Why Is the Developed World Obese?

*Erratum

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obesity, developed countries, energy intake, energy expenditure, drivers of the energy imbalance

Abstract

Obesity has risen dramatically in the past few decades. However, the relative contribution of energy intake and energy expenditure to rising obesity is not known. Moreover, the extent to which social and economic factors tip the energy balance is not well understood. This exploratory study estimates the relative contribution of increased caloric intake and reduced physical activity to obesity in developed countries using two methods of energy accounting. Results show that rising obesity is primarily the result of consuming more calories. We estimate multivariate regression models and use simulation analysis to explore technological and sociodemographic determinants of this dietary excess. Results indicate that the increase in caloric intake is associated with technological innovations as well as changing sociodemographic factors. This review offers useful insights to future research concerned with the etiology of obesity and suggests that obesity-related policies should focus on encouraging lower caloric intake.

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INTRODUCTION

OECD: Organization for Economic Cooperation and Development

Body mass index (BMI): an index for relating a person's body weight (in kilograms) to his or her height (in meters squared)

Today, obesity affects more than 300 million adults, the majority of whom live in the developed world (79). In the past two decades, the average level of obesity in the Organization for Economic Cooperation and Development (OECD) countries has risen by 8%. Unlike previous centuries, where increased weight was a sign of improved health (24), the rapid increase in body mass index (BMI)[1] over the past few decades indicates that a growing share of the population in developed countries is becoming obese (22, 36, 79).

Excess body weight is the fifth most important risk factor contributing to the burden of disease in developed countries (80). Rising BMI steadily increases the risks of type 2 diabetes, hypertension, cardiovascular disease, and some cancers (3). In addition, obesity is responsible for ~6%–10% of national health expenditures in the United States and 2%–4% in other developed countries (3, 8, 21, 46, 73, 75). Moreover, the lifetime medical costs related to diabetes, heart disease, high cholesterol, hypertension, and stroke among the obese are $10,000 higher than among the nonobese (6).

Genetic changes are not the cause of increased obesity over such a short time period. Rather, changes in the energy balance are key: consuming more calories than are expended leads to weight gain (38). However, the relative culpability of energy intake and energy expenditure to the pathogenesis of weight gain is the subject of some dispute. Some studies place blame on increased physical inactivity (31, 55, 63, 76), whereas others point to overconsumption (14, 50, 53, 72).

The complex range of social and economic factors that tip the energy balance are not well understood despite a vast body of research exploring obesity and its determinants (44). Experts increasingly point to technology innovations as a key mechanism driving the energy imbalance (14, 21, 44). Technological innovations refer to improvements that have lowered the costs associated with consumption and a sedentary lifestyle. However, whether obesity is more attributable to dietary excess or physical inactivity as a result of these innovations is unclear. Those in support of the reduced energy expenditure theory point to the increasingly automated work place and rising time costs of physical activity (45, 56). This argument is weakened by the fact that available evidence on declines in work-related physical activity suggests that reductions have been gradual and largely predated the dramatic increase in weight gain across the developed world in the past few decades (2). Those arguing that overconsumption is responsible point to decreases in food prices, increases in the mass preparation of food, increases in the efficiency of food production, and increases in the availability of fast food and calorie-dense foods. Studies linking dietary excess to obesity are supported by empirical evidence indicating that food consumption has increased in parallel with rising obesity (13, 14).

In addition to the behavior and environmental changes fueled by technological innovations, obesity has also been related to changes in sociodemographic factors. We focus on those factors, which are strongly supported by empirical evidence and amenable to data analysis. In particular, we look at urbanization and female labor force participation. A vast body of literature relates urbanization to rising obesity. Rising urbanization is associated with increased opportunities for eating and reduced opportunities for physical activity. For example, food options in urban areas are typically more varied and accessible than rural areas. Moreover, people in rural areas typically have higher levels of physical activity because of the focus on agricultural work (60). The differences between diet and activity patterns in urban and rural areas are

[1]The levels of body mass index (BMI), which distinguish healthy weight from overweight (BMI at or above 25 kg/m^2) and obese (BMI at or above 30 kg/m^2), are based on how much the risk of chronic disease and death increases for populations as weight increases.

lowest in those high-income countries where urbanization is most prevalent as a result of infrastructure development (59).

Increasing female labor force participation has been related to rising obesity through changes in time allocation and food consumption. The proliferation of women in the workforce has meant that women are devoting more time to work and less time to food preparation, a trend that has increased their reliance on convenient food and fast food (13). Not only are such foods inexpensive, but also they have high caloric density to increase palatability, which can accelerate weight gain (30, 48, 67). Healthy food, by contrast, is less convenient, less accessible, and more expensive (17).

Previous research exploring the relative contribution of caloric intake and energy expenditure to weight gain has been limited by the focus on single countries or subpopulations. This study is the first to use a series of cross-sectional observations in a multicountry analysis. Use of data from multiple countries allows us to observe common trends among the OECD countries. The developed world was selected because data are most ubiquitous and obesity rates are among the highest in the world.

The main purpose of this study is to identify the relative contribution of caloric intake and energy expenditure to obesity and the mechanisms driving the energy imbalance. We first discuss our data sources and methods. We next provide evidence about trends in obesity and caloric supply. We then evaluate whether the rise in obesity is attributable more to increased caloric intake or to reduced physical activity. We subsequently look at the factors driving this imbalance, focusing on those with the greatest public sector implications. We conclude with a discussion of policy implications as well as how our findings relate to the broader obesity literature.

We propose a theory based on dietary excess. In particular, we hypothesize that rising obesity is the result of increased caloric intake and that this shift toward overconsumption is driven by technological innovations and changing sociodemographic factors.

RESEARCH METHODS AND PROCEDURES

Data

The data for this study include country-level and individual-level measures obtained from several sources (**Table 1**).

Energy accounting. To evaluate the relative contribution of energy intake and energy expenditure to obesity, we constructed a panel data set of OECD countries using data from the food balance sheets (FBS) from the Food and Agricultural Organization (FAO) and obesity prevalence from the OECD Health database. We also used individual-level data from the United States and England.

The FBS data are compiled from national accounts of the supply and use of foods. Food available for consumption is calculated as total food production (including imports excluding exports) with net losses from processing at the mill and food for animal consumption. These data are widely used and cited because they provide the most comprehensive picture of food consumption at the national level, making it possible to study trends in per capita caloric supply across countries and over time.

Using the FBS does have several limitations (19). The data do not reflect actual consumption and are typically overestimated owing to failure to account for household waste and spoilage, as well as transformation of food composition during the process of cooking (16, 69). The resulting measurement error may vary by country (e.g., United States, 26%; United Kingdom, 10%; Japan, 25%) (9, 41, 70).

