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

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Abstract

The rise of the drugpopulation in the United States has brought concern, debate, and contention to the modern world. Thestrategies of the drug cartels are national and are no longer concentrated in a particular location. In this paper, we present a dynamical model of the interaction between drug cartel and DEA population. The formulation is based on models of interactions between competitive species [3] 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 five parts. Part one analyzes the current populations. Part two analyzes the situation when an additional number of drug users are introduced into the drug population. Part three analyzes the situation when there is a decline in the drug population. Part four analyzes the situation when the drug population goes to zero. Part five presents conclusions based on parts one through four.

Keywords: Drugs,competing species model, equilibrium solutions, stability at equilibrium solutions.

Mathematic subject classification: 62J12, 62G99

Computing Classification: I.4

1. Introduction

Drugsare not a new phenomena. However, there is a marked and exponential increase in the growth of drug users. Drug users wreak havoc to native citizens. These drug users affect all areas of the global economy, markets, and political and social policies. In addition, the strength and presence of drug organization, activities create issues. In particular, the rise of the drug users has reached epidemic proportions. Consequently, countries are faced with extremely difficult, complex, and contentious political and social decisions on the issues of drug users.

The acceptance of drugs provides a Trojan horse of issues, namely, violence, the popularity of drugs in the native country, and the continued growth of drug related problems. Hence, countries face the possibility offurther drug users. Despite these impending threats, there is not much literature that takes a dynamical systems approach to understanding the spread of drug users at a population level. Our primary objective is to bridge the gap.

In our framework, we let D represent the drug population. The neutral population is denoted by N: N can be viewed as the total neutral population of a country. This paper is a first step in providing a mathematical modeling framework to study the evolution and interaction between this neutral and drug population. The neutral population is modeled by standard population growth models

Also, we also consider the addition to the drug population of increased drug users. The paper is organized as follows. In section 2, we develop and analyze the time-dependent autonomous refugee ordinary differential equation (ODE) model. We examine the equilibrium solutions, the stability of the equilibrium solutions and investigate the dynamics numerically. In section 3, we consider the situation when more cartels are introduced into the system.We examine the equilibrium solutions, the stability of the equilibrium solutions and investigate the dynamics numerically for this situation also. In section 4, we present consider the situation where there is a decline in drug popultion. In section 5 we present our conclusions based on the analysis in sections 2 and 3 and 4.

2. Neutral Drug (N, D) ODE Model

Consider the mathematical model

$$N = (a_1/(1+d_1 D) - a_{NR} D/(1+d_2 N) - b_1 N^{)}\ N = 0 = f_N(N, D) \quad (1)$$

$$D = (a_2/(1+d_3 N) - a_{NR} N/(1+d_2 N) - b_2 D^{)}(D) = 0 = g_R(N, D) \quad (2)$$

The populations N(t) and U(t) represent the populations of the neutral and undocumented populations. New undocumented aliens are slowly coming into the undocumented 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 neutral population

a_2 Growth rate of the drug population
b_1 Population loss in N due to intra-species competition and natural mortality
b_2 Population loss in D due to intra-species competition and natural mortality
a_{NR} Maximum per capita loss in N due to recruitment by Druggies
d_1 Measures the effectiveness of CN in disrupting the growth rate of D
d_2 Measures the resilience of N to recruitment strategies by D
d_3 Measures the effectiveness of D in creating more cartels

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 $d_1 >> 1$ then the growth rate of D is reduced. This is interpreted as: a highly effective DEA population, which can greatly hinder the growth rate of N. The growth rate of the cartel population depends on the successful recruitment from the neutral population. Notice, that if $d_2 >> 1$ then the recruitment by D is small, Also, if $d_3 >> 1$, new drug users are introduced into the drugpopulation 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

2.1Neutral Drug (N, D) ODE Model

Consider the mathematical model

$$f_N(N, D) = (a_1/(1+d_1D) – a_{NR}D/(1+d_2N) – b_1N) N = 0 \quad (3)$$

$$f_R(N, D) = (a_2/(1+d_3N) - (a_{NR}N/(1+d_2N)) – b_2D) D = 0 \quad (4)$$

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

The Jacobian for this system is defined as

$$J = \begin{vmatrix} \partial f/\partial N & \partial f/\partial D \\ \partial g/\partial N & \partial g/\partial D \end{vmatrix}$$

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

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

2.2 Equilibrium Points

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

{D = 0., N = 0.},
{D = 4., N = 0.},
{D = 0., N = 4.},
{D = .8213492010, N = .4301871556},
{D = -1.121275136, N = -.4311081397},
{D = .1299378971, N = -.4346164212},
{D = -2.658090053, N = -3.952306486}

2.3Analyzing 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.

Table 2 summarizes the results for the current population levels.

Table 2 – Results for Current Population Levels

Equilibrium Point	Eigen values	Node Type	Stability
(D = 0., N = 0.)	2, 2	Repelling	Unstable
(D = 0., N = 4.)	-2, -86/117	Attracting	Unstable
(D = 4., N = 0.)	-44/9+(2/9)*sqrt(185), -44/9-(2/9)*sqrt(185)	Attracting	Unstable
(D = .8213492010, N = .4301871556)	.631870324280523, -1.35022436018052	Saddle	Unstable
(D = -1.121275136, N = -.4311081397)	124.789757665452, -7.28136719345222	Saddle	Unstable

(D = .1299378971, N = -.4346164212)	-6.62013265655+9.18652446854370*I, -6.62013265655-9.18652446854370*I	Attracting Spiral	Asymptotically Stable
(D = -2.658090053, N = -3.952306486)	3.45507685676904, 1.47441380823096	Repelling	Unstable

