



Relationship between shifts in food system dynamics and acceleration of the global nutrition transition

Barry M. Popkin

Editor's Note:

In celebration of the 75th anniversary of Nutrition Reviews, the journal's editors envisioned the publication of articles that examined the changing landscape of nutrition research and the food systems required to ensure sustainability of the global food supply that feeds the projected 9 billion people on earth. In this Perspective article, Dr. Popkin highlights the global nutrition transition that has been fueled by approximately 4 decades of research on food processing, preservation, and retail. This transition has also been influenced by changes in economic development and dramatic reductions in many communicable diseases (although new infectious agents have also been discovered) with a concomitant rise in chronic, non-communicable diseases that ultimately threaten the well-being of mankind. Whether research will allow scientists to reset the balance for our food supply remains unknown, but the editors of this journal believe that the forthcoming articles in 2017 and beyond will stimulate thought leaders to formulate solutions that will be our "moonshot" to ensure the production of quality food in a sustainable manner with minimal environmental impact to feed the growing population of the world.

Naomi K. Fukagawa, MD, PhD
Editor-in-Chief

Over the past 2 decades a remarkable change in the way the world's population shops and eats has occurred. Related to that has been a transformative change in the chain of food – from farm to fork – and the forces that control it. While most populations in the post World War II era consumed much of their diet in the form of home-cooked basic commodities – vegetable, tuber, or animal-source foods, this has shifted remarkably. Now it seems that the task of cooking has vanished from many households¹ and the food consumed in much of the world is shifting from purchases made at local fresh markets to packaged and processed ready-to-eat or ready-to-heat food.^{2–4}

The broader system that is defined by the activities, infrastructure, and people involved in feeding the global population (eg, the growing, processing, distribution, consumption, and disposal of foods) is referred to here as our "food system." It includes the web of processes by which institutions, organizations, and individuals transform inputs into foods and individual ingredients into the food we consume (eg, seed, fertilizer, chemicals, and

pharmaceuticals go into poultry which becomes chicken nuggets).⁵ All food systems interact with aspects of their environmental, societal, political, and economic contexts.⁶ A core element of all food systems is the "food supply chain" or "food value chain" through which food moves from farm to fork.⁷ Increasingly, environmental sustainability has become one of the major concerns related not only to our food system but also to our modern diet. In my opinion, it is clear that the modern diet must change, and with it our food system, if the human population is to reduce global emissions, cut water use, and enact many other agriculture-related changes that will foster a more sustainable food supply and a healthier population; however, there are key gaps in our knowledge, which are noted below.

My opinions and ideas described herein were first realized while wandering through the modern retail stores of Asia and Africa – be they small convenience stores in villages, or large modern supermarkets, or mega-markets in larger cities. I later realized, the phenomenon I'd been

Affiliation: *B.M. Popkin* is with the Department of Nutrition and the Carolina Population Center, University of North Carolina, Chapel Hill, North Carolina, USA. Correspondence: *B.M. Popkin*, Carolina Population Center, University of North Carolina, 137 E. Franklin St. Chapel Hill, NC 27516, USA. Email: popkin@unc.edu. Phone: +1-919-962-6139.

Key words: convenience, food processing, food system, nutrition transition, processed food, food regulation, sustainability.

©The Author(s) 2017. Published by Oxford University Press on behalf of the International Life Sciences Institute. All rights reserved. For Permissions, please e-mail: journals.permissions@oup.com.

observing had been documented by the agricultural economist Thomas Reardon,^{8–11} who was later joined by other agricultural economists as well as scholars from other disciplines as this present documentation shows. In my own research using 24-hour recall surveys in China in 2011 and Mexico in 2012, my colleagues and I found that large proportions of the foods consumed were packaged and processed. This knowledge allowed us to investigate the dietary intake side of this large growth of packaged and processed foods in the retail sector in other countries as well.^{4,12}

The next major insight was gained by our work in the United States (and globally) aimed at understanding the enormity of the packaged/processed foods and beverages industry and the degree of processing under way. We found major shifts in the United States toward foods and beverages that were mainly ready-to-eat or ready-to-heat,² marked differences in how various racial or ethnic groups purchased highly processed vs minimally processed foods and ingredients, and changing trends in the numbers of people who do and do not cook.^{3,13} This research has been accelerated globally by Carlos Monteiro and his team, who have highlighted the major roles that ultra-processed or highly processed foods have in modern diets.^{14,15}

Finally, Thomas Reardon, Bart Minten, and others who have followed the food chain from the farm to the consumer in India, Bangladesh, and China showed that what farmers grow and to whom they sell is governed by the same economic actors as those seen in high-income countries like the United States for decades (eg, agribusinesses, retailers, food manufacturers, food service companies).²⁵ They additionally highlighted a true transformation in how food is produced and handled throughout the global food system.²⁵

The nutritional implications of the post World War II revolution in production and control of farming has led to a very different set of major actors affecting our diets. The implication of these changes is highly disputed. Some will say that processing has produced many positive improvements with minimal costs,^{16,17} while others will point out potential conflicts,¹⁸ and yet others will entirely disagree and feel that the modern processed food supply is a major cause of widespread poor health.¹⁴

No matter where the causal pathway lies, the world now faces far more obesity and diet-related noncommunicable diseases (NCDs) than in the past. Well over 2 billion individuals are overweight or obese, and most countries face higher mortality from these nutrition-related NCDs than from undernutrition and infectious diseases, which were the scourges of the past millennium. The modern agriculture system poses problems for the way countries must work to improve our diets. The text below takes us through the way our food system has rapidly changed and what this has done to our diet. The overview ends with a discussion of how some nations are attempting to meet

their populations' diet-related health challenges through regulation; however, since no country has reversed obesity rates to date, the global challenge remains immense.

My purpose in writing this piece is to help the nutrition community understand (1) how rapidly the system underlying what we eat has shifted, (2) how these shifts are affecting human health across the world, and (3) how these changes have shifted the ways countries are attempting to encourage healthier diets using the policy options they have available to them.

