Modelling dynamic interactions between risk perception, partner choice, HIV transmission, and HIV interventions

by

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Abstract

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Since the early 1980’s HIV has become a pandemic. Medical research aimed at increasing the lifespan and reducing the burden of those infected has improved dramatically allowing infected individuals the chance at a near normal life expectancy. In addition, researchers hoping to create a prophylactic HIV vaccine appear to be close to reaching their goal.

These recent medical advancements have prompted many researchers to study how this may alter HIV spread. Reasons for this are motivated by the fact that despite awareness campaigns, incidence rates in high-risk groups, such as MSM, have increased. This has led to worry that highly active anti-retroviral treatment (HAART) optimism may worsen the situation. Many researchers have incorporated elements of varying behaviour into compartment HIV transmission models to predict such effects, but the results have been varied.

This thesis explores the behaviour aspect involved in the decision-making and partner selection process using an approach that differs from past papers. Using an agent based
model we explore the dynamics of risk perception shaping individual behaviour, and the impact this has on HIV spread. We demonstrate that distinct groups, as defined by their sexual behaviour, HIV status, and risk perceptions, can emerge. We incorporate age structure to explore behavioural responses to interventions, such as HAART and prophylactic vaccine. We find that interventions can activate several feedback mechanisms that influence decision-making and HIV prevalence. We then explore the noncooperative player interaction by investigating multiplayer nonlinear games solved with variational analysis techniques. We demonstrate the sensitivity of Nash strategies of players with respect to variation of their preferences and beliefs. Our findings use a novel approach to help describe how HIV spread and interventions influence a number of aspects, such as transmission, demography, sexual behaviour and risk perception.
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# Table of Contents

List of Tables viii

List of Figures x

1 Introduction 1

1.1 Background ......................................................... 2
  1.1.1 Beginnings of the AIDS epidemic ................... 2
  1.1.2 Natural History ..................................................... 3
  1.1.3 HIV spread in lower-income countries .............. 5
  1.1.4 Societal Burden ..................................................... 6
  1.1.5 Partner Selection ................................................... 7
  1.1.6 Psychology behind sexual partner serostatus assumptions ...... 10

1.2 Epidemic Models .................................................... 11
  1.2.1 Differential Equation Models ............................. 12
  1.2.2 Agent-based models ........................................ 17

1.3 Behaviour-incidence modelling ................................. 18

1.4 Brief Introduction to Game Theory ............................. 19
  1.4.1 Game Theory and Variational Inequalities .......... 22
  1.4.2 Sequential Games and HIV Transmission ................ 24

1.5 HIV Models ......................................................... 26

1.6 Objective and Rationale .......................................... 28
2 Coevolution of risk perception, sexual behaviour, and HIV transmission in an agent-based model 43
  2.1 Introduction ...................................................... 45
  2.2 Methods .......................................................... 47
    2.2.1 Partner selection model .................................... 48
    2.2.2 Transmission and natural history model .................... 53
  2.3 Results ........................................................... 55
    2.3.1 Baseline scenario ............................................ 55
    2.3.2 Scenario $\beta < 1$ .......................................... 63
    2.3.3 Scenario $\omega < 1$ .......................................... 63
    2.3.4 Sensitivity analysis ......................................... 73
  2.4 Discussion ...................................................... 77
  2.5 Acknowledgements ................................................ 80

3 Sexual behaviour, risk perception, and HIV transmission can respond to HIV antiviral drugs and vaccines through multiple pathways 85
  3.1 Introduction ...................................................... 86
  3.2 Results ........................................................... 91
    3.2.1 Baseline scenario: no HAART or vaccines .................. 92
    3.2.2 Impact of HAART on risk perception, sexual behaviour, and HIV prevalence .................................................. 93
    3.2.3 Impact of prophylactic vaccination .......................... 112
  3.3 Discussion ...................................................... 120
  3.4 Methods .......................................................... 127
    3.4.1 Vital Dynamics and Partner selection ...................... 127
    3.4.2 Risk perception dynamics .................................... 129
    3.4.3 HIV transmission and natural history ...................... 131
    3.4.4 HAART ...................................................... 131
    3.4.5 Prophylactic HIV Vaccine .................................... 135
4 Multiplayer games and HIV prevalence via casual encounters 151

4.1 Introduction ......................................................... 152

4.2 Casual encounter games ............................................. 157
  4.2.1 Brief introduction to nonlinear games ....................... 157
  4.2.2 Two-player casual encounter game ............................ 159
  4.2.3 Computation and uniqueness of Nash equilibria ............. 164
  4.2.4 Sensitivity analysis of the 2-player encounter game .......... 167

4.3 Multiplayer game ................................................... 172
  4.3.1 3-player game .................................................. 173
  4.3.2 Results & Discussion: 3-player game ......................... 176
  4.3.3 4-player game .................................................. 178
  4.3.4 Results & Discussion: 4-player game ......................... 182
  4.3.5 Compounded effect of multiplayer games on HIV prevalence . 182

4.4 Prophylactic HIV vaccine and differentiated HIV group prevalence scenarios 188

4.5 Conclusion and future work ....................................... 189

5 Discussion ............................................................ 195

5.1 Discussion .......................................................... 196

5.2 Future Research ..................................................... 200

6 Supplementary Material .............................................. 203

6.1 Simulation Code: Chapter 2 ......................................... 204

6.2 Simulation Code: Chapter 3 ......................................... 286

6.3 Simulation Code: Chapter 4 ......................................... 484
List of Tables
2.1

Utilities for actor i, given status of actors i and j, and type of sex. . . . . .

51

2.2

Parameter definitions, and parameter values for baseline scenario. . . . . .

54

2.3

Normalized sex acts by type. First three rows show total number of sex acts
between t = 0 and t = 300, second three rows show total number of sex acts
between t = 300 and t = 600, etc. t = 4500 represents cumulative sex acts
between t = 4200 and t = 4500 at equilibria. This table shows evidence of
how the preferred type of sex changes over time. As HIV prevalence and
average b-value increases, we see a reduction in Unprotected Sex among
HIV- couples as expected. . . . . . . . . . . . . . . . . . . . . . . . . . . .

59

Normalized sex acts for type, t = 300:4500 Beta = 0.9. First three rows
show total number of sex acts between t = 0 and t = 300, second three rows
show total number of sex acts between t = 300 and t = 600, etc. t = 4500
represents cum sex acts between t = 4200 and t = 4500 at equilibria. . . .

68

Normalized sex acts for type, t = 300:15000 Omega = 0.2. First three rows
show total number of sex acts between t = 0 and t = 300, second three
rows show total number of sex acts between t = 300 and t = 600, etc. t =
4500 represents cum sex acts between t = 4200 and t = 4500. t = 15000
represents cum sex acts between t = 14700 and t = 15000 at equilibria. . .

72

Parameters adjusted in sensitivity analysis. Values recorded from normal
distribution, with probabilities less than 0 or greater than 1 discarded. . .

74

Parameters adjusted in sensitivity analysis. Results continue to demonstrate
significant divergence between average b-values between HIV + and HIV
population. . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .

75

Parameter definitions and values for baseline scenario. . . . . . . . . . . . .

93

2.4

2.5

2.6
2.7

3.1

viii


3.2 Parameter definitions and parameter values corresponding to HAART and vaccination scenarios. ........................................... 98

3.3 Multiplicative factor $\delta$ controlling overall sexual activity level relative to 20-29-year-olds, by age. ............................................... 128

3.4 Duration of HIV infection stages with and without HAART. .............. 132

3.5 Relative reduction in transmission probability depending on stage of infection. 134

3.6 Utilities for Actor 1, given status of Actor 2, in absence of interventions. This outlines the preferences for different sexual acts given an individual’s status. ......................................................... 143

3.7 Layout of risky sex game between randomly selected actors. Actor 1 makes
the first offer between US and PS. Actor 2 updates their $b_t$-value using equation 3.1 or 3.2. Actor 2 then makes an offer consisting of either Actor 1’s offer or NS. Actor 1 then updates their $b_t$-value and the resulting action occurs. ......................................................... 148

4.1 Utilities for Actor 1, given status of Actor 2. This outlines the preferences for different sexual acts given an individual’s status. ................................. 161

4.2 Parameter definitions and values for baseline scenario. ......................... 167
List of Figures

1.1 Feedback loop between HIV risk perception/behaviour and HIV prevalence. 9
1.2 Sequential game, described further in Chapter 2. 26

2.1 HIV risky sex game tree. Here we can see the game in extensive form. 50
2.2 (a) HIV prevalence over time ($\langle I \rangle$, black). (b) Average b-values over time by type, HIV- (black dashed $\langle b^- \rangle$), HIV+ (grey dashed $\langle b^+ \rangle$). This illustrates the coevolution between the HIV prevalence in the population, and the assessment of risk among its individuals. We also note the divergence of b-values amongst the HIV- and HIV+ groups, demonstrating a significant difference in risk assessment. 56
2.3 (a) HIV Prevalence ($\langle I \rangle$, black) (b) average b-value by type, average HIV negative ($\langle b^- \rangle$, black dashed), average HIV positive, ($\langle b^+ \rangle$, grey dashed). Results similar to original finding with the exception of decreased separation between b-values. This occurs when Actor 1 updates their b-value even when Actor 2 is in agreeance with their choice. 58
2.4 HIV prevalence (% infected, $\langle I \rangle$, black), and total average b ($\langle b \rangle$, grey) for: (a) alpha, (b) transmission, (c) PS Utility. This demonstrates the robustness of the parameters used within the model. As expected, HIV prevalence rates are closely tied to average b-values amongst the population. 61
2.5 Average b-value for HIV- ($\langle b^- \rangle$, dashed black) and HIV+ ($\langle b^+ \rangle$, dashed grey) individuals for: (a) alpha, (b) transmission, (c) PS Utility. This also shows the robustness of the parameters by indicating the cluster separation remains for varying parameter values. 62
2.6 (a) HIV Prevalence ($\langle I \rangle$, black) and average b-value ($\langle b \rangle$, grey for beta, (b) average b-value by type, average HIV negative ($\langle b^- \rangle$, black dashed), average HIV positive, ($\langle b^+ \rangle$, grey dashed). This illustrates the effect of increasing population HIV awareness in the population. As expected clustering rapidly disappears when individuals are made more aware of actual HIV prevalence in the population. .................................................. 64

2.7 (a) HIV Spread over time($\langle I \rangle$ black), and (b) average b-values over time by type, average HIV negative ($\langle b^- \rangle$, black dashed), average HIV positive, ($\langle b^+ \rangle$, grey dashed), Beta = 0.9. Results are similar to the baseline, with a significant reduction in clustering. ................................. 65

2.8 HIV % prevalence ($\langle I \rangle$, black), and total average b ($\langle b \rangle$, grey) for: (a) alpha, (b) transmission, (c) PS Utility, for Beta = 0.9 ............................... 66

