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THE MODELING AND ANALYSIS OF THE INTERACTION BETWEEN DOMESTIC WORKERS AND FOREIGN AND OVERSEAS WORKERS: *A COMPETING SPECIES MODEL*

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A B S T R A C T

Business is the very heart of the free enterprise system. Anything that affects the ability of businesses to make a reasonable profit is of some concern. One of the factors that affect the profitability of a business is the cost of its workforce. In recent years some businesses have turned to hire foreign workers over domestic workers to keep their costs down. The business has also turned to ship many jobs to overseas workers. This practice can have an effect on the local, state and national level. In this paper, we present a dynamic model of the interaction between domestic worker and domestic and overseas worker populations. The formulation is based on models of interactions between competitive species type dynamics. An exploration of the long-term dynamics and stability of homogeneous equilibrium solutions and their stability is given.

K E Y W O R D S

Foreign workers, domestic workers, overseas workers, competing species model, equilibrium solutions, stability at equilibrium solutions.

Mathematic subject classification: 62J12, 62G99

Computing Classification: I.4

Introduction

Business is the very heart of the free enterprise system. Anything that affects the ability of businesses to make a reasonable profit is of some concern. One of the factors that affect the profitability of a business is the cost of their work force. In recent years some businesses have turned to hiring foreign workers over domestic workers to keep their costs down. Foreign workers are willing to work for lower salaries and fewer thus keeping costs down. Business has also turned to shifting operations overseas. This practice can have an effect on the local, state and national level.

In our framework, we let F represent the foreign worker population. The overseas worker population is represented by O. The domestic worker population is denoted by D.D can be viewed as the total domestic worker population of an area. This paper is a first step in providing a mathematical modeling framework to study the evolution and interaction between this domestic worker and foreign worker populations. The domestic population is modeled by standard population growth models.

Also, we also consider the addition to the foreign worker population of increased foreign workers and increased overseas workers. The paper is organized as follows. In section 2, we develop and analyze the time-dependent autonomous worker ordinary differential equation (ODE) model. We examine the equilibrium solutions, the stability of the equilibrium solutions and investigate the dynamics numerically.

2. Domestic, Foreign (D, F) ODE Model

Consider the mathematical model

$$D = (a_1/(1+d_1F) - a_{NR}F/(1+d_2D) - b_1D)D = 0 = f_N(D, F) \qquad (1)$$

$$F = (a_2/(1+d_3D) - a_{NR}D/(1+d_2D) - b_2F)(F) = 0 = f_R(D, F) \qquad (2)$$

The populations D(t) and F(t) represent the populations of the domestic and foreign worker populations. New foreign workers are slowly coming into the foreign worker population. The parameters are all assumed to be positive and their descriptions are given in Table 2.1.

Symbols	Meaning
a_1	Growth rate of the domestic population
a_2	Growth rate of the foreign population
b_1	Population loss in D
b_2	Population loss in F
a_{NR}	Maximum per capita loss in F due to recruitment by foreigners
d_1	Measures the effectiveness of D in disrupting the growth rate of F
d_2	Measures the resilience of D to recruitment strategies by F
d_3	Measures the effectiveness of F creating more workers

Table 2.1: List of parameters used in the differential equation model

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 F is reduced. This is interpreted as: a highly effective domestic population, which can greatly hinder the growth rate of F. The growth rate of the foreign population depends on the successful recruitment from the foreign population. Notice, that if $d_2 >> 1$ then the recruitment by F is small. Also, if $d_3 >> 1$, new foreign workers are introduced into the population more slowly. The values chosen for the variables in this model are listed in Table 2.2.

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

Table 2.2: Values of parameters

2.1 Domestic Foreign (D, F) ODE Model

Consider the mathematical model

$$f_N(D, F) = (a_1/(1+d_1F) – a_{NR}F/(1+d_2D) – b_1D)*D = 0 \qquad (3)$$

$$f_R(D, F) = (a_2/(1+d_3D) - (a_{NR}D/(1+d_2D)) – b_2F)*F = 0 \qquad (4)$$

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

The Jacobian for this system is defined as:

$$J = \begin{vmatrix} \partial f_N/\partial D & \partial f_N/\partial F \\ \partial f_R/\partial D & \partial f_R/\partial F \end{vmatrix}$$

The partial derivatives are,

$$\partial D/\partial D = a1/(1+d_1F) – a_{nr}F(1+d_2D) – a_{nr}d_2FD – 2b_1D$$

$$\partial D/\partial F = -a_1d_1D/(1+d_1F)^2 – a_{nr}D/(1+d_2D)$$

$$\partial F/\partial D = -a_2d_3F/(1+d_1F)^2 –a_{nr}D/(1+d_2D)$$

$$\partial F/\partial F = a_2/(1+d_3D) - a_{nr}F(1+d_2D) – a_{nr}d_2FD – 2b_2F$$

F

Using the values in table for the parameters, the Jacobian becomes.

$$
J = \begin{vmatrix} 2/(1+2F) - 2F(1+2D) - 4FD - D\text{-}4D/(1+2F)^{\wedge}2 - 2D/(1+2D) \\ \\ -4F/(1+2F)^{\wedge}2 - 2D/(1+2D)2/(1+2D) - 2F(1+2D) - 4FD - F \end{vmatrix}
$$

2.2 Equilibrium Points

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

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

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 2.3 summarizes the results for the current population levels.