TRANSFORMATION OF THE GLOBAL RETAIL FOOD SYSTEM

While the first self-service grocery market in the United States was Piggly Wiggly, the first major chain selling retail food nationally was the Greater Atlantic and Pacific Tea Company. At first, this chain sold only tea and coffee (before the 1900s), but over time it developed into the dominant full-service grocery store chain (the A&P) in North America.^{19,20} In Europe, stores such as Tesco in England and Ahold (which began as Albert Heijn) and Aldi in Germany emerged early in the 20th century. The density of European cities delayed the emergence of the larger supermarkets (and mega markets) and today's mega-chains such as Walmart were mainly post-World War II phenomena. The two largest global companies, Carrefour and Walmart, started their major growth in the 1960s and 1970s, respectively.²¹

In the United States, the current dominance of the modern supermarket in the food system is very obvious.^{22,23} While small shops and other types of convenience stores abound and drug stores, gas stations, and other venues sell selected food and beverages, the bulk of purchases occur at grocery stores, supermarkets, and mega-markets for all racial and ethnic subpopulations.^{22,23}

Reardon and others have documented the enormous growth of the retail food sector in Latin America. In 1990, only 15%–20% of all food purchases and food in-kind arrangements occurred at grocery stores, while fresh markets dominated the food purchases of the household, but this shifted dramatically during that decade. By 2000, 60% of the population's share of pesos expended in cash and in kind for food went to supermarkets.²⁴ Such changes have occurred much more recently in Asia.^{4,8,25–29} Reardon and others have defined 3 waves of food purchasing transformation in Asia, the first affecting Korea and Taiwan; the second reaching Indonesia, Malaysia, the Philippines, and Thailand; and the third, and most recent, affecting China and India.^{8,25} China's transformation has not been dominated by Walmart and Carrefour, as seen in other parts of the world, but instead by chains from South Korea

and Hong Kong and, most recently, by domestic clones of these stores.^{28,30} Yet, this major market looms large for all global food retailers.

In Africa, growth in the retail sector has emanated more from South African chains that moved into urban centers on both sides of the continent.^{10,31}

In 2 separate studies, my colleagues and I documented the components of the Mexican and Chinese diets that came from packaged and processed food. In both cases, we used 24-hour recall surveys – the 2012 National Nutrition Survey (ENSANUT) for Mexico and the 2011 China Health and Nutrition Survey for China.^{4,12} In each survey, we asked whether each food consumed came from a wrapped package or a container. In China in 2015, we went a step further and scanned the barcodes of all the food items in each household’s food storage facilities (unpublished data).

Figure 1 shows that in China in 2012, 30% of all food consumed came from packaged and processed food. The sample for that survey represented 12 provinces (containing about 50% of the country’s population). Figure 2 shows that in Mexico in 2011 a much larger proportion of packaged and processed food was consumed, with 58% of all kilocalories per capita per day coming from these food types. In both studies, higher percentages of packaged and processed food consumption were found in the most urbanized cities.

Having identified that consumption of packaged and processed foods has become more common, we now explore the more contentious question: What is the composition of this packaged and processed food, and is it healthful?

THE MODERN PACKAGED AND PROCESSED FOOD SUPPLY: WHAT DO WE KNOW?

There is a great deal of controversy about what people should eat. On one side are many who promote only so-called “real food,” encapsulated by Michael Pollan’s famous quotes: “Eat food, not too much, mostly plants”³² and “Don’t eat anything your great-grandmother wouldn’t recognize as food.” Scholars like Monteiro have promoted a similar diet, as seen in the Brazilian food guidelines.³³ The Pan American Health Organization has adopted an approach to food labeling and diet promotion that is essentially based on Monteiro’s approach to food processing, with the idea of reducing what he called ultra-processed foods from the diet.³⁴ The basic argument of Monteiro, Pollan, and many others is that we need to return to a diet based only on basic, unprocessed, or minimally processed food (such as flour and milk). For Brazil, a diet based on Monteiro’s philosophy would derive from a period in which the foods typically consumed

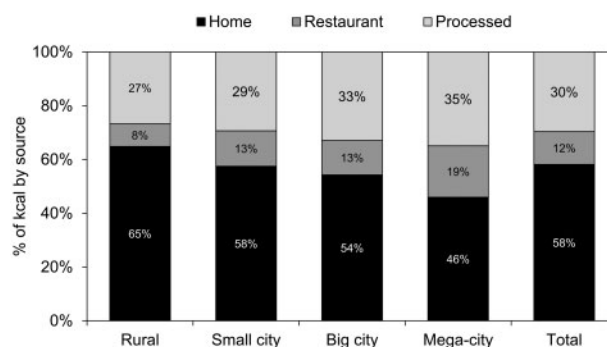


Figure 1 Percentage of foods in China prepared at home, in restaurants, or prepackaged in 2011. Reproduced from Popkin (2014)⁴ with permission.

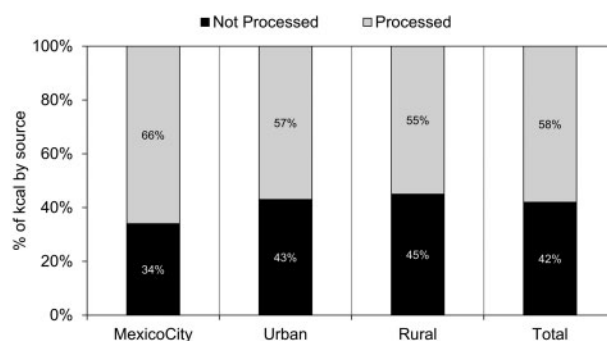


Figure 2 Percentage of non-processed versus processed food consumed in Mexico in 2012. Reproduced from Popkin (2014)⁴ with permission.

were rice, beans, some fish and animal-source foods, and some fruit and vegetables. Is this realistic, or is this romanticism based on an earlier reality? Furthermore, within the modern food supply, which is highlighted below, can we turn back the clock and move to this type of diet, or do we need to work to get a more healthful supply of packaged and processed food while also promoting increased cooking and use of basic foods?

The Global Food Research Program at the University of North Carolina is working with data sets of scanned food purchases for several countries. The segment on which my colleagues and I have focused particular attention is packaged and processed food for the United States. Jennifer Poti has essentially used product descriptions and ingredients to categorize 1.2 million unique packaged and processed foods from 2000 to 2012 into a food system quite comparable to Monteiro’s.^{2,3} In addition to noting the degree of processing, she also categorized food by convenience, in both cases based on detailed descriptors of each food and their ingredients. Both this system and Monteiro’s are different from the International Food Information

Category	Definition	Examples
Unprocessed/ minimally processed	Single foods, no/very slight modifications	Fresh or frozen produce, milk, eggs, fresh meat
Basic processed	Single foods, processed – A) isolated food components or B) modified by preservation methods	Sugar, oil, flour, pasta, white rice, unsweetened canned fruit, veggies canned without salt
Moderately processed	Single foods with addition of flavor additives	Salted nuts, fruit canned in syrup, veggies canned with added salt, whole-grain breads/cereals with no added sugar
Highly processed	Multi-ingredient industrially formulated mixtures	Refined-grain breads, cookies, SSBs, salty snacks, candy, RTE cereal, ketchup, margarine, mayo, pre-prepared mixed dishes

Figure 3 Classifications system for degree of processing of food and beverage products. Data from Poti et al. (2015).²

Council approach, which has been adopted by the American Society for Nutrition and other organizations.^{16,17} These groups use a more simplistic way of categorizing foods and have not gone deeply into product composition or ingredients.

