

Modeling the Spread of Suicide in Greece

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Suicide can be defined as the act of purposely ending one's life. The reasons that explain why people commit suicide are complex and encompass multiple and combined factors (demographic, economic, emotional, social). In recent years, deaths by suicide have increased incessantly in Greece, becoming a social problem. The aim of this study is to build a dynamic model through a system of difference equations that quantifies the number of hidden cases of suicide in Greece during the period July 2015 to January 2019. Then, the results obtained from computing the model are compared with the Spanish ones for the same period from previous research.

Keywords: suicide; risk; quantification; mathematical model; Greece; Spain

1. Introduction

Suicide is a complex phenomenon determined by the interaction among factors such as the individual's environment (personal and family situation), neurobiology, psychology, emotional stress, culture and economic situation. In other words, suicide is an act of despair on the part of the person who considers it to be the only solution to a given situation at that time. Analyzing history, we find out that suicide has always existed. In ancient Greek society, philosophers Plato's and Aristotle's texts on suicide draw attention by their relative absence of concern for individual well-being or rights. Both limit the justifications for suicide largely to considerations about an individual's social roles and obligations. In contrast, the Stoics considered that suicide may be justified when individuals could see in prospect a majority of things in their life were not going in accordance to nature

(e.g., physical health). Also, in the words of the Roman Stoic Seneca, that suicide would be the answer to a life without quality: “lives as long as he ought, not as long as he can” [1].

Understanding why individuals commit suicide, we find that Durkheim [2] describes four pure types of suicide, although it is quite probable that in many cases, suicides result from a combination of several of those. The first is suicide by impulse, which requires an external concrete cause. In particular, this type of suicide is associated with youth, who are incapable of having the patience or ability to cope in the face of adversity. Another type of suicide is the one committed as revenge. These people commit suicide in order to cause pain to others. A third type of suicide is suicide as their last project: the only solution found for their problems. Then, they plan it, even write goodbye letters; they want to stop causing pain to their loved ones. Finally, we consider suicide as a logical solution to physical or psychological illness.

Apart from this classification, it is understood that psychological distress or mental disorder motivates the propensity to commit suicide; thus, many depressive people never become suicidal but many undiagnosed but depressed people commit suicide [3]; the abuse of drugs and alcohol also intensifies the propensity to commit suicide [4].

At the present time, a relevant number of suicides are attributed by the media to natural causes (death as the end result of an illness or an internal malfunction of the body not directly caused by external forces) or accidents instead of reported factually; the main reason for this is to avoid a possible media contagion and to preserve public health [5], but also to avoid victim’s relatives being blamed or suffering from social shame [6]. As a result, the number of suicides attributed by official sources of information and/or reported by media is much lower than the true number of deaths by suicide. Metaphorically speaking, the number of deaths by suicide is the tip of an iceberg—the observable part is visible but hides a large unknown part.

Traditionally, Greece was characterized by its low rate of suicide in comparison with other European countries [7]. However, since 2008, the suicide rate has grown faster than in any other European country. One reason that can explain this trend is the economic hardship beginning in 2007 that drove several European countries into a financial crisis. Greece in particular became the epitome of the brutal economic, political and social fallout that followed the 2008 crisis [8].

Hence, according to the Hellenic Statistical Authority [9], two people attempted suicide in Greece and at least one committed it on a daily basis during the worst years of the crisis. Moreover, Antonakakis and Collins [10] quantified in their study how much the austerity measures taken by the Greek government (as a result of the

financial crisis) impacted negatively on the suicide rate of the Hellenic country. Thus, according to [10], a 1% fall in government spending in Greece led to a 0.43% rise in suicides among men—after controlling for other characteristics that might lead to suicide between 2009 and 2010.

