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Alcohol consumption in Spain and its economic cost: A mathematical modeling approach

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ABSTRACT

In this paper, a mathematical model for alcohol consumption in Spanish population is proposed. Its parameters are estimated by fitting the model to real data from Spanish Ministry of Health. Predictions about the future behavior of the alcohol consumption in Spain are presented using this model. Results are applied to estimate the economic costs (sanitary and non-sanitary) assumed by Spanish society that are derived from this consumption.

1. Introduction

Alcohol consumption is growing at a fast rate in developed and developing countries and it is becoming a serious problem not only from the individual health point of view but also from the public socioeconomic one, motivated by the high cost of the Health Public Care System due to the assistance expenditure of people suffering diseases related with this consumption [1,2]. It has been estimated that the alcohol consumption derived cost is around 3800 millions of Euros per year in Spain [3]. In this paper, we analyze the evolution of alcohol consumption in Spain (see Table 1 [3]) and estimate the economic quantification of the impact of this alcohol consumption in the next few years.

In this article, we present an epidemiological-type mathematical model to study the transmission dynamics and evolution of the alcohol consumption in Spanish population. Additionally, we present estimations of the economic costs of this consumption. These types of epidemiological models also have been used in the study of ecstasy or heroin addiction [4,5] and in the approach to another topics that spread by social contact like obesity or extreme behaviors [6,7].

This paper is organized as follows. In the next section the mathematical model is presented and the model parameters are estimated. Once the mathematical model is established Section 3 contains numerical simulations of the model with consumption predictions for the next few years. In Section 4, we present the economic cost estimations. Section 5 is devoted to the conclusions.

2. Mathematical model

2.1. Building the model

In this paper we assume the proposal showed in [8,9] and treat alcohol consumption as a disease that spreads by social

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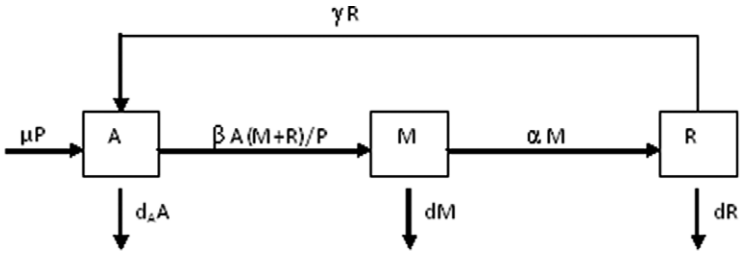

Fig. 1. Flow diagram of the mathematical model for the dynamics of alcohol consumption in Spain.

contact. We suppose that these contacts influence in the probability of transmission of the consumption habits. This fact leads us to propose an epidemiological-type model to study the epidemic evolution.

For model building, 15–64 years old Spanish population is divided into three subpopulations [10]:

- $A(t)$: Non-consumers, individuals that have never consumed alcohol or they infrequently have alcohol consumption.
- $M(t)$: Non-risk consumers, individuals with regular low consumption. To be precise, men who consume less than 50 cc of alcohol every day and women who consume less than 30 cc of alcohol every day.
- $R(t)$: Risk consumers, individuals with regular high consumption, i.e., men who consume more than 50 cc of alcohol every day and women who consume more than 30 cc of alcohol every day.

Furthermore, we consider the following assumptions:

1. We assume population homogeneous mixing. That is, each individual can contact with any other individual [11].
2. The transitions between the different subpopulations are determined as follows:
   - We consider that the new recruited 15 years old individuals become members of the $A(t)$ subpopulation.
   - Once an individual starts regular alcohol consumption he/she becomes a non-risk consumer, $M(t)$. If this person increases his/her consumption habit he/she can become a risk consumer, $R(t)$.
   - Individuals of subpopulation $R(t)$ becomes a member of subpopulation $A(t)$ if the alcohol consumption is reduced at an appropriate rate.
3. The transitions described above can be modeled as follows:
   - An individual in $A(t)$ transits to $M(t)$ because people in $M(t)$ or $R(t)$ transmit the alcohol consumption habit by social contact at rate β. Therefore, this is a nonlinear term modeled by $\beta A(t)(M(t) + R(t))/P(t)$. We consider $P(t) = A(t) + M(t) + R(t)$.
   - An individual in $M(t)$ transits to $R(t)$ at rate α proportionally to the size of $M(t)$ if his/her alcohol consumption increases. Hence, this is a linear term modeled by $\alpha M(t)$.
   - An individual in $R(t)$ transits to $A(t)$ when decides to give up the alcohol consumption and to go into therapy. An individual in $R(t)$ transits to $A(t)$ at rate γ proportionally to the size of $R(t)$. Hence, this is a linear term modeled by $\gamma R(t)$.