Figures 3 and 4 show the Poti method of categorization, which is based on the total packaged food supply of 1.4 million unique barcoded products and uses product descriptors, ingredients, and other data to categorize them.^{3,35} Except for terminology (eg, Poti uses the term “highly processed” rather than “ultra-processed”), it is quite similar to the Monteiro system.^{14,36} What is important to notice are the final 2 categories, highly (or ultra-) processed ingredients and highly processed foods. Much controversy revolves around whether these foods can be manufactured in a way that would be deemed healthful.

Figure 5 shows that in a nationally representative longitudinal sample of US households, processed and ultra-processed foods dominated purchasing patterns by collectively providing over 75% of calories. The ultra-processed foods, which tend to be significantly higher in sodium, saturated fat, and total sugar, represented consistently more than 60% of all food purchases among the packaged and processed foods.³⁷

Figure 6 categorizes these foods and beverages by level of convenience. Most important, over 80% of calories purchased were ready-to-eat or ready-to-heat products. The first Poti paper² describes how convenience was categorized, and the figure provides a good sense of these patterns, which did not change much over the 2000–2012 period.

Most of the negative focus on food processing by journalists and scholars has focused on highly or ultra-processed food^{15,34,36,38} however, others are pushing for a greater shift from processed foods of all types toward real food, with the exception of classic methods of freezing, fermentation, and other types of minimal processing in order to preserve food and reduce food waste. Critical questions that are not addressed by these

Category	Definition	Examples
Requires cooking and/or preparation	Not consumed as purchased, requires significant input of consumer's time, culinary skill, energy, or attention to cook/prepare	Flour, dry pasta or rice, oil, eggs, fresh potatoes, uncooked meat, mixes for grain-based desserts or pancakes, some fresh veggies
Ready-to-heat (RTH)	Not consumed as purchased, requires only a small amount of consumer's time or effort during prep (e.g., by microwaving)	Frozen dinners or pizza, frozen waffles, canned soup, hot dogs, instant oatmeal, canned or frozen veggies
Ready-to-eat (RTE)	Can be consumed immediately with no preparation	Bread, salty snacks, milk, candy, pre-made cookies, most fresh fruit, canned fruit, baby carrots, SSBs & ready-to-drink beverages

Figure 4 Classification system for convenience of food and beverage products. Data from Poti et al. (2015).²

groups are the degree of processing, beyond minimal processing, that is necessary to save food from spoilage and waste, and if it is possible to transform a highly processed food supply into one that is both healthy and plentiful. In contrast, other organizations, including some that receive extensive food industry funding have been less critical of food processing.^{16,17}

But there are many unanswered questions about the current and potential healthfulness of highly processed foods. The missing element in the current research is clinical trials that compare ad libitum real foods-based diets with some version of diets containing highly or ultra-processed food that would be deemed healthful. If the objective is to have a greater proportion of food containing whole grains instead of refined grains, then the resulting food would be defined as moderately processed instead of ultra-processed. I expect this debate will continue, but aside from the limited promotion by governments and nonprofit organizations to eat more fruits and vegetables, the world seems to be increasing its consumption of ultra-processed food. Discussed below are the various types of regulations and taxes that some countries are implementing to reduce intake of the least healthy food and beverage products – those higher in added sugar, sodium, and saturated fats. This is particularly important since the Pan American Organization has come out very strongly against all ultra-processed food and calls for nations in the region to tax, ban marketing of, and attempt to remove these foods from their food supply.³⁴

GLOBAL DIET, BODY COMPOSITION, AND NUTRITION-RELATED NCDs

Over the past several years, there have been some highly publicized meta-analyses related to consumption of certain components of the global diet, such as the recent push against sugar.^{39–41} Similarly, there have been reviews on obesity and overweight prevalence, studies on trends in overweight and obesity, and several on NCDs

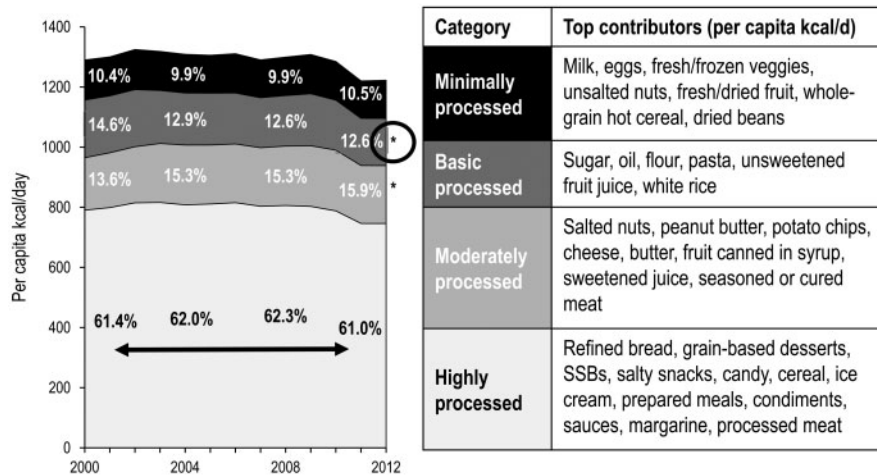


Figure 5 Trends in food and beverage CPG purchases by degree of processing. Data from Poti et al. (2015).²