2.9 Average b-value for HIV - ($\langle b^- \rangle$, dashed black) and HIV + ($\langle b^+ \rangle$, dashed grey) individuals for: (a) alpha, (b) transmission, (c) PS Utility, for Beta = 0.9 ................................................. 67

2.10 (a) HIV Spread over time($\langle I \rangle$ black), and (b) average b-values over time by type, average HIV negative ($\langle b^- \rangle$, black dashed), average HIV positive, ($\langle b^+ \rangle$, grey dashed), Omega = 0.2. This shows the effect of increasing the omega parameter, and delaying the initiation of a risky sex game between two strangers. Here we see similar results to the baseline with the exception that more time was required for the events to transpire. .................. 69

2.11 HIV % prevalence ($\langle I \rangle$, black), and total average b ($\langle b \rangle$, grey) for: (a) alpha, (b) transmission, (c) PS Utility. Omega = 0.2 ................................. 70

2.12 Average b-value for HIV - ($\langle b^- \rangle$, dashed black) and HIV + ($\langle b^+ \rangle$, dashed grey) individuals for: (a) alpha, (b) transmission, (c) PS Utility. Omega = 0.2 ................................. 71

2.13 Prevalence of HIV ( % infected) among those who are aware of their HIV+ status (dark grey), those who are not aware of their HIV+ status (black dashed), and total HIV prevalence in the whole population (black). ........................ 74

2.14 Average b-value among HIV- individuals (black dashed), HIV+ not aware of their status (black), and HIV+ individuals aware of their status (dashed grey). .................................................. 75
2.15 (a) HIV prevalence over time (\% infected, $\langle I \rangle$, black). (b) Average $b$-values over time by type, HIV- (black dashed ($b-$)), HIV+ (grey dashed ($b+$)), for a larger population, $N = 5,000$. Results shown are similar to the baseline $N = 1,000$ (Figure 1).

3.1 Baseline scenario with no interventions. (a) number of HIV– (green) and HIV+ (red) individuals in the population; (b) average $b_t$-value for HIV– individuals by age, 15-20-year-olds (red), 20-30 (orange), 30-40 (yellow), 40-50 (green), and 50+ year-olds (blue); (c) average $b_t$-values for HIV+ individuals by same age groups; (d) number of HIV+ individuals by the same age groups, and with black representing the total number of HIV+ individuals; (e) total average $b_t$-value for HIV+ (red) and HIV– (green) populations; (f) HIV prevalence (percentage of the population currently infected).

3.2 No intervention, varying $\tau$. (a) HIV prevalence as a percentage of the population (black), total average $b_t$-value (grey); (b) average $b_t$-value for HIV– (black dotted) and HIV+ (grey dotted) populations.

3.3 No intervention, varying $PS_{Utility}$. (a) HIV prevalence as a percentage of the population (black), total average $b_t$-value (grey); (b) average $b_t$-value for HIV– (black dotted) and HIV+ (grey dotted) populations.

3.4 Baseline scenario for HAART intervention introduced at year 50. (a) number of HIV– (green) and HIV+ (red) in the population; (b) average $b_t$-value for HIV– individuals by age, 15-20-year-olds (red), 20-30 (orange), 30-40 (yellow), 40-50 (green), and 50+ year-olds (blue); (c) average $b_t$-values for HIV+ individuals by same age groups; (d) number of HIV+ individuals by the same age groups, and with black representing the total number of HIV+ individuals; (e) total average $b_t$-value for HIV+ (red) and HIV– (green) populations; (f) HIV prevalence (percentage of population currently infected).

3.5 Baseline scenario for HAART intervention introduced at year 50. (a) total number of -/+ US acts per year divided by number of HIV– individuals in that age cohort at the end of the year, for age groups 15-20-year-olds (red), 20-30 (orange), 30-40 (yellow), 40-50 (green), and 50+ year-olds (blue), and cumulative number of individuals across all age groups (black); (b) total number of -/+ US acts per year, for same age groups; (c) number of HIV– individuals in each age cohort at the end of the year, for same age groups.
3.6 Baseline scenario with no interventions. (a) total number of -/+ US acts per year divided by number of HIV– individuals in that age cohort at the end of the year, for age groups 15-20-year-olds (red), 20-30 (orange), 30-40 (yellow), 40-50 (green), and 50+ year-olds (blue), and cumulative number of individuals across all age groups (black); (b) total number of -/+ US acts per year, for same age groups; (c) number of HIV– individuals in each age cohort at the end of the year, for same age groups. 101

3.7 HAART intervention, varying $d$. (a) HIV prevalence as a percentage of the population (black), total average $b_t$-value (grey); (b) average $b_t$-value for HIV– (black dotted) and HIV+ (grey dotted) populations. (c) total number of -/+ US acts per year divided by number of HIV– individuals at the end of the year; (d) total number of -/+ US acts per year; (e) number of HIV– individuals; (f) number of HIV+ individuals at end of simulation. 104

3.8 HAART intervention introduced at year 50, $d=0$. (a) number of HIV– (green) and HIV+ (red) individuals in the population; (b) average $b_t$-value for HIV– individuals by age, 15-20-year-olds (red), 20-30 (orange), 30-40 (yellow), 40-50 (green), and 50+ year-olds (blue). 105

3.9 HAART intervention introduced at year 50, $d=-20$. (a) number of HIV– (green) and HIV+ (red) individuals in the population; (b) average $b_t$-value for HIV– individuals by age, 15-20-year-olds (red), 20-30 (orange), 30-40 (yellow), 40-50 (green), and 50+ year-olds (blue). 106

3.10 HAART intervention varying $k$. (a) HIV prevalence as a percentage of the population (black), total average $b_t$-value (grey); (b) average $b_t$-value for HIV– (black dotted) and HIV+ (grey dotted) populations. 108

3.11 HAART varying $\eta$. (a) HIV prevalence as a percentage of the population (black), total average $b_t$-value (grey); (b) average $b_t$-value for HIV– (black dotted) and HIV+ (grey dotted) populations. 109

3.12 HAART intervention, varying $\tau$. (a) HIV prevalence as a percentage of the population (black), total average $b_t$-value (grey); (b) average $b_t$-value for HIV– (black dotted) and HIV+ (grey dotted) populations. (c) total number of -/+ US acts per year divided by number of HIV– individuals at the end of the year; (d) total number of -/+ US acts per year; (e) number of HIV– individuals; (f) number of HIV+ individuals at end of simulation. 110

3.13 HAART intervention, varying $PS_{Utility}$. (a) HIV prevalence as a percentage of the population (black), total average $b_t$-value (grey); (b) average $b_t$-value for HIV– (black dotted) and HIV+ (grey dotted) populations. 111
3.14 Baseline scenario for vaccine intervention introduced at year 50. (a) number of HIV- (green) and HIV+ (red) in the population; (b) average $b_t$-value for HIV- individuals by age, 15-20-year-olds (red), 20-30 (orange), 30-40 (yellow), 40-50 (green), and 50+ year-olds (blue); (c) average $b_t$-values for HIV+ individuals by same age groups; (d) number of HIV+ individuals by the same age groups, and with black representing the total number of HIV+ individuals; (e) total average $b_t$-value for HIV+ (red) and HIV- (green) populations; (f) HIV prevalence (percentage of population currently infected). 113

3.15 Baseline scenario for vaccine intervention introduced at year 50. (a) total number of -/+ US acts per year divided by number of HIV- individuals in that age cohort at the end of the year, for age groups 15-20-year-olds (red), 20-30 (orange), 30-40 (yellow), 40-50 (green), and 50+ year-olds (blue), and cumulative number of individuals across all age groups (black); (b) total number of -/+ US acts per year, for same age groups; (c) number of HIV- individuals in each age cohort at the end of the year, for same age groups. 115

3.16 Vaccination intervention introduced at year 50, $k=8$. (a) number of HIV- (green) and HIV+ (red) individuals in the population; (b) average $b_t$-value for HIV- individuals by age, 15-20-year-olds (red), 20-30 (orange), 30-40 (yellow), 40-50 (green), and 50+ year-olds (blue). 117

3.17 Vaccination intervention introduced at year 50, $k=0.125$. (a) number of HIV- (green) and HIV+ (red) individuals in the population; (b) average $b_t$-value for HIV- individuals by age, 15-20-year-olds (red), 20-30 (orange), 30-40 (yellow), 40-50 (green), and 50+ year-olds (blue). 118

3.18 Vaccine intervention, varying $k$, (a) HIV prevalence as a percentage of the population (black), total average $b_t$-value (grey); (b) average $b_t$-value for HIV- (black dotted) and HIV+ (grey dotted) populations. 119

3.19 Vaccine intervention, varying $η$, (a) HIV prevalence as a percentage of the population (black), total average $b_t$-value (grey); (b) average $b_t$-value for HIV- (black dotted) and HIV+ (grey dotted) populations. 121

3.20 Vaccine intervention, varying $ε$, (a) HIV prevalence as a percentage of the population (black), total average $b_t$-value (grey); (b) average $b_t$-value for HIV- (black dotted) and HIV+ (grey dotted) populations. 122

3.21 Vaccine intervention, varying $τ$, (a) HIV prevalence as a percentage of the population (black), total average $b_t$-value (grey); (b) average $b_t$-value for HIV- (black dotted) and HIV+ (grey dotted) populations. 123
3.22 Vaccine intervention, varying P SU tility , (a) HIV prevalence as a percentage
of the population (black), total average bt -value (grey); (b) average bt -value
for HIV– (black dotted) and HIV+ (grey dotted) populations. . . . . . . . 124
3.23 Flow diagram outlining how individuals progress to AIDS once infected,
both with and without treatment. . . . . . . . . . . . . . . . . . . . . . . . 133
3.24 HAART intervention introduced at year 50, τ =0.03. (a) number of HIV–
(green) and HIV+ (red) individuals in the population; (b) average bt -value
for HIV– individuals by age, 15-20-year-olds (red), 20-30 (orange), 30-40
(yellow), 40-50 (green), and 50+ year-olds (blue); (c) average bt -values for
HIV+ individuals by same age groups; (d) number of HIV+ individuals by
the same age groups, and with black representing the total number of HIV+
individuals; (e) total average bt -value for HIV+ (red) and HIV– (green)
populations; (f) HIV prevalence (percentage of the population currently
infected). . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 149
3.25 HAART intervention introduced at year 50, τ =0.03. (a) total number of -/+
US acts per year divided by number of HIV– individuals in that age cohort
at the end of the year, for age groups 15-20-year-olds (red), 20-30 (orange),
30-40 (yellow), 40-50 (green), and 50+ year-olds (blue), and cumulative
number of individuals across all age groups (black); (b) total number of -/+
US acts per year, for same age groups; (c) number of HIV– individuals in
each age cohort at the end of the year, for same age groups. . . . . . . . . 150
4.1

Heat map for 2-player game showing x2− , x2+ , x1− , and x1+ equilibrium values
for the respective initial conditions. The parameters here are set according
to the baseline values outlined in Table 4.2 . . . . . . . . . . . . . . . . . . 166

4.2

3-dimensional results for 2-player game showing x2+ and + varying U(US,–
,–) and U(US,–,+). Results for x1− remained at 1 across varying US negative
utilities. . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 169

4.3

3-dimensional results for 2-player game showing x1− and + varying β+ and
β− . Results for x2+ remained at 0 varying β values. . . . . . . . . . . . . . 170

4.4

3-dimensional results for 2-player game showing x1− and + varying bself
and
−
self
self
self
2
b+ . Results for x+ remained at 0 varying b− and b+ values. . . . . . . 171

xv


4.5 Results for 3-player game. Figure (a) shows Choices for Player 1 varying $U(US, -, -)$ which appear unchanging. Figure (b) shows choices for Player 2 dependent on $U(US, -, -)$. Results for Player 3 are the same as Player 2. 2-dimensional results for varying $U(US, -, +)$ remained unchanged when $U(US, -, -)$ is set to baseline value.