Equilibrium Point	Eigen values	Node Type	Stability
(F = 0., D = 0	2, 2.	Repelling	Unstable
(F = 4., D = 0.)	-10. -7.77777777800000	Attracting	Stable
(F = 0., D = 4.)	-4.91963492175763, 3.14185714395763	Saddle	Unstable
(F = .6319394087, D = .4891955799)	-.558388551229047, -2.41920366377095	Attracting	Stable
(F = -.6082709305, D = -.4325627635)	-40.4097992538318, 62.9778396954318	Saddle	Unstable
(F = .1197573734, D = -.4345884397),	-2.62016378611131, 16.5910505440113	Saddle	Unstable
(F = -2.874675564, D = -3.074988235)	-33.2330107120919, -34.5763031979081	Attracting	Stable

Table 2.3 – Results for Current Population Levels

2.4 Growth of the Foreign Population

In this section, we consider the situation when the foreign population is increased by 25%. The mathematical model now becomes

$f_N(D, F) = (a_1/(1+d_1(1.25*F)) – a_{NR}(1.25*F)D/(1+d_2D) – b_1D) D = 0$ (3)

$f_R(D, F) = (a_2/(1+d_3D) - (a_{NR}D/(1+d_2D)) – b_2(1.25*F) *(1.25*F) = 0$ (4)

2.5 Equilibrium Points

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

{F=0.D=0.},

{F=4.D=0.},

{F=0.D=4.},

{F=0.6319394087, D=0.4891955799},

{F=-0.6082709305,D=-0.4325627635},

{F=0.1197573734,D=-0.4345884397},

{F=-2.874675564,D=-3.074988235},

2.6 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 a 25% increased foreign population level.

Equilibrium Point	Eigen Values	Type of Node	Stability
{F=0., D=0.},	-2. 2.500	Saddle	Unstable
{F=3.20, D=0.},	-11.7831183980041, -9.49465938199590	Attracting	Stable
{F=0., D=4.},	-7.60, -6.129729730	Saddle	Unstable
{F=0.5055515270, D=0.4891955799},	-5.15842697804865, -.791233670951349	Attracting	Unstable
{F=-0.4866167444, D=-0.4325627635},	11.8478492025000+75.3302521839959*I, 11.8478492025000-75.3302521839959*I	Repelling	Unstable
{F=0.09580589875, D=-0.4345884397},	-5.20171705170115, 19.1560650757012	Saddle	Unstable
{F=-2.299740451, D=-3.074988235}	-.426456457639759, -34.1355867353602	Attracting	Stable

Table 2.4 – Results for Increased Foreign Population

2.7 Decline of the Foreign Population

In this section, we consider the situation where the foreign population is decreased by 25%. The mathematical model now becomes

$f_N(D, F) = (a_1/(1+d_1(0.75*F)) – a_{NR}(0.75*F)/(1+d_2D) – b_1D)*D = 0$ (7)

$f_R(D, F) = -2(0.75F)/(1+3D)^2 - a_{NR}(F*0.75)/(1+d_2D) – b_2(0.75*F)) * (0.75*F) = 0$ (8)

2.8 Equilibrium Points

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

{F = 0., D = 0.},

{F = 5.333333333, D = 0.},

{F = 0, D = 4.},

{F=0.8425858783,D=0.4891955799},

{F=-0.8110279073,D=-0.4325627635},

{F=0.1596764979,D=-0.4345884397},

{F=-3.832900753,D=-3.074988235}

2.9 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 2.5 summarizes the results for a25% decreased foreign population level.

Equilibrium Point	Eigen Values	Type of Node	Stability
{F=0. D=0.},	1.50, 2.	Repelling	Unstable
{F=4., D=0.},	-7.500, -5.7142857140	Attracting	Stable
{F=0. D=4.},	-4.01796567807023, 2.18463234477023	Saddle	Unstable
{F=0.6319394087, D=0.4891955799},	-.173690628143177, -1.81764011345682	Attracting	Stable
{F=-0.6082709305, D=-0.4325627635},	228.921617296507, -182.127661886507	Saddle	Unstable
{F=0.1197573734, D=-0.4345884397},	-1.48833880891855, 12.5604382597185	Saddle	Unstable
{F=-2.874675564, D=-3.074988235}	-24.8752324056236, -25.5010356543764	Attracting	Stable

Table 2.5 – Results for Decreased Foreign Population

3.0 Domestic, Overseas (D, O) ODE Model

Consider the mathematical model

$$D = (a_1/(1+d_1O) - a_{NR}O/(1+d_2D) - b_1D)D = 0 = f_N(D, O) \quad (1)$$

$$O = (a_2/(1+d_3D) \;\; - a_{NR}D/(1+d_2D) \;\; - b_2O)\,(O) = 0 = f_R(D, O) \quad (2)$$

The populations D(t) and O(t) represent the populations of the domestic and overseas worker populations. New overseas workers are slowly coming into the overseas worker population. The parameters are all assumed to be positive and their descriptions are given in Table 3.1.

Symbols	Meaning
a_1	Growth rate of the domestic population
a_2	Growth rate of the overseas population
b_1	Population loss in D
b_2	Population loss in O
a_{NR}	Maximum per capita loss in O due to recruitment by overseas
d_1	Measures the effectiveness of D in disrupting the growth rate of O
d_2	Measures the resilience of D to recruitment strategies by O
d_3	Measures the effectiveness of O creating more workers

Table 3.1: List of parameters used in the differential equation model

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 O is reduced. This is interpreted as: a highly effective domestic population, which can greatly hinder the growth rate of O. The growth rate of the overseas population depends on the successful recruitment from the overseas population. Notice, that if d_2>> 1 then the recruitment by O is small. Also, if d_3>> 1, new overseas workers are introduced into the population more slowly. The values chosen for the variables in this model are listed in Table 1b.