Apart from the economy and the fiscal policy, there are several factors that impacted negatively on this social problem. In a previous study, De la Poza and Jódar [11] point out the divergence between the official suicides reported in Spain and the real number of cases that occurred; the authors propose in their study a dynamic model to quantify the hidden cases of suicide in Spain during the economic recession. In Greece, reliability of data has been an issue [12]. Antonakakis and Collins [10] quantified the number of daily suicides at two, doubling the official data from [9]. In addition, Tragaki and Lenos [12] found out that police records about deaths for suicide were higher than reported by [9]. Also, according to the results obtained in [10], the group most vulnerable to suicide is composed of men in their sixth decade, but women in their thirties are also at risk. Finally, Tragaki and Lenos [12] show how apart from the economy, other factors like social attitudes toward negative events affect this social problem. In the same line, De la Poza and Jódar [11] model the rise of suicides in Spain, taking into account the combination of economic, political, emotional and demographic factors.

This study applies the population dynamic model built in [11] to quantify the hidden cases of suicide in Greece during the study period July 2015 to January 2019. The population of the study is composed of citizens aged 16 to 78 in Greece. The proposed model allows identifying and quantifying the drivers that propel an individual's behavior toward higher or lower risk levels of committing suicide. In addition, the dynamic model enables us to compare and contrast this social phenomenon in two countries: Greece and Spain [11]. The results obtained are useful for providing recommendations to authorities about how to handle this phenomenon.

The model is a compartmental one, which implies individuals are classified in categories in accordance with their level of risk to commit suicide. This classification is based on several sciences: sociology [13], philosophy [14], cognitive science [15] and neuroscience [16]. In fact, [13] shows that everything is contagious; [14] proposed that we humans are mimetic beings; [15] postulates that humans practice herding. Finally, Damasio [16], unlike Aristotle and Descartes, suggests that humans are moved by emotions rather than rational arguments.

The paper is structured as follows: first, the study population is presented; second, the transition coefficients are modeled and the mathematical model applied is shown. Afterward, we present the results and a sensitivity analysis is performed. To conclude the study,

the suicide rate in Greece is compared with the situation in Spain and conclusions are detailed.

2. Study Population

In agreement with the Goldthorpe approach [17], the target population model (S) splits the target population living in Greece aged within the interval 16 to 78 into four subpopulations.

The study period starts in July 2015 and it finishes in January 2019. The study period is split into semesters. Semester 0 ($n = 0$) corresponds to the start of the study period (July 2015) and $n = 7$ corresponds to the end of the study period (January 2019).

The first hypothesis of the model construction consists of splitting the $S(n)$ population into four categories, following [11] (Figure 1):

- Zero-risk subpopulation, $Z(n)$: those individuals who have no indicator suggesting a relation to the problem. A proportion of them, for instance, the clergy and members of religious orders and regular practitioners of sports, will not transition to another subpopulation.
- Pre-risk subpopulation, $P(n)$: those individuals who have relevant personality traits and/or have experienced previous episodes of violence, and due to their labor have access to weapons and suffer from labor stress.

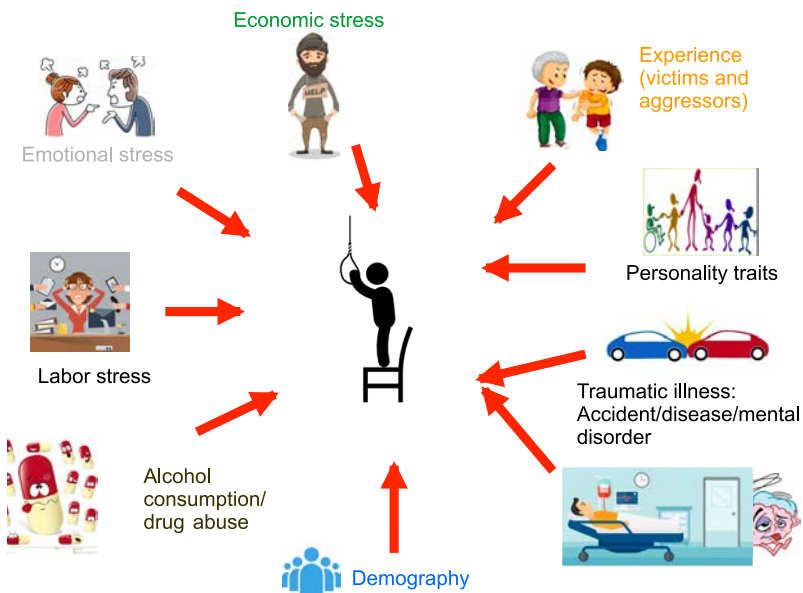


Figure 1. Factors influencing suicide behavior, [11].