4.6 Results for 3-player game. Shows $\epsilon_+$ for the total population.

4.7 Heat map for 3-player game showing $x_{1-}, x_{1+}, x_{2-}, x_{2+}, x_{3-}, x_{3+}$ equilibrium values for the respective initial conditions. The parameters here are set according to the baseline values outlined in Table 4.2.

4.8 Results for 3-player game. Figure (a) showing choices for varying $\beta_+$ for Player 1. Results of Player 3 and Player 2 don’t vary for $\beta_-$ given the baseline utilities. Figure (b) shows a 3-dimensional results for 3-player game showing $\epsilon_+$ of population for varying $\beta$ values.

4.9 Heat map for 4-player game showing $x_{1-}, x_{1+}, x_{2-}, x_{2+}, x_{3-}, x_{3+}, x_{4-}, x_{4+}$, and $x_{3+}$ equilibrium values for the respective initial conditions. The parameters here are set according to the baseline values outlined in Table 4.2.

4.10 2-dimensional results for 4-player game showing choices for varying $U(US, -, -)$ utilities for Player 1 and 2.

4.11 2-dimensional results for 4-player game showing choices for varying $U(US, -, -)$ utilities for Player 3 and 4.

4.12 2-dimensional results for 4-player game showing choices for varying $U(US, -, +)$ utilities for Player 1 and 2.

4.13 2-dimensional results for 4-player game showing choices for varying $U(US, -, +)$ utilities for Player 3 and 4.

4.14 3-dimensional results for 4-player game showing $\epsilon_+$ of population for varying $U(US, -, -)$ and $U(US, -, +)$.

4.15 Compound $\epsilon_+$ using U.S. census data comparing $U(US, -, -)$ and $U(US, -, +)$.

4.16 Compound $\epsilon_+$ using U.S. census data comparing $\mu$ and $U(US, -, -)$ with $U(US, -, +, vac) = 1$. 

xvi
Chapter 1

Introduction
1.1 Background

1.1.1 Beginnings of the AIDS epidemic

Early instances of what would later be recognized as HIV/AIDS (human immunodeficiency virus/acquired immunodeficiency syndrome) was first observed in California in 1980 [2]. Local physicians began to treat young patients suffering from intense fever, diarrhea, weight loss, and swollen lymph nodes, indicating a possibly deficient immune syndrome. After several more cases the CDC issued an announcement, indicating numerous patients with severe pneumonia within Los Angeles hospitals. The age of the men afflicted, plus the fact all of which were homosexual prompted the response, as it was unusual. The conclusion implicated a “cellular-immune dysfunction that predisposes individuals to opportunistic infections” [3].

Around this time, similar cases were appearing in New York and spreading quickly, with 600 cases reported in 1982 by the CDC, with 75% identifying as homosexual or bisexual males. An early name for the condition was “GRID”, an acronym for gay-related immune deficiency. However by late 1982 the CDC named the disease AIDS after determining that it was not isolated strictly within the gay population [4]. By 1984, AIDS had claimed 1500 lives and had the makings of an epidemic through its exponential spread. With no cure available, hospitals administered antibiotics.

Increasing fears related to AIDS was motivated by the unknown. In 1985, a poll indicated that nearly half of the Canadian population was concerned with becoming infected, and had gross misunderstandings of how it was transmitted [5]. While AIDS continued to
spread, so to did homophobia and bigotry throughout infected areas [6]. By late 1985, scientists were able to finally define the cause of AIDS, calling it the human immunodeficiency virus (HIV).

### 1.1.2 Natural History

HIV is unique amongst other viruses. It can incorporate its own DNA into a host’s cell’s DNA quickly, while also containing proteins that takeover a host cell’s replication ability and use it to aid in replication. Infection with HIV can lead to immune system failure leading to life threatening opportunistic infections. The transfer occurs by transfer of blood, semen, vaginal fluid, or breast milk [7]. HIV is recognized as a pandemic, according to the World Health Organization (WHO), affecting 0.6% of the world’s population [7].

Once infected with HIV, an individual enters the acute stage lasting for several months with no impactful symptoms aside from fever, and sore throat. Following this is the latency stage, which has an average length of eight years barring treatment. Symptoms range from little during the beginning, to more severe fevers, weight loss and muscle pains generally towards the end. Without any intervention an individual will eventually enter the acquired immunodeficiency syndrome stage. This is defined when an individual’s CD4\(^+\) T cell count falls below 200 cells per µL. CD4\(^+\) T cell’s refer to a type of T cell. T cells are a type of lymphocyte, a class of white blood cells that play an important roll in the immune system [8]. During this stage, opportunistic infections are likely to occur. Without treatment, an individual is likely to continue living for an average of 4 years [9].
HIV Treatment

In 1986, the first AIDS drug was released, offering much hope to those suffering with the disease. AZT (azidothymidine) an antiretroviral drug, was able to reduce viral loads. However, there were side effects, such as being highly toxic to bone marrow, often requiring blood transfusions, as well as initial costs reported as nearly $10,000 per year of treatment [10]. By 1994, AZT was still the primary treatment, despite it only being able to delay death for a year on average [11]. Over time, combination therapy helped to increase this to an average of 46 months by the end of the century.

Treatments continued to improve, with infected individual’s taking multiple drugs aimed at varying viral stages. Today this is referred to as highly active antiretroviral treatment (HAART). The treatment not only protects an individual’s immune system, preventing opportunistic infections, but also reduces their viral load count within blood and genital secretions. However, there still remain drawbacks, such as severe health risks if the treatment is ever periodically halted, as well as high risk of cardiovascular, renal, liver and neurologic disease [12]. It is expected that an individual should remain on treatment indefinitely. The success of this treatment lead many to believe that the best method for preventing HIV is through implementation of the treatment [13].

In lower income countries, such as many in sub-saharan Africa, prices are beginning to drop as earlier drugs are no longer patented [14]. By 2012, it was estimated 7 million people in sub-saharan Africa now had access to treatment, and the figure is believed to be increasing. This is in contrast to the 2011 estimate of 24 million people living in Sub-Saharan Africa with HIV [15].
Providing further optimism, are the current HIV vaccines being studied. Vaccine research was thought to be hampered by the fact that countries that would benefit the greatest were least likely to be able to afford it. HIV prevalence in high income countries was thought too low to justify implementing a mass vaccination. While there is currently no available vaccine available, there are many research groups aiming to create one. A researcher at the University of Western Ontario is in the process of developing a prophylactic HIV vaccine. Despite many obstacles in development, the vaccine phase 1 clinical trial testing safety and immune response ended late 2013 showing promising results [16]. It is currently undergoing phase 2 trials, to assess immune response in over 600 HIV-individuals in high risk categories, such as men who have sex with men (MSM), and commercial sex employees [17].

1.1.3 HIV spread in lower-income countries

In 1986, cases in the US were roughly 15,000 while estimates in Africa were nearing half a million [18]. While future investigations of old blood samples would estimate HIV originating in central Africa as early as the late 1960’s ([19]) giving it a head start, it was unclear as to why it was spreading at such an alarming rate. The spread of the disease appeared different compared to the spread in high income nations, in that it affected men and women. Early studies were finding the spread was primarily focussed within highly promiscuous people. Oddly It appeared to be affecting the middle to upper class population [20]. Studies concluded this occurrence was likely due to a number of variables. During the 1980’s Africa was experiencing increased rural to urban migration. The splitting up of
families due to job opportunities resulted in a high increase in prostitution, and allowed for rapid spread of the virus. Transmission was significantly increased due to extremely low condom use. It was estimated that 5% of Zairian prostitutes employed condoms with clients, compared with 90% of prostitutes from the US during the 1980’s [21]. Hinder- ing further, was gender roles biased towards the male side when outlining sexual choices [22]. Additional studies concluded that low circumcision rates also impacted the spread of the virus, as AIDS rates were significantly lower in circumcised males, when compared to uncircumcised individuals of the same sample [23].

1.1.4 Societal Burden

HIV is unique amongst many infectious diseases. Aside from the devastating impact upon those infected, the spread of HIV placed unfair blame on the homosexual population, resulting in unfair treatment and often persecution. During 1980, San Francisco held a gay population exceeding 100,000 [24]. It is believed that this migration was likely prompted by the actions of gay rights activists forming the Gay Liberation Front during the Stonewall protests in New York during 1969. By 1975 5,000 gay men were moving to the city of San Francisco yearly [25].

After the outbreak, rising homophobia and antigay discrimination began to spread. In 1985, population polls in New York and Los Angeles found over 60% of surveyed adults found homosexuality wrong, along with hate crimes targeting gays tripling since the beginning of the epidemic [26]. Fortunately, with newer treatments, and better awareness practices, the discrimination began to subside. This is particularly evident in a 2012 Cana-
dian top court ruling aimed at removing the burden placed upon HIV+ individuals who have adhered to treatment while practicing safe sex, and still struggle with the stigma placed upon them by society. The Canadian Supreme Court of Canada ruled that HIV+ individuals with a low viral count, who agree to use protection need not disclose their status to their partner [27]. This has helped in eliminating HIV burden for those affected.

HIV stands apart from other communicable diseases, such as flu, or other sexually transmitted diseases. Not only has there been human loss, but detrimental effects on homosexual rights. Understanding how antiretrovirals have changed the disease and what impacts may occur through a prophylactic vaccine, helps to explain HIV’s ever changing role in society.

