North Carolina Journal of
Mathematics and Statistics
Volume 3, Pages 1–6 (Accepted April 3, 2017, published April 10, 2017)
ISSN 2380-7539

Modeling Gun Ownership As A Social Disease

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ABSTRACT. Gun violence is a leading cause of premature deaths in the United States. Evidence has linked higher levels of firearm ownership to an increased risk for violent crimes perpetrated with a firearm. Given that connection, the goal of this study is to use mathematical modeling techniques to better understand how different social conditions may impact gun-ownership rate. To accomplish that goal, we formulate an SIR-type model that treats gun ownership like a contagious social disease. The model divides the population into three classes: non-susceptible, susceptible, and gun owners. Model simulations are conducted to assess the effectiveness of different approaches in lowering gun-ownership rate. Model predictions suggest that anti-gun propaganda and stricter gun laws may have a significant effect in reducing the gun ownership population and the prevalence of gun-related violence in North Carolina.

1. Introduction

Gun violence in the United States results in thousands of deaths and injuries each year. For example, in 2013, firearms were used in 84,258 non-fatal injuries, 11,208 homicides, and 21,175 suicides (CDC, 2015). The prevalence of gun violence in the US can be even better understood through a comparison to the rest of the world: The US currently has the most gun-related murders per 100,000 people in the developed world, at a little over 3 gun murders per 100,000 people (CDC, 2015). Immediately after the US is Chile, at just over 2 murders involving a gun per every 100,000 people (Walselfisz, 2013). In third place is Turkey, which has below one gun-related murder per 100,000 people (WHO, 2013).

In the wake of every mass shooting, gun control debates intensify, with firearm safety supporters suggesting an increase in the regulation of firearms to reduce violent firearm-related crime. Unfortunately, despite repeated calls for stricter gun control laws, little progress has been made, and access to firearms has remained relatively easy and widespread. For example, to obtain a gun in North Carolina, one must be at least 18 years of age—three years before one is allowed access to alcohol. A state permit is required to purchase or carry a handgun, but not a rifle or shotgun.

In previous studies, Taylor (1995) applied a game theoretic model and Correa (2001) used an elementary model to analyze the effects of different gun control policy. Green et al. (2017) used a network model to explain and predict gun violence in Chicago. The goal of this study is to analyze the impacts of societal and cultural factors on the prevalence of gun ownership. Specifically, we examine gun ownership in North Carolina. To accomplish that goal, we consider the spread of small firearms to be analogous to that of an infectious disease, and we develop an SIR-type model to simulate the prevalence of gun ownership. We then apply the model to assess the effects of key

Received by the editors January 11, 2017, revised version received April 1, 2017.
2010 *Mathematics Subject Classification.* 92B05; 92F05.
Key words and phrases. SIR model; gun ownership; simulations.

factors including the culture of hunting, personal insecurity, age, social and economic elements, and political motivations.

2. Model Formulation

We model the spread of gun ownership among the population of North Carolina by adopting the Susceptible-Infected-Recovered model, or the SIR model (Kermack and McKendrick, 1927). Instead of having an "Infected" class, our gun-ownership model represents a "Gun owner" class; and instead of the "Recovered" class, our model represents a "Non-susceptible" class.

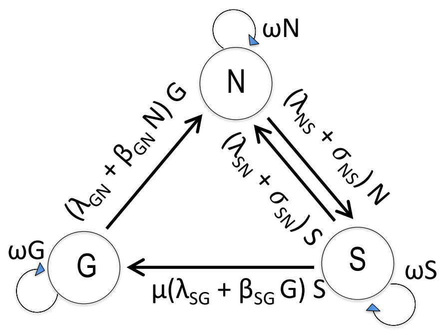

FIGURE 2.1. Model structure. N, non-susceptible; S, susceptible; G, gun owners. Symbols are defined in Table 2.1.