Under the above assumptions, dynamic alcohol consumption model for Spanish population is given by the following nonlinear system of ordinary differential equations:

$$A'(t) = \mu P(t) + \gamma R(t) - d_A A(t) - \beta A(t) \frac{[M(t) + R(t)]}{P(t)} \tag{1}$$

$$M'(t) = \beta A(t) \frac{[M(t) + R(t)]}{P(t)} - dM(t) - \alpha M(t) \tag{2}$$

$$R'(t) = \alpha M(t) - \gamma R(t) - dR(t) \tag{3}$$

$$P(t) = A(t) + M(t) + R(t) \tag{4}$$

where the constant parameters of the model are:

- μ, birth rate in Spain.
- γ, rate at which a risk consumer becomes a non-consumer.
- d_A, death rate in Spain.
- β, transmission rate due to social pressure to increase the alcohol consumption (family, friends, marketing, TV, etc.).
- d, augmented death rate due to alcohol consumption. Accidents at work, traffic accidents and diseases derived by alcohol consumption are considered.
- α, rate at which a non-risk consumer moves to the risk consumption subpopulation.

Fig. 1 shows the diagram for the dynamic alcohol consumption model. The boxes represent the subpopulations and the arrows represent the transitions between the subpopulations. Arrows are labeled by the parameters of the model.

2.2. Scaling the model

Data obtained in Table 1 is related to the percentages of population meanwhile model (1)–(4) is related to the number of individuals. It leads us to transform (by scaling) the model into the same units as data, because one of our objectives is to fit data with the model. Hence, following ideas developed in [7] about how to scale models where the population is varying in size we obtain:

Adding Eqs. (1)–(3) one gets

$$P'(t) = \mu P(t) - d_A A(t) - dM(t) - dR(t). \tag{5}$$

Dividing both members of (5) by $P(t)$ we have that

$$\frac{P'(t)}{P(t)} = \mu\frac{P(t)}{P(t)} - d_A\frac{A(t)}{P(t)} - d\frac{M(t)}{P(t)} - d\frac{R(t)}{P(t)}. \tag{6}$$

If we define the rates (depending on time)

$$a = \frac{A}{P}, \qquad m = \frac{M}{P}, \qquad r = \frac{R}{P}. \tag{7}$$

Eq. (6) can be transformed into

$$\frac{P'}{P} = \mu - d_A a - dm - dr. \tag{8}$$

On the other hand, we compute the derivative of a defined in (7) and using (8) we obtain that

$$a' = \frac{A'P - AP'}{P^2} = \frac{A'}{P} - \frac{A}{P}\frac{P'}{P} = \frac{A'}{P} - a[\mu - d_A a - dm - dr]. \tag{9}$$

In an analogous way, we also have that

$$m' = \frac{M'}{P} - m[\mu - d_A a - dm - dr],$$

$$r' = \frac{R'}{P} - r[\mu - d_A a - dm - dr].$$

Now, consider Eq. (1). If we multiply it by $1/P$, we have

$$\frac{A'}{P} = \mu\frac{P}{P} + \gamma\frac{R}{P} - d_A\frac{A}{P} - \beta\frac{A}{P}\frac{(M+R)}{P}$$

and using (9) and substituting by the corresponding rates defined in (7) one gets

$$a' = \mu + \gamma r - d_A a - \beta a(m+r) - a[\mu - d_A a - dm - dr]. \tag{10}$$

Remainder equations can be scaled in the same way to obtain

$$m' = \beta a(m+r) - \alpha m + d_A am - dam - \mu m, \tag{11}$$

$$r' = \alpha m - \gamma r + d_A ar - dar - \mu r. \tag{12}$$

2.3. Estimation of parameters

We obtained all the parameters of the model except β and α using the following sources:

- The technical report published by the Valencian Health Department where the profile of the alcohol consumers admitted to treatment is described and its rate is provided [12]. Taking into account that the region of Valencia is a part of Spain, it is reasonable to consider the Valencian rate as the Spanish rate.
- The paper [13] where the authors study the years that an alcohol risk consumer takes to go into therapy.
- The paper [14] where the author studies the therapy success rates.
- Spanish birth and death time series are obtained from Spanish Statistic Institute [15].
- The book [16] and the article [17] where the authors study the increase of the death rate by alcohol consumption.

Now, the estimation of the parameters, for time t in years, is presented:

- $\mu = 0.01$ years^{-1} is the average Spanish birth rate between years 1997–2007 [15].
- $d_A = 0.008$ years^{-1} is the average Spanish death rate between years 1997–2007 [15].
- $d = 0.009$ years^{-1} is the average Spanish alcohol consumption death rate between years 1997–2007. We considered that approximately 4% of mortality is due to the alcohol consumption [16,17].

Table 1
Evolution of the proportion of non-consumer ($A(t)$), non-risk consumer ($M(t)$), and risk consumer ($R(t)$) subpopulations for different years.