1.1.5 Partner Selection

Partner selection and safe sex practices are a major determinant of HIV prevalence. Understanding how HIV+ and HIV- individuals value protected sex and sex without a condom, or risky sex, can help us to understand how HIV is propagated. Although many people adopt safe strategies to prevent contracting HIV, research has shown evidence of fatalism among some IV drug users and homosexuals in developed countries, as well as continuing high levels of prostitution in high risk areas within countries in Africa and Asia [28]. This reasoning is also supported from a sample of HIV+ homosexual men from 2002 which showed that only 39.3% of subjects with casual partners practiced protected sex[29]. This proposes that some HIV+ individuals knowingly expose their partners to HIV because of their preferences for unprotected sex (US).
After the outbreak, studies were done to estimate the risk perception amongst the homosexual population. A University of California research team in 1983 concluded that men who still used bath houses, had hardly changed their behaviour since news of the outbreak [30]. While, the rate of decrease of infectives was beginning to decline, comparing with young gay men the rate of infection appeared to nearly remain steady [31] [32]. Between 1994 and 2000, the percentage of gay men reporting unsafe sex with numerous partners increased from 23.4% to 48.8% and those claimed to have used a condom for every occasion dropped from 69.6% to 49.7% [33]. Between 1995 and 2000 in San Francisco, the rate of new infections tripled [34].

In recent years, medical treatment has reduced the annual rate of AIDS cases dramatically, however, the rate of new HIV infection has not dropped significantly. Studies show that the number of sexual partners is positively correlated with the incidence of HIV [35]. It is estimated that in the United States, 80% of HIV cases are a result of US, with the remaining a resultant of injecting drug use [36]. It is unquestionable that US is a major contributor to the spread of HIV in most populations. This implies that the process by which an individual makes a choice while interacting with their partner needs to be better understood. According to a poll of heterosexual young adults living in the United States, 74% of males and 88% of females reported never or rarely worrying about a sexually transmitted disease (STD) [37]. This percentage varies considerably however, when investigating different age groups, countries, or homosexual populations [38, 39]. What is unclear is whether individuals are forgoing precautions due to lack of worry, lack of information, due to a stronger desire to engage in their preferred method of sex, or some combination of factors.
Reports have demonstrated that homosexual men may change their preference to risky sex when perceiving less threat of HIV/AIDS [40]. Crucially, this suggests a potential feedback loop between risk perception and disease transmission. Since the availability of HAART, this has become more of a concern. As such, it is important to be able to assess a population’s belief in the risks associated with contracting HIV, as well as their interpretation of what offers of different types of sex could reveal about the individual they are engaging with. Blower et al [41], discuss calculating the odds of HIV infection due to sexual partner selection within the male homosexual population of San Francisco. Using logistic regression modelling, Blower indicated evidence of partner selection being a definite risk factor in HIV acquisition, particularly amongst individuals with different preferences from different age cohorts.

The existing literature suggests a strong feedback mechanism between risk perception and partner selection processes on the one hand, and HIV transmission and prevalence on the other (Figure 1.1).

![Figure 1.1: Feedback loop between HIV risk perception/behaviour and HIV prevalence.](image-url)
1.1.6 Psychology behind sexual partner serostatus assumptions

There have been numerous studies and surveys aimed to better understand the decision making process of both HIV- and HIV+ individuals. This process is ranked by the notion that individual’s undertake a risk assessment when engaging in a sexual act as most men reportedly found condom use to reduce pleasure, and intimacy [42]. A survey conducted from 157 HIV+ men, and 205 HIV- men showed that the majority of HIV- gay men prefer partners who are also HIV- (83%). For HIV+ men, it was found that most (63%) have no preference with respect to the status of their partner in terms of engaging in a romantic relationship [43]. Additional studies focussed on HIV+ individuals found further evidence of HIV+ men being less concerned about US with a partner who is also HIV+ [44]. This unfortunately also carries risk of additional infections. Another study for HIV+ men asked to record possible justifications that might have been used for engaging in US without feeling guilt. Many of the justifications were based upon assumptions about partner status, believing that the partners they were engaging with were also seropositive [45]. Motivated reasoning concerning HIV risk may influence behaviour. It is also believed individuals can tend to be optimistic, where HIV- men are motivated to believe their partner is HIV-, and HIV+ men are motivated to believe their partner is HIV+ [46] [47].

While serodiscordant couples are unlikely to practice US together under full knowledge, HIV+ individuals may be unlikely to disclose status due to fear of rejection, or possibly violence [48]. It is estimated that only 23% of gay and bisexual men in the U.S. claim to always ask potential sex partners about their status [49]. Evidence supports that many highly active individuals use their personal assumptions in their sexual decision making.
Results of a group of HIV+ men showed that often assumptions are made that an HIV-partner would make their status known before sex, and if they didn’t, then they are likely HIV+ as well [50]. Surveys have also suggested that when gay men are given a fictional biographical list of gay men and asked to rate the likelihood that these men were infected, results showed that the assessment was influenced by many attributes such as sexual behaviour, preferred role in sex, as well as preferred venue (public sex environment) [51]. Additionally, partners that appeared to be unconcerned for their own safety through risky sexual behaviour were presumed to be infected [52].

From this it is apparent that estimating a partner’s sexual status through sexual behaviour as an indicator is a predominant method. This is all the more important as the majority of interactions don’t involve a verbal exchange personal serostatus. As such, it is important to further understand how individual’s make these decisions and what implications these have on the population.

1.2 Epidemic Models

The origins of applying mathematics to better understand infectious diseases is believed to begin with Daniel Bernoulli in 1760. His research focussed on the effectiveness of variolation against smallpox in an attempt to change policy by showing a predicted increase in life expectancy [53]. Since then, many varying methods of epidemic modelling have been established.
1.2.1 Differential Equation Models

First instances of modelling using deterministic epidemiological modelling started fairly early in the 20th century [54]. Such a mathematical model can be used to describe a population or biological system using a set of differential equations. While investigating infectious diseases, it can be used to help predict the spread throughout a population. This method is used by numerous researchers to study the spread of HIV. The most basic form of a deterministic ordinary differential equation (ODE) model is a Susceptible-Infected-Recovered, or (SIR) model. This type of model is used for a wide variety of infectious diseases. The letters that consist of SIR represent the number of people in the respective compartment at a particular time.

\[
S(t) = \text{number of susceptible individuals at time } t; \\
I(t) = \text{number of infected individuals at time } t; \\
R(t) = \text{number of recovered individuals at time } t;
\]  

This format can be expanded to suit the needs of the infectious disease in question. As an example, an SIRS model can be used to describe a scenario where individuals eventually return to the susceptible class. This could be applicable to studying aspects of the common cold, where there is no long-term lasting natural immunity. We define a SIRS model structure as:
\begin{align*}
\dot{S} &= -\lambda S + \rho R \\
\dot{I} &= -\lambda S - \gamma I \\
\dot{R} &= \gamma I - \rho R
\end{align*} (1.2)

\(\gamma\) represents the recovery rate of individuals leaving the infected class to the removed class. The average amount of time an individual is infectious for is defined as \(1/\gamma\). \(\rho\) represents the rate at which recovered people re-enter the susceptible class, with \(1/\rho\) representing the average unit of time until the recovered individual enters the susceptible class. \(\lambda\) is the force of infection defining the transition of individuals from susceptible to infected. This term is formulated by, \(\lambda = \beta \frac{I}{N}\), with \(N\) referring to the total population \((N = S + I + R)\), and \(\beta\) as the transmission rate. This creates a non-linear term, and generates a dynamic transmission model since the risk of transmission is not constant and depends on the number of infected in a population which varies. If the total population size remains constant, the \(\lambda\) term increases proportionally to the total number of infected individuals, or the contact rate for a susceptible for a constant population. In terms of an HIV model, this could be implemented while investigating a small group over a short amount of time with an unchanging population, compared to a model where enough time passes to change the population, or if the birth and death rate are not equal. SIR models that include vital dynamics would incorporate a parameter to describe the mortality rate for each group. The mortality rate is associated with individuals leaving the model generally through death or no longer becoming relevant to the question being investigated. Additionally, there is the recruitment rate, or birth rate depending on the population in question, representing the incoming susceptible people into the population. This may be equal to the death rate,
keeping the population the same size.

Formulation of the basic reproductive ratio, $R_0$, for an infection can also be estimated through the model shown in Equation 1.2. $R_0$ describes the mean number of secondary infections obtained from an infected individual within a susceptible population. This term is useful in determining if an intervention option could stand to decrease this value to the point where the disease may be eliminated from the population. This occurs when the threshold $R_0 < 1$. Formulating $R_0$ from this model is derived from the steady states of the system [55]. The SIRS model has two steady states:

\[
\begin{align*}
\bar{S} &= N, \bar{I} = 0, \bar{R} = 0 \\
\bar{S} &= \frac{\gamma}{\beta}, \bar{I} = \frac{N - \bar{S}}{\gamma + \rho}, \bar{R} = \frac{\gamma \bar{I}}{\rho}. 
\end{align*}
\]

The first instance involves an eradicated disease. In the second steady state, the population remains as proportions of each class. If the second $\bar{I}$ is to be positive, $N$ must be greater than $\bar{S}$. With $\bar{S} = \frac{\gamma}{\beta}$, the disease will exist if $\frac{N\beta}{\gamma} > 1$. So we define $R_0$ as

\[
R_0 = N \frac{\beta}{\gamma}.
\]

Stochastic models assume the probability of spread is unaffected by the evolving population or an intervention [56]. These models are often referred to as static models and are possibly more suited for studying non-infective diseases. The non-linearity of the deterministic model is also useful for capturing the effects of herd immunity. Herd immunity occurs
when a protected or vaccinated portion of a population provides protection to unprotected individuals through impacting the force of infection as captured in dynamic models. This aspect is particularly important for vaccination studies as it is argued that when a significant portion of the population has achieved protection and the disease is less likely to spread, unvaccinated individuals may lose incentive to vaccinated themselves. This is natural to assume when comparing a lower risk of being infected to the potential harmful risks of a vaccine in question.

The aforementioned model, can be expanded to incorporate age structure into the model. This is especially important when the age of the population has an impact on how the disease spreads. Adjusting the model as shown below, we are able to account for two age classes.

\[
\begin{align*}
\dot{S}_1 &= -\lambda_1 S - a_1 S_1 - \mu_1 S_1 + \mu N \\
\dot{I}_1 &= -\lambda_1 S_1 - \gamma_1 I_1 - \mu_1 I_1 - a_1 I_1 \\
\dot{R}_1 &= \gamma_1 I_1 - \mu_1 R_1 - a_1 R_1 \\
\dot{S}_2 &= a_1 S_1 - \lambda_2 S_2 - \mu_2 S_2 \\
\dot{I}_2 &= a_1 I_1 - \lambda_2 S_2 - \gamma_2 I_2 - \mu_2 I_2 \\
\dot{R}_2 &= a_1 R_1 \gamma_2 I_2 - \mu_2 R_2
\end{align*}
\] (1.6)

Where age class \( i \), ages at a rate of \( a_i \). This allows for other parameters to better accurately reflect the differences associated with each particular age group. The force of
infection term becomes \( \lambda_i = \sum_{k=1}^{2} \beta_k \nu_{i,k} \frac{I_k}{N_k} \), while investigating infection in group \( k \) and describing the force of infection for group \( i \). \( \nu_{i,k} \) represents the contact factor between the different age groups. Vital dynamics are introduced with \( \mu \) representing the mortality rate, and the \( \mu N \) term representing the rate of recruitment rate to the susceptible group.