2.1. Model equations

The model separates the population into three distinct classes based on their relation to guns:

- the **N**on-susceptibles (denoted 'N'), who have absolutely no interest in owning guns;
- the **S**usceptibles (denoted 'S'), who do not own guns but may be persuaded into purchasing some;
- the **G**un-owners (denoted 'G').

Figure 2.1 shows the processes by which people may move among the three subpopulations. The rate of change of each of the subpopulations is given by the following equations:

$$\frac{dN}{dt} = \omega N - (\lambda_{\text{NS}} + \sigma_{\text{NS}})N + (\lambda_{\text{SN}} + \sigma_{\text{SN}})S + (\lambda_{\text{GN}} + \beta_{\text{GN}}N)G \tag{2.1}$$

$$\frac{dS}{dt} = \omega S - (\lambda_{\text{NS}} + \sigma_{\text{NS}})S + (\lambda_{\text{NS}} + \sigma_{\text{NS}})N - \mu(\lambda_{\text{SG}} + \beta_{\text{SG}}G)S \tag{2.2}$$

$$\frac{dG}{dt} = \omega G - (\lambda_{\text{GN}} + \beta_{\text{GN}}N)G + \mu(\lambda_{\text{SG}} + \beta_{\text{SG}}G)S \tag{2.3}$$

Non-susceptible individuals may become susceptible due to societal and cultural influence (represented by the term $\lambda_{\text{NS}}N$ in (2.1)). Such influence includes factors such as personal insecurity and societal unrest. Additionally, when teenagers become old enough to buy guns, they become susceptible. This demographic movement of young people into susceptible class is represented by $\sigma_{\text{NS}}N$ in (2.1). ω represents population growth rate.

Susceptible individuals may become non-susceptible due to societal and cultural factor such as improved sense of personal and societal security, represented by the term $\lambda_{\text{SN}}S$ in (2.2). Also, when people become older, they may become less interested in owning guns. This demographic movement of young people out of susceptible class is represented by $\sigma_{\mathrm{SN}} S$.

On the other hand, susceptible individuals may become gun owners due to societal and cultural influence (represented by $\mu\lambda_{\mathrm{SG}} S$ in (2.2)). Through personal contacts or propaganda, gun owners may exert influence on susceptible individuals' decision to purchase guns. This process is represented by the term $\mu\beta_{\mathrm{SG}} GS$), where μ represents the availability of fire-arms.

Finally, gun owners may give up guns due to societal and cultural factors (represented by $\lambda_{\mathrm{GN}} G$ in (2.3)), and to their interactions with the non-susceptible population (represented by $\beta_{\mathrm{GN}} NG$).

2.2. Model parameters

Table 2.1 shows base case model parameters. Population growth rate ω was estimated from North Carolina population in the past decade (DemographicData.org, 2012). Demographic change rates σ_{NS} and σ_{SN} were estimated based on the assumption that the residents are uniformly distributed among the age groups 1–78. The societal factors λ's were chosen to represent a slightly pro-gun culture; thus, $\lambda_{\mathrm{NS}} > \lambda_{\mathrm{SN}}$ and $\lambda_{\mathrm{GN}} \ll 1$. Overall, parameters were chosen so that the steady-state solution $\lim_{t\to\infty} G(t)$ without population growth (i.e., $\omega = 0$) matches the known gun owner population in 2012 (41.3% of 9.748 million North Carolinians (DemographicData.org, 2012)).

TABLE 2.1. Model parameters. Rates are given per day.