	$A(t)$ (%)	$M(t)$ (%)	$R(t)$ (%)
1997	36.2	58.1	5.7
1999	38.3	57.8	3.9
2001	36.3	58.1	5.6
2003	35.9	58.8	5.3
2005	35.4	59.1	5.5
2007	40.0	56.6	3.4

Table 2
Evolution of proportion of risk consumer ($R(t)$) and non-risk consumer ($M(t)$) subpopulations for the next few years. Percentages are defined by the deterministic model.

Year	$R(t)$ (%)	$M(t)$ (%)
2011	4.9	58.7
2013	4.8	58.8

- $\gamma = 0.00144$ years^{-1}. From [12] it can be obtained that around 32% of risk consumers begin a therapy program every year. Furthermore, using data from Table 1, corresponding to National Drug Observatory Reports [3], we obtain that the mean value of population with risk consumption is 5.2%. Moreover, the conclusion obtained in [13] is that a risk consumer takes around ten years before to go into therapy. Therefore, the percentage of risk consumers in therapy per year is 0.16% ($0.052 * 0.32 * 1/10 = 0.0016$). On the other hand, [14] concludes that around 45% of the individuals on therapy recover in six months. Then, $\gamma = 0.0016 * 0.45 * 1/0.5 = 0.00144$. Hence, we can consider $\gamma = \gamma_1 * \gamma_2 * \gamma_3 * \gamma_4 * 1/0.5$, where $\gamma_1 = 0.052$, $\gamma_2 = 0.32$, $\gamma_3 = 1/10$ and $\gamma_4 = 0.45$.

Additionally, taking as the initial condition of the scaled model (year 1997, i.e., $t = 0$), $A(t = 0) = 0.362$, $M(t = 0) = 0.581$ and $R(t = 0) = 0.057$, the parameters β and α have been estimated by fitting the model with data from Table 1, and we obtained $\beta = 0.0284534$ and $\alpha = 0.000110247$.

In order to compute the best fitting, we carried out computations with *Mathematica* [18] and we implemented the function

$$\begin{aligned} &\mathbb{F} : \mathbb{R}^2 \longrightarrow \mathbb{R} \\ &\quad (\beta, \alpha) \longrightarrow \mathbb{F}(\beta, \alpha) \end{aligned}$$

which variables are β and α and such that:

1. Solve numerically (*NDSolve[]*) the system of differential equations (10)–(12) with initial values ($A(t = 0) = 0.362$, $M(t = 0) = 0.581$ and $R(t = 0) = 0.057$).
2. For t = 1997, 1999, 2001, 2003, 2005 and 2007 evaluate the computed numerical solution for each subpopulation $A(t)$, $M(t)$, $R(t)$.
3. Compute the mean square error between the values obtained in Step 2 and the data from Table 1.

Function $\mathbb{F}$ takes values in $\mathbb{R}^2$ (β and α) and returns a positive real number. Hence, we can try to minimize this function using the Nelder–Mead algorithm [19,20], that does not need the computation of any derivative or gradient, impossible to know in this case.

In order to find a global minimum the feasible chosen domain is

$$D = [0, 1] \times [0, 1] \subset \mathbb{R}^2,$$

and it is divided in disjoint subdomains where, in each one, Nelder–Mead algorithm is applied. We stored all the minima obtained and, among them, the values of β and α that minimize the function $\mathbb{F}$ are

$$\begin{aligned} \beta &= 0.0284534 \\ \alpha &= 0.000110247. \end{aligned} \tag{13}$$

3. Numerical simulation

Table 2 shows numerical values of alcohol consumption in the next few years. It can be noted a slight increasing trend in non-risk consumer population ($M(t)$) and a slight decreasing of risk consumer population ($R(t)$).

4. Economic cost predictions

Once carried out alcohol consumption predictions we calculated the economic costs produced by this expected consumption. Economic costs are calculated as follows:

- *Economic cost per consumer*. We compute these costs taking into account an average of 280 euros/year per consumer (non-risk consumers and risk consumers). It is measured with the value of the euro in year 2000. We used [3,15,21] to estimate it. In [3,21] total costs of alcohol consumption in Spain is presented. Spanish Statistic Institute [15] allows us to know Spanish population.
- *Consumer population in the next years*. To estimate this value we use the predictions simulated by the model (10)–(12) and the expected population by years 2011 and 2013 [15].

Now the estimation of economic costs of alcohol consumption assumed by Spanish society in the next few years is presented. Mathematical model (10)–(12) and Spanish Statistic Institute predict that there will be around 20,161,048 alcohol consumers in 2011 and 20,289,302 in 2013. Hence, we can predict that alcohol consumption in Spain will cause a cost approximate of 5645 million of euros in 2011 ($20, 161, 048 * 280$ euros) and 5681 million of euros in 2013 ($20, 289, 302 * 280$ euros).