In addition to being used to model different age classes, this can also be used to implement heterogeneity into a model. Differences in heterogeneity, can refer to differences in environment, behaviour, or possibly number of contacts. With respect to HIV, it is often used to describe high risk individuals, particularly commercial sex workers, who interact with more individuals than other members of the population. This method can also be used to define spatial differences which may occur in the population being examined, the SIRS model described in Equation 1.6 describes a homogeneous mixing population.

Introducing heterogeneity into a model may also be necessary to address certain research questions. For instance, if we were to investigate which age group to administer a vaccine to, in order to best reduce costs or prevent disease spread, we would need to create a model with age structure. Many papers include aspects such as, sex of an individual, age, likeliness to engage in risky behaviour, individuals with many partners, etc [57, 58, 59]. Hallett et al created a heterogeneous dynamic simulation model which included a gender specific, age-stratified population, as well as three sexual activity groups representing spousal partnerships, those with long-term casual partners, and those with high numbers of sexual partners [58]. By doing this he was able to estimate the effects of risk behaviour on HIV transmission.

In contrast to ODE models, partial differential equation (PDE) models can be used to
study spatial variables in the population. This method is useful in studying different groups with respect to differing geographical placement. These compartmental models often focus on studying a population. Studying infectious diseases through network modelling allows for spatial differences to be incorporated, as well as analysis at the individual level.

1.2.2 Agent-based models

Differing modelling methods come with both strengths and weaknesses which are important to assess when studying an infectious disease. Compartmental models, have the advantage of often quick computation speed, as well as use of analytical tools. The downside can be the homogeneous mixing that can occur \cite{69}. Networks for disease modelling aid in allowing further heterogeneity to be incorporated into the model. In order to better study changes at the individual level, agent-based models (ABMs) are often used. The motivative reasoning behind ABMs is to study how the collective behaviour of a group emerges via agents following set rules. ABMs began to rapidly spread in the late 1990’s, when computers were finally computationally able to assist \cite{70}. Agents within an ABM can also exist within a network structure.

While ABMs are unable to employ many analytic methods generally used to characterize an equilibrium, or study stable states, ABMs themselves are capable of generating the equilibrium as well as explore a systems robustness of variables. This is useful in identifying how a complex system may adapt to changes posed upon individuals or the population. This helps to mimic the complexity of the actual population. The general process of an ABM may consist of initializing a population of individuals each with their
own characteristics, then deciding upon the decision making process of these individuals during interactions and how these individuals learn or adapt to changes. Interest generally lies in studying how changing behaviour may influence the population.

1.3 Behaviour-incidence modelling

Incorporating human behaviour in a model generally focusses on individual strategies and beliefs. This can include disease awareness, which may or may not relate to population views. In cases where an individual’s awareness is influenced by the population, we encounter a feedback loop occurring between behaviour and incidence. Studying behavioural changes is important as it can have dramatic effects [71]. Policy resistance is an important aspect to consider, particularly with respect to vaccination programs. Policy resistance occurs when policies that are implemented to promote the overall public health and welfare end up failing or worsening the problems that they intended to solve, due to nonlinear behavioural feedbacks [72]. With respect to HIV, policy resistance is sometimes referred to as HAART optimism. HAART or vaccine optimism would essentially refer to individuals changing their behaviour in light of a new treatment. The result of which may include adopting more risky behaviours due to standing beliefs in the treatment. The unintended consequence would be HIV incidence increasing within the population.

A paper from Blower et al showed that HIV prevalence could increase if risk behaviour increased during a mass vaccination campaign, even with a vaccine with high efficacy [73]. Numerous papers that investigate prevalence-dependant behaviour offer confirmation of this [74] [75] [76] [77] [1] [78]. These papers approach the subject of behavioural response
from a variety of ways. Some papers are modelled after the specific demographic data of a country, often focussing on low-income nations [76] [77] [78]. The majority of papers focus of vaccine intervention, while some explore HAART [75]. The most common method of spread studied is through sexual intercourse, however some focus on intravenous drug users [76]. These papers differ on elements such as demographics, vaccine characteristics, different intervention strategies, and how behaviour is defined in the model. However, they focus on behavioural scenarios and conditions where HAART or vaccine optimism may occur. This is done through each paper developing or building upon existing deterministic, and stochastic differential equation models and either examine changes to HIV incidence or $R_0$. These papers incorporate behaviour by representing it as parameter integrated into their compartmental model by either a static variable, or a prevalence-dependent parameter.

1.4 Brief Introduction to Game Theory

Game theory is a mathematical area of research initially developed in the late 1940’s with the works of von Neumann and Morgenstern [79] and later those of Nash [80] in early 50’s. A game is a mathematical framework to describe decision making by individuals engaged in competitive situations, where they can behave noncooperatively or cooperatively. Noncooperative game theory is nowadays widely used in applied areas such as economics, engineering, operations research, evolutionary biology and social sciences (psychology and cognitive sciences) [81][82]. The strength of game theoretical modelling is that preferences can be concisely described and individual behaviour can be predicted, assuming that they optimize their expected utility given the preferences and likely actions of others. It is
assumed every player is rational, and wishes to leave the game with the optimum payoff they can achieve [81].

It is often the case that applications of game theory in areas other than mathematics use classes of games which are generally well studied, and for which the concept of an (Nash) equilibrium point is well-defined. These classes of games are those with linear payoff functions (2 player or multiplayer matrix games), be it zero- or non-zero-sum games [83] [84]. More advanced modelling requires nonlinear payoffs and multiplayer contexts, in which case the methods of finding Nash equilibrium points of such games varies depending on the complexity of the game in question: it can be a reaction curves method, or an optimization type problem, a variational inequality problem, a computational method (such as genetic algorithms, evolutionary computation), or a replicator dynamics equilibrium, etc.. [85] [86] [87].

A popular example of a game theoretical model is Prisoner’s Dilemma. For this game two men arrested must individually decide either to betray their partner by confessing to the police to the crime they committed, or to remain silent. Ideally both would remain silent and both given a minor charge, however, if one testifies against the other they are given the incentive of no penalty. A Nash equilibrium, which is a solution of a game involving two or more players in which each player is assumed to know the equilibrium strategies of the other players, can be applied to this situation. Interestingly, we see that when these individuals act in their own best interests we find a Nash equilibrium where both players confess to the police [81].

In general, a multiplayer game involves a finite number of players, denoted here by
A generic player $i \in \{1, ..., N\}$ is thought to have a strategy set $S_i \subset \mathbb{R}^{n_i}$, whose strategies are vectors $x_i \in S_i$ and a payoff function $f_i : S_i \to \mathbb{R}$. A Nash equilibrium of a multiplayer game is defined as follows:

**Definition 1** Assume each player is rational and wants to maximize their payoff. Then a Nash equilibrium point is a vector $x^* \in S := S_1 \times ... \times S_N$ which satisfies the inequalities:

$$\forall i, \quad f_i(x^*_i, x^*_{-i}) \geq f_i(x_i, x^*_{-i}), \quad \forall x_i \in S_i$$

where $x_{-i} := (x_1, ..., x_{i-1}, x_{i+1}, ..., x_N)$.

We can also think of a game as a set of coupled optimization problems as described:

**Definition 2** Given a multiplayer game as in Definition 1, for each player $i \in 1, ..., N$, its problem is:

$$\max f_i(x_i, x^*_{-i})$$

subject to $x_i \in S_i$

There are many results regarding the existence of Nash equilibria, in either pure or mixed strategies [88]. We cite one of these below for the benefit of the reader:

**Theorem 1** If there exists a game with a strategy set $S = S_1 \times ... \times S_N$ that is compact and convex, and with payoff functions $f_i(x_i, x_{-i})$ that are continuous in $x \in K$ and quasi-convex in $x_i \in S_i$ for any given $x_{-i}$, then there exists a pure strategy Nash equilibrium of the multiplayer game.
1.4.1 Game Theory and Variational Inequalities

One approach for finding criteria of existence of Nash equilibria of multiplayer games as well as devising computational methods is that of variational analysis [89] [90] [91]. This consists of equivalently reformulating the Nash game of Definition 1 into a variational problem of the type:

**Definition 3** Given a set $K \subset \mathbb{R}^n$, closed and convex, and given $F : K \to \mathbb{R}^n$ a continuous function, the variational inequality (VI) problem is to find a vector $x^* \in K$ such that

$$\langle F(x^*), y - x^* \rangle \geq 0, \forall y \in K.$$ 

The existence of a solution to the VI problem in Definition 3 can be shown to exist (see [89]) through the following theorem:

**Theorem 2** Let $K \subseteq \mathbb{R}^n$ be compact and convex, and let $F : K \to \mathbb{R}^n$ be continuous. Then, the VI$(K,F)$ has at least one solution.

Monotonicity in variational analysis is as important as convexity in optimization. Types of monotone mappings (as defined below) play a crucial role in existence and uniqueness results regarding solutions of VI problems.

**Definition 4** A mapping, $F : K \to \mathbb{R}^n$ is:

1. monotone on $K$ if $(x - y)^T (F(x) - F(y)) \geq 0, \forall x, y \in K$
2. strictly monotone on K if 
\[(x - y)^T (F(x) - F(y)) > 0, \forall x, y \in K\]

It is interesting to remark whenever \(F = \nabla f\), the monotonicity properties \(F\) can be directly related to the convexity properties of \(f\):

1. If \(f\) convex then \(\nabla f\) monotone and \(\nabla^2 f \geq 0\)

2. If \(f\) strictly convex then \(\nabla f\) strictly monotone and \(\nabla^2 f > 0\)

It is known that there is a direct connection between a VI problem and a minimization problem as follows: [89]

**Lemma 1** Given a convex optimization problem:

\[
\min g : K \rightarrow \mathbb{R}
\]

subject to \(x \in K \subset \mathbb{R}^n\)

and assuming \(x^* \in K\) is a solution of this problem, then \(x^*\) is also a solution of the VI problem

\[
\langle F(x^*), y - x^* \rangle \geq 0 \quad \forall y \in K
\]

where \(F(x) := \left( \frac{\partial g_1(x)}{\partial x_1}, ..., \frac{\partial g_N(x)}{\partial x_N} \right) : \mathbb{R}^{n_1 + ... + n_N} \rightarrow \mathbb{R}\) and \(g\) is a convex function of class \(C^1\).