Parameter	Description	Value
ω	population growth	0.015/365
λ_{NS}	societal factors facilitating the migration from N to S	1/5
λ_{SN}	societal factors facilitating the migration from S to N	1/7
λ_{GN}	societal factors facilitating the migration from G to N	1/200
λ_{SG}	societal factors facilitating the migration from S to G	1/30
σ_{NS}	demographic changes that facilitate the migration from N to S	1/78/365
σ_{SN}	demographic changes that facilitate the migration from S to N	1/78/365
β_{GN}	impact of non-susceptible individuals on gun-owners	0.01
β_{SG}	impact of gun owners on susceptible individuals	0.1
μ	gun availability	0.1

3. Model Results

3.1. Base case results

The model equations 2.1–2.3 were implemented in `matlab`. Base case parameter values (Table 2.1) were used. The equations were integrated numerically using `ode15s`. Model solutions are shown in Fig. 3.1. The populations $S(t)$, $G(t)$, and $N(t)$ are increasing over time due to population growth factor ($\omega > 0$).

3.2. Effects of varying gun availability

We conducted simulations to assess the impact of varying gun availability (represented in the model by the parameter μ). We computed model solutions for two new cases, in which μ is varied

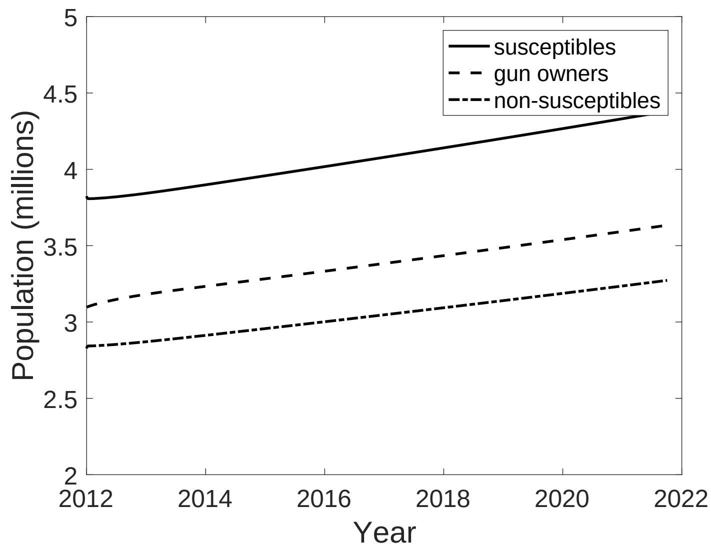

FIGURE 3.1. Base case results, showing populations of susceptible individuals, gun owners, and non-susceptible individuals as functions of time.

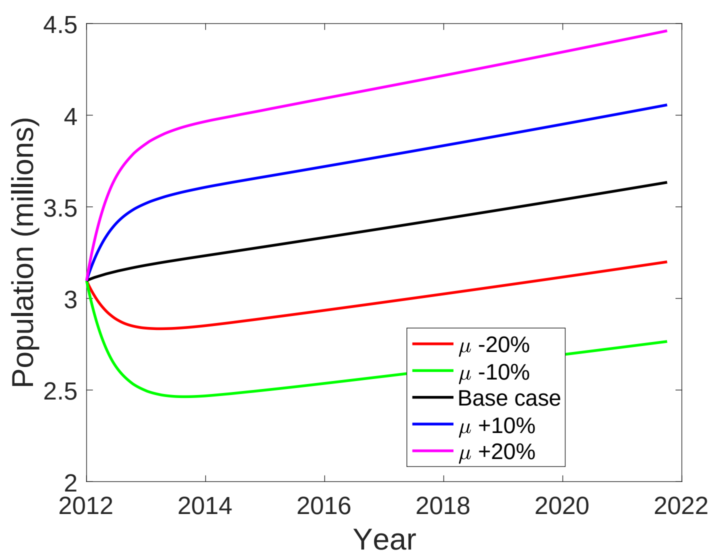

FIGURE 3.2. A comparison of gun ownership obtained for differing levels of gun availability: $\mu = \pm 20\%$ and $\pm 10\%$. Baseline $\mu = 0.1$.

by $\pm 10\%$ and $\pm 20\%$. Predicted gun owner populations corresponding to these four cases and base case are shown in Fig. 3.2. Gun availability is predicted to have a significant effect on gun owner population. Substantially lowering gun availability, which is represented by reducing μ by 20%, decreases the gun owner population by 23.9% in 10 years. In contrast, substantially raising gun availability, represented by increasing μ by 20%, raises the gun owner population by 22.8% in 10 years.