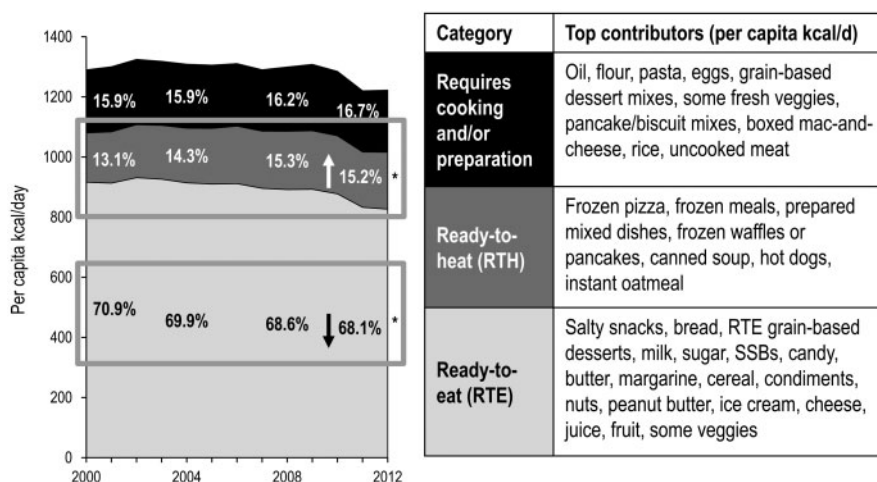


Figure 6 Trends in food and beverage CPG purchases by level of convenience. Data from Poti et al. (2015).²

related to these conditions.⁴² There is little value in repeating discussion of the vast changes in diets,⁴³ body composition, or nutrition-related NCDs, but I want to emphasize a few puzzles related to body composition.

Global shifts in diets

Mozaffarian and colleagues have used a compilation of individual dietary surveys of varying quality and representativeness from across the globe to provide a careful global review of sugar-sweetened beverages (SSBs), fruit juices and milk, fats and oils, and dietary quality.^{43–46} A recent review looked at sodium increases globally based on dietary and urinary sodium excretion studies.⁴⁷ Our work and in-depth studies by others in China, Brazil, Mexico, and elsewhere show growth in the levels of consumption of nonessential foods containing excessive added sugars, added salt,

refined carbohydrates (namely, SSBs), grain-based desserts, and savory snacks.^{48–52}

In a separate review of recent trends in SSB sales with identical sales data, it was shown that SSB consumption is going down in select high-income countries and regions and increasing in most low- and middle-income countries (LMIC) and regions.⁵³

Two major shifts in diet are of particular concern for global sustainability: (1) the shift toward accelerating consumption of animal-source food in LMICs while higher income countries have barely reduced their consumption of these products and (2) the increase in consumption of ultra-processed food. To date, there is an extensive body of literature on the changes in animal-source food intake and the effects this is having on climate emissions, water use, and antibiotics in our water supply, so these issues are not addressed here.^{54–59} However, there is really no study that has attempted to

establish the global sustainability footprint for packaged, highly processed food. Many companies have worked to reduce both water and energy use at their factories in attempts to reduce their overall environmental footprint; however, tracking the entire system from farm to fork for one food product let alone the entire set of processed food products has not been done.

The global dietary shifts examined here have not occurred in a vacuum. The roles of supply and demand are terribly complex; however, one of the themes addressed here is that of the diminishing role of government in food systems due to the shift in influence of farm production from governments to retailers, food manufacturers, agribusinesses, and food service chains. At the same time, there is great documentation of the impact that modern marketing, peer pressure, and convenience is having on our diets.^{60–67} Those issues are not addressed here.

Body composition

Many studies have documented large increases in the proportion of people who are overweight and obese.^{68–70} Some of these have shown that body mass index (BMI) levels have increased among the obese. That is, the entire distribution of BMIs among those called obese with a BMI ≥ 30 have shifted rightward.⁷¹ What is most perplexing is that among individuals with normal and overweight BMI levels that remained the same we have seen an increase in waist circumference. This has been observed in data from the few LMICs and high-income countries where nationally representative repeated surveys collected this information along with weight and height data.^{71–73}

While I do not want to discuss the relative merits of various measures of body composition,^{74,75} it is important to remember that current BMI guidelines that delineate cutoffs of 25 and 30 for overweight and obesity, respectively, are inappropriate cutoffs for the cardiometabolic outcome risks faced by many populations. Hispanics, Asians, and many other subpopulations across the globe have very different distributions of fat, different genetic predispositions to disease, and face many nutrition and health conditions going back to pregnancy and infancy. All of this means that, for many, the risks of diabetes, hypertension, and other diseases rises at BMI levels of 20–23 and not 25 and 30.^{76–80}

There is much speculation related to dietary changes and shifts in physical activity that might explain the observed increases in waist circumference, but there is so little research on it that we cannot highlight a clear cause with any confidence. Is it the excess sugar and fructose consumed, with their linkage with visceral

fat?^{81–89} Diets with a high glycemic index have been linked to a greater accumulation of abdominal fat.³⁰

Non-communicable diseases

In general, in all LMICs, the proportion of deaths, disabilities, and years lived with disability have increased.⁹⁰ NCDs have risen generally over the last several decades, but particularly in LMICs.⁴² Diabetes and hypertension seem to be the first diseases to emerge in most of the Asian, African, and Latin American countries, which get clear publicity and lead to regulatory actions.⁹¹

While the focus of my own work is obesity and obesity-related NCDs, more recent research suggests that many health problems related to poor infant feeding practices may be linked to these same food supply shifts. Documentation presently indicates that large proportions of infants are fed SSBs, savory snacks, and many other types of highly processed nutrient-poor foods, even in the first 6 month of life.^{92–94}

GOVERNMENT ACTIONS TO IMPROVE DIETS

Most government efforts have focused around 4 activities: (1) taxation of SSBs and other broader categories of nonessential or junk foods, (2) marketing control with much of the focus on marketing to children, (3) front-of-package labeling profiles with a positive or negative logo, (4) special regulations related to schools and/or other government facilities.

There are excellent resources where one can see the full list of actions taken by various levels of government around the world.⁹⁵ The “Nourishing Framework” section of the World Cancer Research Fund International website is, by far, the most up-to-date resource.⁹⁶

At least one city in the United States, Berkeley, California, has implemented a tax on sugar-sweetened beverages (SSB). The only evaluation of that action to date was a limited short-term impact study on the frequency of intake, with data acquired using a survey of low-income individuals intercepted in Berkeley, San Francisco, and Oakland. The survey reported positive results in terms of reduced SSB intake and increased water consumption.⁹⁷ Previously, the same authors showed that retail prices of SSBs increased.⁹⁸ Both studies were based on only 4 months of tax implementation, so the magnitude of the results showing a 21% decline in the frequency of SSB intake based on about a 10% tax are quite unusual. Other more complete research by this group of researchers is expected to be published that includes changes in retail sales and revenue, price

dynamics, and usual dietary intake over the full first year of the Berkeley tax.