We included FBS data only from countries with a reputation for high-quality data-collection methods and that scored well above average in terms of data completeness. However, differences in methodologies

FBS: Food balance sheets

FAO: Food and Agricultural Organization

Table 1 Description of dependent and independent variables included in the analysis

Indicator	Year[a]	Unit	Description	Source
Prevalence of obesity				
All countries	1978–2002	% of population	Percentage of population with a body mass index (BMI) ≥ 30 kg/m^2	OECD Health[b]
United States	1988, 2001	% of population	BMI was calculated from measured height and weight	NHANES III, IV[c]
England	1991, 2003	% of population	BMI was calculated from measured height and weight	HSE[d]
Caloric supply	1961–2002	kcal/person/day	Total amount of food available for consumption (including imports excluding exports); net losses from processing at the mill and food for animal consumption	FBS[e]
Evidence on energy expenditure	See Appendices A, B, and C			
Technology variables				
Relative food prices	1980–2002	Ratio	Ratio of the food price index to the consumer price index; reflects changes in the cost of food prices relative to consumer goods	WDI[f]
Pricing freedom	1984–2002	Point estimate	The freedom of businesses to set prices; measured on an index from 0 to 10 where high scores indicate little or no government interference	EFW[g]
Market entry	1995–2002	Point estimate	The ease with which businesses can enter into the market place; measured on a scale from 0 to 10 where high scores signify little or no regulation to entering the market place	EFW[g]
Sociodemographic variables				
Urbanization	1961–2002	% of total population	Percentage of population residing in urban areas in each country according to national definition	WDI[f]
Women working	1961–2002	% of total population	Percentage of female labor force participation as a percent of the total labor force	WDI[f]
Economic variable				
GDP(PPP)	1961–2002	1000 U.S. PPP$/capita	The per capita GDP expressed in purchasing power parity (PPP)	WDI[f]

[a]The survey years included in each analysis vary. Details are provided in the text.
[b]Organization for Economic Cooperation and Development (OECD) Health Database.
[c]National Health and Nutrition Examination Survey III and IV.
[d]Health Survey for England.
[e]Food Balance Sheets.
[f]World Development Indictors.
[g]Economic Freedom of the World Index.

or definitions between countries may lead to some incomparability. We employed methods to reduce the impacts of these limitations (described below).

The OECD Health Data are the most comprehensive source of health-related data, including obesity prevalence, for the OECD countries. Survey respondents are classified as obese if their self-reported or measured BMI is 30 kg/m^2 or higher. To account for the fact that, on average, women under report weight and men over report height (18), we control for whether the BMI measure is observed or self-reported.

For the United States and England, individual-level data were obtained from two nationally representative surveys: the National Health and Nutrition Examination Surveys (NHANES) III (1988–94) and IV (1999–2002) and the Health Survey for England (HSE) for 1991 and 2003.

Energy expenditure. We have no single, comparable source of information on energy expenditure across OECD countries. Therefore, we used World Development Indicators (WDI) and a number of individual-level data sources to measure physical activity, which was categorized into four broad types: highly active work, less active work, active leisure time,[2] and everything else (see Appendices A and B in this article's **Supplemental Material online**. Follow the Supplemental Material link from the Annual Reviews home page at **http://www.annualreviews.org**).

The physical activity data used for this study had several limitations. The employment categories in the WDI are broad, making it difficult to capture variations in work-related physical activity. The data-collection methods for leisure time activity and the accuracy and methodology used by the reporting country are not uniform across countries. Moreover, the leisure time activity data include only measures of physical exercise. Ideally, we would have also included measures of other activities such as television use, household chores, or errands because of the potentially large effect of sedentary or household activity for some countries or population subgroups. Unfortunately, those data were not available.

Drivers of the energy imbalance. To measure drivers of the energy balance, we use the WDI and the Economic Freedom of the World index (EFW). The EFW measures the degree to which the policies and institutions of countries are supportive of economic freedom. We use the following measures of economic freedom as previously validated proxies for technological innovation: relative food prices (WDI), market entry (the ease with which new businesses can enter the market place) (EFW), and pricing freedom (the freedom of businesses to set their own prices) (EFW) (14, 29). Sociodemographic change is measured as the degree of urbanization (WDI) and female labor force participation (WDI).

NHANES: National Health and Nutrition Examination Survey

HSE: Health Survey for England

WDI: World Development Indicators

EFW: Economic Freedom of the World index

Analysis

This study is conducted in two parts. In part I, we use two methods of energy accounting and a 24-h time budget of energy expenditure to assess the relative contributions of caloric intake and energy expenditure to the rising prevalence of obesity in developed countries. Consistency in results across these methods should provide a relatively convincing explanation for increasing obesity in spite of data limitations. In part II, we use ordinary least squares (OLS) regression to assess whether technological innovation and sociodemographic changes are associated with changes in the energy balance.

Part I: Calories In or Energy Out

Energy accounting. To calculate the relative contribution of energy intake and energy expenditure to rising obesity, we use two methods of energy accounting. The first method uses country-level data and the second method uses individual-level data.

Each energy accounting model is based on the biological fact that the energy balance is equal to the difference between net energy intake and net energy expenditure (28, 38). The energy accounting analyses address the question of whether people are eating more or exercising less. We examine factors that drive changes in the energy balance in the second part of this article.

[2] Trends in work commuting (included in Appendix B) were placed in the "everything else" category, given that changes over the period were very small.

At the individual level, a change in the energy balance is equal to the summation of changes in energy intake and energy expenditure over time:

$$\text{Energy balance}_{t,t+\alpha} = \sum_{t}^{t+\alpha} \text{energy intake} \times \sum_{t}^{t+\alpha} \text{energy expenditure},$$

where t is time and α is the number of years. Energy expenditure is the sum of three parts:

$$K = \alpha + (\beta + E)^{*} Weight + 0.1^{*} K,$$

where K represents the daily calories consumed; $\alpha + \beta^{*}$ *Weight* represents the basal metabolic rate, energy associated with keeping the body alive (~60% of daily energy expenditure); E represents activity-related energy expenditure (~30% of daily energy expenditure); and 0.1^{*} K represents the thermic effect of food, energy necessary to process food (~10% of daily energy expenditure). This weight equation was parameterized by Cutler et al. (14) from the most commonly used estimates in the literature (68, 77).[3] Because it describes a biological phenomenon, we can be reasonably confident that this equation can be applied across developed countries and aggregated to the population level (20).

Given that individual-level BMI data are not available for all of the countries included in this analysis, we rely on an aggregate measure of percent obese. We compared trends in mean BMI and percent obese using individual-level data from England, Japan, and the United States to estimate the linear relationship between BMI and obesity and found a high level of correlation.[4]

Method 1. The first energy accounting model estimated the relationship between caloric intake and obesity as described below:

$$\text{percent obese}_{c,t} = \beta_0 + \beta_1(\text{total caloric supply})_{c,t} + \text{country}_c + \text{time}_t + e_{c,t},$$

where c indicates country and t indicates year. For this model, the country is the unit of analysis. The outcome variable is percent obese, and the primary independent variable of interest is total caloric supply.[5] The inclusion of country- and year-fixed effects control for shifts in waste and other unobserved factors across countries and over time. The time-fixed effects are measured in five-year increments (e.g., 1990–1994, 1995–1999, 2000–2002).