3.3. Effects of societal and cultural factors

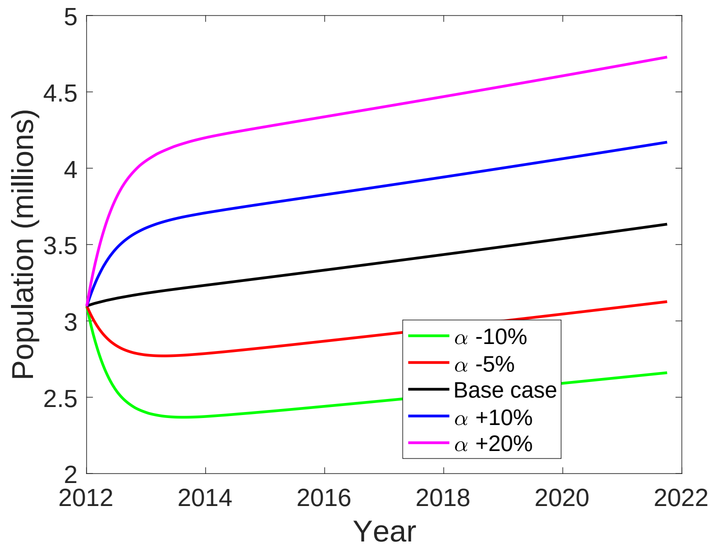

FIGURE 3.3. A comparison of gun ownership obtained for differing gun culture: $\alpha = \pm 0.1$ and ± 0.05. Baseline $\alpha = 0$.

In the next set of simulations, we assessed the impact of societal and cultural factors on the proliferation of gun ownership. We captured variations in societal and cultural factors by adjusting the relevant parameters λ's. Specifically, we introduced a new perturbation parameter α and set $\lambda_{\mathrm{NS}} = \lambda^0_{\mathrm{NS}}(1+\alpha)$, $\lambda_{\mathrm{SN}} = \lambda^0_{\mathrm{SN}}(1-\alpha)$, $\lambda_{\mathrm{GN}} = \lambda^0_{\mathrm{GN}}(1-\alpha)$, and $\lambda_{\mathrm{SG}} = \lambda^0_{\mathrm{SG}}(1+\alpha)$, where the λ^0's denote base case values.

Figure 3.3 shows predicted gun owner population for a less pro-gun society ($\alpha = -0.1$ and -0.05), for the base case, and for a more pro-gun society ($\alpha = 0.1$ and 0.05). The model predicted that in a less pro-gun society ($\alpha = -0.1$), gun owner population was lower than base case by 26.7% in 10 years. In contrast, in a more pro-gun society ($\alpha = 0.1$), in 10 years gun owner population was predicted to be larger than base case by 33.1%.

4. Discussion

The results of this study suggest that anti-gun propaganda and stricter gun laws may have a significant effect in reducing the number of gun owners and the prevalence of gun-related violence in North Carolina. Now, one may wonder whether limiting gun ownership may lead to a reduction in the number of gun murders, or whether it may have the opposite effect. Indeed, although some view the ownership of firearms as a deterrent to crime, the relationship between population-level firearm ownership rates and violent criminal perpetration is still considered controversial. Some people promote more widespread firearm availability as a deterrent to crime and as a way to enhance personal defense. Given this debate, it is noteworthy that in a recent study, Monuteaux et al. (2015) tested the association between state-level firearm ownership and violent crime. They analyzed state-level rates of household firearm ownership and criminal acts. Their findings indicate that states with higher levels of firearm ownership have an increased risk for violent crimes perpetrated with a firearm. The authors concluded that public health stakeholders should consider the outcomes associated with private firearm ownership.

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