- At-risk subpopulation, $R(n)$: those individuals who have ideated/planned a suicide.
- High-risk subpopulation, $H(n)$: those people who have attempted suicide at least once in their lives.

The vector of subpopulations (1) represents the subpopulations at the n^{th} semester:

$$X(n) = [Z(n), P(n), R(n), H(n)]^T. \quad (1)$$

Next, the S population is quantified at the beginning of our study period ($n = 0$, July 2015). $S(0) = 8\,600\,034$ is the number of individuals aged 16 to 78 in July 2015 in Greece, [9]. Then, by collecting and managing data from [11], we obtained the initial subpopulations at $n = 0$ in July 2015.

Following [9, 18–21] the initial values of the subpopulations are quantified:

$$Z(0) = 5\,927\,638 \text{ represents } 68.93 \% \text{ of } S(0).$$

$$P(0) = 1\,749\,624 \text{ represents } 20.34 \% \text{ of } S(0).$$

$$R(0) = 912\,192 \text{ represents } 10.61 \% \text{ of } S(0).$$

$$H(0) = 10\,580 \text{ represents } 0.12 \% \text{ of } S(0).$$

3. Modeling Transit Coefficients

In spite of the complexity of the problem, suicide is not an unpredictable event. In fact, there is an evolution of people's behavior toward this fatal event. The lack of expectations in individuals' lives and their incapability to face adversity motivates the ideation of suicide as a solution for their problems.

This section explains briefly the transit coefficients, following [11].

Starting with the net balance of the demographic factor, it quantifies the number of individuals who come into the model when they become 16 years old and leave the model when they become 79 or die each semester. Then, the number of individuals is distributed in accordance with the initial proportions of each subpopulation at the initial time, $n = 0$.

Those proportions are assumed constant for the short study period. Thus, the demographic factor also takes into account the net emigration effect; this is split into the Z and P subpopulations.

The mathematical expression of the net demographic factor is determined by [11] as follows:

$$\begin{aligned}
 B(n) = \begin{bmatrix} b_1 \\ b_2 \\ b_3 \\ b_4 \end{bmatrix} (n) &= \frac{N - O}{2} \cdot \begin{bmatrix} r_1 \\ r_2 \\ r_3 \\ r_4 \end{bmatrix} - E(n) \cdot \begin{bmatrix} 0.9 \\ 0.1 \\ 0 \\ 0 \end{bmatrix} = \\
 &= \frac{-292\,538}{2} \cdot \begin{bmatrix} 0.6893 \\ 0.2034 \\ 0.1059 \\ 0.0012 \end{bmatrix} - E(n) \cdot \begin{bmatrix} 0.9 \\ 0.1 \\ 0 \\ 0 \end{bmatrix}
 \end{aligned}
 \tag{2}$$

where $N = 50\,321$ represents the newcomers in the model and $O = 342\,859$ represents the leavers, which is the sum of those who have left the system as they are older than 78 years old or they have died. The vector r contains the initial proportion of each subpopulation and $E(n)$ denotes the net emigration balance at semester n . Data was obtained from [9].

Table 1 contains the values of the dynamic demographic factor for the study period.

