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A system dynamics model of the nutritional stages of the Colombian population

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Abstract

Purpose – Overweight, obesity, and physical inactivity have in recent years become an important public health problem worldwide. Investigations that study obesity using a systemic approach in low- and middle-income countries (LMICs) are limited. Therefore, the purpose of this paper is to study the nutritional stages dynamics within the Colombian urban population.

Design/methodology/approach – The authors used a population-level systems dynamics (SD) model that captures the transitions of population by body mass index (BMI) categories. The authors proposed a heuristic to estimate the transference rates (TRs) between BMI categories using data from the Colombian Demographic and Health Survey 2005 and 2010.

Findings – The Colombian urban population is moving to overweight and obese categories. The TRs from not overweight to overweight and from overweight to obese (0.0076 and 0.0054, respectively) are higher than the TRs from obese to overweight and from overweight to not-overweight ($1.025 \times 10e{-7}$

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and 3.47 × 10e−7, respectively). The simulation results show that the prevalences of overweight and obesity will increase by 6.2 and 7.5 percent by 2015, and by 13.4 and 18.9 percent by 2030, respectively.
Originality/value – Investigations that study obesity using a systemic approach in LMICs are limited. A SD model was proposed to examine changes in the population's nutritional stages using population accumulation structures by BMI categories. The authors propose a heuristic to estimate the TRs of individuals between BMI categories. The proposed model can be used to study the effects of policy interventions to prevent overweight and obesity. The authors analyze a few policy intervention strategies.

Keywords Public health, Mathematical modelling, Obesity, System dynamics, Behaviour science, Nutritional stages

Paper type Research paper

1. Introduction

Overweight, obesity, and physical inactivity have in recent years become an important public health problem worldwide (Ng *et al.*, 2014; Swinburn *et al.*, 2011). These are risk factors associated with non-communicable diseases (NCDs) like diabetes, cancer, and cardiovascular diseases (Calle *et al.*, 1999; Eriksson, 2007; Fontaine *et al.*, 2003; Pate *et al.*, 1995; Wilson *et al.*, 2002). Between 2001 and 2004, these factors have gone from seventh and eighth to among the top five leading risk factors of attributable death in the world, with a higher mortality in low- and middle-income countries (LMICs) (World Health Organization, 2008). Furthermore, the prevalence of overweight and obesity has risen in the last years with different dynamics across regions, countries, and sexes (Ng *et al.*, 2014). According to Ng *et al.* (2014) the proportion of overweight or obese adults has increased from 28.8 percent in 1980 to 36.9 percent in 2013 in men, and from 29.8 to 38 percent in women worldwide. In the case of children and adolescents, between 1980 and 2013, the prevalence of overweight and obesity has increased from 16.9 to 23.8 percent in boys, and from 16.2 to 22.6 percent in girls in high-income countries (HICs). In the case of LMICs, the increased was from 8.1 to 12.9 percent in boys, and from 8.4 to 13.4 percent in girls (Ng *et al.*, 2014). In fact, countries experiencing rapid-urbanization, globalization of food systems, and nutrition transition processes have contributed to shift the global burden of NCDs from HICs to LMICs (Lopez *et al.*, 2006).

In this respect, Latin American countries are also experiencing an increase in the prevalence of overweight and obesity (Ng *et al.*, 2014). In the case of Colombia, according to (Ng *et al.*, 2014) the prevalence of overweight and obesity combined has increased in 63 percent for men, 22 percent for women, 50 percent for boys, and 17 percent for girls between 1980 and 2013. As a consequence, Latin American countries are suffering a shift in the burden of chronic diseases due to demographic and nutritional transitions, with significant changes in diet and lifestyle (Gaziano, 2005). The rate of mortality due to NCDs, mainly cardiovascular diseases and cancers, has increased during the last years (Cuevas *et al.*, 2009). In Colombia, chronic diseases, in particular cardiovascular diseases, are the main causes of morbidity and mortality among the male and female adult populations. According to the Colombian National Department of Statistics (Departamento Administrativo Nacional de Estadística (DANE)), 63 percent of adult mortality is due to chronic diseases (Departamento Administrativo Nacional de Estadística, 2005).