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

Table 3.2: Values of parameters

3.1 Domestic Overseas (D, O) ODE Model

Consider the mathematical model

$$f_N(D, O) = (\, a_1/(1+d_1O) - a_{NR}O/(1+d_2D) - b_1D\,)\, D = 0 \quad (3)$$

$$f_R(D, O) = \;(a_2/(1+d_3D) - (a_{NR}D/(1+d_2D)) \;- b_2O\,)\;\; O = 0 \quad (4)$$

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

The Jacobian for this system is defined as

$$J = \begin{vmatrix} \partial D/\partial D & \partial F/\partial O \\ & \\ \partial D/\partial D & \partial F/\partial O \end{vmatrix}$$

Taking the partial derivatives are

$\partial D/\partial D = a1/(1+d_1O) – a_{nr}O(1+d_2D) – a_{nr}d_2OD – 2b_1D$

$\partial D/\partial O = -a_1d_1D/(1+d_1O)^2 – a_{nr}D/(1+d_2D)$

$\partial O/\partial D = -a_2d_3O/(1+d_1O)^2 –a_{nr}D/(1+d_2D)$

$\partial O/\partial O = a_2/(1+d_3D) - a_{nr}O(1+d_2D) – a_{nr}d_2OD – 2b_2O$

Using the values in table for the parameters, the Jacobian becomes.

$$J = \begin{vmatrix} 2/(1+2O) – 2O(1+d_2D) – 4OD –D & -4D/(1+2O)^2 – 2D/(1+2D) \\ & \\ -4O/(1+2O)^2 –2D/(1+2D) & 2/(1+2D) - 2O(1+2D) – 4OD –O \end{vmatrix}$$

3.2 Equilibrium Points

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

{O = 0., D = 0.},

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

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

{O = .6319394087, D = .4891955799},

{O = -.6082709305, D = -.4325627635},

{O = .1197573734, D = -.4345884397},

{O = -2.874675564, D = -3.074988235},

3.3 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 3.3 summarizes the results for the current population levels.

Equilibrium Point	Eigen values	Node Type	Stability
(O = 0., D = 0	2, 2.	Repelling	Unstable
(O = 4., D = 0.)	-10. -7.77777777800000	Attracting	Stable
(O = 0., D = 4.)	-4.91963492175763, 3.14185714395763	Saddle	Unstable
(O = .6319394087, D = .4891955799)	-.558388551229047, -2.41920366377095	Attracting	Stable
(O = -.6082709305, D = -.4325627635)	-40.4097992538318, 62.9778396954318	Saddle	Unstable
(O = .1197573734, D = -.4345884397),	-2.62016378611131, 16.5910505440113	Saddle	Unstable
(O = -2.874675564, D = -3.074988235)	-33.2330107120919, -34.5763031979081	Attracting	Stable

Table 3.3 – Results for Current Population Levels

3.4 Growth of the Overseas Population

In this section, we consider the situation when the overseas population is increased by 25%. The mathematical model now becomes

$f_N(D, O) = (a_1/(1+d_1(1.25*O)) – a_{NR}(1.25*O)D/(1+d_2D) – b_1D) D = 0$ (3)

$f_R(D, O) = (a_2/(1+d_3D) - (a_{NR}D/(1+d_2D)) – b_2(1.25*O) (1.25*O) = 0$ (4)

3.5 Equilibrium Points

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

{O=0.D=0.},

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{O=0.6319394087, D=0.4891955799},

{O=-0.6082709305,D=-0.4325627635},

{O=0.1197573734,D=-0.4345884397},

{O=-2.874675564,D=-3.074988235},

3.6 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 a 25% increased overseas population level.

Equilibrium Point	Eigen Values	Type of Node	Stability
{O=0., D=0.},	-2. 2.500	Saddle	Unstable
{O=3.20, D=0.},	-11.7831183980041, -9.49465938199590	Attracting	Stable
{O=0., D=4.},	-7.60, -6.129729730	Saddle	Unstable
{O=0.5055515270, D=0.4891955799},	-5.15842697804865, -.791233670951349	Attracting	Unstable
{O=-0.4866167444, D=-0.4325627635},	11.8478492025000+75.3302521839959*I, 11.8478492025000-75.3302521839959*I	Repelling	Unstable
{O=0.09580589875, D=-0.4345884397},	-5.20171705170115, 19.1560650757012	Saddle	Unstable
{O=-2.299740451, D=-3.074988235}	-.426456457639759, -34.1355867353602	Attracting	Stable

Table 3.4 – Results for Increased Overseas Population

3.7 Decline of the Overseas Population

In this section, we consider the situation where the overseas population is decreased by 25%. The mathematical model now becomes

$f_N(D, O) = (a_1/(1+d_1(0.75*O)) – a_{NR}(0.75*D)/(1+d_2D) – b_1D) D = 0$ (7)

$f_R(D, O) = -2O/(1+3D)^2 - a_{NR}O/(1+d_2D) – b_2(0.75*O)) (0.75*O) = 0$ (8)

3.8 Equilibrium Points

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

{O = 0., D = 0.},

{O = 5.333333333, D = 0.},

{O = 0, D = 4.},

{O=0.8425858783,D=0.4891955799},

{O=-0.8110279073,D=-0.4325627635},

{O=0.1596764979,D=-0.4345884397},

{O=-3.832900753,D=-3.074988235}

3.9 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 a25% decreased overseas population level.