The coefficient for caloric supply (β_1) represents the association between caloric supply and percent obese. To obtain a predicted estimate of average percent obese, this coefficient is multiplied by the actual change in caloric supply for each country individually and for all countries as a group (e.g., pooled) over the respective survey period. The difference between our calculation (predicted percent obese) and the actual percent obese indicates how much of the change in percent obese is due to reductions in physical activity (i.e., residual unexplained variance). Countries were included in the pooled model if they had three or more obesity surveys from 1990 to 2002. For those countries with four or more

[3]The estimates from the literature are as follows. α: men = 879 and women = 829; β: men = 11.6 and women = 8.7 (68). The estimates from Schofield et al. were accepted as the standard by the FAO/WHO/UNU (United Nations University) expert consultation on the Energy Requirements of Adults in 2001 (20).

[4]For England, we used data from the Health Survey for England fielded annually from 1991 to 2003. For Japan, we used data from the National Nutrition Survey fielded annually from 1976 to 2002. For the United States, we used data from the National Health and Examination Survey (NHES), NHANES I, NHANES II, NHANES III, and NHANES IV. The correlations between mean BMI and percent obese were very high: Japan (0.93), England (0.95), and U.S. (0.99).

[5]There is disagreement in the literature regarding the relative importance of the key dietary factors that have been most associated with obesity, including high-fat, energy-dense foods and carbohydrate-rich foods with high sugar content. Given this lack of consensus, we do not address the possibility that calories may differentially impact obesity and instead focus on the relationship between total caloric intake and percent obese, where the data are most clear.

obesity surveys, only three data points were used in the analysis.

Using the same basic model structure described above, we also estimated the association between the change in caloric supply and the change in the percent obese, excluding fixed effects.

To the extent that caloric supply and physical activity are highly correlated, the coefficient on caloric supply above could absorb some of the effect of physical activity, leading to a biased estimate of the independent contributions of these behaviors.[6] We found evidence of a slight correlation but nothing to suggest that the model cannot produce unbiased estimates of the independent effects of caloric supply and physical activity.[7]

Method 2. The second energy-accounting analysis evaluated the effect of additional weight from calories on obesity using individual-level data. We first translated the actual change in food supply for a particular country into the predicted weight gain, which was then allocated proportionally across individuals within each country according to their BMI percentile. We then compared the predicted BMI gain with the actual BMI gain over the period to estimate the portion of obesity attributable to increased calories. We ran this model for the United States using the NHANES III and IV and for England using the Health Survey for England 1991 and 2003. If the hypothesis of dietary excess is correct, we would expect this model to overpredict the growth in obesity, given that our caloric supply measure does not account for household waste. We show that the results of this model are robust against the overconsumption error of the caloric supply data.

Energy expenditure. As an alternative approach to the energy-accounting method described above, we calculated a 24-h time budget of energy expenditure for each country with available physical activity data, including highly active work, less active work, active leisure time, and everything else. Each activity was assigned a metabolic equivalent (MET) score on the basis of the classification from Compendium of Physical Activities (1), producing MET hours for each activity. We then estimated the change in calories expended for each MET score, translated the change in calories into pounds, calculated the aggregate change in energy expenditure, and determined the effect of weight change on the percent obese. These calculations are detailed in Appendix C in the Supplemental Material online.

To validate our energy expenditure findings, we also related several crude proxies of physical activity (the number of passenger cars per 1000, the number of Internet users per 1000, and the number personal computers per 1000) to the percent obese using an OLS model with country- and year-fixed effects. The model includes data from approximately 1990 to 2002.

Part II: Drivers of the Energy Imbalance

We use a series of OLS models with country- and year-fixed effects and all years of data from all OECD countries to estimate the impact

[6]Correlations between caloric supply and unmeasured waste will underestimate the impact of caloric supply on percent obese, causing our estimate of the coefficient for caloric supply to shrink toward zero. Correlations between caloric supply and physical activity could go in either direction. Our estimate would be biased downward if individuals who eat more also exercise more (less likely). Our estimate would be biased upward if individuals who eat more also exercise less (more likely).

[7]Using country-level data, we empirically tested the possible correlations between caloric supply and physical activity proxies using an OLS regression model and found that our coefficient estimate for caloric supply remained relatively constant with ($\beta = 0.0042$) and without ($\beta = 0.0039$) the inclusion of physical activity proxies (e.g., number of cars per 1000, type of employment: agricultural, industrial, and service). However, given the limitations of these proxies, we also looked to the individual-level data to help understand the direction of the bias. Using data from the NHANES IV we estimated correlations between caloric intake and a series of physical activity variables measuring exercise related to moderately active work ($r = 0.08$), leisure-time activity ($r = 0.10$), housework ($r = 0.09$), and commuting ($r = 0.03$). Each association was positive but small.

of technological innovation and sociodemographic factors on caloric supply. Technological innovation is represented by three proxy measures: food prices, pricing freedom, and market entry. Food prices are measured as the ratio of the food price index to the consumer price index and serve as a proxy for efficiency in food production. We expect reduced food prices to be associated with increased caloric consumption given that individuals consume more when prices are low (58). Reduced food prices should lead to the biggest increase in caloric intake when food prices are falling faster than overall prices.

Pricing freedom is measured as the ability of businesses to set their own prices and is measured on a scale from 0 to 10, where 0 indicates high government interference and 10 indicates little or no government interference. Market entry is defined as the ease of starting a new business and is measured on a scale of 0 to 10; low scores signify that countries have regulations that retard entry into the marketplace and high scores indicate ease of market entry. The critical relationship between pricing freedom/market entry and the broader concept of technological innovation is the role of regulation. Empirical evidence suggests that regulation can stop new technology (15). There is an inverse relationship between regulation and technological innovation. Therefore, we expect that countries with more regulation (e.g., more price controls and more barriers to market entry) would have lower technological innovation and, subsequently, lower caloric supply. Ideally, we would have included a variable that measures the ease of market entry only for food venders. Unfortunately, these data were not available.

Changing sociodemographic factors were represented by two variables: percent urban and percent female labor force participation (as a percent of the total labor force). We expect urbanization and women working to be positively associated with consumption.

The influence of each of these factors was modeled separately, controlling for GDP, which is measured in purchasing power parity (PPP). We do not present a multivariate regression including all the independent variables for two reasons. First, the data for each independent variable are sparse, so putting them all together in one model significantly reduces the total number of observations and results in low explanatory power. Second, normal practices of imputation are not designed to work well on time-series data (42). The model relating urbanization to caloric supply is shown below:

$$\text{caloric supply}_{c,t} = \beta_0 + \beta_1\,\text{GDP(PPP)}_{c,t} + \beta_2\,\text{urbanization}_{c,t} + \text{country}_c + \text{year}_t + e_{c,t},$$

where we control for country- and time-fixed effects represented by *c* and *t*, respectively.