The high prevalence of overweight, obesity, and physical inactivity has an important effect on annual health-care costs of countries. They have effects on the costs of public health systems, the sustainability of retirement pension systems, and economic and social stability (Colditz, 1999; Gobierno Federal, 2010; Thorpe *et al.*, 2004). For instance, Finkelstein *et al.* (2003) estimated that overweight and obesity-attributable medical spending accounted for 9.1 percent of total annual US medical expenditures in 1998. Other studies reported that obese and overweight individuals have higher annual health-care costs than normal-weight individuals (Thompson *et al.*, 2001; Thorpe *et al.*, 2004; Zarate *et al.*, 2009).

In Latin America the health care costs associated with obesity, overweight, and physical inactivity are significant. In Mexico, people who develop diseases related to overweight and obesity live an average of 14.5 years in a sick state, and their life expectancy is reduced by seven years. Furthermore, the estimated direct cost resulting from the medical care associated with diseases related to overweight and obesity increased by 61 percent between 2000 and 2008. In 2008, that cost represented 33.2 percent of the federal spending for health services. Additionally, the indirect costs of the lost productivity due premature death attributable to overweight and obesity have increased from approximately US$0.95 billion in 2000 to US$2.4 billion in 2008 (Gobierno Federal, 2010). Likewise, Zarate *et al.* (2009) showed that annual health care costs for obese workers in a mining company in Chile were 17 percent higher than those of normal-weight workers, and they took 25 percent more days of sick leave per year.

Hence, the obesity and associated consequences have become a challenging public health problem due to the diversity of actors with different motivations (families, schools, retailers, industry, government agencies, the media, health-care providers, and city planners, among others), who interact to produce a variety of outcomes at the different levels and scales involved (genes, neurobiology, psychology, family structure, social context and social norms, environment, markets, and public policy) (Hammond, 2009); and different complex factors (food and physical, cultural, or economic environment) with linkages and feedbacks between them that influence the development of obesity in individuals; that impact the success or failure of the prevention efforts (Huang *et al.*, 2009; Karanfil *et al.*, 2011). The previous features are classic characteristics of a complex system in which a large number of internal and external elements affect the dynamics of the system in nonlinear and unexpected manners; therefore, it is natural to expect that the obesity and its associated features can be studied using a complex-system approach (Hammond, 2009).

Although different researchers have studied the obesity and its associated features using statistical analysis (Dearth-Wesley *et al.*, 2008; Dinsa *et al.*, 2012; Martorell *et al.*, 2000; McLaren, 2007; Monteiro *et al.*, 2000, 2004a, b, 2007; Ng *et al.*, 2014; Popkin *et al.*, 2012; Swinburn *et al.*, 2011; Wang and Lim, 2012), researches that study this problem using complex system approaches are limited (Dangerfield and Zainal Abidin, 2010). In particular, the researches that have been studying the obesity dynamics and its associated features tend to adopt one of three different frameworks: system dynamics (SD) (Dangerfield and Zainal Abidin, 2010; Abdel-Hamid, 2003; Flatt, 2004; Homer *et al.*, 2006; Dangerfield and Norhaslinda, 2011; Karanfil *et al.*, 2011; Rahmandad, 2012; Rahmandad and Sabounchi, 2012; Karanfil, 2009; Sabounchi *et al.*, 2014; Fallah-Fini *et al.*, 2014), network analysis (Christakis and Fowler, 2007; De la Haye *et al.*, 2010; Sawka *et al.*, 2013), and agent-based modeling (ABM) (Auchincloss *et al.*, 2011; Phillips, 1999). Particularly, at the population level, which is the interest of this research, Rahmandad and Sabounchi (2011) built individual SD models for both childhood and adulthood to capture the energy balance and weight change throughout the individuals' lives and aggregated these individual models to population-level trends. Similarly, Homer *et al.* (2006) studied changing obesity trends on the entire US population, using four BMI categories in conjunction with the annual aging of population cohorts. However, investigations that study the obesity dynamics using a systemic approach in LMICs are limited. Therefore, the purpose of this research is to study and model the nutritional stages dynamics, separated in body mass index (BMI) categories (e.g, not overweight, overweight, and obese), within the Colombian urban population using a SD model. In particular, we propose a model that can be used to: study the dynamics of the prevalences of overweight and obesity over time; and estimate the transference rates (TRs) between BMI categories.

2. Methods

Hence, to study the nutritional stages dynamics within the Colombian urban population, we propose a population-level SD model that captures the transitions of population by BMI categories. We then propose a heuristic to estimate the TRs between BMI categories using data from the Colombian Demographic and Health Survey (*Encuesta Nacional de Demografía y Salud* (*ENDS*)) (Profamilia, 2005) and (Profamilia, 2010).

