Supplementary Information 3

Supplement to: Using a system dynamics model to understand the obesity transition by socioeconomic status in Colombia at the country, regional, and department level.

Meisel JD, *et al. BMJ Open* 2020; 10:e036534. doi: 10.1136/bmjopen-2019-036534

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Section 1. Model of nutritional stage dynamics

We developed a population-level system dynamics (SD) model which was based on a validated and calibrated model [1,2]. We used the following set of mathematical forms to study the obesity dynamics by socioeconomic status (SES) and gender at the country level. Specifically, equations (1-3) which correspond to the net rate of change of the population in each body mass index (BMI) category for the age group of zero to four years and equations (4-6) which correspond to the net rate of change of the population in each BMI category for the rest of the age groups:

$$\frac{dN_{0,j,k}(t)}{dt} = B_{N,j,k}(t) + \tau_{4,0,j,k}W_{0,j,k}(t) - \tau_{1,0,j,k}N_{0,j,k}(t) - E^{N}_{0,j,k}(t)\left(1 - S_{0,j}\right) - E^{N}_{0,j,k}(t)S_{0,j} \quad (1)$$

$$\frac{dW_{0,j,k}(t)}{dt} = B_{W,j,k}(t) + \tau_{1,0,j,k}N_{0,j,k}(t) + \tau_{3,0,j,k}O_{0,j,k}(t) - W_{0,j,k}(t)\left(\tau_{2,0,j,k} + \tau_{4,0,j,k}\right) - E^{W}_{0,j,k}(t)\left(1 - S_{0,j}\right) - E^{W}_{0,j,k}(t)S_{0,j} \quad (2)$$

$$\frac{dO_{0,j,k}(t)}{dt} = B_{O,j,k}(t) + \tau_{2,0,j,k}W_{0,j,k}(t) - \tau_{3,0,j,k}O_{0,j,k}(t) - E^{O}_{0,j,k}(t)\left(1 - S_{0,j}\right) - E^{O}_{0,j,k}(t)S_{0,j} \quad (3)$$

$$\frac{dN_{i,j,k}(t)}{dt} = E^{N}_{i-1,j,k}(t)S_{i-1,j} + \tau_{4,i,j,k}W_{i,j,k}(t) - \tau_{1,i,j,k}N_{i,j,k}(t) - E^{N}_{i,j,k}(t)\left(1 - S_{i,j}\right) - E^{N}_{i,j,k}(t)S_{i,j} \quad (4)$$

$$\frac{dW_{i,j,k}(t)}{dt} = E^{W}_{i-1,j,k}(t)S_{i-1,j} + \tau_{1,i,j,k}N_{i,j,k}(t) + \tau_{3i,j,k}O_{i,j,k}(t) - W_{i,j,k}(t)\left(\tau_{2,i,j,k} + \tau_{4,i,j,k}\right) - E^{W}_{i,j,k}(t)\left(1 - S_{i,j}\right) - E^{W}_{i,j,k}(t)S_{i,j} \quad (5)$$

$$\frac{dO_{i,j,k}(t)}{dt} = E^{O}_{i-1,j,k}(t)S_{i-1,j} + \tau_{2,i,j,k}W_{i,j,k}(t) - \tau_{3,i,j,k}O_{i,j,k}(t) - E^{O}_{i,j,k}(t)\left(1 - S_{i,j}\right) - E^{O}_{i,j,k}(t)S_{i,j} \quad (6)$$