Equilibrium Point	Eigen Values	Type of Node	Stability
{O=0. D=0.},	1.50, 2.	Repelling	Unstable

{O=4., D=0.},	-7.500, -5.7142857140	Attracting	Stable
{O=0. D=4.},	-4.01796567807023, 2.18463234477023	Saddle	Unstable
{O=0.6319394087, D=0.4891955799},	-.173690628143177, -1.81764011345682	Attracting	Stable
{O=-0.6082709305, D=-0.4325627635},	228.921617296507, -182.127661886507	Saddle	Unstable
{O=0.1197573734, D=-0.4345884397},	-1.48833880891855, 12.5604382597185	Saddle	Unstable
{O=-2.874675564, D=-3.074988235}	-24.8752324056236, -25.5010356543764	Attracting	Stable

Table 3.5 – Results for Decreased Overseas Population

4.0 Domestic, Foreign, Overseas (D, F, O) ODE Model

Consider the mathematical model:

$D = a_1D/(1+d_1F) - a_{NR}FD/(1+d_2D) + a_1D/(1+d_1O) - a_{NR}OD/(1+d_2D) - b_1D^2 = 0)$

$F = a_2F/(1+d_3D) - a_{nr}FD/(1+d_2D) + a_2F/(1+d_4O) - a_{nr}FO/(1+d_4O) - b_2F^2 = 0$

$O = a_2O/(1+d_3D) - a_{nr}OD/(1+d_2D) + a_2O/(1+d_4F) - a_{nr}FO/(1+d_4F) - b_2O^2 = 0$

The populations D,F and O represent the populations of the domestic, foreign worker and overseas populations. New foreign workers are slowly coming into the foreign worker population as are overseas workers. The parameters are all assumed to be positive and their descriptions are given in Table 4.1.

Symbols	Meaning
a_1	Growth rate of the D population
a_2	Growth rate of the F, O population
b_1	Population loss in D
b_2	Population loss in F, O
a_{NR}	Maximum per capita loss in D due to recruitment by F/O
d_1	Measures the effectiveness of D in disrupting the growth rate of F, O
d_2	Measures the resilience of D to recruitment strategies by F/O
d_3	Measures the effectiveness of F/O creating more workers
d_4	Measures the resilience of F, O to strategies by D

Table 4.1: List of parameters used in the differential equation model

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 F is reduced. This is interpreted as: a highly effective domestic population, which can greatly hinder the growth rate of F. The growth rate of the foreign/overseas population depends on the successful recruitment from the foreign population. Notice, that if d_2>> 1 then the recruitment by F is small. Also, if d_3>> 1, new foreign/overseas workers are introduced into the population more slowly. The values chosen for the variables in this model are listed in Table 1b.

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

Table 4.2: Values of parameters

4.1 Domestic Foreign, Overseas (D, F, O) ODE Model

Consider the mathematical model

$D = a_1D/(1+d_1F) – a_{NR}FD/(1+d_2D) + a_1D/(1+d_1O)– a_{NR}OD/(1+d_2D) - b_1D^2 = 0)$
$F = a_2F/(1+d_3D) - a_{nr}FD/(1+d_2D) + a_2F/(1+d_4O) –a_{nr}FO/(1+d_4O) – b_2F^2 = 0$
$O = a_2O/(1+d_3D) - a_{nr}OD/(1+d_2D) + a_2O/(1+d_4F) – a_{nr}FO/(1+d_4F) – b_2O^2 = 0$

Since this system is nonlinear, the first step is linearization and using the Jacobian. The Jacobian for this system is defined as

J =

$$\begin{vmatrix} \partial D/\partial D & \partial D/\partial G & \partial D/\partial O \\ \partial F/\partial D & \partial F/\partial F & \partial F/\partial O \\ \partial O/\partial D & \partial O/\partial F & \partial O/\partial O \end{vmatrix}$$

The partial derivatives are,

$\partial D/\partial D = a_1/(1+d_1F) – (a_{nr}F(1+d_2D) – a_{nr}d_2FD)/(1+d_2D)^2 + a_1/(1+d_1O) – (a_{nr}O(1+d_2D) – a_{nr}d_2OD)/(1+d_2D)^2 – 2b_1D$
$\partial N/\partial F = -a_1d_1D/(1+d_1F)$^2 $– a_{nr}D/(1+d_2D)$
$\partial D/\partial O = -a_1d_1D/(1+d_1O)$^2 $– a_{nr}D/(1+d_2D)$
$\partial F/\partial D = -a_2d_3F/(1+d_2D)$^2 $–(a_{nr}F(1+d_2D) –a_{nr}d_2FD)/(1+d_2D)^2$
$\partial F/\partial F = a_2/(1+d_3D) - a_{nr}D/(1+d_2D) + a_2/(1+d_4O) – a_{nr}O/(1+d_4O) – 2b_2F$
$\partial F/\partial O = -a_2d_4F/(1+d_4O)^2 – (a_{nr}F(1+d_4O) – a_{nr}d_4FO)/(1+d_4O)^2$
$\partial O/\partial D = -a_2d_4O/(1+d_1D)$^2 $– (a_{nr}O(1+d_2D) – a_{nr}d_2OD)/(1+d_2D)^2$
$\partial O/\partial F = -a_2d_4/(1+d_4F) - (a_{nr}O(1+d_4F) – a_{nr}d_4OF)/(1+d_4F)^2$
$\partial O/\partial O = a_2/(1+d_3D) - a_{nr}D/(1+d_2D) – a_{nr}GD/(1+d_4G) – 2b_2O$