Using the coefficients from these models, we use Monte Carlo simulation[8] (Clarify software in Stata) to calculate the expected change in caloric supply due to changes in technological innovation and sociodemographic factors (43).

RESULTS

Descriptive Trends

Trends in obesity. **Figure 1** illustrates the level and trend of obesity in developed countries with measured (as opposed to self-reported) BMI data.[9] The United States has the highest level of obesity at all points in time. However, the rate of increase is quite similar across countries. For example, Korea, which has a much lower level of obesity than the United States, has a comparable rate of increase. Similarities in the speed with which obesity prevalence has increased across all countries with measured data suggest a

[8] Monte Carlo simulation is a procedure that generates possible outcomes by sampling from a theoretical distribution with predefined parameters. For this analysis, estimates are drawn from a normal distribution. To increase precision, each simulation uses 1000 draws.

[9] Although Mexico is included in the OECD countries, it is not a developed country. For this reason, it is not included in the analyses conducted for this article.

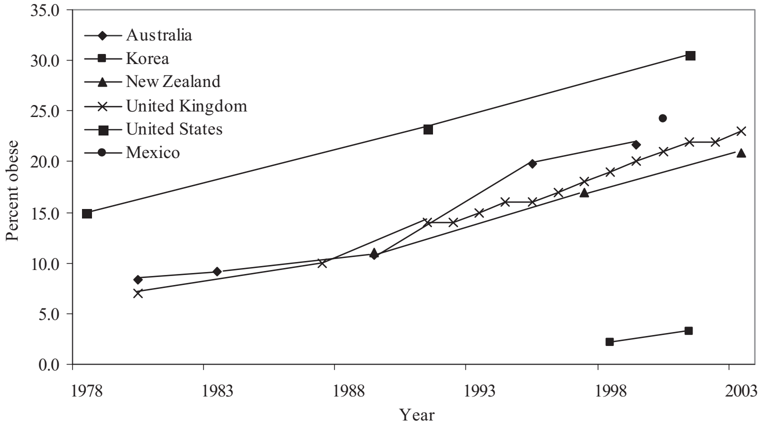

Figure 1

Level and trend of obesity in selected countries. Obesity is measured and defined as ≥ 30 kg/m^2; for detailed information about country surveys, see **http://www.ecosante.org/OCDEENG/814010.html.** Note: For the United Kingdom, estimates are from England only from 1991 forward. Source: OECD Health Data (71).

worldwide time-related phenomenon rather than a country-specific trend.

This consistent increase in adult obesity across the developed world is further illustrated in **Figure 2**, which shows the annual average change in the percent obese across all OECD countries. We observe the highest annual change in the United States (0.8%) and lowest in Japan (0.1%). Although this annual change in the United States may seem small, it represents ~1.5 million more adults becoming obese each year.

In **Figure 3**, we compare percentiles of BMI over time for England, Japan, and the United States. In particular, the value for each BMI percentile in the distribution in an earlier survey period (x-axis) is compared with the same BMI percentile of the distribution in a later survey period (y-axis). The 45° equivalence line is included to highlight the BMI percentiles demonstrating the largest changes over time. For example, in the early 1970s, the 95th percentile of BMI in the United States was 35. By the early 2000s this number had risen to 40. We observe similar trends in England and Japan. Consistent with other evidence, BMI in all three countries is increasing more rapidly at the higher percentiles (23, 40): Heavier people are getting heavier at a faster rate and thinner people are getting heavier at a slower rate.

International Evidence on Energy Intake

Trends in caloric supply for selected countries are shown in **Figure 4**. In each country, increases in caloric supply appear to be rising in parallel with obesity. Starting with the United States, we can see that caloric supply increased at a modest rate in the 1970s. However, from 1985 to 2000 caloric supply rose by ~12% or 300 calories a day (64). The size of this increase is more than sufficient to explain rising obesity in the United States, which, the literature has suggested, may have resulted from an average net increase in calories as small as 50–100 calories per day (33). In Canada, we see a similar trend: modest increases in caloric supply until after the mid-1980s, followed by a sharp increase in trend. From 1985 to 2002, per capita caloric supply in Canada increased by 530 kcal compared with the period from 1970 to 1984, where it increased by only 67 kcal. We observe the same pattern in the United Kingdom, where

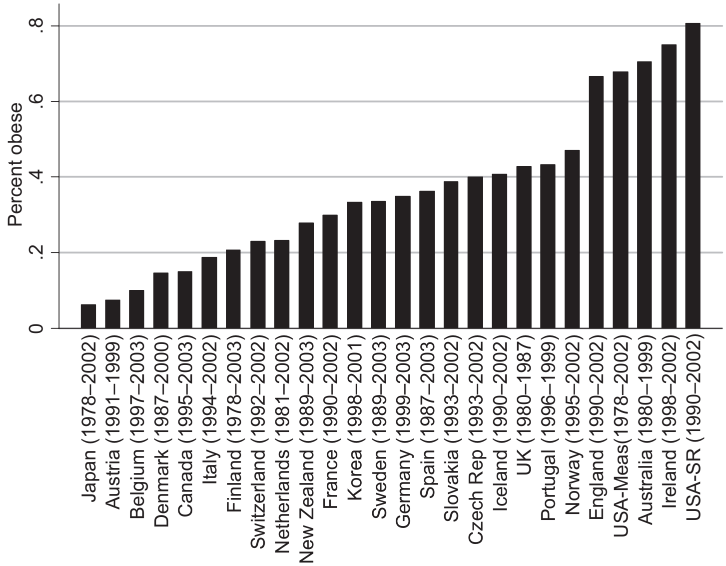

Figure 2

Average annual change in the percent obese. For detailed information about country surveys, see **http://www.ecosante.org/OCDEENG/814010.html**. Note: The years of available survey data differ by country. The United Kingdom and England have been separated on the graph because the most recent obesity data are not available for the entire country. "USA-Meas" refers to data from the National Health and Nutrition Examination Surveys (NHANES), and "USA-SR" refers to data from the Behavioral Risk Factor Surveillance Surveys (BRFSS). Source: OECD Health data (71).

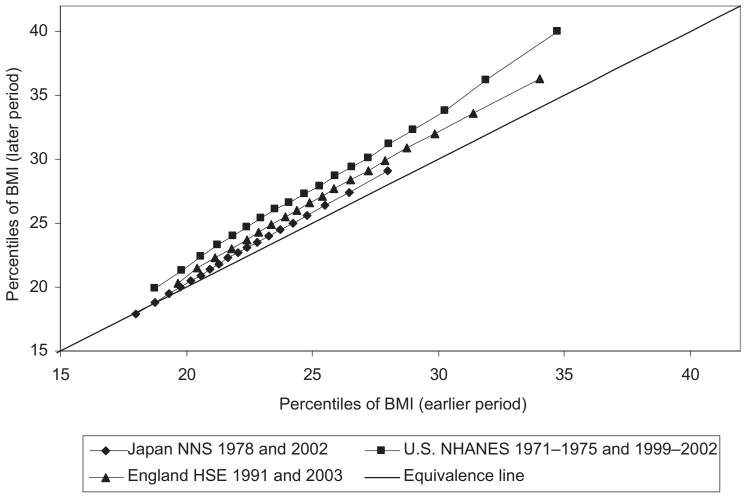

Figure 3

Changes in BMI percentiles over time: England, Japan, and the United States. Note: This figure shows the value for each BMI percentile in the distribution in an earlier survey period (x-axis) compared with the same BMI percentile of the distribution in a later survey period (y-axis). The 45° equivalence line is included to highlight the BMI percentiles demonstrating the largest changes over time. Source: Japan, National Nutrition Survey (NNS) (51, 52); England, Health Survey for England (HSE) (39); United States, National Health and Nutrition Examination Survey (NHANES) (12).