where $i \in (0,\ldots,11)$ represents the age groups, in intervals of 5 years, $j \in$ (1=men, 2=women) represents the gender, and $k \in$ (1=lower, 2=middle, and 3=higher SES) represents the SES group of the simulated population; $N_{i,j,k}(t)$, $W_{i,j,k}(t)$, and $O_{i,j,k}(t)$ are the populations of *not-overweight*, *overweight*, and *obese* individuals in the age group i, gender j and SES group k, respectively, at time t (unit: people); $B_{N,j,k}(t)$, $B_{W,j,k}(t)$, and $B_{O,j,k}(t)$ are the births for each BMI category, gender j, and SES group k at time t (unit: people per year); and $E_{i,j,k}{}^{N}(t)$, $E_{i,j,k}{}^{W}(t)$, and $E_{i,j,k}{}^{O}(t)$ are the exit rates, which correspond to the total number of individuals per year that leave each age group i for each gender j, SES group k, and BMI category at time t (unit: people per year). $E_{i,j,k}{}^{N}(t)S_{i,j}$, $E_{i,j,k}{}^{W}(t)S_{i,j}$, and $E_{i,j,k}{}^{O}(t)S_{i,j}$ are the individuals who mature into the next age group for each BMI category, age group i, gender j, and SES group k, respectively, at time t (unit: people per year), and $E_{i,j,k}{}^{N}(t)(1\text{-}S_{i,j})$, $E_{i,j,k}{}^{W}(t)(1\text{-}S_{i,j})$, and $E_{i,j,k}{}^{O}(t)(1\text{-}S_{i,j})$ correspond to the individuals who die for each BMI category, age group i, gender j, and SES group k, respectively, at time t (unit: people per year). $S_{i,j}$ is the survival fraction per year for each age group i and gender j (unit: % per year). The parameters $\tau_{1,i,j,k}$ and $\tau_{2,i,j,k}$ are the transference rates (TRs) that correspond to the fraction of individuals per year from the *not overweight* and the *overweight*

categories that become *overweight* and *obese* for each age group *i*, gender *j,* and SES group *k*, respectively (unit: % per year). The parameters $\tau_{3,i,j,k}$ and $\tau_{4,i,j,k}$ are the TRs of individuals from the *obese* to the *overweight* category and from the *overweight* to the *not overweight* category, respectively, from each age group *i,* gender *j,* and SES group *k*, respectively (unit: % per year). We used a heuristic to estimate the TRs between BMI categories by age, gender, and SES group using historical data from "Encuesta Nacional de la Situación Nutricional en Colombia" (ENSIN) of 2005 and 2010. This heuristic identifies the TRs that minimize the difference between prevalence rates by BMI category from 2010 ENSIN, and the model estimated prevalence rates by age, gender, and SES group. It does this by comparing ENSIN data from at least two points in time. Figure 1 shows the global view of the SD model structure at the country-level.

The number of births per year for each BMI category, gender, and SES group was determined using the following equations:

$$B_{N,j,k}(t) = \mu_j \theta_{N,j,k} \left(\frac{f(t)}{(Y_F - Y_I + 1)}\right) \sum_{i=Y_I}^{Y_F} \left(N_{i,2,k}(t) + W_{i,2,k}(t) + O_{i,2,k}(t)\right) \quad (7)$$

$$B_{W,j,k}(t) = \mu_j \theta_{W,j,k} \left(\frac{f(t)}{(Y_F - Y_I + 1)}\right) \sum_{i=Y_I}^{Y_F} \left(N_{i,2,k}(t) + W_{i,2,k}(t) + O_{i,2,k}(t)\right) \quad (8)$$

$$B_{O,j,k}(t) = \mu_j \theta_{O,j,k} \left(\frac{f(t)}{(Y_F - Y_I + 1)}\right) \sum_{i=Y_I}^{Y_F} \left(N_{i,2,k}(t) + W_{i,2,k}(t) + O_{i,2,k}(t)\right) \quad (9)$$

where μ is the total fraction of births by gender *j* (unit: % per year); $\theta_{N,j,k}$, $\theta_{W,}j,k$ and $\theta_{O,j,k}$ are the fraction of births (percent per year) for each BMI category, gender *j,* and SES group *k*, respectively, (also assumed to be the prevalence rates of children aged 0 to 12 months, by BMI category); $\sum_{i=YI}^{YF}((N_{i,2,k}(t) + W_{i,2,k}(t) + O_{i,2,k}(t))$ is the size of the female population of childbearing age at time *t*; *f* is the total number of children born from each woman during the childbearing years (fertility rate) at time *t*; and Y_I and Y_F are the first and last childbearing years considered, which we assumed to be 15 to 49, respectively.