Model of the nutritional stages dynamics of population

The model propose in this work seeks to understand the nutritional stages dynamics of the Colombian urban population. The model includes accumulation structures for three BMI categories (not overweight, overweight, and obese). The population was classified into each BMI category according to the 2006 WHO child growth standards for children under five (World Health Organization, 2006), 2006 WHO child growth references for children 5-17 (De Onis *et al.*, 2007), and WHO cutoff points for adults $\geqslant$18 years (Author, 1998). For children and adolescents aged 0-17 years, the WHO system defines not overweight as a BMI for age and sex *z*-score $\leqslant 1$ standard deviation, overweight as a BMI for age and sex *z*-score > 1 standard deviation and $\leqslant 2$ standard deviations, and obese as a BMI for age and sex *z*-scores > 2 standard deviations. For adults, the WHO system defines not overweight as a BMI $< 25\,\mathrm{kg/m^2}$, overweight as a BMI $\geqslant 25$ and $< 30\,\mathrm{kg/m^2}$, and obese as a BMI $\geqslant 30\,\mathrm{kg/m^2}$. The accumulation structures of population also includes births and deaths for each BMI category. We used nationally representative data from ENDS for individuals of urban areas aged 0-59 years to calculate the distributions of BMI categories (Profamilia, 2005).

The mathematical form of the model is as follows:

$$\frac{dN(t)}{dt} = B_N(t) + \tau_4 W(t) - \tau_1 N(t) - E^N(t)(1-S) - E^N(t)S \tag{1}$$

$$\frac{dW(t)}{dt} = B_W(t) + \tau_1 N(t) + \tau_3 O(t) - W(t)(\tau_2 + \tau_4) - E^W(t)(1-S) - E^W(t)S \tag{2}$$

$$\frac{dO(t)}{dt} = B_O(t) + \tau_2 W(t) - \tau_3 O(t) - E^O(t)(1-S) - E^O(t)S \tag{3}$$

where $N(t)$, $W(t)$, $O(t)$ are the population of not-overweight, overweight, and obese individuals, respectively at time t (people); B_N, B_W, B_O are the births for each BMI category (people per year); E^N, E^W, E^O are the exit rates of individuals per year for each BMI category at time t (people per year); and S is the survival fraction. We consider the population up to a maximum age of 60 years, so that people reaching this age exit the system. The exit rate is the total number of individuals per year that mature to the next age (60 ages) by BMI category and is divided into two flows: those who mature into the next age S and those who die $(1-S)$. The parameters τ_1 and τ_2 are the TRs, which corresponds to the fraction of individuals per year from the not overweight and the overweight categories that become overweight and obese, respectively. The parameters τ_3 and τ_4 are the TRs of individuals from the obese to the overweight category and from the overweight to the not overweight category, respectively (see the flow diagram of Figure 1 for a global view of the mathematical model).

The number of births per year by each BMI category is given by (Sterman, 2000):

$$B_N(t) = \mu\theta_N\left(\frac{f(t)}{(Y_F - Y_I + 1)}\right)(N(t) + W(t) + O(t)) \tag{4}$$

$$B_W(t) = \mu\theta_W\left(\frac{f(t)}{(Y_F - Y_I + 1)}\right)(N(t) + W(t) + O(t)) \tag{5}$$

$$B_O(t) = \mu\theta_O\left(\frac{f(t)}{(Y_F - Y_I + 1)}\right)(N(t) + W(t) + O(t)) \tag{6}$$

where μ is the total fraction of woman in the population in reproductive ages (15-49); θ_N, θ_W, θ_O are the fractions of births by each BMI category; f is the total number of children born from each woman during the childbearing years (fertility rate) at time t (births for each woman); the ratio $\left(f(t)/(Y_F - Y_I + 1)\right)$ is the average number of births per woman per year during childbearing years; and Y_I and Y_F are the first and last childbearing years considered, respectively. In this case, we assumed the childbearing years to be ages 15-49.