The following countries are also worth highlighting for their unique efforts.

Mexico. Mexico was the first LMIC to pass a reasonably high SSB tax of about 10%. They also passed a non-essential food tax of 8% on much of what might be called junk food. Rigorous evaluations that looked at how the taxes shifted trends in consumption of these products and their substitutes have been undertaken by a joint National Institute of Public Health (Mexico) and University of North Carolina team. First, the evaluations showed that the taxes were passed through to consumers.⁹⁹ Using detailed household food purchase data representing urban Mexico, the researchers found significant declines in purchases for these taxed beverages, with great negative purchasing effects on lower socioeconomic status households.^{100,101} The impact of this same tax in year 2 will be forthcoming.¹⁰²

Chile. Officially now a higher income country, Chile has instituted a series of laws and continues to prepare for new ones. This government truly wants to improve diets and reduce the very high levels of obesity and NCDs. As a first step, they increased their value-added tax on SSBs by 5% and reduced the tax on other beverages by 3%. That change is currently being evaluated by the Global Food Research Program in cooperation with colleagues from the Institute of Nutrition and Food Technology, University of Chile. Second, Chile began a very comprehensive marketing law applying to all foods and beverages deemed unhealthful. They are implementing that law in 3 stages (see Table 1). This country is also planning to implement a law that will forbid most advertising of the same food and beverage products deemed unhealthful in all media from 6 am to 10 pm.

Colombia and South Africa. Both of these countries are in the midst of serious consideration of implementing taxes of 18% and 20%, respectively, on SSBs. In each country, the Ministries of Health and of Finance support the taxes and the government backs the tax as a critical step towards addressing obesity, diabetes, and other cardiometabolic problems linked with excessive SSB consumption. Both measures face strong industry opposition but, thus far, the governments remain supportive of implementing the taxes.

Thailand. Thailand has adopted a front-of-package-label similar to the Choices International logo under the name “Healthier Choice.” This is similar to the Healthy Choices program Singapore has used for decades, but it

Table 1 Nutrient limits and implementation dates for front-of-package logo requirements and marketing bans in Chile

Nutrient type	July 16, 2016	July 16, 2017	July 16, 2018
Solid foods			
Energy, kcal/100 g	350.0	300.0	275.0
Sodium, mg/100 g	800.0	500.0	400.0
Total sugar, g/100 g	2.5	15.0	10.0
Saturated fat, g/100 g	6.0	5.0	4.0
Liquids			
Energy, kcal/100 g	100.0	80.0	70.0
Sodium, mg/100 g	100.0	100.0	100.0
Total sugar, g/100 g	6.0	5.0	5.0
Saturated fat, g/100 g	3.0	3.0	3.0

initially covers a limited subset of foods and beverages deemed most unhealthy.¹⁰³

Pacific Islands. Thirteen islands have adopted various levels of SSB taxes over the past decade.¹⁰⁴ No evaluation of these taxes has been conducted to date.

Many countries have initiated revisions of school food programs to increase their healthfulness and reduce consumption of SSBs and junk food. The most innovative school food program in Brazil has yet to be evaluated. Brazil passed a law requiring that 30% of the food served in schools be real food purchased from local farmers and an additional 40% of the food to be minimally processed.^{105,106}

SUSTAINABLE DEVELOPMENT GOALS AND THE MODERN DIET

The new Sustainable Development Goals (SDGs), which were adopted by most countries in a United Nations consensus, have paid limited attention to nutrition and NCDs.¹⁰⁷ One of the 169 proposed targets of the SDGs is to reduce premature deaths from NCDs by 1/3; another is to end malnutrition in all forms. The remarkable transformation of food systems across the LMICs of the world stands in stark contrast to the goals of the SDGs. The transformation to modern food systems began in the period following World War II with policies designed to meet a very different set of nutritional and food needs and continued with globalization in the 1990s and beyond. There are huge challenges and knowledge gaps in 2 areas. The first is that no country has truly attempted to create programs to significantly reduce animal-source food consumption with its immense environmental footprint not only on carbon emissions but also water, fertilizer, and the use of antibiotics and pesticides. An even bigger gap exists in our knowledge of the environmental impact of packaged, processed foods and beverages. Creating a sustainable

diet requires a much greater effort aimed at reducing our intake, particularly of beef and milk. It also requires greater effort to fill existing research gaps and then to create policies around the issues that are identified as affecting the sustainability of our modern diet. It is my opinion that we all must work hard to meet the SDGs, and this will involve all countries seriously considering ways to address the harmful effects that the modern diet and the underlying food system are having on health. This is indeed the challenge facing populations across the world.

Acknowledgments

The following individuals are thanked for their assistance: Dr Phil Bardsley and Dr Donna Miles for exceptional assistance with the data management, Dr Jennifer Poti for providing several of the figures and many discussions regarding food processing, Mrs Frances D. Burton for administrative assistance, and Ms Denise Ammons for graphics support.

Funding. This author's work is supported by the National Institutes of Health (grant numbers R01DK108148, DK098072; DK56350, HD30880), the Bloomberg Philanthropies, and the Carolina Population Center and its NIH Center grant (P2C HD055092A). None of the funders had a direct role in the design, analysis, or preparation of this work.

Declaration of interest. The author has no relevant interests to declare.