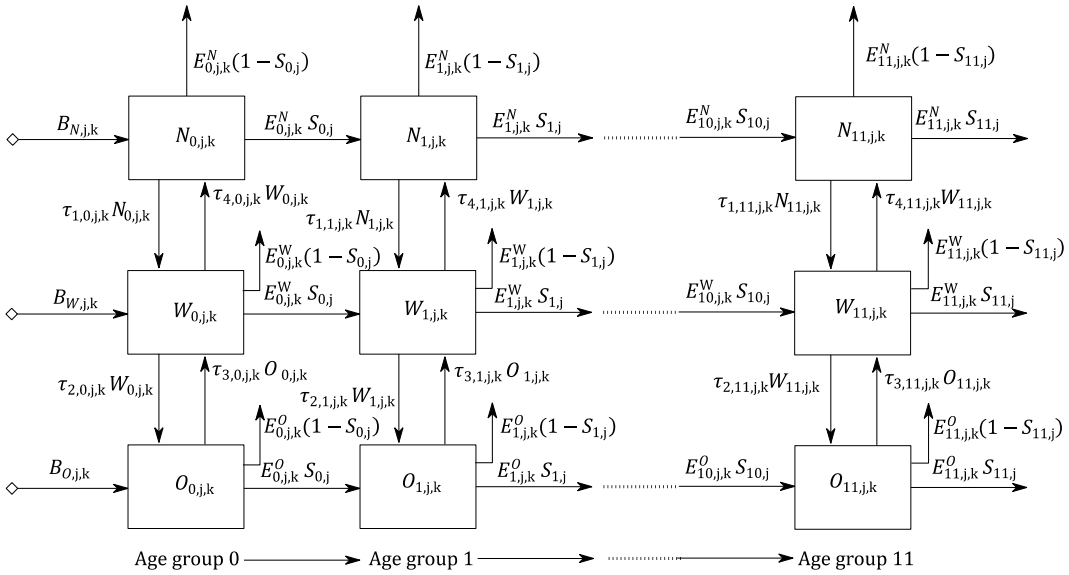

Figure 1. Overview of the SD model structure at country level.

The exit rates per year by BMI category, age group *i*, gender *j*, and SES group *k* were modelled using the following equations:

$$E^{N}_{0,j,k}(t) = \left(\frac{B_{N,j,k}(t)+\tau_{4,0,j,k}W_0(t)-\tau_{1,0,j,k}N_{0,j,k}(t)}{Y}\right) \quad (10)$$

$$E^{W}_{0,j,k}(t) = \left(\frac{B_{W,j,k}(t)+\tau_{1,0,j,k}N_{0,j,k}(t)+\tau_{3,0,j,k}O_{0,j,k}(t)-W_{0,j,k}(t)(\tau_{2,0,j,k}+\tau_{4,0,j,k})}{Y}\right) \quad (11)$$

$$E^{O}_{0,j,k}(t) = \left(\frac{B_{O,j,k}(t)+\tau_{2,0,j,k}W_{0,j,k}(t)-\tau_{3,0,j,k}O_{0,j,k}(t)}{Y}\right) \quad (12)$$

$$E^{N}_{i,j,k}(t) = \left(\frac{E^{N}_{i-1,j,k}(t)S_{i-1,j}+\tau_{4,i,j,k}W_{i,j,k}(t)-\tau_{1,i,j,k}N_{i,j,k}(t)}{Y}\right) \quad (13)$$