5. Conclusions

In this article, we estimate the economic cost produced by alcohol consumption in Spain in the next few years. The estimation are based on *cost of illness* estimations that include sanitary costs and non-sanitary costs, such as treatment of alcohol-related occupational accidents or sick payment and cost related to productivity decrease. These economic estimations are also based on a epidemiological-type mathematical model that predicts the proportions of Spanish alcohol consumers in the next few years.

This study concludes that we expect a cost to Spanish society derived from alcohol consumption at least of 5645 million of euros by 2011 and 5680 million of euros by 2013 (this predictions are estimated with the value of the euro in year 2000). To put this cost in context, the estimated cost attributable to alcohol consumption by 2011 (or by 2013) is approximately 2.5% of the Spanish government expenditure for year 2009 [22].

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References

[1] Word Health Organization—WHO, Framework for alcohol policy in the WHO European Region, WHO Europe, 2006.
[2] European Comisin—EU, Attitudes towards alcohol, Report, Special Eurobarometer, EC, 2007.
[3] Spanish Ministry of Health, National Drug Observatory Reports, 2008, Retrieved 13th November 2008 from: http://www.pnsd.msc.es/Categoria2/observa/estudios/home.htm.
[4] B. Song, M. Castillo-Garsow, K.R. Ros-Soto, M. Mejran, L. Henso, C. Castillo-Chávez, Raves, clubs and ecstasy: the impact of peer pressure, Mathematical Biosciences and Engineering 3 (1) (2006) 249–266.
[5] E. White, C. Comiskey, Heroin epidemics, treatment and ODE modeling, Mathematical Biosciences 208 (1) (2007) 312–324.
[6] L. Jódar, F.J. Santonja, G. González-Parra, Modeling dynamics of infant obesity in the región of Valencia, Spain, Computers and Mathematics with Applications 56 (3) (2008) 679–689.
[7] F.J. Santonja, A.C. Tarazona, R.J. Villanueva, A mathematical model of the pressure of an extreme ideology on a society, Computers and Mathematics with Applications 56 (3) (2008) 836–846.
[8] S. Galea, C. Hall, G.A. Kaplan, Social epidemiology and complex system dynamic modelling as applied to health behaviour and drug use research, International Journal of Drug Policy 20 (3) (2009) 209–216.
[9] D.M. Gorman, J. Mezic, I. Mezic, P.J. Gruenewald, Agent-based modeling of drinking behavior: a preliminary model and potential applications to theory and practice, American Journal of Public Health 96 (11) (2006) 2055–2060.
[10] R. Altisent, R. Córdoba, J.M. Martín-Moros, Operative criteria for the prevention of the alcoholism, Medicina Clínica 99 (1992) 584–588.
[11] J.D. Murray, Mathematical Biology, third ed., Springer, New York, 2002.
[12] Valencian Health Department, Profile of drug user to treatment in Valencian Health Department, Report 2006, Retrieved 13th November 2008 from: http://www.sp.san.gva.es.
[13] S. Tomás-Dols, J.C. Valderrama-Zurián, A. Vidal-Infer, T. Samper-Gras, M.C. Hernández-Martínez, M.J. Torrijo-Rodrigo, Barriers of accessibility to treatment in alcohol consumers of the region of Valencia, Adicciones 19 (2) (2007) 169–179.
[14] N. Heather, Beyond alcoholism: modern perspectives on alcohol dependence and problems, Adicciones 11 (2) (1999) 463–474.
[15] Spanish Statistic Institute, Retrieved 13th November 2008 from: http://www.ine.es.
[16] T. Stockwell, P.J. Gruenewald, J. Toumbourou, W. Loxley (Eds.), Preventing Harmful Substance Use: The Evidence Base for Policy and Practice, Wiley, Chichester, 2005.
[17] M.T. Gómez-Talegón, C. Prada, M.C. Del Río, F.J. Álvarez, Evolution of the alcohol consumption of the Spanish population between 1993, 1995 and 1997, from the database of the National Health Survey, Adicciones 17 (1) (2005) 17–28.
[18] http://www.wolfram.com.
[19] J.A. Nelder, R. Mead, A simplex method for function minimization, The Computer Journal 7 (1964) 308–313.
[20] W.H. Press, B.P. Flannery, S.A. Teukolsky, W. Vetterling, Numerical Recipes: The Art of Scientific Computing, Cambridge University Press, 1986.
[21] A. García-Sempre, E. Portella, Cost of illness studies: conceptual framework, limits and results in Spain, Adicciones 14 (1) (2002) 141–153.
[22] Spanish Expenditures for 2009, Spanish Ministry of Economic, Retrieved 29th July 2009 from: http://www.igae.meh.es/SGPG/Cln_Principal/Presupuestos/Estadisticas.