REFERENCES

- Smith LP, Ng SW, Popkin BM. Resistant to the recession: US adults maintain cooking and away-from-home eating patterns during times of economic turbulence. *Am J Public Health*. 2014;104:840–846.
- Poti JM, Mendez MA, Ng SW, et al. Is the degree of food processing and convenience linked with the nutritional quality of foods purchased by US households? *Am J Clin Nutr*. 2015;99:162–171.
- Poti JM, Mendez MA, Ng SW, et al. Highly processed and ready-to-eat packaged food and beverage purchases differ by race/ethnicity among US households. *J Nutr*. 2016;46:1722–1730.
- Popkin BM. Nutrition, agriculture and the global food system in low and middle income countries. *Food Policy*. 2014;47:91–96.
- Babu SC, Blom S. Building capacity for resilient food systems. In: S Fan, R Pandya-Lorch, S Yosef, eds. *Resilience for Food and Nutrition Security*. Washington, DC: International Food Policy Research Institute. 2014:119–226.
- Eriksen P, Stewart B, Dixon J, et al. The value of a food system approach. In: J Ingram, P Eriksen, D Liverman, eds. *Food Security and Global Environmental Change*. London: Earthscan; 2014:25–45.
- Hawkes C. Identifying innovative interventions to promote healthy eating using consumption-oriented food supply chain analysis. *J Hunger Environ Nutr*. 2009;4:336–356.
- Reardon T, Timmer CP, Minten B. Supermarket revolution in Asia and emerging development strategies to include small farmers. *Proc Natl Acad Sci*. 2012;109:12332–12337.
- Reardon T, Timmer CP. The economics of the food system revolution. *Ann Rev Resource Econ*. 2012;4:225–264.
- Reardon T, Timmer CP, Barrett CB, et al. The rise of supermarkets in Africa, Asia, and Latin America. *Am J Agr Econ*. 2003;85:1140–1146.
- Reardon T, Berdegue J. The rapid rise of supermarkets in Latin America: challenges and opportunities for development. *Dev Policy Rev*. 2002;20:371–388.
- Zhou Y, Du S, Su C, et al. The food retail revolution in China and its association with diet and health. *Food Policy*. 2015;55:92–100.
- Smith LP, Ng SW, Popkin BM. Resistant to the recession: US adults maintain cooking and away-from-home eating patterns during times of economic turbulence. *Am J Public Health*. 2014;104: 840–846.
- Monteiro CA, Levy RB, Claro RM, et al. Increasing consumption of ultra-processed foods and likely impact on human health: evidence from Brazil. *Public Health Nutr*. 2011;14:5–13.
- Monteiro C. The big issue is ultra-processing [commentary]. *World Nutr*. 2010;1:237–269.
- Eicher-Miller HA, Fulgoni VL, Keast DR. Contributions of processed foods to dietary intake in the US from 2003–2008: a report of the Food and Nutrition Science Solutions Joint Task Force of the Academy of Nutrition and Dietetics, American Society for Nutrition, Institute of Food Technologists, and International Food Information Council. *J Nutr*. 2012;142(Suppl):2065S–2072S.
- Dwyer JT, Fulgoni VL, Clemens RA, et al. Is "Processed" a four-letter word? The role of processed foods in achieving dietary guidelines and nutrient recommendations. *Adv Nutr*. 2012;3:536–548.
- Botelho R, Araujo W, Pineli L. Food formulation and not processing level: conceptual divergences between public health and food science and technology sectors. *Critical Rev Food Sci Nutr*. 2016;doi:10.1080/10408398.10402016.11209159.
- Levinson M. *The Great A&P and the Struggle for Small Business in America*. New York, New York: Macmillan; 2011.
- Walsh WI. *The Rise and Decline of the Great Atlantic & Pacific Tea Company*. Fort Lee, New Jersey: Lyle Stuart; 1986.
- Walton S, Huey J. *Sam Walton, Made in America: My Story*. New York, New York: Bantam; 1993.
- Stern D, Poti JM, Ng SW, et al. Where people shop is not associated with the nutrient quality of packaged foods for any racial-ethnic group in the United States. *Am J Clin Nutr*. 2016;103:1125–1134.
- Stern D, Robinson WR, Ng SW, et al. US household food shopping patterns: dynamic shifts since 2000 and socioeconomic predictors. *Health Aff*. 2015;34:1840–1848.
- Reardon T, Berdegue JA. The rapid rise of supermarkets in Latin America: challenges and opportunities for development. *Dev Policy Rev*. 2002;20:371–388.
- Reardon T, Chen KZ, Minten B, et al. The quiet revolution in Asia's rice value chains. *Ann NY Acad Sci*. 2014;1331:106–118.
- Reardon T, Barrett CB, Berdegue JA, et al. Agrifood industry transformation and small farmers in developing countries. *World Dev*. 2009;37:1717–1727.
- Wang H, Dong X, Rozelle S, et al. Producing and procuring horticultural crops with Chinese characteristics: The case of Northern China. *World Dev*. 2009;37:1791–1801.
- Zhang QF, Pan Z. The transformation of urban vegetable retail in China: wet markets, supermarkets and informal markets in Shanghai. *J Contemporary Asia*. 2013;43:497–518.
- Garnett T, Wilkes A. *Appetite for Change: Social, Economic and Environmental Transformations in China's Food System*. Oxford, UK: Food Climate Research Network; 2014.
- Hu D, Reardon T, Rozelle S, et al. The emergence of supermarkets with Chinese characteristics: challenges and opportunities for China's agricultural development. *Dev Policy Rev*. 2004;22:557–586.
- Tschirley D, Reardon T, Dolislager M, et al. The rise of a middle class in East and Southern Africa: implications for food system transformation. *J Int Dev*. 2015;27:628–646.
- Pollan M. *In Defense of Food: An Eater's Manifesto*. New York, NY: Penguin Press; 2008.
- Dietary Guidelines for the Brazilian Population, 2nd edn. Brasilia: Brazil Ministry of Health, Secretariat of Health Care Primary Health Care Department; 2014:152.
- Pan American Health Organization. *Pan American Health Organization Nutrient Profile Model*. Washington, DC: PAHO; 2016:32.
- Poti JM, Mendez MA, Ng SW, et al. Is the degree of food processing and convenience linked with the nutritional quality of foods purchased by US households? *Am J Clin Nutr*. 2015;99:162–171.
- Monteiro CA, Moubarac JC, Cannon G, et al. Ultra-processed products are becoming dominant in the global food system. *Obes Rev*. 2013;14:21–28.
- Smith Tallie L, Poti JM. Associations of cooking with dietary intake and obesity among Supplemental Nutrition Assistance Program participants. *Am J Prev Med*. In Press.
- Monteiro C, Gomes F, Cannon G. The snack attack. *Am J Public Health*. 2010;100:975–981.
- World Health Organization. *Guideline: Sugar Intake for Adults and Children*. Geneva, Switzerland; World Health Organization, Department of Nutrition for Health and Development; 2015:50.