Putting these into the Jacobian yields:

J =

| $a_1/(1+d_1F) - (a_{nr}F(1+d_2D) - a_{nr}d_2GD)/(1+d_2D)^2 + a_1/(1+d_1O) - (a_{nr}O(1+d_2D) - a_{nr}d_2O)/(1+d_2D)^2 - 2b_1D$ |

| $-a_1d_1D/(1+d_1F)^{\wedge}2 - a_{nr}D/(1+d_2D)$ |

| $-a_2d_4F/(1+d_4O)^{\wedge}2 - (a_{nr}D/(1+d_2D)$ |

| $-a_2d_3F/(1+d_2D)^{\wedge}2 - (a_{nr}F(1+d_2D) - a_{nr}d_2FD)/(1+d_2D)^2$ |

| $a_2/(1+d_3D) - a_{nr}D/(1+d_2D) + a_2/(1+d_4O) - a_{nr}O/(1+d_4O) - 2b_2F$ |

| $-a_2d_4F/(1+d_4O)^2 - (a_{nr}F(1+d_4O) - a_{nr}d_4FO)/(1+d_4O)^2$ |

| $-a_2d_4O/(1+d_3D)^{\wedge}2 - (a_{nr}O(1+d_2D) - a_{nr}d_2OD)/(1+d_2D)^2$ |

| $-a_2d_4/(1+d_4F) - (a_{nr}O(1+d_4F) - a_{nr}O/(1+d_4F) - 2b_2F$ |

| $a_2/(1+d_3D) - a_{nr}D/(1+d_2D) - a_{nr}FD/(1+d_4F) - 2b_2O$ |

4.2 Equilibrium Points

Using the Maple CAS, we obtained the real valued equilibrium points:

{O=0.,F=2.886000936,D=2.886000936},

{O=0.,F=-1.386000936,D=-1.386000936},

{O=1.500000000,F=3.500000000,F=0.},

{O=0.,F=3.179449472,D=2.043559577},

{O=0.,F=-1.179449472,D=-1.443559577}

{O=0.6663492972,F=0.8750730641,D=0.8026799460},

{O=0.2653920796,F=0.5682408219,D=4.124768937},

{O=-7.158932779,F=-3.780423019,D=3.976946247},

{O=-0.5973136278,F=-0.7089388654,D=-0.4120730198},

{O=-7.916697282,F=-4.982715615,D=-5.688310577},

{O=0.,F=0.,D=0.},

{O=-0.8000000000,F=-8.,D=0.},

{O=0.,F=0.,D=8.},

{O=0.,F=8.,D=0.},

{O=12.,F=0.,D=0.}

4.3 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 2 summarizes the results for the current population levels.

Equilibrium Points	Eigenvalues	Node Type	Stability
{O=0., F=2.886000936, D=2.886000936},	-.981729408472435, 1.34996041158318, -6.64609108611074	Saddle	Unstable
{O=0., F=-1.386000936, D=-1.386000936},	3.37228605902377+2.02684604974168*I, 3.37228605902377-2.02684604974168*I, -17.7097675990475	Saddle	Unstable
{O=1.50, F=3.50, D=0.},	-1.94060148566472, -6.57050962533528, -9.250	Attracting	Stable
{O=0., F=3.179449472, D=2.043559577},	-.480739598545902, 1.55203019982847, -6.91802482728257	Saddle	Unstable
{O=0., F=-1.179449472, D=-1.443559577},	3.08296676859391+1.30701987585797*I, 3.08296676859391-1.30701987585797*I, -29.7025326141878	Saddle	Unstable
{O=0.6663492972, F=0.8750730641, D=0.8026799460},	0.581177228598734, -3.74240958142869, -.751071867170040	Saddle	Unstable
{O=0.2653920796, F=0.5682408219, D=4.124768937},	-2.07979473553723, -3.13019263056733, 0.402667332504560	Saddle	Unstable
{O=-7.158932779, F=-3.780423019, D=3.976946247},	-3.95645432641909, 2.04685291960921, -1.17483211519011	Saddle	Unstable
{O=-0.5973136278, F=-0.7089388654, D=-0.4120730198},	55.2162666499610+46.4182336071202*I, 55.2162666499610-46.4182336071202*I, -12.2473811979218	Saddle	Unstable
{O=-7.916697282, F=-4.982715615, D=-5.688310577},	5.62895884086411, 2.77966693558065, 0.285396884555236	Repelling	Unstable
{O=0., F=0., D=0.},	4., 2., 0	Repelling	Unstable
{O=-0.80, F=-8., D=0.},	11.1142857145000+22.2747042383162*I, 11.1142857145000-22.2747042383162*I, 14.133333340	Repelling	Unstable
{O=0.,	-4.,	Saddle	Unstable

F=0., D=8.},	-.82352941180, . 941176470600000		
{O=0., F=8., D=0.},	1.99999999940984, -11.5555555554098, -13.882352940	Saddle	Unstable
{O=12., F=0., D=0.}	-10., -21.920, -3.6923076920	Attracting	Stable

Table 4.3 – Results for Current Population Levels

4.4 Growth of the Foreign Population

In this section, we consider the situation when the foreign population is increased by 25%. The mathematical model now becomes

$D = a_1D/(1+d_1F) – a_{NR}(F*1.25)D/(1+d_2D) + a_1D/(1+d_1O) – a_{NR}OD/(1+d_2D) - b_1D^2 = 0)$

$F = a_2F/(1+d_3D) - a_{nr}(1.25*F)D/(1+d_2D) + a_2(1.25*F)/(1+d_4O) – a_{nr}(F*1.25)O/(1+d_4O) – b_2(1.25F)^2 = 0$