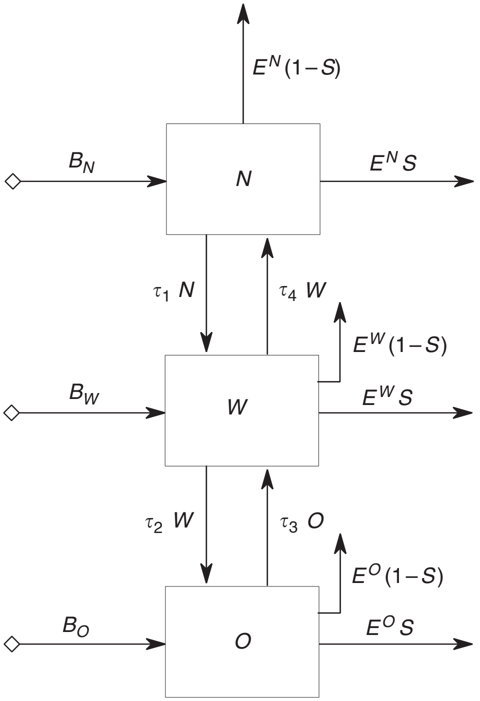


Figure 1.
Overview of the population accumulation structures by BMI category

The exit rates per year by each BMI category are modeled as (Sterman, 2000):

$$E^{N}(t) = DELAY1(B_N(t) + \tau_4 W(t) - \tau_1 N(t), Y) \tag{7}$$

$$E^{W}(t) = DELAY1(B_W(t) + \tau_1 N(t) + \tau_3 O(t) - W(t)(\tau_2 + \tau_4), Y) \tag{8}$$

$$E^{O}(t) = DELAY1(B_O(t) + \tau_2 W(t) - \tau_3 O(t), Y) \tag{9}$$

where DELAY1 function represents a first-order material delay using an exponential delay time of delay duration Y. In this case, the delay time was $Y = 60$ years consistent with the 60 year size of the population in the accumulation structures. Finally, the survival fraction is given by (Sterman, 2000):

$$S = exp(RY) \tag{10}$$

In this formulation, R is the mortality rate per year. We assume that the mortality rate is the same for each BMI category.

Details of the source of the data for the model is described in Table I. We conducted data processing in SAS, version 9.3 (SAS Institute Inc., Cary, NC, USA) and Mathematica, version 9.0.1 (Wolfram research, Inc.). We conducted all simulations in iThink software, version 9.0.2 (ISEE systems, Inc.).

Additionally, we propose four attributes that can have an effect on the TRs between BMI categories: leisure time physical activity (LTPA), transportation physical activity (TPA), consumption of processed foods and sugar drinks (PFSD), and screen time (ST) (Figure 2, Table II). We chose these four attributes because, according to the literature

Table I. Data sources used in the model[a]

Item	Data source
Prevalence rates by BMI category	
Height-for-age *z*-score and BMI for age and sex *z*-score for children and adolescents 0-17	ENDS (2005-2010)
BMI category prevalence by age	
Population composition	
Population size aged 0-59	DANE. Estimations and population projections 1985-2020 (Departamento Administrativo Nacional de Estadística (DANE), nd)
Mortality rate (0-59)	DANE. Vital Statistics (2005) (Departamento Administrativo Nacional de Estadística (DANE), nd)
Fertility rate	World Data Bank. World Development Indicators. (2005-2012) Projections for 2013-2030. Forecast series using the Holt-Winters no seasonal method in EViews 5 (Quantitative Micro Software, LLC)
Fraction of births by BMI category	ENDS (2005)

Notes: [a]ENDS, Colombian Demographic and Health Survey; DANE, Colombian National Department of Statistics (for the Spanish acronym); WHO, World Health Organization; BMI, body mass index