The next transit coefficient is explained by the contagion effect or depressive effect on those individuals who take care of close relatives with physical and mental disabilities, following [11]:

$$\alpha_c(n, Z, P, R) = 0.9 \cdot \frac{1}{10} \cdot \left(\left(\frac{P(n) - P(n-1)}{Z(n)} \right) + \left(\frac{R(n) - R(n-1)}{Z(n)} \right) \right)
 \tag{3}$$

Semester	$b_1(n)$	$b_2(n)$	$b_3(n)$	$b_4(n)$
$n = 1$	-82 990	-27 769	-15 489	-440
$n = 2$	-82 990	-27 769	-15 489	-440
$n = 3$	-91 906	-58 511	-15 489	-440
$n = 4$	-91 906	-58 511	-15 489	-440
$n = 5$	-96 365	-59 006	-15 489	-440
$n = 6$	-96 365	-59 006	-15 489	-440
$n = 7$	-98 594	-59 254	-15 489	-440

Table 1. Dynamic demographic factor.

However, there are two groups of individuals characterized by their religion or by practicing sports regularly who are not affected by the contagion effect [11]. In Greece, 3% of the population regularly practice sports and they are assumed to belong to the $Z(n)$ category [9]. According to the official website of the church of Greece [21], the total number of archbishops, priests and nuns amounts to $N^* = 19\,338$.

Next, the economic coefficient:

$$\alpha_p(n)^* = 0.9 \cdot \alpha_p(n) = \begin{cases} 0.9 \cdot \frac{1}{2} \cdot (\rho(n) - \rho(n-1)), & \rho(n) \geq \rho(n-1) \\ 0, & \rho(n) \leq \rho(n-1) \end{cases} \quad (4)$$

where $\rho(n)$ denotes the Greek annual poverty rate, which according to [22] was 21.4% in 2015. The coefficient is dumped in a factor 0.9 because there are rich individuals who will not be affected by the economic situation.

The next transit coefficient is α_1 . It explains the shift from $P(n)$ to $R(n+1)$. According to [11], this transit is motivated by the combination of at least three factors (emotional stress, labor or economic stress, alcohol and/or drug abuse, traumatic illness, a violent life experience). The estimation of each factor F_i ($i = 1, 2, 3, 4, 5$) is expressed as follows [9, 11, 23]:

- Emotional stress (F1): $F_1 = 0.27 \cdot \frac{1}{2} = 0.135$
- Labor and economic stress (F2): $F_2 = 0.55 \cdot \frac{1}{2} = 0.275$
- Alcohol and drug abuse (F3): $F_3 = 0.432 \cdot \frac{1}{2} = 0.216$
- Traumatic illness (F4): $F_4 = 0.01$
- A violent life experience (F5): $F_5 = 0.25 \cdot \frac{1}{2} = 0.125$

We start with emotional stress, estimated as the semi-annual probability of couples splitting up [11]. Then $F_1 = 0.27 \cdot \frac{1}{2} = 0.135$, where 0.27 is the annual rate of separation [9]. F_2 measures economic and labor stress. For the study period considered, economic stress was measured by the variation of the poverty rate by semester, which was 0 due to the economic recovery [9, 11]. Labor stress is quantified by [9, 24]. Thus $F_2 = 0.275$. The abuse of drugs and alcohol is estimated as 43.5% annually [9]. Thus, $F_3 = 0.432 \cdot \frac{1}{2} = 0.216$. Then, traumatic illness is quantified (F_4) as 0.01 [11]. Finally, those who experienced violent experiences (bullying or domestic violence) represent 25% of the population by year; then, $F_5 = 0.125$ by semester.

Hence, the combination of the effect of at least two of the five preceding factors results in the term $f = 0.181893875$. The transit coefficient α_1 results from:

$$a_1 = 0.9 \cdot f = 0.9 \cdot 0.181893875 = 0.1637044875,$$

where 0.9 represents the proportion of the working population [11].

Also, a number of people will not transit to the $R(n+1)$, because of their physical or mental conditions; they remain at category P , $J^* = 429\,189$, [18].