$O = a_2O/(1+d_3D) - a_{nr}OD/(1+d_2D) + a_2O/(1+d_4(F*1.25)) – a_{nr}(1.25*F)O/(1+d_4(1.25*F)) – b_2O^2 = 0$

4.5 Equilibrium Points

Using the Maple CAS we obtained the following real valued equilibrium points:

{O=0.,F=0.,D=0.},
{O=-0.8000000000,F=-8.,D=0.},
{O=1.500000000,F=3.500000000,D=0.},
{O=0.,F=8.,D=0.},
{O=0.,F=3.179449472,D=2.043559577},

{O=0.,F=-1.179449472,D=-1.443559577},
{O=0.6663492972,F=0.8750730641,D=0.8026799460},
{O=0.2653920796,F=0.5682408219,D=4.124768937},
{O=-7.158932779,F=-3.780423019,D=3.976946247},
{O=-0.5973136278,F=-0.7089388654,D=-0.4120730198},

{O=-7.916697282,F=-4.982715615,D=-5.688310577},
{O=0.,F=2.886000936,D=2.886000936},
{O=0.,F=-1.386000936,D=-1.386000936},
{O=12.,F=0.,D=0.},
{O=0.,F=0.,D=8.}

4.6 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 a 25% increased foreign population level.

Equilibrium Points	Eigenvalues	Node Type	Stability
{O=0., F=0., D=0.},	4., 2., 0.	Repelling	Unstable
{O=-0.80, F=-8., D=0.},	.100000000350+12.0842559535239*I, .100000000350-12.0842559535239*I, 15.866666670	Repelling	Unstable
{O=1.50, F=3.50, D=0.},	-1.31464835938447, -6.24785164061553, -10.078947370	Attracting	Stable
{O=0., F=8., D=0.},	5.43983947615177, -13.3221924173518, -13.882352940	Saddle	Unstable
{O=0., F=3.179449472, D=2.043559577},	-.169877692829532, 3.59421823866899, -7.95635883283946	Saddle	Unstable
{O=0., F=-1.179449472, D=-1.443559577},	3.13073927808989+2.05283423504000*I, 3.13073927808989-2.05283423504000*I, -6.97946026817977	Saddle	Unstable
{O=0.6663492972, F=0.8750730641, D=0.8026799460},	.411562866999724, -3.42002370806810, -.889904263931623	Saddle	Unstable
{O=0.2653920796, F=0.5682408219, D=4.124768937},	-2.21241416611010, -3.14050695678477, 0.470989905994870	Saddle	Unstable
{O=-7.158932779, F=-3.780423019, D=3.976946247},	-3.94420363081456, 5.96617904173929, 1.04900517407528	Saddle	Unstable
{O=-0.5973136278, F=-0.7089388654, D=-0.4120730198},	57.2484117865965+55.0509625075048*I, 57.2484117865965-55.0509625075048*I, -42.6939544431929	Saddle	Unstable
{O=-7.916697282, F=-4.982715615,	5.46891153152769, 6.56009854801399,	Saddle	Unstable

D=-5.688310577},	2.59982159645832		
{O=0., F=2.886000936, D=2.886000936},	-.820977358652597, 3.42247226876414, -7.61335717811155	Saddle	Unstable
{O=0., F=-1.386000936, D=-1.386000936},	3.35180536646949+2.45142427441773*I, 3.35180536646949-2.45142427441773*I, -6.43480402193897	Saddle	Unstable
{O=12., F=0., D=0.},	-13., -27.935483870, -3.120	Attracting	Stable
{O=0., F=0., D=8.}	-4., -.82352941180, 0.94117647060	Saddle	Unstable

Table 4.4 – Results for Increased Foreign Population

4.7 Decline of the Foreign Population

In this section, we consider the situation where the foreign population is decreased by 25%. The mathematical model now becomes

$D = a_1D/(1+d_1F) - a_{NR}(0.75*F)D/(1+d_2D) + a_1D/(1+d_1O) - a_{NR}OD/(1+d_2D) - b_1D^2 = 0)$

$F = a_2F/(1+d_3D) - a_{nr}(0.75*F)D/(1+d_2D) + a_2(0.75*F)/(1+d_4O) - a_{nr}(0.75*F)O/(1+d_4O) - b_2(0.75*F)^2 = 0$

$O = a_2O/(1+d_3D) - a_{nr}OD/(1+d_2D) + a_2O/(1+d_4(0.75*F)) - a_{nr}(0.75*F)O/(1+d_4(0.75*F)) - b_2O^2 = 0$

4.8 Equilibrium Points

Using the Maple CAS we obtained the following real valued equilibrium points:

{O=0.,F=2.886000936,D=2.886000936},

{O=0.,F=-1.386000936,D=-1.386000936},

{O=0.9681454523,F=0.8001862195,D=0.7747395738},

{O=0.3573969791,F=0.5501984868,D=4.157002013},

{O=-7.028627381,F=-3.884660968,D=3.531846117},

{O=-0.7975871716,F=-0.7094899737,D=-0.4113564284},

{O=-7.901889872,F=-5.169923083,D=-5.361668229},

{O=12.,F=0.,D=0.},

{O=0.,F=0.,D=8.},

{O=0.,F=8.,D=0.},

{O=-1.200000000,F=-5.500000000,D=0.},

{O=0.,F=0.,D=0.},

{O=0.,F=3.179449472,D=2.043559577},
{O=0.,F=-1.179449472,D=-1.443559577},
{D=1.333333333,F=4.,D=0.}

4.9 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 4 summarizes the results for a25% decreased foreign population level.