Using the information in Definition 2 and Lemma 1, there is a way to equivalently reformulate some classes of games into a variational inequality problem (Definition 3). The advantages are two-fold: one can assert existence of solutions to the VI problem, as well as one can use computational methods developed in the VI theory, to analyze and compute Nash equilibria for the game. One such equivalence result is the one below (see [92]):
**Theorem 3** Assume a multiplayer game as defined above. Provided for each player \( i \) assumed to maximize its payoffs, its payoff function \( f_i \) is of class \( \mathcal{C}^1 \) and is concave with respect to the variable \( x_i \in S_i \), then \( x^* \in K \) is a Nash equilibrium if and only if it satisfies the VI

\[
\langle F(x^*), y - x^* \rangle \geq 0 \quad \forall y \in K
\]

where \( F(x) := (-\frac{\partial f_1(x)}{\partial x_1}, \ldots, -\frac{\partial f_N(x)}{\partial x_N}) \).

We will use Theorem 2 and 3 to assert existence of Nash equilibria for our multiplayer games described later in Chapter 4. We also use the VI formulation of the games for computing the equilibria and conducting sensitivity analyses of the Nash strategies and overall HIV prevalence in the population.

### 1.4.2 Sequential Games and HIV Transmission

When applying game theory to sexually transmitted diseases, we formulate a sexual interaction as a game. The payoff is what a player, or individual, chooses as the action resulting in the highest personal value. Concerning the propagation of HIV, a game will be a sexual interaction. The payoff a player wishes to optimize will be a ranking of different sexual experiences. Risky, or unprotected sex, is one of the options each player considers as this is the primary cause of HIV spread. Schroeder *et al* created a game theoretical analysis of sexually transmitted disease epidemics. This was done by investigating if a person can deduce the HIV status of a potential sexual partner from observed behaviour, as well as the implications of a game theoretical analysis for infection rate dynamics [29]. Schroeder’s model can be defined as a Bayesian game.
Definition 5 (Bayesian game) Bayesian games assume incomplete information. They may introduce Nature to assign a random variable to each player. The type of player will also determine that player’s payoff function. There is incompleteness of information where at least one player is unsure of the type (and so the payoff function) of another player. Players have initial beliefs about the type of other player and can update their beliefs according to Bayes’ Rule as play progresses in the game.

Definition 6 (Bayes’ rule) For an assumption A, and evidence supporting B.

\[ P(A|B) = \frac{P(B|A)P(B)}{P(A)} \]

where \( P(A) \) is the prior probability, \( P(A|B) \), the conditional probability and \( P(B) \) is the probability of event B.

The game Schroeder describes is also a dynamic signalling game [29], which is an example of a Bayesian game. In game theory a sequential game is one in which one player chooses their action before another chooses theirs [81]. A generic signalling game is a sequential game with two players, the sender and the receiver [81, 82]. Both the sender and receiver have a certain type. The sender observes his own type while the receiver does not know the type of the sender. The sender chooses to send a message from a set of possible messages. The receiver then observes the message but not the type of the sender. The receiver proceeds to choose an action.

This game can also be given an extensive form representation. For instance, Figure 1.2 describes the sequential game we used in Chapter 2. In our context, a player chooses a preferred sexual act to offer. This choice is based on the utility assigned to the player’s personal preferences. After the decision is made, the player offers this choice to the other
player. Upon receiving the offer, the second player’s personal preference is adjusted, before they themselves choose their preferred sexual act to offer in return.

Figure 1.2: Sequential game, described further in Chapter 2.

1.5 HIV Models

Despite attempts to reduce the spread of HIV through awareness campaigns, the HIV pandemic has spread worldwide, infecting both industrial and impoverished nations [36]. Due to limitations every country has on health care spending, including HIV/AIDS prevention efforts, it is crucial to have an informative understanding on what factors propagate this disease, and what methods can be best utilized to slow, or stop, its progression. As a result, many researchers have studied HIV spread using a variety of mathematical methods.
These are often focussed on a specific geographical location, group of people, or both.

Velasco-Hernandez, *et al* analyzed HIV spread through the MSM population using a compartmental model. The model researched how sexual behaviour changes with prevalence. The infected individuals were divided into two groups, those that are infected and are aware of their serostatus, and those that are not. Velasco-Hernandez concluded only significant reductions in transmission probability could halt the spread of HIV [93].

Hsieh *et al* constructed a similar model, instead investigating HIV spread amongst heterosexual individuals. Females divided into two compartments, commercial sex workers of brothels, and of commercial establishments. With males divided into two classes of varying sexual activity. The model examined how changes in behaviour (condom use) and activity class occurred when HIV proliferated. Hsieh *et al* concluded that behaviour change in commercial sexual workers was more impactful than in males, as well as commenting on the complicated dynamics of the sex industry [94].

Hallett *et al* created a dynamic simulation model to assess the effectiveness of interventions to reduce HIV transmission [58]. Hallett fitted data from the natural evolution of a previous HIV epidemic during 2006. By doing this, Hallett was able to discover strong evidence of the reduction in risk behaviour amongst a population in Zimbabwe. This paper demonstrated the effect behavioural change can have on an HIV epidemic.

Kremer created a standard epidemiological mathematical model to observe the dynamics of the spread of HIV in a heterogeneous population. Kremer also integrated behavioural choice into the equations in order to include a risk assessment for low and high sexually active people. His studies showed that if high activity people reduce their activity by a
smaller proportion than low activity people, the result is a worse off pool of available partners, leaving low activity people to reduce their sexual activity, and high activity people to become fatalistic [95].

Smith et al discusses how disease modifying HIV vaccines may affect the population. By using a mathematical model, Smith defined a fitness ratio to find a threshold at which disease modifying agents must provide protection against infection in order to prevent the disease from worsening [1].

Greenhalgh et al examined the spread of HIV through intravenous drug users. In the United States, 20% of HIV+ individuals are believed to have contracted HIV by sharing of contaminated needles. By calculating the basic reproduction number under different scenarios, they were able to estimate the likelihood of eliminating HIV. Interestingly, Greenhalgh et al created both a deterministic and stochastic model to examine such effects. They discovered that under certain behavioural assumptions, their deterministic and stochastic models show similar results [96].

1.6 Objective and Rationale

Over the years, our understanding of how HIV spreads and what factors primarily contribute to its spread have helped change the efforts being implemented to stop the spread. Primarily, partner selection and safe sex practices are a major determinant of HIV prevalence. However, recent advances in medication, such as HAART has changed perception of HIV from a universally fatal disease to a chronic disease wherein HIV is not cured, but an
individual’s viral load can be reduced to lessen the probability of transmission and increase lifespan [1]. This could in turn possibly contribute to the notion that contracting HIV is not as dangerous as it used to be, and therefore individuals may engage in more risky behaviour once again.

This has become a concern for people who potentially could be at higher risk for contracting HIV, such as in homosexual men if their preferences change to risky sex when perceiving less threat of HIV/AIDS. As such, it is important to be able to assess a population’s belief in the risks associated with contracting HIV, determine whether those will change under a new intervention, and if so, how those new beliefs will in turn change prevalence. Surveys can provide valuable information on what a population is thinking at a specific time. Numerous dynamical compartmental models study the population effect, but need to explain how this perception evolves over time and in response to changes in disease prevalence. If we are to understand HAART and vaccine optimism we require a way of demonstrating how an individual develops their perception of risk, and what effect this has on the population in terms of average risk perceptions, and overall HIV prevalence. Assessing human behaviour is important in assessing the policy of any intervention.

My overall objective is to better understand how HIV prevalence interacts with risk perception and partner selection. This thesis will consist of three projects, each devoted to understanding a different aspect of interactions between HIV spread and risk perception evolution. My specific objectives are:

1. **Coevolution of risk perception, sexual behaviour, and HIV transmission in an agent-based model**
i to understand further the mechanisms that drive behaviour and partner selection.

ii to model a population on an individual level.

iii to observe the dynamics between perceived risk, and sexual behaviour.

iv to understand how HIV- and HIV+ behaviour can differ, and the implications this has on the population.

v to understand how decisions are formed, and the role HIV+ and HIV- people play in the spread of HIV.

2. Sexual behaviour, risk perception, and HIV transmission can respond to HIV antiviral drugs and vaccines through multiple pathways

i to understand how various age groups may affect the prevalence of HIV in a population.

ii to understand of how risk perception evolves, and how it reacts to the introduction of HAART and prophylactic vaccines.

iii to identify how different age groups react to treatment and intervention, as well as what implications this may have on the population.

iv to analyze the effect of different infectious rates, the perception of HIV, and how different age groups react under different scenarios to predict the spread of HIV.

3. Multiplayer games and HIV prevalence via casual encounters

i to expand upon the game-theoretical structure established in a novel way.

ii to explore the effect of single iteration games for 2, 3, and 4 player scenarios.
iii to observe how structuring these games across different age cohorts may effect results.

iv to incorporate HIV vaccines to explore what impact this has on behaviour and spread.

Ultimately, we hope to answer the question using a unique approach: How does perception of HIV, partner choice, transmission and intervention strategies interact with each other? Little work has explored this feedback mechanism using a game theoretical approach, and where research has been done, the models have been very theoretical, with little attention to important age structure or theoretical vaccines.

Bibliography


AIDS.GOV. *What are the stages of HIV infection?*, Dec 2013.


Clinical Trials. Safety and immune response assessment study of killed-whole HIV-1 vaccine (SAV001-H) in chronic HIV-1 infected patients, Sept 2013.


Chapter 2

Coevolution of risk perception, sexual behaviour, and HIV transmission in an agent-based model

Abstract

Risk perception shapes individual behaviour, and is in turn shaped by the consequences of that behaviour. Here we explore this dynamic in the context of human immunodeficiency virus (HIV) spread. We construct a simplified agent-based model based on a partner selection game, where individuals are paired with others in the population, and through a decision tree, agree on unprotected sex, protected sex, or no sex. An individual’s choice is conditioned on their HIV status, their perceived population-level HIV prevalence, and the preferences expressed by the individual with whom they are paired. HIV is transmitted during unprotected sex with a certain probability. As expected, in model simulations, the perceived population-level HIV prevalence climbs along with actual HIV prevalence. During this time, HIV-negative individuals increasingly switch from unprotected sex to protected sex, HIV+ individuals continue practicing unprotected sex whenever possible, and unprotected sex between HIV+ and HIV- individuals eventually becomes rare. We also find that the perceived population-level HIV prevalence diverges according to HIV status: HIV- individuals develop a higher perceived HIV prevalence than HIV+ individuals, although this result is sensitive to how much information is derived from global versus local sources. This research illustrates a potential mechanism by which distinct groups, as defined by their sexual behaviour, HIV status, and risk perceptions, can emerge through coevolution of HIV transmission and risk perception dynamics.
2.1 Introduction

The World Health Organization (WHO) has classified HIV as a pandemic; the infection continues to spread in most nations, and is particularly prevalent in some of the worlds poorest nations [1]. Medical treatment has reduced annual rate of AIDS cases dramatically, however, the rate of new HIV infections has not dropped significantly [2]. Infection occurs by transfer of blood, semen, vaginal fluid, or breast milk [1], but in many countries the primary mode of transmission is sexual contact. For example, it is estimated that in the United States, 80% of new HIV cases are a result of unprotected sex [3]. Much of this infection is driven by so-called “core groups” that are responsible for a disproportionate amount of infection, and can drive the epidemic in some populations [4].