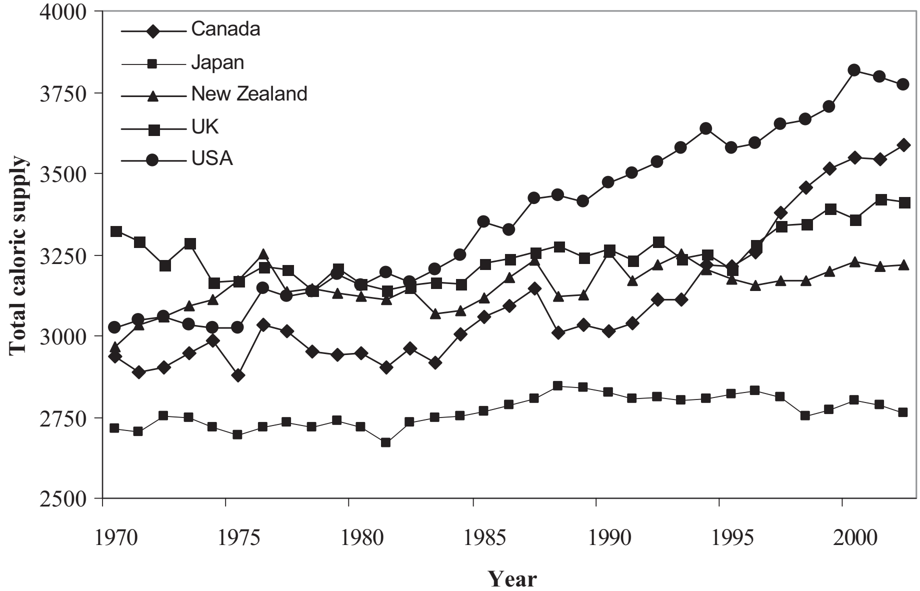

Figure 4

Trends in per capita daily energy supply, selected countries. Source: FAOSTAT (25).

caloric supply jumped by 190 kcal from 1985 to 2002 and by only 63 kcal from 1970 to 1984. Of the countries shown in **Figure 4**, Japan shows the most modest increases in caloric supply. This preliminary evidence suggests that trends in energy supply since mid-1980 may be of a sufficient magnitude to explain the rise in weight gain.

Part I: Energy In or Energy Out

Energy accounting. The findings from the first energy-accounting method are shown in **Figure 5**. The graph includes the results for the individual countries as well as the pooled model, represented by the last bar on the right. Excluding Australia and Finland, the portion of obesity due to increased calories

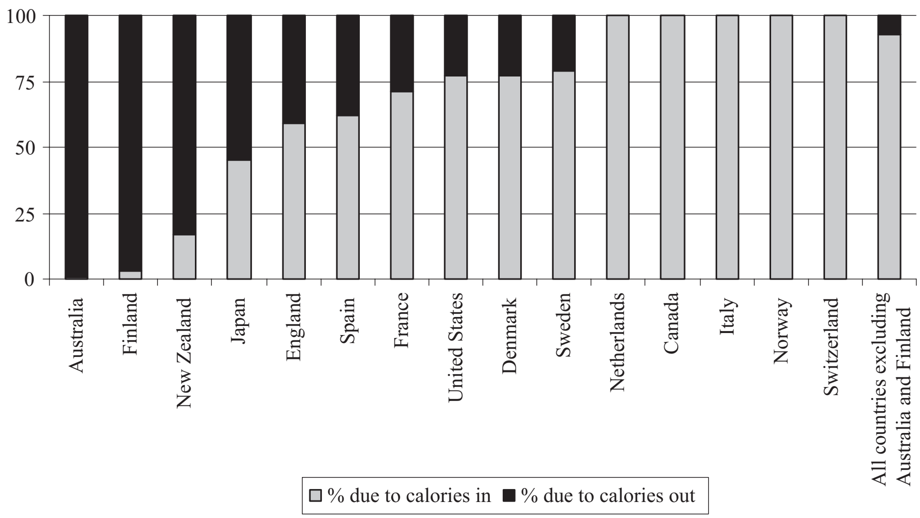

Figure 5

Attributable fraction of obesity due to calories in and calories out. For detailed information about country surveys, see **http://www.ecosante.org/OCDEENG/814010.html**. Source: FAOSTAT and OECD Health database (25, 71).

ranges from 17% in New Zealand to 100% in the Netherlands, Canada, Italy, Norway, and Switzerland, with almost all of the countries attributing 60% or more of their weight gain to dietary excess. The pooled model results, excluding Australia and Finland, suggest that calories account for 93% of the change in obesity from 1990 to 2002. The typical confidence interval for the percent change in obesity in a typical country is plus or minus 2%.

The patterns in Australia and Finland are puzzling because they suggest that decreased physical activity is the driving force behind obesity in these countries. Why do these two countries follow an opposite pattern? One explanation is that the patterns in Australia and Finland reflect a true reduction in physical activity. However, this is not supported by evidence on energy expenditure (**Table 2**) presented in the following section. An alternative explanation is that the caloric supply measures for these countries are unreliable. Individual-level dietary data from Australia (National Nutrition Survey) and Finland (National Public Health Institute) conflict with data from the FBS for the same time period (5, 57), indicating that the FBS from these two countries may lack face validity. For these reasons, we present the pooled result on the right-hand side of **Figure 5** without Australia and Finland.

Results from the model using a difference approach (i.e., outcome = change in obesity) show that an additional 100 calories was associated with a 1.6% increase in the percent obese ($\beta = 0.016$; 95% confidence interval 0.01 to 0.02). This increase suggests that countries with higher increases in food consumption have higher increases in obesity.

The results from the second energy-accounting method are shown in **Figures 6*a*** and ***6b***. This method evaluates the effect of additional weight from calories on obesity in the United States (**Figure 6*a***) and in England (**Figure 6*b***). From 1991 to 2000, caloric supply in the United States increased by 296 kcal, or a weight equivalent of 26 lbs, resulting in an estimated proportional weight gain of 19 pounds for those in the bottom percentile and ~40 pounds for those in the top percentile of BMI. We estimate the corresponding weight gain to be 26%, more than three times the actual increase (8%) from 1991 to 2000. We found a similar overestimation for England shown in **Figure 6*b***. There, caloric supply increased by 179 kcal from 1991 to 2002, which translated into 16 lbs or 7.1 kg. When we proportionately assigned this additional weight and recalculated BMI, we predicted an increase in obesity of 17%. The actual increase in obesity over the period was only 9%.