$$E^{W}_{i,j,k}(t) = \left(\frac{E^{W}_{i-1,j,k}(t)S_{i-1,j}+\tau_{1,i,j,k}N_{i,j,k}(t)+\tau_{3,i,j,k}O_{i,j,k}(t)-W_{i,j,k}(t)(\tau_{2,i,j,k}+\tau_{4,i,j,k})}{Y}\right) \quad (14)$$

$$E^{O}_{i,j,k}(t) = \left(\frac{E^{O}_{i-1,j,k}(t)S_{i-1,j}+\tau_{2,i,j,k}W_{i,j,k}(t)-\tau_{3,i,j,k}O_{i,j,k}(t)}{Y}\right) \quad (15)$$

where *Y = 5 years,* corresponding to the average time individuals spend in a given age group before maturing into the next age group. Equations (10-12) correspond to the exit rates per year by BMI category for the age group zero to four years. Finally, the survival fraction for each age group *i* and gender *j* is determined by:

$$S_{i,j} = exp\left(R_{i,j}Y\right) \qquad (16)$$

where, $R_{i,j}$ is the mortality rate (percent per year) for each age group *i* and gender *j* .

Section 2. Estimation of transferences rates between nutritional stages by age group, gender, and SES group

We used a heuristic, which was based on previously published research [1,2], to estimate the TRs between nutritional stages by age, gender, and SES using historical data obtained from ENSIN of 2005 and 2010. For the purpose of the model, we assumed that the TRs are uniform within each five-year age group, but differed across age groups. The heuristic differs slightly depending on the level of analysis.

We adapted the heuristic to estimate the TRs using prevalence rates by nutritional stage grouped into age groups of 5 years. The heuristic did not use the prevalence rates by nutritional stage for each year between zero and 59 years to estimate the TRs by nutritional stage in 2010 for each age group, gender, and SES group. Instead, we adapted the heuristic to estimate the TRs by nutritional stage in 2010 using prevalence rates by nutritional stage grouped into age groups of five years. Using these estimates, the heuristic approximates the prevalence rates by nutritional stage in 2010 for each age group *i*, gender *j*, and SES group *k* independently using the following system of equations:

$$P'_{i+1,j,k} = A_{i,j,k}.P_{j,k} \qquad (1)$$

where

$$B_{i,j,k} = A_{i,j,k}.(A_{i,j,k}.\left(A_{i,j,k}.\left(A_{i,j,k}.A_{i,j,k}\right)\right));$$

$$A_{i,j,k} = \begin{pmatrix} \alpha_{1,i,j,k} - \tau_{1,i,j,k} & \tau_{4,i,j,k} & 0 \\ \tau_{1,i,j,k} & \alpha_{2,i,j,k} - \tau_{2,i,j,k} - \tau_{4,i,j,k} & \tau_{3,i,j,k} \\ 0 & \tau_{2,i,j,k} & \alpha_{3,i,j,k} - \tau_{3,i,j,k} \end{pmatrix}; P'_{i+1,j,k} = \begin{pmatrix} p'_{N10,i+1,j,k} \\ p'_{W10,i+1,j,k} \\ p'_{O10,i+1,j,k} \end{pmatrix};$$

$$P_{i,j,k} = \begin{pmatrix} P_{N05,i,,j,k} \\ P_{W05,i,j,k} \\ P_{O05,i,j,k} \end{pmatrix};$$