How individuals choose sexual partners and how they perceive their risk of infection within those partnerships appear to be major determinants of sexually risky behaviour as well as HIV infection risk [5, 6]. For example, in men who have sex with men (MSM), a lower perceived risk of infection within a partnership is correlated with a higher probability of engaging in unsafe sex [6]. Another study in MSM found that, although most HIV-positive males practiced safer sex with HIV-negative or HIV-status-unknown partners, having more lifetime male sexual partners was correlated with being more likely to practice unsafe sex with such partners [7]. Hence, risk perception, safe sex practices, and sexual partner selection are determinants of HIV transmission between sex partners [8], and thus HIV prevalence in the population.

However, HIV prevalence in turn determines risk perception and sexual behaviour. For example, evidence from African HIV epidemics suggests that individuals adopt safer sex
practices in response to rising HIV prevalence [9]. Individuals also appear to respond to how severe they expect HIV infection to be, with evidence that both HIV+ and HIV-individuals engage in more unprotected sex when anti-retroviral therapy (ART) is available; this occurs because ART causes HIV to be perceived to be more of a chronic disease than a fatal disease [10]. These findings highlight the feedback loop between risk perception and sexual partner selection/safe sex practices on the one hand, and HIV prevalence on the other hand: when HIV prevalence is low, individuals perceive less infection risk and engage in riskier sexual behaviour, but that in turn can increase HIV prevalence. When HIV prevalence is high, individuals change their sexual behaviour to protect themselves.

In the field of behavioural epidemiology, models of behavioural influences on HIV transmission were some of the first to be developed. These approaches have analyzed, for example, the impact of contact patterns between various groups and other population heterogeneities, and how these factors interact with behavioural effects pertaining either to adherence to interventions or sexual behaviour, where behavioural change is either imposed through changes in a fixed parameter, or where it responds in a more fluid way to changes in HIV prevalence, as a model variable or a prevalence-dependent parameter [9, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20].

A few of these models have focussed specifically on the topic of sexual partner selection and how that influences HIV transmission [11, 18]. Game theory provides a very natural framework for addressing such topics [18], since it allows individual preferences to be concisely described and provides a way of determining the collective outcomes of these individual-level strategic decision-making processes [21] (as opposed to modelling the effects of behaviour in a more phenomenological way, such as a functional form describing how the
person-to-person transmission rate declines with increasing prevalence). However, it also requires assuming that individuals will maximize their expected utility given the preferences and likely actions of others. In the context of partner selection and HIV transmission, the ‘game’ is a sexual interaction between two partners, and the payoff is the utility outcome of a player’s choice of unprotected or safe sex, given what they believe is the HIV status of their partner [18].

In this paper, we develop an agent-based simulation model that extends a previous game theoretical model of sexual partner selection and HIV transmission [18]. Individual perception of HIV infection risk evolves a function of the individual’s past sexual encounters, and individuals decide on either unprotected sex, protected sex, or no sex with the individuals with whom they are paired in each time step. Instead of exogenously imposing a pre-existing population structure where individuals engage in either high-risk or low-risk behaviour, our objective is to explore how distinct population groups—as defined by differing risk perception, HIV status, and sexual behaviours—can emerge from the coevolution of individual-level risk perception and HIV transmission, through partner selection games. We also wish to gain insight into potential mechanisms for how assortative sexual mixing with respect to level of riskiness in sexual behaviour might emerge from this coevolutionary process.

2.2 Methods

The partner selection model is based on the dynamic signalling game described in Ref. [18], except modifications are made regarding how individuals perceive their risk of HIV infection
as a function of their encounters, and how this perception is carried into future rounds of the game. A game represents a strategic interaction between two or more individuals. A dynamic signalling game is a type of sequential game with two players passing signals back and forth [18, 21, 22]. The players may be of differing types. Only the sender knows his/her own type: the receiver observes the signal but not the type of the sender. The receiver proceeds to choose an action while updating their beliefs regarding the type of the other player.

2.2.1 Partner selection model

The population consists of $N$ individuals forming a highly active core group population of MSM, such as the patrons of an urban bathhouse. The population is not structured with respect to age, gender, or other forms of social/cultural heterogeneity. In each round, individuals are paired at random to play a “Risky Sex Game”. One of the pair is randomly assigned to be actor 1 (the initiator) and the other is assigned to be actor 2. The strategy options are Unprotected Sex (US), Protected Sex (PS) and No Sex (NS). Individual status is either HIV+ or HIV-, hence there are three possible pairs in each round: two HIV-, two HIV+ and HIV+/HIV-. The interaction describes a potential casual sexual encounter between two actors who may or may not have had an interaction before. Each actor knows whether or not they carry HIV, but do not know the HIV status of those they are paired with. Actors hold their own HIV status as private. Everyone knows the sexual preferences of HIV+ and HIV- actors, and based on their sexual preferences, an actor will alter their belief about the HIV status of the individual they are paired with. HIV- actors will not
have unprotected sex with those that they believe are HIV+, while HIV+ actors prefer unprotected sex regardless of HIV status of partner. Both actors have a belief regarding the HIV status of their partner, but they do not know with certainty and do not find out the truth, even if they eventually have sex (unless they become infected). This game will be embedded in an agent-based simulation model.

After being paired, the actors choose whether to play the Risky Sex Game with their partner with probability

$$\rho(c) = \frac{\omega + c}{1 + c}$$  \hspace{1cm} (2.1)

where $$\rho(c)$$ represents the probability that they will play the game, $$c$$ represents the cumulative sex acts that have occurred between actor 1 and actor 2 until this point in time, and the “gregariousness” parameter $$\omega$$ controls the how the probability of the game being played depends on how often the actors have engaged in sex previously. Equation (2.1) partially captures the effect of learning and reputation. In our baseline analysis, we assume $$\omega = 1$$, hence $$\rho = 1$$, but we explore $$\omega < 1$$ in sensitivity analysis. If the actors decide not to play the game this round, they must wait until the next round of the game to be re-paired.

Should the actors decide to interact further, the game will commence as follows:

1. Actor 1 offers to have either protected sex (PS) or unprotected sex (US).

2. Actor 2 either accepts or makes a counter offer of PS or US.

3. Actor 1 either accepts final offer or ends the interaction with no sex (NS).

The decisions available to each individual in each step of the Risky Sex Game are depicted in Figure 2.1.
A utility is a value assigned to a possible outcome representing how an individual ranks their preferences. The utility $U_i$ for actor $i$ of outcome $k$ ($k=$US, PS, NS) when the HIV status of actor $i$ is $s_i$ ($s_i=+,-$) and the HIV status of actor $j$ with whom they are paired is $s_j$ ($s_j=+,-$) is given by

$$U_i(k, s_i, s_j)$$  \hfill (2.2)

where the utilities for various outcomes as they depend on HIV status follow the inequalities contained in Table 2.1, which also contains the baseline utility values.

Because actors do not actually know the HIV status of their partner, each actor accrues an expected utility that depends on how strongly they believe their partner is HIV+. The
Table 2.1: Utilities for actor $i$, given status of actors $i$ and $j$, and type of sex.

<table>
<thead>
<tr>
<th>$s_i$</th>
<th>$s_j$</th>
<th>$x_{US}$</th>
<th>$x_{PS}$</th>
<th>$x_{NS}$</th>
<th>preferences of actor $i$</th>
</tr>
</thead>
<tbody>
<tr>
<td>HIV+</td>
<td>HIV+</td>
<td>100</td>
<td>50</td>
<td>0</td>
<td>$US &gt; PS &gt; NS$</td>
</tr>
<tr>
<td>HIV+</td>
<td>HIV-</td>
<td>100</td>
<td>50</td>
<td>0</td>
<td>$US &gt; PS &gt; NS$</td>
</tr>
<tr>
<td>HIV-</td>
<td>HIV+</td>
<td>-50</td>
<td>50</td>
<td>0</td>
<td>$PS &gt; NS &gt; US$</td>
</tr>
<tr>
<td>HIV-</td>
<td>HIV-</td>
<td>100</td>
<td>50</td>
<td>0</td>
<td>$US &gt; PS &gt; NS$</td>
</tr>
</tbody>
</table>

Expected utility is a way of weighting utilities with an individual’s inherent belief of HIV prevalence in the population, as represented by the $b$-value. The expected utility $E_i$ for actor $i$ in a given round when the outcome is $k$ is therefore given by

$$E_i(b_t, s_i) = b_t U_i(k, s_i, +) + (1 - b_t) U_i(k, s_i, -)$$  \hspace{1cm} (2.3)$$

where $b_t$ is the probability with which actor $i$ believes that their partner is HIV+, in the current round $t$ of the game. With probability $b_t$, actor $i$ believes that their partner is HIV+ and hence actor $i$ would receive utility $U_i(k, s_i, +)$. Otherwise, actor $i$ would receive utility $U_i(k, s_i, -)$. It is assumed that actors will maximize their personal expected utility.

The quantity $b_t$ is specific to each actor (agent), and varies over the course of the simulation as actors update their $b$ values based on their encounters. The value of $b_t$ can be updated during a round, as well as between rounds. At the start of a round, actor 1 offers actor 2 their optimal choice of outcome $k$ based on equation (2.3), using their current value of $b_t$ based on previous interactions. If actor 1 offers US, then actor 2 increases his/her $b$-value according to

$$b_t \rightarrow \alpha + (1 - \alpha)b_t$$  \hspace{1cm} (2.4)$$
where $\alpha$ is called the “historical influence parameter”, since it measures how much of $b_t$ is from past encounters versus the current offer. If $\alpha$ is high, then actor 2’s assessment of actor 1’s HIV status is strongly dependent on the fact that actor 1 made an offer of unprotected sex, whereas if $\alpha$ is low, actor 1’s offer had little impact on actor 2’s evaluation of whether or not actor 1 is HIV+. On the other hand, if actor 1 offers PS, then actor 2 decreases his/her $b$-value according to

$$b_t \mapsto (1 - \alpha)b_t \quad (2.5)$$

Actor 2 then evaluates their new expected utility from equation (2.3), using the updated value of $b_t$, and responds to actor 1 with their own optimal outcome. If the two choices of outcome are in agreement, the actors will engage in that type of sex (US or PS). However, if they are in disagreement, Actor 1 will receive Actor 2’s counter-proposal, and Actor 1 will update their $b_t$ value in the same way, using equations (2.4) and (2.5) depending on the counter-offer. Actor 1 then uses this updated $b_t$ value to determine their new expected utility, again according to equation (2.3). If the optimal outcome for Actor 1 has changed and the actors are now in agreement, then they engage in that optimal choice of sex. If they remain in disagreement, then outcome is no sex (NS).