Equilibrium Points	Eigenvalues	Node Type	Stability
{O=0., F=2.886000936, D=2.886000936},	-.825405575926250, 3.43324546378208, -7.61970215585583	Saddle	Unstable
{O=0., F=-1.386000936, D=-1.386000936},	5.26260928836890, 1.50827854273281, -6.50208112010172	Saddle	Unstable
{O=0.9681454523, F=0.8001862195, D=0.7747395738},	.657624268165402, -3.34884162076320, -.754599161202198	Saddle	Unstable
{O=0.3573969791, F=0.5501984868, D=4.157002013},	-1.97219696463732, -3.18970763501768, 0.442617993255002	Saddle	Unstable
{O=-7.028627381, F=-3.884660968, D=3.531846117},	-3.48238470337450, 2.43594781393668, 1.43928349743782	Saddle	Unstable
{O=-0.7975871716, F=-0.7094899737, D=-0.4113564284},	290.248459874468, -173.878031421148, -49.2617418323199	Saddle	Unstable
{O=-7.901889872, F=-5.169923083, D=-5.361668229},	5.35997912664614, 1.96913784528716, 3.60961713406670	Repelling	Unstable
{O=12., F=0., D=0.},	-7., -15.894736840, -2.640	Attracting	Stable
{O=0., F=0., D=8.},	-4., -.82352941180, 0.94117647060	Saddle	Unstable
{O=0.,	5.43983947615177,	Saddle	Unstable

F=8., D=0.},	-13.3221924173518, -13.882352940		
{O=-1.20, F=-5.50, D=0.},	.742857142500000+2.26834624848752*I, .742857142500000-2.26834624848752*I, 10.10	Repelling	Unstable
{O=0., F=0., D=0.},	4., 2., 0.	Repelling	Unstable
{O=0., F=3.179449472, D=2.043559577},	-.176951238268382, 3.60813329531591, -7.96320034404753	Saddle	Unstable
{O=0., F=-1.179449472, D=-1.443559577},	6.45333202030004, -0.0308354923670802, -7.14047823993296	Saddle	Unstable
{O=1.333333333, F=4., D=0.}	-.312571131860554, -6.46520664573945, -9.1111111110	Attracting	Stable

Table 4.5 – Results for Decreased Foreign Population

4.10 Increases in the Foreign and Overseas Populations

In this section, we consider the situation when the foreign and overseas population are increased by 25%. The mathematical model now becomes

$D = a_1D/(1+d_1(F1.25)) – a_{nr}(F*1.25)D/(1+d_2D) + a_1D/(1+d_1(O*1.25))– a_{NR}(O*1.25)D/(1+d_2D) - b_1D^2 = 0)$

$F = a_2(F*1.25)/(1+d_3D) - a_{nr}(F*1.25)D/(1+d_2D) + a_2(F1.25)/(1+d_4(O*1.25)) – a_{nr}(F1.25)(O*1.25)/(1+d_4(O*1.25)) – b_2(1.25*F)^2 = 0$

$O = a_2(O*1.25)/(1+d_3D) - a_{nr}(O*1.25)D/(1+d_2D) + a_2(O*1.25)/(1+d_4(F*1.25)) – a_{nr}(F*1.25)(O*1.25)/(1+d_4(F*1.25)) – b_2(1.25*O)^2 = 0$

4.11 Equilibrium Points

Using the Maple CAS we obtained the following real valued equilibrium points:

{O=-6.825508444,F=-3.778104588,D=4.538572709},

{O=0.5514238389,F=0.6965354493,D=0.8799445614},

{O=0.2322891399,F=0.4624443307,D=3.999690490},

{O=-0.4770701941,F=-0.5652193108,D=-0.4132326659},

{O=-7.608072302,F=-4.866322713,D=-6.124690515},

{O=0.,F=8.,D=0.},

{O=0.,F=-1.325514418,D=-1.402116071},

{O=0.,F=-0.8549725776,D=-1.550798184},

{O=0.,F=0.,D=0.},

{O=1.243398113,F=3.460388679,D=0.},

{O=-0.6433981132,F=-7.860388679,D=0.},

{O=0.,F=0.,D=8.},

{O=12.,F=0.,D=0.}

4.12 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 5 summarizes the results for a25% increased foreign, overseas population level.

Equilibrium Points	Eigenvalues	Node Type	Stability
{O=-6.825508444, F=-3.778104588, D=4.538572709},	-4.52805533750428, 5.59706756242742, 2.00140884107686	Saddle	Unstable
{O=0.5514238389, F=0.6965354493, D=0.8799445614},	.516293167327847, -3.46250764877014, -.583100327957707	Saddle	
{O=0.2322891399, F=0.4624443307, D=3.999690490},	-1.94335618418178, -3.28193666699896, .647482654780733	Saddle	
{O=-0.4770701941, F=-0.5652193108, D=-0.4132326659},	-11.6146830136172+45.8488230351971*I, -11.6146830136172-45.8488230351971*I, 168.552590267235	Attracting	Stable
{O=-7.608072302, F=-4.866322713, D=-6.124690515},	5.72668363788299, 6.42725692719325, 3.68455453992376	Repelling	Unstable
{O=0., F=8., D=0.},	5.68235015264247, -15.5871120576425, -17.90476190	Saddle	
{O=0., F=-1.325514418, D=-1.402116071},	3.49298783266368+2.28046422070449*I, 3.49298783266368-2.28046422070449*I, -5.74625878232737	Saddle	
{O=0., F=-0.8549725776, D=-1.550798184},	2.17247903196303, 3.74977479942698, -7.28715062539000	Saddle	
{O=0.,	4.,	Repelling	Unstable