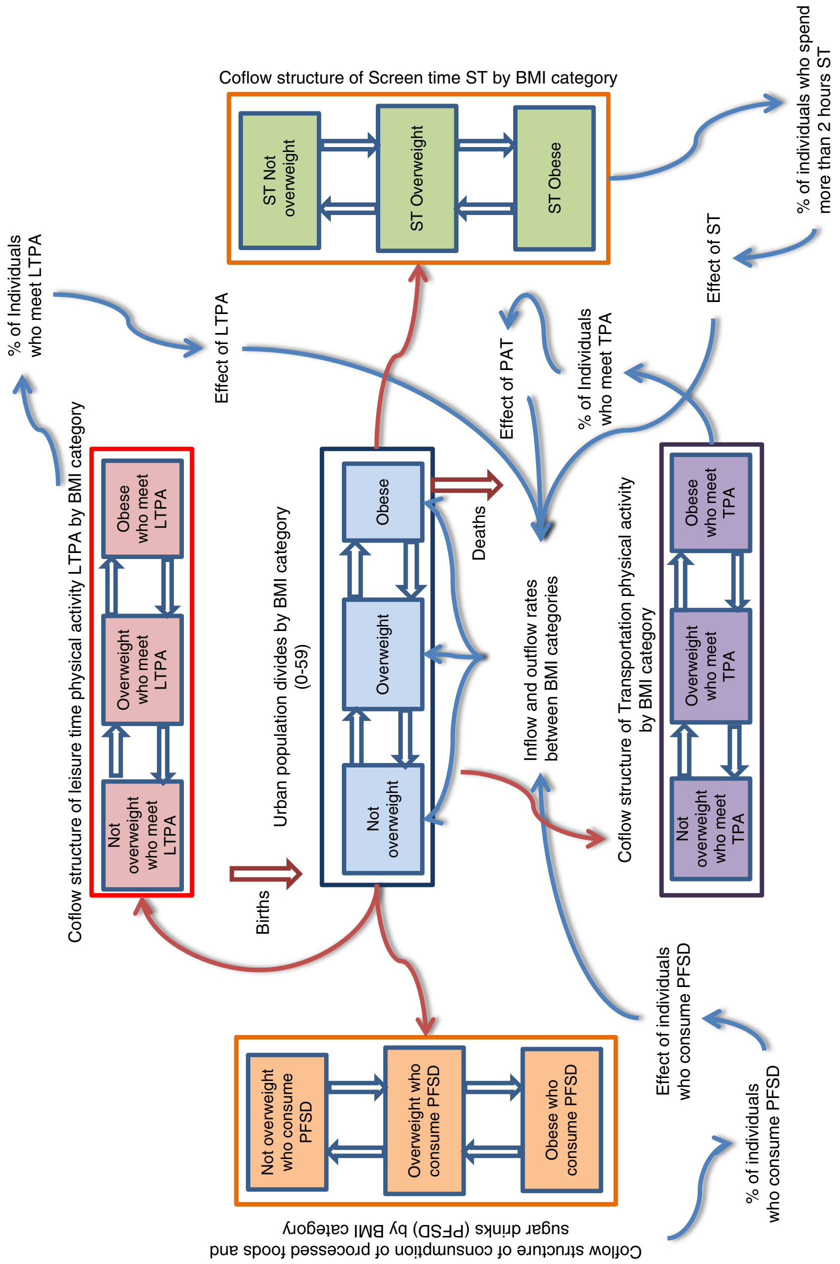


Figure 2.
Overview of the model structure

review, these factors are important variables associated with obesity and the nutritional transition (Popkin, 2009; Popkin *et al.*, 2012; Schmidhuber and Shetty, 2005). These attributes are modeled using coflow structures due to the importance of keeping track of them as the individuals travel through the system's stock and flow structure (Sterman, 2000). The coflow for each attribute is a stocks and flows structure that exactly replicate the population accumulation structure to keep track of the attribute of individuals in each BMI category. The coflow structures used in this model are conserved (Sterman, 2000), i.e., the attribute stocks by BMI category can only change when individuals travel through the population accumulation structures by BMI categories. The average values of the coflow structures (attributes) have an effect on the TRs between the BMI categories. The average value of a coflow structure by each BMI category is the total attribute level divided by the total number of individuals in the corresponding stock of the population accumulation structure. Here, there are different feedback structures between the population accumulation structures by BMI categories and the coflows by each attribute. For example, the coflow structure of LTPA attribute track the number of individuals who meet the requirements of LTPA as persons move between the BMI categories. And the average values of the LTPA coflow structure (percentages of individuals who meet the requirements of LTPA) by BMI category have an effect on the TRs between BMI categories of the population accumulation structures (Figure 2). The conceptualization of the complete model is shown in Figure 2 (Table II). We do not take into account in the simulation the coflow structures of the four attributes LTPA, TPA, PFSD, and ST, because in the ENDS and the National Nutrition Survey in Colombia (name Encuesta Nacional de la Situación Nutritional en Colombia (ENSIN)) (Instituto Colombiano de Bienestar Familiar (ICBF), 2005, 2010) the information of these attributes were not collected for all BMI categories and ages. Therefore, we do not have data to run the complete model.