The next coefficient, α_{AD} , is produced by abusing alcohol and/or drugs,

$$a_{AD} = 0.9 \cdot 0.15 \cdot F_3 = 0.135 \cdot 0.216 = 0.02916.$$

According to [9, 24], 15% of abusers of alcohol and drugs in Greece are at high risk of suicide. In addition, an individual can recover and this is modeled [11] at each degree of risk. Thus:

- The recovery from $P(n)$ to $Z(n+1)$ due to an economic recovery: $\beta_{r1} = 0.01$.
- The recovery from $R(n)$ to $P(n+1)$ through medical treatments: $\beta_{r2} = 0.02$.
- The recovery from $H(n)$ to $R(n+1)$ due to emotional factors: $\beta_{r3} = 0.025$.

Finally and following [11], one of 20 attempted suicides per year ends in a fatal event. This means that during each semester, 2.5% of individuals in category H commit suicide, so we have the suicide transit coefficient, $\alpha_s = 0.025$.

4. Mathematical Model

Following [11], by computing the difference system of equations, subpopulations $Z(n)$, $P(n)$, $R(n)$ and $H(n)$ are quantified for each semester. The model lets us explain the value of each subpopulation at the end of semester n and, in particular, at the end of the study period (July 2019):

$$Z(n+1) - Z(n) = -\alpha_c(n, Z, P, R) \cdot (Z(n) - N^*) - \alpha_p^*(n) \cdot (Z(n) - N^*) + \beta_{r1} \cdot (P(n)) + b_1$$

$$P(n+1) - P(n) = -\alpha_1 \cdot (P(n) - J^*) + \alpha_p(n) \cdot (Z(n) - N^*) + \alpha_c \cdot (n, Z, P, R) \cdot (Z(n) - N^*) - \beta_{r1} \cdot (P(n)) + \beta_{r2} \cdot (R(n)) + b_2$$

$$R(n+1) - R(n) = -\alpha_{AD}^* \cdot (R(n)) + \alpha_1 \cdot (P(n) - J^*) - \beta_{r2} \cdot (R(n)) + \beta_{r3} \cdot (H(n)) + b_3$$

$$H(n+1) - H(n) = \alpha_{AD}^* \cdot (R(n)) - \alpha_s \cdot (H(n)) - \beta_{r3} \cdot (H(n)) + b_4.$$

5. Results

We present the quantitative results obtained by solving the model according to the initial data and the assumed hypotheses, following [11]. Consequently, Table 2 shows the results of each subpopulation per semester for the study period (2015 to 2019).

As Table 2 indicates, zero-risk population Z stably decreases, and subpopulation P also decreases, while low-risk and high-risk subpopulations R and H grow during the study period. The results obtained show evidence of how the initial data reported by [9] was far from reality, hiding the seriousness of the problem. Figure 2 draws the trend of each subpopulation for the study period.

Then, Table 3 shows the change in the proportions of each subpopulation during the study period. As shown, the initial value of the high-risk subpopulation has multiplied 23.3-fold.

Semester	Z	P	R	H
0	5927638	1749624	912192	10580
1	5859002	1509581	1069284	35210
2	5793339	1309004	1178973	64189
3	5716968	1114506	1251159	94918
4	5639497	954391	1288724	126215
5	5555973	822339	1299013	157043
6	5471107	713452	1287950	186950
7	5382874	623096	1260345	214415

Table 2. Model results by subpopulation.

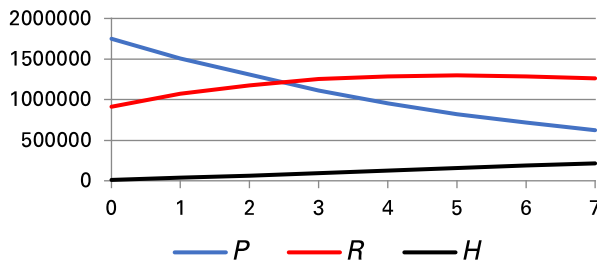


Figure 2. Trend of $P(n)$, $R(n)$ and $H(n)$ subpopulations by semester during the study period 2015 to 2019.