40. World Cancer Research Fund International. Curbing Global Sugar Consumption: Effective Food Policy Actions to Help Promote Healthy Diets and Tackle Obesity. 2015. Available at: <http://www.wcrf.org/int/policy/our-policy-work/curbing-global-sugar-consumption>. Accessed December 18, 2016
41. Johnson RK, Appel LJ, Brands M, et al. Dietary sugars intake and cardiovascular health: a scientific statement from the American Heart Association. *Circulation*. 2009;120:1011–1020.
42. Kwan GF, Mayosi BM, Mocumbi AO, et al. Endemic cardiovascular diseases of the poorest billion. *Circulation*. 2016;133:2561–2575.
43. Singh GM, Micha R, Khatibzadeh S, et al. Global, regional, and national consumption of sugar-sweetened beverages, fruit juices, and milk: a systematic assessment of beverage intake in 187 countries. *PLoS ONE*. 2015;10:e0124845.
44. Singh GM, Micha R, Khatibzadeh S, et al. Estimated global, regional, and national disease burdens related to sugar-sweetened beverage consumption in 2010. *Circulation*. 2015;doi:10.1161/CIRCULATIONAHA.114.010636.
45. Imamura F, Micha R, Khatibzadeh S, et al. Dietary quality among men and women in 187 countries in 1990 and 2010: a systematic assessment. *Lancet Global Health*. 2015;3:e132–e142.
46. Micha R, Khatibzadeh S, Shi P, et al. Global, regional, and national consumption levels of dietary fats and oils in 1990 and 2010: a systematic analysis including 266 country-specific nutrition surveys. *BMJ*. 2014;348:g2272.
47. Powles J, Fahimi S, Micha R, et al. Global, regional and national sodium intakes in 1990 and 2010: a systematic analysis of 24 h urinary sodium excretion and dietary surveys worldwide. *BMJ Open*. 2013;3:e003733.
48. Stern D, Piaras C, Barquera S, et al. Caloric beverages were major sources of energy among children and adults in Mexico, 1999–2012. *J Nutr*. 2014;144:949–956.
49. Zhai FY, Du SF, Wang ZH, et al. Dynamics of the Chinese diet and the role of urbanicity, 1991–2011. *Obes Rev*. 2014;15:16–26.
50. Du SF, Wang HJ, Zhang B, et al. China in the period of transition from scarcity and extensive undernutrition to emerging nutrition-related non-communicable diseases, 1949–1992. *Obes Rev*. 2014;15:8–15.
51. Pereira R, Souza A, Duffey K, et al. Beverages consumption in Brazil: Results from the first national dietary survey. *Public Health Nutr*. 2015;18:1164–1172.
52. Pereira RA, Duffey KJ, Sichieri R, et al. Sources of excessive saturated fat, trans fat and sugar consumption in Brazil: an analysis of the first Brazilian nationwide individual dietary survey. *Public Health Nutr*. 2014;17:113–121.
53. Popkin BM, Hawkes C. Sweetening of the global diet, particularly beverages: patterns, trends, and policy responses. *Lancet Diabetes Endocrinol*. 2016;4:174–186.
54. Anand SS, Hawkes C, de Souza RJ, et al. Food consumption and its impact on cardiovascular disease: importance of solutions focused on the globalized food system a report from the Workshop convened by the World Heart Federation. *J Am Coll Cardiol*. 2015;66:1590–1614.
55. Delgado CL. Rising consumption of meat and milk in developing countries has created a new food revolution. *J Nutr*. 2003;133(Suppl 2):3907S–3910S.
56. Food and Agriculture Organization of the United Nations. *Livestock's Long Shadow: Environmental Issues and Options*. Rome, Italy: Food and Agriculture Organization of the United Nations; 2007.
57. Weis T. *The Ecological Hoofprint: The Global Burden of Industrial Livestock*. London: Zed Books; 2013.
58. Zhai FY, Du SF, Wang ZH, et al. Dynamics of the Chinese diet and the role of urbanicity, 1991–2011. *Obes Rev*. 2014;15:16–26.
59. Landers TF, Cohen B, Wittum TE, et al. A review of antibiotic use in food animals: perspective, policy, and potential. *Public Health Rep*. 2012;127:4–22.
60. Common Sense Media. *Advertising to Children and Teens: Current Practices*. 2014. Available at: <https://www.common SenseMedia.org/research/advertising-to-children-and-teens-current-practices>. Accessed on December 21, 2016.
61. Montgomery KC, Chester J. Interactive food and beverage marketing: targeting adolescents in the digital age. *J Adolesc Health*. 2009;45(Suppl):S18–S29.
62. Cheyne AD, Dorfman L, Bukofzer E, Harris JL. Marketing sugary cereals to children in the digital age: a content analysis of 17 child-targeted websites. *J Health Commun*. 2013;18:563–582.
63. McGinnis JM, Gootman JA, Kraak VI. *Food marketing to children and youth: threat or opportunity?*: National Academies Press; 2006.
64. Palmer E, Carpenter C. *Food and Beverage Marketing to Children and Youth: Trends and Issues*. Media Psychology. 2006;8:165–190.
65. Federal Trade Commission. *A Review of Food Marketing to Children and Adolescents: Follow-Up Report*. 2012. Available at: <https://www.ftc.gov/sites/default/files/documents/reports/review-food-marketing-children-and-adolescents-follow-report/121221foodmarketingreport.pdf>. Accessed on December 21, 2016.
66. Harris JL, Pomeranz JL, Lobstein T, Brownell KD. A crisis in the marketplace: how food marketing contributes to childhood obesity and what can be done. *Annu Rev Public Health*. 2009;30:211–225.
67. Cairns G, Angus K, Hastings G, Caraher M. Systematic reviews of the evidence on the nature, extent and effects of food marketing to children. A retrospective summary. *Appetite*. 2013;62:209–215.
68. Ng M, Fleming T, Robinson M, et al. Global, regional, and national prevalence of overweight and obesity in children and adults during 1980–2013: a systematic analysis for the Global Burden of Disease Study 2013. *Lancet*. 2014;384:766–781.
69. Jaacks LM, Slining MM, Popkin BM. Recent trends in the prevalence of under- and overweight among adolescent girls in low- and middle-income countries. *Pediatr Obes*. 2015;10:428–435.
70. Jaacks LM, Slining MM, Popkin BM. Recent underweight and overweight trends by rural–urban residence among women in low- and middle-income countries. *J Nutr*. 2015;145:352–357.
71. Popkin BM, Slining MM. New dynamics in global obesity facing low- and middle-income countries. *Obes Rev*. 2013;14:11–20.
72. Albrecht SS, Gordon-Larsen P, Stern D, et al. Is waist circumference per body mass index rising differentially across the United States, England, China and Mexico? *Eur J Clin Nutr*. 2015;69:1306–1312.
73. Albrecht SS, Barquera S, Popkin BM. Exploring secular changes in the association between BMI and waist circumference in Mexican-Origin and white women: a comparison of Mexico and the United States. *Am J Hum Biol*. 2014;26:627–634.
74. World Health Organization. *BMI Classification*. 2006. Updated 2016. Available at: http://apps.who.int/bmi/index.jsp?introPage=intro_3.html. Accessed on December 18, 2016.
75. World Health Organization. *Physical Status: The Use and Interpretation of Anthropometry: Report of a WHO Expert Committee*. Geneva, Switzerland: World Health Organization; 1995.
76. Albrecht S, Mayer-Davis B, Popkin B. The association with BMI and diabetes and pre-diabetes in US adults: an examination of secular and race/ethnic trends. *Diabetes/Metabolism Res Rev*. In Press.
77. Wells JC, Pomeroy E, Walimbe SR, et al. The elevated susceptibility to diabetes in India: an evolutionary perspective. *Front Public Health*. 2016;4:45.
78. Popkin BM, Adair LS, Ng SW. Global nutrition transition and the pandemic of obesity in developing countries. *Nutr Rev*. 2012;70:3–21.
79. World Health Organization Expert Consultation. *Appropriate body-mass index for Asian populations and its implications for policy and intervention strategies*. *Lancet*. 2004;363:157–163.
80. Colin Bell A, Adair LS, Popkin BM. Ethnic differences in the association between body mass index and hypertension. *Am J Epidemiol*. 2002;155:346–353.
81. Stanhope KL. Sugar consumption, metabolic disease and obesity: the state of the controversy. *Crit Rev Clin Lab Sci*. 2016;53:52–67.
82. Stanhope KL. Role of fructose-containing sugars in the epidemics of obesity and metabolic syndrome. *Annu Rev Med*. 2012;63:329–343.
83. Stanhope KL, Griffen SC, Bremer AA, et al. Metabolic responses to prolonged consumption of glucose- and fructose-sweetened beverages are not associated with postprandial or 24-h glucose and insulin excursions. *Am J Clin Nutr*. 2011;94:112–119.
84. Bray GA, Popkin BM. Dietary sugar and body weight: have we reached a crisis in the epidemic of obesity and diabetes?: Health be damned! Pour on the sugar. *Diabetes Care*. 2014;37:950–956.
85. Stephan BC, Wells JC, Brayne C, et al. Increased fructose intake as a risk factor for dementia. *J Gerontol A Biol Sci Med Sci*. 2010;65:809–814.
86. Bray GA. Fructose: pure, white, and deadly? Fructose, by any other name, is a health hazard. *J Diabetes Sci Technol*. 2010;4:1003–1007.
87. Bray GA. Fructose: should we worry? *Int J Obes*. 2008;32 (Suppl 7):S127–S131.
88. Lustig RH. Fructose: It's "alcohol without the buzz". *Adv Nutr*. 2013;4:226–235.
89. Lustig RH, Mulligan K, Noworolski SM, et al. Isocaloric fructose restriction and metabolic improvement in children with obesity and metabolic syndrome. *Obesity*. 2016;24:453–460.
90. Vos T, Flaxman AD, Naghavi M, et al. Years lived with disability (YLDs) for 1160 sequelae of 289 diseases and injuries 1990–2010: a systematic analysis for the Global Burden of Disease Study 2010. *Lancet*. 2012;380:2163–2196.
91. World Health Organization. *Global Action Plan for the Prevention and Control of NCDs 2013–2020*. Geneva, Switzerland: World Health Organization; 2013:55.
92. Pries AM, Huffman SL, Mengkheang K, et al. High use of commercial food products among infants and young children and promotions for these products in Cambodia. *Matern Child Nutr*. 2016;12:52–63.
93. Pries AM, Huffman SL, Adhikary I, et al. High consumption of commercial food products among children less than 24 months of age and product promotion in Kathmandu Valley, Nepal. *Matern Child Nutr*. 2016;12:22–37.
94. Feeley AB, Ndeye Coly A, Sy Gueye NY, et al. Promotion and consumption of commercially produced foods among children: situation analysis in an urban setting in Senegal. *Matern Child Nutr*. 2016;12:64–76.
95. Hawkes C, Jewell J, Allen K. A food policy package for healthy diets and the prevention of obesity and diet-related non-communicable diseases: the NOURISHING framework. *Obes Rev*. 2013;14:159–168.
96. World Cancer Research Fund International. *Nourishing framework*. Available at: <http://www.wcrf.org/int/policy/nourishing-framework>. Accessed on December 18, 2016.
97. Falbe J, Thompson HR, Becker CM, et al. Impact of the Berkeley excise tax on sugar-sweetened beverage consumption. *Am J Public Health*. 2016;106:1865–1871.
98. Falbe J, Rojas N, Grummon AH, et al. Higher retail prices of sugar-sweetened beverages 3 months after implementation of an excise tax in Berkeley, California. *Am J Public Health*. 2015;105:2194–2201.