Estimation of transferences rates between BMI categories

To calibrate the model, we estimated the TRs by BMI categories using 2005 and 2010 data from the ENDS survey. We initialize the model by using the distribution of BMI categories from ENDS 2005. We propose a heuristic to calculate the TRs between BMI categories. The heuristic seeks to find the TRs that minimize the

Attribute/coflow	Definition	Data sources/literature
Leisure time physical activity (LTPA)	Number of individuals who meet the requirements of leisure time physical activity (150 min/week)	ENSIN 2010 WHO. Global recommendations on physical activity for health. Geneva: World Health Organization; 2010
Transportation physical activity (TPA)	Number of individuals who meet the requirements of physical activity associated with transport (150 min/week)	
Consumption of processed foods and sugar drinks (PFSD)	Number of individuals who consume frequently (three or more times for week) processed foods and sugar drinks	ENSIN 2010
Screen Time (TP)	Number of individuals who spend more than 2 of hours watching television, playing video games, or browsing the internet	ENSIN 2010

Table II. Attributes used to model the coflow structures by BMI category and age group difference between the prevalence rates by BMI categories and the estimated prevalences. To calculate the TRs by BMI category we built the following system of equations:

$$P' = B.P \tag{11}$$

where:

$$B = A.(A.(A.(A.A)))$$

$$A = \begin{pmatrix} \alpha_1 - \tau_1 & \tau_4 & 0 \\ \tau_1 & \alpha_2 - \tau_2 - \tau_4 & \tau_3 \\ 0 & \tau_2 & \alpha_3 - \tau_3 \end{pmatrix};\ P' = \begin{pmatrix} p'_{N10} \\ p'_{W10} \\ p'_{O10} \end{pmatrix};\ P = \begin{pmatrix} P_{N05} \\ P_{W05} \\ P_{O05} \end{pmatrix}$$

where $P_{N05}, P_{W05}, P_{O05}$ are the prevalence rates by BMI category of the population aged 0-59 in 2005; $\alpha_1, \alpha_2, \alpha_3$ are the retention rates for individuals by BMI category, which corresponds to the fraction of individuals who stay in the same BMI category between 2005 and 2010; τ_1 and τ_2, respectively, are the TRs of individuals from not overweight to overweight and from overweight to obese; τ_3 and τ_4, respectively, are the TRs of individuals from obese to overweight and from overweight to not overweight; and $p'_{N10}, p'_{W10}, p'_{O10}$ are the estimated prevalence rates by BMI category of the population aged 5-64 in 2010, five years later. We suppose that the individuals aged 5-64 in 2010 are the same individuals aged 0-59 in 2005. The system of Equations (11) is solved by minimizing the following equation:

$$Min\ SC = \left(P_{N10} - p'_{N10}\right)^2 + \left(P_{W10} - p'_{W10}\right)^2 + \left(P_{O10} - p'_{O10}\right)^2, \tag{12}$$

with the restrictions:

$$\begin{gathered} \alpha_1 + \tau_1 = 1 \\ \alpha_2 + \tau_2 + \tau_4 = 1 \\ \alpha_3 + \tau_3 = 1 \\ 0 \leqslant \alpha_k \leqslant 1, \quad (k = 1, 2, 3) \\ 0 \leqslant \tau_l \leqslant 1, \quad (l = 1,\ 2,\ 3,\ 4) \end{gathered} \tag{13}$$

where $P_{N10}, P_{W10}, P_{O10}$ are the prevalence rates by BMI category of the population aged 5-64 in 2010 from ENDS. To minimize Equation (12) and calculate the TRs, we use the FindMinimum function in Mathematica 9, which searches for a local minimum in a function for several variables and constraints.

3. Results

Nutritional stage dynamics of Colombian urban population

Using the heuristic described previously and data from ENDS 2005 and 2010, we estimated the TRs between BMI categories. The results showed that the Colombian urban population is moving to overweight and obese categories. The TRs from not overweight to overweight and from overweight to obese was $\tau_1 = 0.0076$ and $\tau_2 = 0.0054$, respectively. Additionally, the estimated TRs show that Colombian population is not moving to a healthy weight. The TRs from obese to overweight and from overweight to not-overweight are almost zero. The retention rates of individuals by BMI category (α_1, α_2, α_3) were close to 1, and consistent with the restrictions mentioned above.

With the model just constructed, we use the estimated TRs to model the nutritional stages dynamics of the population from 2005 to 2030. We take 2005 as the initial condition. The result of the simulation show that the prevalences of overweight and obesity increase from 27.1 and 11.5 percent in 2005 to 30.7 and 13.6 percent by 2030, respectively (Figure 3). Figure 3 shows that simulated curves of BMI categories closely replicate the observed prevalences in 2010. The differences are mainly minimizing errors and variations in the overall population.

