

Modeling and Analysis of the Interaction of Neutral Populations and Violent Cop Populations: A Competing Species Model

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Abstract

The rise of police violence in the United States has brought concern, debate, and contention to the modern world. Police violence is national and is no longer concentrated in a particular location. In this paper, we present a dynamical model of the interaction between neutral population and violence. The formulation is based on models of interactions between competing species type dynamics. An exploration of the long-term dynamics and stability of homogeneous equilibrium solutions and their stability is given. The paper is given in three parts. Part one analyzes the current level of violence. Part two *analyzes* the situation when police violence increases. Part three analyzes the situation when police violence decreases

Keywords: Drug cartels, DEA, competing species model, equilibrium solutions, stability at equilibrium solutions.

1. Introduction

Police violence are not a new phenomena. However, there is a marked and exponential increase in the growth of police violence. This violence wreak havoc to native citizens. This violence affects political and social policies and creates serious issues. Consequently, countries are faced with extremely difficult, complex, and contentious political and social decisions on the issues of police violence.

The acceptance of continued violence provides a tolerance for more violence, and a failing belief that police are actually there to protect and serve. Hence, countries face the possibility of ever increasing police violence. Despite these impending threats, there is not much literature that takes a dynamical systems approach to understanding the spread of police violence. Our primary objective is to bridge the gap.

In our framework, we let V represent the level of police violence. This police violence denoted by V : V can be viewed as the amount of police violence in a community. This paper is a first step in providing a mathematical modeling framework to study the evolution and interaction between this neutral population and growing police violence. The neutral population is modeled by standard population growth models and is represented by N .

The paper is organized as follows. In section 2, we develop and analyze the time-dependent autonomous police violence ordinary differential equation (ODE) model. We examine the equilibrium solutions, the stability of the equilibrium solutions and investigate the dynamics numerically. In section 2, we consider the situation of the current level of police violence in the system. We examine the equilibrium solutions, the stability of the equilibrium solutions and

investigate the dynamics numerically for this situation also. In section 3, we consider the situation where more police violence is encountered. In section 4 we consider the affect of reducing police violence In part 5 we present our conclusions based on the analysis in sections 2, 3 and 4.

2. Neutral Violence (NV) ODE Model

Consider the mathematical model

$$N = a_1N/(1+d_1U) - a_{nr}VN/(1+d_2N) - b_1N^2 = 0 = f_N(N, V) \tag{1}$$

$$V = a_2V/(1+d_3V) - a_{nr}N/(1+d_2N) - b_2V^2 = 0 = f_R(C, D) \tag{2}$$

The populations $N(t)$ and $V(t)$ represent the populations of the neutral and violent policepopulations. More policeviolent are slowly coming into the police population. The parameters are all assumed to be positive and their descriptions are given in Table 1a.

Table 1a: List of parameters used in the differential equation model

Symbols Meaning

a_1	Growth rate of the Police population
a_2	Growth rate of the Neutral population
b_1	Population loss in N due to intra-species competition and natural mortality
b_2	Population loss in V due to intra-species competition and natural mortality
a_{NR}	Maximum per capita loss in N due to police violence
d_1	Measures the effectiveness of V in disrupting the growth rate of N
d_2	Measures the resilience of N to violent strategies by V
d_3	Measures the effectiveness of V in avoiding neutral punishment

In the case of $d_i = b_i = 0$, the mathematical model becomes similar to the competing species model. The parameters d_i influence the carrying capacity of the individual populations. Or instance, if $d_1 \gg 1$ then the growth rate of V is reduced. This is interpreted as violent police population, which can greatly hinder the growth rate of N. Notice, that if $d_2 \gg 1$ then the recruitment by V is small, Also, if $d_3 \gg 1$, new cartels are introduced into the violent police population more slowly The values chosen for the variables in this model are listed in Table 1b.

Table1b: Values of parameters

a_1	a_2	b_1	b_2	a_{NR}	d_1	d_2	d_3
2	2	0.5	0.5	2	2	2	3

2.1 Neutral Violent (NV) ODE Model

Consider the mathematical model

$$f_N(N, V) = (a_1/(1+d_1V) - a_{nr}V/(1+d_2N) - b_1N) N = 0 \tag{3}$$

$$f_R(N, V) = (a_2/(1+d_3N)) - a_{nr}N/(1+d_2N) - b_2V) V = 0 \tag{4}$$

Since this system is nonlinear, the first step is linearization using the Jacobian.

The Jacobian for this system is defined as

$$J = \begin{vmatrix} \frac{\partial f}{\partial N} & \frac{\partial f}{\partial V} \\ \frac{\partial g}{\partial N} & \frac{\partial g}{\partial V} \end{vmatrix}$$

Taking the partial derivatives, simplifying and using the values in table for the parameters, the Jacobian becomes.

$$J = \begin{vmatrix} 2/(1+2V)-2V/(1+2N)^2-N & -2/(1+2V)^2-2N/(1+2N) \\ -6V/(1+3N)^2-2V/(1+2N)^2 & 2/(1+3N)-2N(1+2N)-V \end{vmatrix}$$

2.2 Equilibrium Points

Using the Maple CAS from Maplesoft on (3) and (4) and obtained the following real valued equilibrium points:

- {N = 0., V = 0.},
- {N = 0., V = 4.},
- {N = 4., V = 0.},
- {N = .4891955799, V = .6319394087},
- {N = -.4325627635, V = -.6082709305},
- {N = -.4345884397, V = .1197573734},
- {N = -3.074988235, V = -2.874675564}

2.1.1 Analyzing equilibrium points for stability

In this section we use the equilibrium points to generate the eigenvalues for the system and establish whether the equilibrium point is stable or unstable.

2.1.2 Summarization

Table 2 summarizes the results for the current violence levels.