Semester	Z	P	R	H
2015, $n = 0$	68.9%	20.3%	10.6%	0.12%
2019, $n = 7$	71.9%	8.30%	16.8%	2.80%

Table 3. Results by subpopulation at $n = 0$ and $n = 7$.

One of the purposes of this study was to provide evidence of hidden suicides through the quantification of subpopulations. Following [11], 2.5% of the $H(n)$ subpopulation is expected to commit suicide per semester. Thus, Table 4 collects the number of suicides committed each semester by applying the model.

Semester	Suicides
July 2015, $n = 0$	264
$n = 1$	880
$n = 2$	1604
$n = 3$	2372
$n = 4$	3155
$n = 5$	3926
$n = 6$	4665
January 2019, $n = 7$	5360

Table 4. Quantification of suicides by semester in Greece.

6. Model Simulations

6.1 Sensitivity Analysis to Changes in F_3 at $n = 7$

According to [11], the proportion of drug/alcohol abuse (F_3) remains uncertain and instead of the value of 43.2%, we simulate the range 41% to 44%. Thus, a sensitivity analysis was performed to measure the variation in results by changing this proportion. Table 5 and Figure 3 show the number of individuals in the at-risk (R) and high-risk (H) subpopulations when modifying the F_3 value at $n = 7$ (July 2019). As we can see, the growth of the abuse of alcohol and drugs has a negative impact on the subpopulations R and H , which keep increasing, showing higher levels of abuse of drugs/alcohol.

Table 5 shows how an increase in the abuse of drugs or alcohol results in an increase of the R and H subpopulations. Figure 3 shows the trend of both subpopulations $R(n)$ and $H(n)$.

F_3	Z	P	R	H
41.0%	5382203	628164	1266405	204785
43.2%	5382874	623096	1260345	214415
44.0%	5385385	612244	1265564	220186

Table 5. Results of subpopulations to changes in F_3 at $n = 7$.

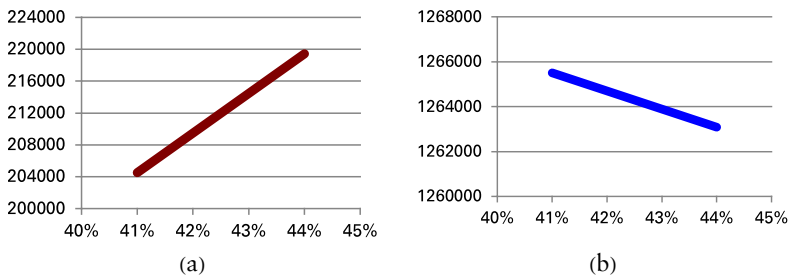


Figure 3. Sensitivity analysis of subpopulations (a) R and (b) H to the changes in F_3 at $n = 7$.

6.2 Sensitivity Analysis to Changes in the Rate of Ownership of Weapons in Greece

Finally, we decided to perform a sensitivity analysis on the rate of ownership of weapons in Greece. According to [24], the percentage of households with one or more guns was reported to be 20.6% in Greece (2017), while the estimated rate of private gun ownership (both licit and illicit) per 100 people in Greece was 17.6 in 2017. By definition [11], the P subpopulation includes individuals with access to weapons due to their jobs.

Thus, the impact of cutting half of the permits for weapons in the country was simulated. Table 6 and Figure 4 show how the P subpopulation would decrease, while the R subpopulation would still grow but in a lesser degree than the baseline model.

Table 7 compares the value of each subpopulation at $n = 7$ without implementing the measure (baseline results) and implementing the measure (reducing by half the weapons in the hands of the population in Greece). As can be seen, limiting the access to weapons of the population in Greece would have a positive impact on the subpopulations H and R (at risk) but also on P (pre-risk).