Simulation of the effect of interventions on the nutritional stage dynamics

We conduct simulations to show the potential of the proposed model for testing the effectiveness of policy interventions related to overweight and obesity. In particular, we simulate the effect of three interventions: first, the TR from overweight to not overweight is changed from $3.47 \times 10e{-7}$ to a value of 0.02 from 2011 to 2030; second, The TR from obese to overweight is changed from $1.025 \times 10e{-7}$ to a value of 0.02 from 2011 to 2030; and finally, the TRs from obese to overweight and from overweight to not overweight are changed from $1.025 \times 10e{-7}$ and $3.47 \times 10e{-7}$, respectively, to a value of 0.01 from 2011 to 2030. The results of scenario 1 show that the prevalence rates of overweight and obesity are reduced in 7.7 and 0.24 percent by 2015, and 23.2 and 2.7 percent by 2030, respectively, compared with the base scenario (Figure 4(a)). The results of scenario 2 show that the prevalence rate of overweight is increased in 3.29 percent by 2015 and 22.2 percent by 2030, respectively, while the prevalence rate of obesity is reduced in 7.8 percent by 2015 and 26.5 percent by 2030, respectively, compared with the base scenario (Figure 4(b)). Finally, the results of scenario 3 show that the prevalence rates of overweight and obesity are reduced in 2.26 and 4.13 percent by 2015, and 5.7 and 14.3 percent by 2030, respectively, compared with the base scenario (Figure 4(c)). In general, the results show that there is different effects on the prevalence of overweight and obesity over time, depending where we intervene the system.

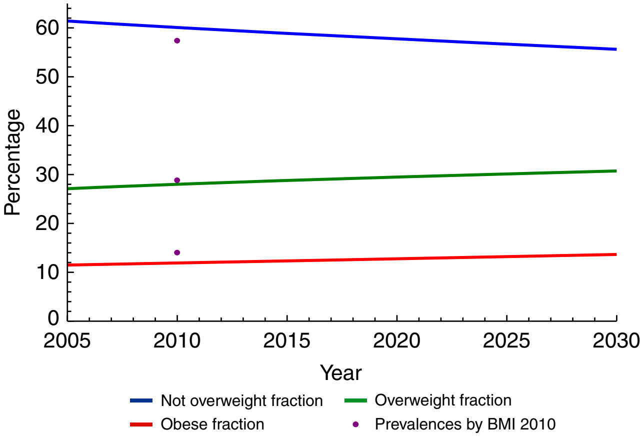
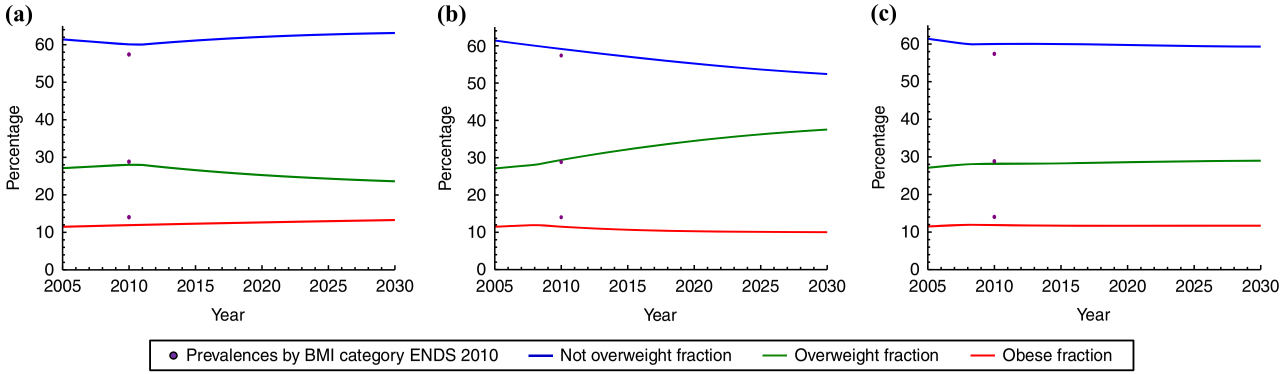


Figure 3.
Estimated fractions of the population by BMI categories over time



Notes: (a) The TR from overweight to not overweight is changed from 3.47×10e−7 to a value of 0.02 from 2011 to 2030; (b) the TR from obese to overweight is changed from 1.025×10e−7 to a value of 0.02 from 2011 to 2030; (c) the TRs from obese to overweight and from overweight to not overweight are changed from 1.025×10e−7 and 3.47×10e−7, respectively, to a value of 0.01 from 2011 to 2030

Figure 4.
Estimated fractions of the population by BMI categories over time for three scenarios

4. Discussion

Obesity is a growing epidemic and, in recent years, has emerged as a one of the major challenges in public health (Ng *et al.*, 2014). In this context, the analysis of the nutritional stages dynamics at population level is crucial. From the systemic approach, this study shows that Colombian urban population is moving to overweight and obese categories. The TRs toward overweight and obese categories are higher than the TRs toward the not overweight category. In general, Colombian population is not moving to a healthy weight. In fact, the simulation results show that the prevalences of overweight and obesity will increase in 6.2 and 7.5 percent by 2015, and 13.4 and 18.9 percent by 2030, respectively, if the estimated TRs do not change.