99. Colchero MA, Salgado JC, Unar-Munguía M, et al. Changes in prices after an excise tax to sweetened sugar beverages was implemented in Mexico: evidence from urban areas. *PLoS ONE*. 2015;10:e0144408.
100. Colchero MA, Popkin BM, Rivera JA, et al. Beverage purchases from stores in Mexico under the excise tax on sugar sweetened beverages: observational study. *BMJ*. 2016;352:h6704.
101. Batis C, Rivera JA, Popkin BM, et al. First-year evaluation of Mexico's tax on non-essential energy-dense foods: an observational study. *PLoS Med*. 2016;13:e1002057.
102. Colchero MA, Rivera JA, Popkin BM, et al. Sustained consumer response: evidence two-years after implementing the sugar-sweetened beverage tax in Mexico. *Health Aff*. In Press.
103. Foo LL, Vijaya K, Sloan RA, et al. Obesity prevention and management: Singapore's experience. *Obes Rev*. 2013;14:106–113.
104. Snowdon W, Thow AM. Trade policy and obesity prevention: challenges and innovation in the Pacific Islands. *Obes Rev*. 2013;14:150–158.
105. Jaime PC, da Silva ACF, Gentil PC, et al. Brazilian obesity prevention and control initiatives. *Obes Rev*. 2013;14:88–95.
106. Coitinho D, Monteiro CA, Popkin BM. What Brazil is doing to promote healthy diets and active lifestyles. *Public Health Nutr*. 2002;5:263–267.
107. Hawkes C, Popkin BM. Can the sustainable development goals reduce the burden of nutrition-related non-communicable diseases without truly addressing major food system reforms? *BMC Med*. 2015;13:1–3.