F=0. ,D=0.},	2., 0		
{O=1.243398113, F=3.460388679, D=0.},	-.890921838447044, -7.09949089655296, -11.065437730	Attracting	Stable
{O=-0.6433981132, F=-7.860388679, D=0.},	-2.02979363970000+29.0489518771471*I, -2.02979363970000-29.0489518771471*I, 17.865437730	Saddle	
{O=0., F=0., D=8.},	-4., -.82352941180, .94117647060	Saddle	
{O=12., F=0., D=0.}	-13., -27.935483870, -3.120	Attracting	Stable

Table 4.6 – Results for Increased Foreign, Overseas Population

4.13 Decrease in the Foreign, Overseas Populations

In this section, we consider the situation where the foreign and overseas population is decreased by 25%. The mathematical model now becomes

$D = a_1D/(1+d_1F*0.75) - a_{NR}(F*0.75)D/(1+d_2D) + a_1D/(1+d_1O*0.75) - a_{NR}(O*0.75)D/(1+d_2D) - b_1D^2 = 0$

$F = a_2(F*0.75)/(1+d_3D) - a_{nr}(F*0.75)D/(1+d_2D) + a_2(F*0.75/(1+d_4(O*0.75)) - a_{nr}(F0.75)(O0.75)/(1+d_4(O*0.75)) - b_2(F*0.75)^2 = 0$

$O = a_2(O*0.75)/(1+d_3D) - a_{nr}(O*0.75)D/(1+d_2D) + a_2(O*0.75)/(1+d_4(F*0.75)) - a_{nr}(F*0.75)(O*0.75)/(1+d_4(F*0.75)) - b_2(0.75*O)^2 = 0$

4.14 Equilibrium Points

Using the Maple CAS we obtained the following real valued equilibrium points:

{O=0.,F=0.,D=0.},

{O=12.,F=0.,D=0.},

{O=0.,F=3.805141256,D=1.161919803},

{O=0.,F=2.685795468,D=3.874482104},

{O=0.8281937217,F=1.186053465,D=0.6951151836},

{O=0.3046397579,F=0.7414476255,D=4.313224807},

{O=-0.7986726153,F=-0.9508638111,D=-0.4100471378},

{O=-7.787004684,F=-3.775286081,D=3.314440188},

{O=-8.418036609,F=-5.149481362,D=-5.236017926},

{O=0.,F=0.,D=8.},

{O=0.,F=8.,D=0.},

{O=1.890983834,F=3.563935338,D=0.},

{O=-1.057650501,F=-8.230602004,D=0.}

4.15 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 6 summarizes the results for a25% decreased foreign, overseas population level.

Equilibrium Points	Eigenvalues	Node Type	Stability
{O=0., F=0., D=0.},	4., 2., 0	Repelling	Unstable
{O=12., F=0., D=0.},	-7., -15.894736840, -2.640	Attracting	Stable
{O=0., F=3.805141256, D=1.161919803},	.331996319418428, 3.80032971953449, -7.46669223795292	Saddle	Unstable
{O=0., F=2.685795468, D=3.874482104},	-1.62597244850920, 3.16211591697277, -6.45357052746357		
{O=0.8281937217, F=1.186053465, D=0.6951151836},	.671740800376438, -3.41301737917158, -.540114068804861		
{O=0.3046397579, F=0.7414476255, D=4.313224807},	-2.22408690336067, -3.10650884597160, .648980136232268		
{O=-0.7986726153, F=-0.9508638111, D=-0.4100471378},	51.1105877207415+36.4904858901933*I, 51.1105877207415-36.4904858901933*I, -37.1374895994829		
{O=-7.787004684, F=-3.775286081, D=3.314440188},	-3.33894851835633, 2.75727326627312, .515333939083215		
{O=-8.418036609, F=-5.149481362, D=-5.236017926},	5.28637924601138, 2.84454843356426, 1.60588211142437	Repelling	Unstable
{O=0., F=0., D=8.},	-4., - .82352941180, .94117647060		

{O=0., F=8., D=0.},	5.13000143299376, -10.9761552789938, -9.846153850		
{O=1.890983834, F=3.563935338, D=0.},	-.849616800923489, -5.10133152607651, -7.3459030070	Attracting	Stable
{O=-1.057650501, F=-8.230602004, D=0.}	.787106108400000+3.09564839890968*I, .787106108400000-3.09564839890968*I, 10.345903020	Repelling	Unstable

Table 4.7 – Results for Decreased Foreign, Overseas Population

5.0 CONCLUSIONS

In this paper we modeled and analyzed the interaction of domestic and foreign worker and overseas worker populations. A comparison of the results in Tables 2 indicates that the system already contains some instability, the entire system becomes more unstable and Tables 3 indicates that with an increase in foreign population the system becomes more unstable Tables 4 indicates that with a decline in foreign population the system becomes more stable.

In real terms what this indicates is the instability of domestic the domestic worker population. As more foreign workers are employed and as more jobs are shipped overseas this has a significant impact on the domestic workers. Domestic workers can be seriously hurt by these actions. Business reaps the benefit of lower production costs but at the expense of the domestic work force. These domestic workers find themselves out of jobs and turning to unemployment. Depending on their circumstances, some of these workers can end up on welfare. Neither of these situations leads to a strong and stable economy.

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