These discrepancies between the actual change in obesity and the predicted change in obesity for both the United States and the United Kingdom beg the question, why has obesity not risen as much as the models predict? A possible, but unlikely explanation is that people are exercising more over the respective periods. However, as we show in the following section, physical activity in the United States and United Kingdom has remained largely constant. Given these trends in energy expenditure, a more plausible explanation for the discrepancy we observe between the predicted level of obesity and the actual level of obesity is that the increase in food supply overstates the increase in food consumption. Thus caloric intake has not increased as much as has caloric supply. We calculate the overestimation of the change in caloric supply and find that the FBS data do overestimate consumption. This analysis is detailed in Appendix D in the Supplemental Material online.

International Evidence on Energy Expenditure

As a final piece of evidence to support our theory of dietary excess, we present available data on cross-country comparisons of changes in energy expenditure from 1990 to 2001 in **Table 2**. The allocation of time to each type of activity is remarkably stable over time and across countries. Where energy expenditure

Table 2 Evidence on trends in physical activity[a,b]

Country	Activity type	Hours 1990	Hours 2001	Δ in METS	Δ in kcal per day	Steady-state Δ in pounds	Δ% Obese
Australia	Highly active work	1.1	0.9				
	Less active work	2.5	2.7				
	Active leisure time	0.3	0.3				
	Everything else	20.1	20.1				
	Total	24	24	−0.9	55.3	3.25	1.66
Canada	Highly active work	1.1	1.0				
	Less active work	2.8	2.8				
	Active leisure time	0.4	0.5				
	Everything else	19.7	19.8				
	Total	24	24	−0.4	26.8	1.50	0.86
Finland	Highly active work	1.4	1.2				
	Less active work	2.2	2.3				
	Active leisure time	0.5	0.6				
	Everything else	19.8	19.9				
	Total	24	24	−1.1	69.9	3.47	1.98
Japan	Highly active work	1.5	1.3				
	Less active work	2.1	2.3				
	Active leisure time	0.8	1.3				
	Everything else	19.7	19.3				
	Total	24	24	−0.4	26.1	1.11	0.23
New Zealand	Highly active work	1.3	1.1				
	Less active work	2.3	2.4				
	Active leisure time	0.7	0.7				
	Everything else	19.7	19.8				
	Total	24	24	−0.7	43.9	2.19	1.25
United Kingdom	Highly active work	1.2	0.9				
	Less active work	2.4	2.6				
	Active leisure time	0.3	0.3				
	Everything else	20.1	20.2				
	Total	24	24	−1.3	82.7	4.79	3.10
United States	Highly active work	1.1	0.9				
	Less active work	2.7	2.9				
	Active leisure time	0.2	0.3				
	Everything else	20.0	19.9				
	Total	24	24	−0.7	47.1	2.78	2.12

[a]Notes: For United Kingdom, data on leisure time is for England only. Highly active work refers to agriculture, hunting, forestry, fishing, mining, quarrying (including oil production), manufacturing, construction, and public utilities. Less active work refers to wholesale and retail trade and restaurants and hotels; transport, storage, and communications; financing, insurance, real estate, and business services; and community, social, and personal services. Each activity was weighted by a MET score and an average number of hours per day. MET scores were obtained from the Compendium of Physical Activity (1). Detailed notes about the calculations for this table can be found in Appendix C in the Supplemental Material online. The time between which the change in calories turns into steady-state pounds is not known, but probably does not exceed a few months.
[b]Sources: World Development Indicators, LABORSTA database (35), Health Survey for England 1991 (39), Japanese National Nutrition Survey (51, 52), NHANES III (12).

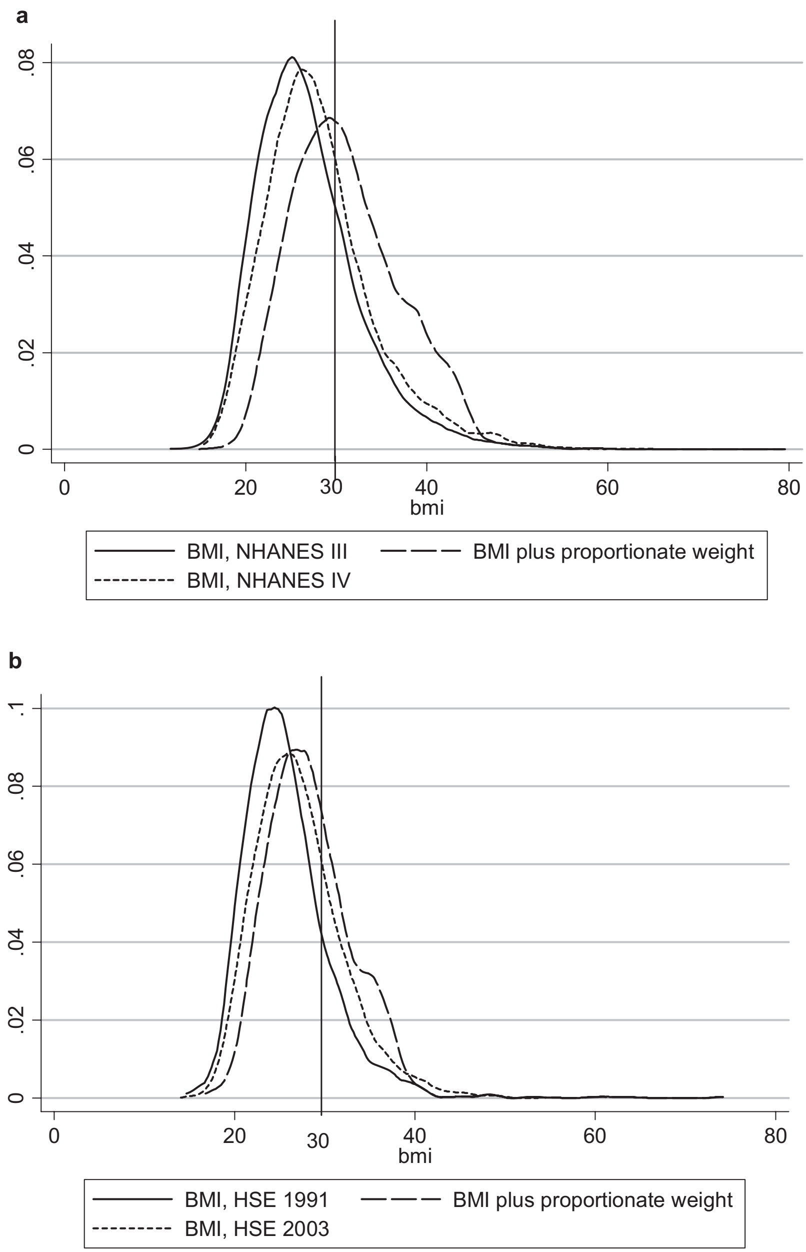

Figure 6

(*a*) Predicted and actual BMI: United States. Note: BMI plus proportionate weight is calculated from the formula $K = \alpha + (\beta + E)^{*}$ $Weight + 0.1^{*}\ K$, from Cutler et al. (14). Source: NHANES III and FAOSTAT (12, 25) (*b*) Predicted and actual BMI: England. Note: BMI plus proportionate weight is calculated from the formula $K = \alpha + (\beta + E)^{*}$ $Weight + 0.1 * K$, from Cutler et al. (14). Source: Health Survey for England 1991 and 2003, FAOSTAT (25, 39).