Table 2 – Results for Current Violence Levels

Equilibrium Point	Eigen values	Node Type	Stability
(N = 0., V = 0.)	2, 2	Repelling	Unstable
(N = 0., V = 4.)	-44/9+(2/9)*sqrt(185), -44/9-(2/9)*sqrt(185)	Attracting	Stable
(N = 4., V = 0.)	-2, -86/117	Attracting	Stable
(N = .4891955799, V = .6319394087)	.812643939172984, -1.05727942377298	Saddle	Unstable
(N = -.4325627635, V = -.6082709305)	29.1880923942500+55.5122280784733*I, 29.1880923942500-55.5122280784733*I	Repelling	Unstable
(N = -.4345884397, V = .1197573734)	-6.003222251700+9.00214635655358*I, -6.003222251700-9.00214635655358*I	Attracting	Stable
(N = -3.074988235, V = -2.874675564)	2.15399521750000+.302594212184905*I, 2.15399521750000-.302594212184905*I	Repelling	Unstable

3. Growth of the Violent Population

In this section, we consider the situation where there is a 25% increase in violence. The mathematical model now becomes

$$f_N(N, V) = (a_1/(1+d_1(1.25V)) - a_{NR}(1.25V)/(1+d_2N) - b_1N) N = 0 \tag{5}$$

$$f_V(N, V) = (a_2/(1+d_3N) - a_{NR}N/(1+d_2N) - b_2(1.25V)) (1.25V) = 0 \tag{6}$$

Using the Maple CAS on (5) and (6) we obtained the following real valued equilibrium points:

3.1.1 Analyzing equilibrium points for stability

In this section we use the equilibrium points to generate the eigenvalues for the system and establish whether the equilibrium point is stable or unstable.

$$\{N = 0., V = 0.\},$$

$$\{N = 0., V = 3.200000000\},$$

$$\{N = 4., V = 0.\},$$

$$\{N = .4891955799, V = .5055515270\},$$

$$\{N = -.4325627635, V = -.4866167444\},$$

$$\{N = -.4345884397, V = 0.9580589875e-1\},$$

$$\{N = -3.074988235, V = -2.299740451\}$$

3.1.2 Summarization

Table 3 summarizes the results for an increased violence level.

Table 3 – Results for Increased Violence Levels

Equilibrium Point	Eigen values	Node Type	Stability
(N = 0., V = 0.)	2, 2	Repelling	Unstable
(N = 0., V = 3.200000000)	-6.31260878122594, -1.01712094877406	Attracting	Asymptotically Stable
(N = 4., V = 0.)	-2, -86/117	Attracting	Asymptotically Stable
(N = .4891955799, V = .5055515270)	2.35085912240317, 1.20431576659683	Repelling	Unstable
(N = -.4325627635, V = -.4866167444)	-40.8902957221704, -14.0745709068296	Attracting	Asymptotically Stable
(N = -.4345884397, V = .09580589875)	-4.55934547537500+8.41236264515438*I, -4.55934547537500-8.41236264515438*I	Attracting	Asymptotically Stable
(N = -3.074988235, V = -2.299740451)	2.35085912240317, 1.20431576659683	Repelling	Unstable

4. Decrease in the Violent Population

In this section, we consider the situation where the violence is reduced by 25%. The mathematical model now becomes

$$f_N(N, V) = (a_1/(1+d_1(.75V)) - a_{NR}(.75V)/(1+d_2N) - b_1N) N = 0 \tag{7}$$

$$f_R(N, V) = (a_1/(1+d_3(N) - a_{NR}(N)/(1+d_2N) - b_2(.75V)) (.75V) = 0 \tag{8}$$

4.1 Equilibrium Points

Using the Maple CAS on (7) and (8) and obtained the following real valued equilibrium points:

$$\{N = 0., V = 0.\},$$

$$\{N = 0., V = 5.333333333\},$$

$$\{N = 4., V = 0.\},$$

$$\{N = .4891955799, V = .8425858783\},$$

$$\{N = -.4325627635, V = -.8110279073\},$$

$$\{N = -.4345884397, V = .1596764979\},$$

$$\{N = -3.074988235, V = -3.832900753\}$$

4.2 Analyzing equilibrium points for stability

In this section we use the equilibrium points to generate the eigenvalues for the system and establish whether the equilibrium point is stable or unstable.

4.3 Summarization

Table 3 summarizes the results for adecreased violence level.

Table 3 – Results for Decreased Violence Levels

Equilibrium Point	Eigen values	Node Type	Stability
(N = 0., V = 0.)	2, 2	Repelling	Unstable
(N = 0., V = 5.3333333)	-10.5817315137926, -3.24683990620742	Attracting	Asymptotically Stable
(N = 4., V = 0.)	-2, -86/117	Attracting	Asymptotically Stable
(N = .4891955799, V = .8425858783)	.651325662915316, -1.35285239051532	Saddle	Unstable
(N = -.4325627635, V = -.8110279073)	88.4262919206642, -1.53454758536415	Saddle	Unstable
(N = -.4345884397, V = .1596764979)	-8.40445002895+9.519407358943*I, -8.40445002895-9.519407358943*I	Attracting	Asymptotically Stable
(N = -3.074988235, V = -3.832900753)	2.72977251800000+.817145809380968*I, 2.72977251800000-.817145809380968*I	Repelling	Unstable

5 Conclusions

As Table 2 indicates, at the current level of police violence, there is not much stability in the system. Table three indicates that more police violence keeps the system very unstable, where we interpret instability as those points where police action is inappropriate or even excessive. At these points, the neutral population begins to mistrust police actions and may engender fear that such actions could be turned on even otherwise peaceful citizenry. Even in Table 4, where police tone down the level of violence the system is still unstable.

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