where $i \in (0,\ldots,11)$ represents age groups of five years (0–4, 5–9,...,55–59); $j \in (1, 2)$ represents gender (men and women, respectively); $k \in (1, 2, 3)$ represents the SES groups (lower, middle, and higher SES., respectively); $P_{N05,i,j,k}$, $P_{W05,i,j,k}$, and $P_{O05,i,j,k}$ are the prevalence rates by nutritional stage in 2005 for age group *i,* gender *j,* and SES group *k*; $\alpha_{1,i,j,k}$, $\alpha_{2,i,j,k}$, and $\alpha_{3,i,j,k}$ are the retention rates for individuals by nutritional stage, age group *i,* gender *j* and SES group *k*, corresponding to the fraction of individuals who remain in the same nutritional stage between 2005 and 2010; $\tau_{1,i,j,k}$, $\tau_{2,i,j,k}$ $\tau_{3,i,j,k}$, and $\tau_{4,i,j,k}$ are the TRs that are used to run the SD model; and $P'_{N10,i+1,j,k}$, $P'_{W10,i+1,j,k}$, and $P'_{O10,i+1,j,k}$ are the estimated prevalence rates by nutritional stage in 2010 for age group *i,* gender *j,* and SES group *k* five years later. The matrix $A_{i,j,k}$ represents the equations used to calculate the estimated prevalence rates by nutritional stage in the year *t+1* for age group *i,* gender *j,* and SES group *k,* where *t* is 2005. The heuristic estimates the TRs aggregated over five years.

Then, the heuristic calculates the TRs by nutritional stage for each age group, gender, and SES group by minimizing the difference between prevalence rates by nutritional stage reported in the 2010 ENSIN and the estimated 2010 prevalence rates informed by data from the 2005 ENSIN. Specifically, the TRs were estimated by solving the system of equations (1) for each age group *i,* gender *j,* and SES group *k* independently, and minimizing the following equation:

$$Min\ QD_{i,j,k} = \Big[\big(P_{N10,i+1,j,k} - p'_{N10,i+1,j,k}\big)^2 + \big(P_{W10,i+1,j,k} - p'_{W10,i+1,j,k}\big)^2 + \big(P_{O10,i+1,j,k} - p'_{O10,i+1,j,k}\big)^2\Big], \quad (2)$$

with the restrictions

$$\alpha_{1,i,j,k} + \tau_{1,i,j,k} = 1$$

$$\alpha_{2,i,j,k} + \tau_{2,i,j,k} + \tau_{4,i,j,k} = 1$$

$$\alpha_{3,i,j,k} + \tau_{3,i,j,k} = 1 \qquad (3)$$

$$0 \le \alpha_{l,i,j,k} \le 1, \quad (l = 1, 2, 3)$$

$$0 \le \tau_{m,i,j,k} \le 1, \quad (m = 1, 2, 3, 4)$$

where $P_{N10,i+1,i,j,k}$, $P_{W10,i+1,i,j,k}$, and $P_{O10,i+1,i,j,k}$ are the prevalence rates by nutritional stage and age *i* in 2010 for age group *i+1,* gender *j* and SES group *k*. At the department level, we did not include gender to estimate the TRs between nutritional stages; the sub index gender is therefore not included. We made these adaptations in the heuristic at the country, regional, and state levels because the ENSIN 2005 and 2010 data could not be used to generate good estimates of TRs by nutritional stage, age group, gender, and SES at the national and subnational level.

Section 3. Map of Colombia by departments

Figure 2. Map of Colombia by departments [3]. Atlántica region: 08=Atlántico, 13= Bolívar, 20= Cesar, 23= Córdoba, 44= La Guajira, 47= Magdalena, 70= Sucre, 88= San Andrés; **Oriental región:** 15= Boyacá, 25= Cundinamarca, 50= Meta, 54= Norte de Santander, 68= Santander; **Central región:** 05= Antioquia, 17= Caldas, 18= Caquetá, 41= Huila, 63= Quindío, 66= Risaralda, 73= Tolima; **Pacífica region:** 19= Cauca, 27= Chocó, 52= Nariño, 76= Valle; B**ogotá = 11; Orinoquia y Amazonía región:** 81= Arauca, 85= Casanare, 86= Putumayo, 91= Amazonas, 94= Guainía, 95= Guaviare, 97= Vaupés, 99= Vichada. The map was created using ArcGIS online.

References

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