Semester	Z	P	R	H
0	5927638	1749624	486513	10580
1	5859002	1498250	663531	23797
2	5792994	1291811	791026	41515
3	5716129	1092862	878902	62065
4	5638139	933644	926123	84590
5	5554123	728228	949801	106906
6	5469941	627079	943664	120842
7	5380503	545145	917803	141875

Table 6. Forecast subpopulations.

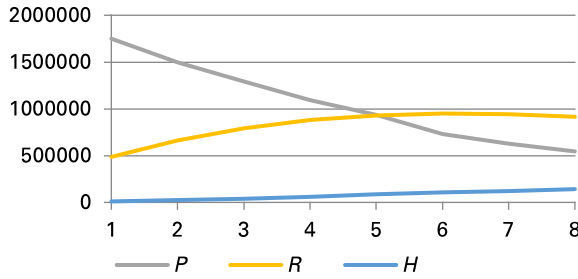


Figure 4. The trend of subpopulations P , R and H per semester for the study period 2015 to 2019.

Semester	Z	P	R	H
2019, $n = 7$				
Baseline results	71.9%	8.3%	16.8%	2.8%
2019, $n = 7$				
Measure implemented	72.3%	7.3%	12.3%	1.9%

Table 7. Subpopulation results at $n = 7$.

7. Comparison between Greece and Spain

We compared the P and R subpopulations in Greece with the respective subpopulations in Spain [11]. As we can observe, at the beginning of the research ($n = 0$) (see Table 8), there was a great difference in the subpopulation $P(0)$ between the countries. To be more specific, the difference between values was 9.39%. In contrast, the difference of the $H(0)$ subpopulation between the two countries was 0.14%, and in this case the $H(0)$ was larger in Spain.

After applying the model in both countries, we can observe that both subpopulations $R(7)$ and $H(7)$ grow in Spain and Greece, but at different magnitudes. The $R(7)$ subpopulation grew 0.27% in Spain during the study period, while in Greece it grew 6.2% during the same period. In contrast, as Table 9 shows, the $H(7)$ subpopulation multiplied by 4 in Spain and by 23 in Greece from $n = 0$. One of the reasons that could explain the divergence in the growth trends of the R and H subpopulations is the rate of civilian firearm possession per 100 people in both countries combined with the hard economic situation. In Greece this rate was 17.6% in 2017, while in Spain it was 7.5%. In addition, one in five households in Greece has a firearm, while in Spain the proportion drops to one in 10; this factor affects the results and creates a larger gap between Greece and Spain.

	$R(0)$	$H(0)$
Spain	1.21%	0.26%
Greece	10.6%	0.12%

Table 8. R and H subpopulation results at $n = 0$.

	$R(7)$	$H(7)$
Spain	1.48%	1.24%
Greece	16.8%	2.80%

Table 9. R and H subpopulation results at $n = 7$.

8. Conclusion

This study has quantified the hidden number of suicides in Greece by applying the dynamic population model developed by [11], taking into account economic, demographic, sociological and psychological factors. One of the potential utilities of the model is demonstrated in this study: the model can be extrapolated to other regions where data is available by taking into account the peculiarities of the study area. The proposed model quantifies the number of individuals at different risk levels of committing suicide in Greece during a short study period. For the study period, several research assumptions were followed, such as the subpopulation might transit to higher, but also to lower risk categories, because individual recovery is possible.

The results obtained in the study show the number of individuals in the high-risk and at-risk subpopulations is higher than the official statistics shown in Greece [9]. Our results corroborate previous study [12]; thus, this means this phenomenon requires special attention from authorities due to its gravity and the social magnitude. Moreover, our model simulations state the relevance of weapon access as an amplifier of the suicide risk. In consequence, weapon possession should be restricted in Greece, and those who own a weapon should pass a psychological test periodically.

The model results also present an alarming difference between Greece and Spain; Greece shows a much larger population at risk of committing suicide than Spain. In addition to weapon access, the Greek economic instability has unleashed poverty and the worsening of standards of living of the population. The Greek authorities should foster the creation of jobs and work on developing better economic perspectives to minimize this social problem.

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