3. Growth of the Drug Population

In this section, we consider the situation where 5000000 new drug users are added to the population. The mathematical model now becomes

$$f_N(N, D) = (a_1/(1+d_{1(}D+5000000)) - a_{NR(}D+5000000)N/(1+d_2N) - b_1N)\ N = 0 \qquad (3)$$

$$g_R(N, D) = (a_2/(1+d_3N) - (a_{NR}N/(1+d_2N)) - b_{2(}D+5000000)\ (D+5000000) = 0 \qquad (4)$$

3.1 Equilibrium Points

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

{D = -5.000000*10^6, N = 0.},
{D = -4.999996*10^6, N = 0.},
{D = -5.000000*10^6, N = 4.},
{D = -4.999999179*10^6, N = .4301871556},
{D = -5.000001121*10^6, N = -.4311081397},
{D = -4.999999870*10^6, N = -.4346164212},
{D = -5.000002658*10^6, N = -3.952306486}

3.2 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.

Table 3 summarizes the results for an increased undocumented population level.

Table 3 – Results for Increased Drug Population Levels

Equilibrium Point	Eigen values	Node Type	Stability
(D = -4.999996*10^6, N = 0.),	1.0000000*10^7, 5.000002*10^6	Repelling	Unstable

(D = -5.000000*10^6, N = 0.)	9.999992*10^6, 4.999998*10^6	Repelling	Unstable
(D = -5.000000*10^6, N = 4.),	1.23452844960607*10^5, 4.99999921013939*10^6	Repelling	Unstable
(D = -4.999999179*10^6, N = .4301871556)	2.88934551996940*10^6, 4.99999770403060*10^6	Repelling	Unstable
(D = -5.000001121*10^6, N = -.4311081397)	5.26749692299691*10^8, 4.99999006030869*10^6	Repelling	Unstable
(D = -4.999999870*10^6, N = -.4346164212)	5.84793624029869*10^8, 4.99998950513101*10^6	Repelling	Unstable
(D = -5.000002658*10^6, N = -3.952306486)	2.09763520857376*10^5, 5.00000121804262*10^6	Repelling	Unstable

4. Decline of the Drug Population

In this section, we consider the situation where 5000000 are removed from the drug population. The mathematical model now becomes

$$f_N(N, D) = (a_1/(1+d_1(D-5000000)) – a_{NR}(D-5000000)/(1+d_2N) – b_1N) N = 0 \quad (7)$$

$$g_R(N, D) = -2D/(1+3N)^2 - a_{NR}D/(1+d_2N) – b2(D-5000000)) \ (D-5000000) = 0 \quad (8)$$

4.1 Equilibrium Points

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

{D = 5.000000*10^6, N = 0.},
{D = 5.000004*10^6, N = 0.},
{D = 5.000000*10^6, N = 4.},
{D = 5.000000821*10^6, N = .4301871556},
{D = 4.999998879*10^6, N = -.4311081397},
{D = 5.000000130*10^6, N = -.4346164212},
{D = 4.999997342*10^6, N = -3.952306486}

4.2Analyzing 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.

Table 3 summarizes the results for an decreased undocumented population level.

Table 3 – Results for Decreased Drug Population Levels

Equilibrium Point	Eigen values	Node Type	Stability
(D = 5.000004*10^6, N = 0.)	-1.0000008*10^7, -5.000002*10^6	Attracting	Stable
(D = 5.000000*10^6, N = 0.)	-1.0000008*10^7, -5.000002*10^6	Attracting	Stable
(D = 5.000000*10^6, N = 4.)	-1.23460735239320*10^5, -5.00000078986068*10^6	Attracting	Stable
(D = 5.000000821*10^6, N = .4301871556)	-2.88934355603247*10^6, -5.00000229596753*10^6	Attracting	Stable
(D = 4.999998879*10^6, N = -.4311081397)	-5.26749434300308*10^8, -5.00000993969177*10^6	Attracting	Stable
(D = 5.000000130*10^6, N = -.4346164212)	-5.84793632770131*10^8, -5.00001049486937*10^6	Attracting	Stable
(D = 4.999997342*10^6, N = -3.952306486)	-2.09755171342874*10^5, -4.99999878195713*10^6	Attracting	Stable

5. Elimination of Drug Population

In this section, we consider the situation where a mere 300,000 new undocumented aliens are added to the Radical population. The mathematical model now becomes

$$f_N(N, D) = (a_1/(1+d_1(0)) – a_{NR}(0)/(1+d_2N) – b_1N) N = 0 \quad (9)$$

$$g_R(N, D) = a_{NR}D/(1+d_2N) – b_2(0)) \ (0) = 0 \quad (8)$$

5.1 Equilibrium Points

Using the Maple CAS on (9) and (10) we obtained the following real valued equilibrium points

{N = 0., D = 0},
{N = 4., D = 0}

5.2Analyzing 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

Table 5 summarizes the results for a zero drug population level.

Table 5 – Results for ZeroDrug Population Levels

Equilibrium Point	Eigen values	Node Type	Stability
(N = 0., D = 0)	2, 2	Repelling	Unstable
(N = 4., D = 0)	-2, -86/117	Attracting	Asymptotically stable

6. Conclusions

In this paper we modeled and analyzed the interaction of neutral and drug populations. A comparison of the results in Table 2 indicates that the system already contains some instability, the entire system becomes more unstable and Table 3 indicates that with an increase in drug population the system becomestotally unstable Table 4 indicates that with a decline in drug population the system becomes more stable, While table 5 indicates that one node is stable while the other is unstable. We interpret this to the fact that drug population could once again rise

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