appears to have changed the most is with respect to highly active work, which is consistent with patterns observed worldwide (60). We observe the largest declines in highly active work in the United Kingdom and the lowest in Canada. Despite this variation, the changes in highly active work differ at most by 30 min between the countries, and research suggests that moderate-intensity activity of ∼45 to 60 min per day is required to prevent the transition to overweight or obese (66). The small changes we observe in highly active work are expected given that most of the shift away from manual labor occurred in the 1960s and 1970s, before the rapid rise in obesity (78). The importance of employment-related energy expenditure to weight gain is also challenged by the fact that obesity among children and the elderly has been rising in tandem with adult obesity, yet these two subgroups largely fall outside of the employment sector.

For each country, the total change in calories and total change in METs are small (**Table 2**). The effect of these changes in energy expenditure on weight gain is less than 3.5% for all countries (**Table 2**, column 5). For example, for the average 143-pound (65 kilogram) person in the United States, the decrease in physical activity was associated with a small 2.8-pound (1.3 kg) increase in weight, resulting in a rise in obesity of 2.1%. This is hardly sufficient to explain the 8% increase in obesity in the United States over that time period. Our finding of decreasing energy expenditure in the United States is supported by recent research suggesting that physical activity has, on average, declined for adults and children (10). Of note, the time between which the change in calories turns into steady-state pounds is not known but probably does not exceed a few months.

The results of our model relating several crude proxies of physical activity (the number of passenger cars per 1000, the number of Internet users per 1000, and the number personal computers per 1000) to the percent obese support our finding that declining energy expenditure is not the primary driver of excess weight gain. We found a significant inverse relationship between passenger cars per 1000 and percent obese ($\beta = -0.017$; $p < 0.0001$), which is the opposite direction we expected. This result is similar to a recent study of environmental and policy correlates of obesity in Europe (65). We found no effect of Internet users and personal computers users per 1000 on percent obese.

Part II: Drivers of the Energy Imbalance

The results of the OLS models of caloric supply as a function of technological innovations and changing sociodemographic factors are presented in **Table 3**. Simulated results are shown in the bottom two rows.

The first column shows the association between caloric supply and relative food prices, which is measured as the ratio of the food price index to the consumer price index. A ratio above one implies that food prices are increasing faster than the overall cost of living. We find a negative and statistically significant relationship between relative food prices and caloric supply ($\beta = -317.38$; $p < 0.0001$). Our results suggest that a decrease in the relative food price of 8%, equivalent to the change in the United States between 1980 and 2002, was associated with a corresponding higher caloric intake of 25 calories (0.08* 317). Across the developed world, average food prices fell by 12% from 1980 to 2002.

Model 2 (**Table 3**, column 2) examined the relationship between pricing freedom and caloric intake. We find no statistically significant relationship between pricing freedom and caloric intake.

Model 3 (**Table 3**, Column 3) explored the relationship between market entry and caloric supply. We find a positive and statistically significant relationship between the ease of starting a new business and caloric supply ($\beta = 19.73$; $p < 0.001$).

The results of the model investigating the association between female labor force participation (measured in percent) and caloric supply are presented in column 4. Female labor force participation is positively and significantly associated with caloric supply ($\beta = 7.05$; $p < 0.001$). A 10% increase in female labor force participation is associated with an increase of ~70 calories.

The last column in **Table 3** relates urbanization (measured in percent) and caloric supply. Urbanization is positively and significantly associated with caloric supply ($\beta = 11.25$; $p < 0.0001$).

The last two rows of **Table 3** report the results from the first difference analysis using Monte Carlo simulation. For these simulations, we consider how much caloric supply would change if we increased each

Table 3 Technological and social drivers of caloric intake (dependent variable: kilocalories)

Independent variables	1	2	3	4	5
Ratio fpi to cpi[d]	−317.38[c]				
	(85.06)				
Pricing freedom[e]		2.05			
		(8.37)			
Market entry[f]			19.73[b]		
			(9.5)		
% women working				7.05[b]	
				(3.37)	
% urban					11.25[c]
					(1.67)
GDP (PPP)	0.01[c]	0.01[a]	0.01[c]	0.01[b]	0.01[c]
	(0.00)	(0.01)	(0.03)	(0.01)	(0.00)
Constant	3134.98	2840.23	2758.12	3219.36	1881.30
	(104.75)	(121.40)	(159.77)	(68.05)	(146.18)
Observations	569	152	106	703	728
Adjusted R-squared	0.80	0.82	0.95	0.78	0.80
Simulated Δ (min and max)	1.5 → 0.5	0 → 10	0 → 10	0% → 100%	0% → 100%
Effect of Δ	−317 kcal	19 kcal	192 kcal	707 kcal	1127 kcal

[a]$p < 0.05$; [b]$p < 0.01$; [c]$p < 0.001$. Standard errors are in parentheses under the coefficients estimates. Standard errors <0.001 are reported as zero (0.00). Simulated results are estimated using the coefficients from the models. The values selected for the simulation represent the minimum and maximum for each independent variable.

[d]fpi (food price index); cpi (consumer price index).

[e]Measured on a scale from 0 to 10; where 0 indicates high government interference and 10 indicates little or no government interference.

[f]Measured on a scale of 0 to 10; low scores signify that countries have regulations which retard entry into the market place while high scores indicate ease of market entry.

Sources: FAOSTAT (25), OECD Health database (71), Economic Freedom of the World Index (29), and the World Development Indicators.

independent variable from its lowest value to its highest value. This action is useful for understanding the maximum change in caloric supply possible for each model. For example, if we look at column three, we can see that changing the ease with which businesses can enter into the market place from the most difficult [0] to the easiest [10] is associated with an increase of 192 calories. We observe the largest effect for urbanization. Increasing urbanization from 0% to 100% is associated with an increase of 1127 kcal.