These findings are consistent with the results found by Ng *et al.* (2014), who showed that the proportion of overweight and obesity population in Colombia is on the rise. In fact, they estimated that the prevalence of overweight and obesity combined has increased in 20 percent for men, 6 percent for women, 16 percent for boys, and 0 percent for girls between 2000 and 2013. Additionally, our results are consistent with the results of the prevalences of overweight and obesity of the Colombian urban population aged 0-59 reported in the ENDS and ENSIN surveys in 2010. According to these data, the prevalences of overweight and obesity has increased in 6 and 21.5 percent, respectively between 2005 and 2010 (Profamilia, 2005, 2010).

The proposed model offer a tool for researchers to model the obesity dynamics, a complex public health issue. In fact, it employs accumulation structures (stock and flow relationships) by three BMI category (not overweight, overweight, and obese) to study the nutritional stages dynamics of a population. Accumulation structures allow the characterization of the system and provide the information to support the decisions and actions to be taken (Sterman, 2000). Additionally, the proposed model takes into account the feedback structures that there are between population accumulation structures by BMI categories and the coflows by each attribute. The model could be used to understand the effects of LTPA, TPA, PFSD, and ST on the nutritional stages dynamics of a population. The complex behavior of a system normally arises over time from the interactions (feedbacks) among its components (Sterman, 2000). Furthermore, the proposed model can be used to study the effects of policy interventions to prevent overweight and obesity. In particular, opens the possibility to test the effect of policy interventions by BMI category, such as interventions on the TRs rates between BMI categories.

Additionally, the proposed model has some differences from the other SD models that have been developed to study the obesity dynamics and its associated features at the population level. First, this study seek to understand the nutritional stages dynamics of Colombian urban population (population aged 0-59 years), which is a middle income country, with a high burden of NCDs. Investigations about the obesity dynamics at population level using a systemic approach have been developed, particularly, in HICs (Dangerfield and Zainal Abidin, 2010; Fallah-Fini *et al.*, 2014; Homer *et al.*, 2006). Second, we proposed a heuristic that minimize the difference between the prevalence rates and the estimated prevalences by BMI categories to estimate the TRs of individuals between BMI categories. In contrast, Homer *et al.* (2006) used a method to estimate the flow rates between BMI categories. They proposed an equation that takes into account the cut-points for BMI categories, the median BMI within each BMI category, and the median height, to translate the change in caloric balance into a change in a flow rate.

The proposed model present some limitations. Due to the lack of longitudinal data to trace the growth of individuals by BMI categories, we only used data from ENDS 2005 and 2010 to estimate the TRs between BMI categories. In future studies, it is important include data of the next ENDS 2015 to validate the heuristic. Although we showed that the model can be used to study the effects of public health interventions to prevent overweight and obesity, it was developed to study the nutritional stages dynamics of a complete population. Futures studies should focus on understanding how the nutritional stages dynamics can be separated by different age and socioeconomic status (SES) groups with the purpose to identify risk subgroups of the population (e.g. by BMI category, age, and SES) that ought to be targeted. Another limitation is that in this work we could not assess the effect of the four attributes LTPA, TPA, PFSD, and ST on the TRs between BMI categories because in the ENDS and ENSIN surveys the information of these attributes was not collected for all BMI categories and ages. The next ENDS and ENSIN surveys, for which the collecting data is planned for 2015, will measure the different factors associated with physical activity, consumption of food, and sedentary behaviors for the all ages. Futures studies could include these data to assess the effects of these attributes on the TRs.

In conclusion, the prevalences of overweight and obesity of Colombian urban population, as it is worldwide, are increasing over time. In this study, we proposed a SD model that offer an innovative tool to policy makers to help understanding the nutritional stages dynamics at population level. In particular, it can be used to study and track the changes on the dynamics of the prevalences of BMI categories over time. In addition, the model can be used as a guide to analyze the effects of public health interventions on the TRs rates between BMI categories.

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