.
[64] Wagner KH, Brath H. A global view on the development of non communicable diseases. Prev Med 2012; 54 Suppl: S38-41.
[65] Wiener N. Cynbernetics of Control Communications in the Animal and the Machine. New York: John Wiley; 1948.
[66] Fleischhacker SE, Evenson KR, Rodriguez DA, Ammerman AS. A systematic review of fast food access studies. Obes Rev 2011; 12(5): e460-71.
[67] Ng SW, Popkin BM. Time use and physical activity: a shift away from movement across the globe. Obes Rev 2012; 13(8): 659-80.
[68] Assembly UG. Report submitted by the Special Rapporteur on the right to food, Olivier De Schutter. In: Council HR, editor. New York2010.
[69] Wiist W. We must reclaim public health from private corporate interests. BMJ 2012; 345: e6160.
[70] Wiist WH. Citizens United, public health, and democracy: the Supreme Court ruling, its implications, and proposed action. Am J Public Health 2011; 101(7): 1172-9.
[71] Gearhardt AN, Grilo CM, DiLeone RJ, Brownell KD, Potenza MN. Can food be addictive? Public health and policy implications. Addiction 2011; 106(7): 1208-12.
[72] NCHS. Health, United States, 2012: In Brief2013. [Cited March 3 2014] Available at http://www.cdc.gov/nchs/data/hus/hus13_InBrief.pdf
[73] Subramanian SV, Perkins JM, Ozaltin E, Davey Smith G. Weight of nations: a socioeconomic analysis of women in low- to middle-income countries. Am J Clin Nutr 2011; 93(2): 413-21.
[74] Monteiro CA, Moura EC, Conde WL, Popkin BM. Socioeconomic status and obesity in adult populations of developing countries: a review. Bull World Health Organ 2004; 82(12): 940-6.
[75] Jones-Smith JC, Gordon-Larsen P, Siddiqi A, Popkin BM. Is the burden of overweight shifting to the poor across the globe? Time trends among women in 39 low- and middle-income countries (1991-2008). Int J Obes (Lond) 2012; 36(8): 1114-20.
[76] Forrester JW. Urban Dynamics. Portland, OR: Productivity Press; 1961.
[77] Gagliardino JJ, Aschner P, Baik SH, Chan J, Chantelot JM, Ilkova H, *et al*. Patients' education, and its impact on care outcomes, resource consumption and working conditions: Data from the International Diabetes Management Practices Study (IDMPS). Diabetes & Metabolism 2012; 38(2): 128-34.
[78] Gortmaker SL, Swinburn BA, Levy D, Carter R, Mabry PL, Finegood DT, *et al*. Changing the future of obesity: science, policy, and action. The Lancet.378(9793): 838-47.
[79] World Health Organization. World Population to Increase by 2.6 Billion Over Next 45 Years. In: Division P, editor. New York2005.
[80] Finucane MM, Stevens GA, Cowan MJ, Danaei G, Lin JK, Paciorek CJ, *et al*. National, regional, and global trends in body-mass index since 1980: systematic analysis of health examination surveys and epidemiological studies with 960 country-years and 9.1 million participants. Lancet 2011; 377(9765): 557-67.
[81] Lounsbury DW, Mitchell SG. Introduction to special issue on social ecological approaches to community health research and action. American Journal of Community Psychology 2009; 44(3-4): 213-20.

[82] Pretty J. Agricultural sustainability: concepts, principles and evidence. Philos Trans R Soc Lond B Biol Sci 2008; 363(1491): 447-65.
[83] Altieri MA, Farrell JG, Hecht SB, Liebman M, Magdoff F, Murphy W, *et al*. Agroecology: The Science of Sustainable Agriculture. Boulder, CO: Westview Press; 1995.
[84] Karnik S, Kanekar A. Childhood obesity: A global public health crisis. Int J Prev Med 2012; 3(1): 1-7.
[85] Nalubwama SM, Mugisha A, Vaarst M. Organic livestock production in Uganda: potentials, challenges and prospects. Trop Anim Health Prod 2011; 43(4): 749-57.
[86] Franceschi S, Wild CP. Meeting the global demands of epidemiologic transition - the indispensable role of cancer prevention. Mol Oncol 2013; 7(1): 1-13.
[87] Ramanadhan S, Mendez SR, Rao M, Viswanath K. Social media use by community-based organizations conducting health promotion: a content analysis. BMC Public Health 2013; 13(1): 1129.
[88] Farley TA. The role of government in preventing excess calorie consumption: the example of New York City. JAMA 2012; 308(11): 1093-4.
[89] Emery JD, Shaw K, Williams B, Mazza D, Fallon-Ferguson J, Varlow M, *et al*. The role of primary care in early detection and follow-up of cancer. Nat Rev Clin Oncol 2014; 11(1): 38-48.
[90] Fan S. Public expenditures, growth, and poverty: Lessons from developing countries. In: IFPRI, editor 2008.
[91] Forrester JW. Counterintuitive behavior of social systems. Technology Review 1971; 73(January): 52-68.
[92] Forrester JW. Principles of Systems. 2nd ed. Cambridge: Wright-Allen Press; 1971.
[93] Forrester JW. Lessons from system dynamics modelling. System Dynamics Review 1987; 3: 136-49.
[94] Forrester JW, Senge PM. Tests for building confidence in system dynamics models. TIMS Studies in the Management Science 1980; 14: 201-28.