Our results suggest that changes in consumption can be addressed through policy intervention. **Table 4** considers the impact of some potential policies based on the results of our analysis, which considered the possible drivers in increased caloric intake. The first column shows the impact of increased food prices on caloric supply. Specifically, a 12% increase in food prices is associated with a decrease of 38 calories. Although this caloric change may seem small, it would lead to a reduction of ∼3 pounds (1.5 kg) for a 143-pound (65-kg) person at a steady state. The second column relates market entry to caloric supply and indicates that the average 143 pound (65-kg) person would lose almost 4 pounds (1.6 kg) if entry into the market place was retarded by 20%. The third column shows the relationship between urbanization and

Table 4 Impact of potential policies

	Food prices	Market entry	Urban
Simulated Δ	↑ 12%	↓ 20%	↓ 5%
Effect of Δ	−38 kcal	−40 kcal	−56 kcal
Δ in weight for 143-lb (65 kg person)	−3.4 lbs	−3.6 lbs	−5.0 lbs

Notes: Values are estimated by Monte Carlo simulation using the coefficient values from **Table 3**. The predicted change in weight is calculated from the formula $K = \alpha + (\beta + E) * Weight + 0.1 * K$, from Cutler et al. (14).

caloric supply. Decreasing urbanization by 5% is associated with a decrease of 5 pounds (2.3 kg) for the average 143-pound (65-kg) person.

DISCUSSION AND CONCLUSIONS

The purpose of this exploratory study is to assess the relative impact of caloric intake and energy expenditure on the rising obesity epidemic in developing countries and to explore the drivers of the energy imbalance. The available data on energy expenditure, albeit limited, suggest that physical activity has declined but that the magnitude of the change is probably too small to explain most of the rise in adult obesity. With the exception of Australia and Finland, our analyses suggest that increased caloric intake is the driving force behind the growing obesity epidemic. However, we do not diminish the importance of energy expenditure to weight management and overall health.

Also, in our study, we examine two main mechanisms driving increases in caloric supply: technological innovations and changing sociodemographic factors. Technological innovations refer to those factors that reduce the costs associated with consumption and a sedentary lifestyle. We focus on technological innovations associated with consumption, given our finding that increased caloric intake is the primary driver of weight gain in the developed world. In particular, we consider relative food prices, the ease of businesses to enter the marketplace, and the ease with which businesses can set their own prices. In support of our hypothesis, we find lower relative food prices to be associated with increased caloric supply. Our analysis of technological and sociodemographic drivers of this energy imbalance indicates that certain characteristics of development (i.e., lower food prices, higher percentage of women working, increasing urbanization, and GDP) are associated with greater weight gain, even among developed nations.

Our results are consistent with recent U.S. evidence that the increase in adult weight gain is attributable primarily to overconsumption (50). In addition, evidence from two longitudinal studies, one using infants and the other using Pima Indians, found caloric intake to be the primary determinant of weight gain (72, 74). In contrast, research using food recall—during which time respondents detail everything they ate in the previous 24-h period—blames primarily physical inactivity for excess body weight (63). However, a major limitation of food recall data is underreporting, which makes it very difficult to capture an accurate picture of consumption (47, 62).

Our findings with respect to the drivers of overconsumption are supported by other research evidence (4, 7, 13, 14, 44, 49, 59, 61). Although we do not model the relationship between these factors and physical activity, changing sociodemographic characteristics such as increased urbanization have been linked to more sedentary lifestyles (59). Above and beyond the determinants of the energy imbalance explored in this study, the literature has also identified advertisements, television use, and limited access to healthy food options as important (27, 32, 34, 54).

Certain limitations of our analysis deserve discussion. We cannot draw causal inferences from this observational data analysis. Therefore, our conclusions are restricted to associations between factors. This article relies mostly on a country-level analysis, which prohibits us from accounting for the natural heterogeneity within populations and may limit our generalizability to individuals. In addition, using data from a variety of sources is both a strength and a weakness of this study. Lack of consistent data across countries required the use of data from different sources, resulting in measurement error, noncomparable measures, and unequal time periods for analysis. Furthermore, we had to use proxy measures for many of our key covariates because of the absence of direct measures at the country level. For example, the overestimation of actual BMI for England and the United States using the second energy accounting method indicates that caloric supply is a poor proxy for actual consumption.

Despite these limitations, our data consistently demonstrate that caloric supply, driven by changing technological and sociodemographic factors, is highly associated with the increase in obesity among the OECD countries. Our findings also highlight potential unintended consequences of positive societal trends such as increased food availability and increased participation of women in the workforce.

Our findings suggest that relatively small changes in the price of food (e.g., junk food tax) could slow the obesity trend. However, more research is needed to assess whether these programs disproportionately affect vulnerable populations (e.g., poor, adolescents) in areas where access to healthy foods is limited. Other strategies may include increased access to weight-loss services (e.g., bariatric surgery, pharmacological treatments, commercial weight-loss programs) and population-based interventions such as healthy eating programs, or price reductions of healthy foods (11, 26, 27, 37).

The uncertainties about the etiology and macro drivers of obesity remain chief barriers to our understanding of weight gain. As developed countries continue to develop and innovate, the factors associated with increased caloric intake identified in this research and elsewhere will likely increase, potentially making it increasingly more difficult for individuals to maintain a healthy weight. Additional research is necessary to understand better the questions explored in this study. An ideal study investigating the relative contribution of energy intake and energy expenditure to obesity would use comparable data on food consumption and total physical activity across countries and over time. This requires the development of accurate tracking systems. The field also needs more research within countries and subpopulations to improve our understanding of the drivers of the energy imbalance. Improved knowledge in this area will allow for the development of effective targeted and universal interventions.

However, improving the precision of our estimates and gaining a stronger understanding of the causes of obesity are necessary but not sufficient. The creation of effective interventions will require collaboration across a diverse set of stakeholders, including legislators, educators, the food and health industries, media, community organizations, researchers, and public health organizations. And the complexity of obesity dictates that the solution may not be simple. Without sustained commitment from the broader society and an improved understanding of its determinants, the prevalence of obesity itself and the associated morbidity and mortality from excess body weight are likely to rise.

SUMMARY POINTS

1. The rapid increase in obesity across the developed world suggests a common cause.
2. Increased caloric intake is primarily responsible for adult weight gain in developed countries.

3. The shift toward increased caloric intake is associated with technological innovations such as reduced food prices as well as changing sociodemographic factors such as increased urbanization and increased female labor force participation.
4. Efforts should be made to reduce consumption and encourage low-calorie diets.

FUTURE DIRECTIONS

1. The literature is in disagreement regarding the relative importance of the key dietary factors that have been most associated with obesity: high fat, energy-dense foods, and carbohydrate-rich foods with high sugar content. Going forward, research is needed to understand the differential impact of caloric type on weight gain.
2. Within-country analyses are needed to understand better the key factors driving increased consumption in the developed world.
3. Accurate tracking systems of food consumption and physical activity that are comparable across countries and over time are needed to understand better the relative contribution of energy intake and energy expenditure to weight gain.
4. A diverse set of stakeholders must collaborate to allow for the development of creative policy alternatives and effective interventions to reduce the obesity epidemic.

DISCLOSURE STATEMENT

The authors are not aware of any biases that might be perceived as affecting the objectivity of this review.

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