The value of $b_t$ is also updated between rounds, based on information the actors are assumed to be able to receive regarding the actual prevalence of HIV in their population. This updating follows the equation

$$b_t = \beta b_{t-1} + (1 - \beta) \frac{I_t}{N} \quad (2.6)$$
where $I_t$ is the prevalence of HIV in the population at the start of round $t$ and $\beta$ is the “local information” parameter governing the extent to which an actor’s $b_t$ value is based on information from their interactions versus globally available, accurate information on HIV prevalence in their population. $b_t$ is the value a player carries into round $t$, based on their $b_t$ value at the end of the previous round $t - 1$ and how it has been modified through equation (2.6) inbetween rounds. For our baseline analysis we assume $\beta = 1$ and we explore $\beta < 1$ in sensitivity analysis. In general, we expect $\beta$ to be close to 1 since the timescale of an HIV epidemic in a small core group population can be quite rapid [23, 24].

At the end of each round, each pair breaks up and individuals are paired randomly again for the next round. Each player draws their initial $b$-value $b_0$ randomly from a normal distribution of mean $\mu = 0.05$ and standard deviation $\sigma = 0.1$; sampled values less than 0 or greater than 1 were discarded. We chose a relatively small value for the initial $b$-value because recruited individuals in the model are assumed to be younger, and both the perceived prevalence of HIV in a population as well as the perceived risk of contacting HIV or other STI’s are less in younger individuals [25, 26, 27]. Table 2.2 describes the different parameters used in the model and also provides their baseline values.

2.2.2 Transmission and natural history model

We assume a time scale on the order of a single HIV outbreak in a core group population. Hence, we neglect recruitment and death, and assume a Susceptible-Infected (SI) natural history where individuals are initially susceptible, and remain infectious indefinitely once they are infected. Each round of the game corresponds to a timestep of the simulation
<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
<th>Baseline value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$b_0$</td>
<td>Initial b-value: Initial probability value individually chosen from a beta distribution of mean 0.05 and a standard deviation of 0.1</td>
<td>0.05</td>
</tr>
<tr>
<td>$\alpha$</td>
<td>Historical influence parameter: Measures how much of the b-value will be based on past experience</td>
<td>0.015</td>
</tr>
<tr>
<td>$\tau$</td>
<td>Transmission probability: Probability of HIV spread from an HIV+ player to an HIV- player through US</td>
<td>0.01 [28]</td>
</tr>
<tr>
<td>$u_{PS}$</td>
<td>Protected Sex utility</td>
<td>50</td>
</tr>
<tr>
<td>$\beta$</td>
<td>Local information parameter: Proportion of the b-value that is a combination of an individual’s interpretation of risk, and an accurate value of the actual proportion of infected individuals in the population</td>
<td>1</td>
</tr>
<tr>
<td>$\omega$</td>
<td>Gregariousness parameter: Degree of willingness to interact with strangers</td>
<td>1</td>
</tr>
<tr>
<td>$N$</td>
<td>Population size</td>
<td>1000</td>
</tr>
<tr>
<td>$I_{initial}$</td>
<td>Initial number of infected players at the beginning</td>
<td>5%</td>
</tr>
<tr>
<td>$I$</td>
<td>Number of infected individuals in the population</td>
<td>5%</td>
</tr>
</tbody>
</table>

Table 2.2: Parameter definitions, and parameter values for baseline scenario.

model, and each timestep corresponds to approximately three days. If an outcome of Unprotected Sex occurs between an HIV+ and an HIV- actor, then HIV is transmitted with probability $\tau = 0.01$. For simplicity we assume Protected Sex is perfectly effective in preventing transmission [28]. The population size is $N = 1000$ players, with 5% of the population being infected at $t = 0$. 

54
2.3 Results

2.3.1 Baseline scenario

The time series of HIV prevalence \(I(t)\) initially shows a typical Susceptible-Infected natural history outbreak pattern, with prevalence increasing exponentially quickly in the early stages. However, instead of infecting the vast majority of the population, HIV prevalence subsequently approaches an equilibrium \(I\) comprising approximately 60% of the population (Figure 2.2a).

The approach to \(I\) is asymptotic, and this stabilization occurs because HIV+ and HIV-actors evolve differing b-values in the course of the outbreak. For the first 50 time steps (150 days), the average b value of HIV+ actors, \(\langle b^+ \rangle\), increases rapidly and at roughly the same rate as the average b value of HIV- actors, \(\langle b^- \rangle\). However, divergence between \(\langle b^+ \rangle\) and \(\langle b^- \rangle\) emerges suddenly after 50 time steps (150 days): \(\langle b^- \rangle\) continues to climb with increasing HIV prevalence while \(\langle b^+ \rangle\) stabilizes. Before long, \(\langle b^+ \rangle\) and \(\langle b^- \rangle\) have diverged considerably (Figure 2.2a). The heightened b value of HIV- actors means they often assume those who offer them US are HIV+ and hence they respond with a counteroffer of PS, avoiding HIV infection. Hence, HIV- actors are protected from infection by their high b-values, and this slows down the transmission of HIV, resulting in stabilization of HIV prevalence at approximately 60%. By time step 1500, the population is divided into two groups: one group is HIV+ and tends to have a low perception of HIV prevalence in the population, and the other groups is HIV- and tends to have a higher perception of HIV prevalence in the population.
Figure 2.2: (a) HIV prevalence over time ($\langle I \rangle$, black). (b) Average b-values over time by type, HIV- (black dashed $\langle b- \rangle$), HIV+ (grey dashed $\langle b+ \rangle$). This illustrates the coevolution between the HIV prevalence in the population, and the assessment of risk among its individuals. We also note the divergence of b-values amongst the HIV- and HIV+ groups, demonstrating a significant difference in risk assessment.
The divergence of $\langle b^- \rangle$ and $\langle b^+ \rangle$ occurs primarily because actor b-values are updated only when a counter-offer is called for. As HIV prevalence increases, an HIV- Actor 2 will increase his b-value when paired with an HIV+ Actor 1 offering US, but not when paired with an HIV- Actor 1 offering PS. Hence, as HIV prevalence increases, HIV- actors are increasingly being offered US, and they conclude that HIV prevalence is increasing. Similarly, an HIV+ Actor 2 will decrease his b-value when paired with an HIV- Actor 1 offering PS, but not when paired with an HIV+ Actor 1. Hence, the b-value for HIV+ actors is lower than for HIV- actors. A modification of the model allowing actors to update their b-values even when the preferences of the actors are in agreement shows that $I(t)$ and $\langle b \rangle$ are similar, but there is less divergence in $\langle b^- \rangle$ and $\langle b^+ \rangle$ (Figure 2.3).

The divergence is also driven by a positive feedback loop: actors with slightly higher b-values in the beginning are somewhat more likely to avoid HIV infection, which in turn drives their b-value to higher levels according to the mechanism described in the previous paragraph. Likewise, actors with slightly lower b-values are more likely to become infected, and their lower b-value will be reinforced by the same mechanism.

A stratification of outcomes by HIV status of actors provides more detail on how these two groups emerge and interact (Table 2.3). In the early stages of the outbreak when $I(t)$ is still small, the most common type of outcome for all three types of pairs is Unprotected Sex. HIV+/+ pairs always engage in Unprotected Sex, and HIV-/- or HIV+/- pairs engage in Unprotected Sex significantly more often than Protected Sex or No Sex. However, by the time that HIV is highly prevalent, the most common outcome is Unprotected Sex in HIV+/+ pairs. Unprotected Sex hardly ever happens in HIV+-/- or HIV-/- pairs, where Protected Sex is instead the most common outcome. In summary, when HIV is highly

57
Figure 2.3: (a) HIV Prevalence (⟨I⟩, black) (b) average b-value by type, average HIV negative (⟨b−⟩, black dashed), average HIV positive, (⟨b+⟩, grey dashed). Results similar to original finding with the exception of decreased separation between b-values. This occurs when Actor 1 updates their b-value even when Actor 2 is in agreement with their choice.
prevalent, HIV+ actors engage in Unprotected Sex with other HIV+ actors but Protected Sex with HIV- actors, whereas HIV- actors engage in Protected Sex with both HIV+ and HIV- actors, or oftentimes No Sex if the other actor is HIV+. Hence, by this stage, the population has assorted into two distinct groups with very distinct perception and sexual practices.

<table>
<thead>
<tr>
<th>Time (days)</th>
<th>+/+</th>
<th>+/-</th>
<th>-/-</th>
</tr>
</thead>
<tbody>
<tr>
<td>300</td>
<td>US 0.42</td>
<td>10.32</td>
<td>58.51</td>
</tr>
<tr>
<td>600</td>
<td>US 0.92</td>
<td>11.64</td>
<td>24.71</td>
</tr>
<tr>
<td>900</td>
<td>US 2.15</td>
<td>14.68</td>
<td>18.08</td>
</tr>
<tr>
<td>1200</td>
<td>US 3.64</td>
<td>17.61</td>
<td>13.53</td>
</tr>
<tr>
<td>1500</td>
<td>US 7.21</td>
<td>20.57</td>
<td>8.69</td>
</tr>
<tr>
<td>4500</td>
<td>US 34.96</td>
<td>1.44</td>
<td>0</td>
</tr>
<tr>
<td>4800</td>
<td>US 34.96</td>
<td>1.44</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 2.3: Normalized sex acts by type. First three rows show total number of sex acts between $t = 0$ and $t = 300$, second three rows show total number of sex acts between $t = 300$ and $t = 600$, etc. $t = 4500$ represents cumulative sex acts between $t = 4200$ and $t = 4500$ at equilibria. This table shows evidence of how the preferred type of sex changes over time. As HIV prevalence and average b-value increases, we see a reduction in Unprotected Sex among HIV- couples as expected.

As expected, HIV prevalence at the pseudo-equilibrium $\bar{I}$ and the average b-value $\langle b \rangle$
are insensitive to changes in the utility for protected sex, $u_{PS}$ (Figure 2.4), since changes in the range $0 < u_{PS} < 100$ do not impact the relative utility rankings (Table 2.1). Increasing the transmission probability $\tau$ increases both the HIV prevalence at the pseudo-equilibrium as well as $\langle b \rangle$ (Figure 2.4). Changes in the historical influence parameter $\alpha$ also do not have much impact on $T$ and $\langle b \rangle$ unless $\alpha = 0$, in which case actors’ b-values are fixed and actors never use information from their interactions to modify their b-value (Figure 2.4). The differentiation in b-values between HIV+ and HIV- individuals is also very robust to changes in $u_{PS}$, $\tau$, and $\alpha$ (Figure 2.5).
Figure 2.4: HIV prevalence ( % infected, ⟨I⟩, black), and total average b ⟨⟨b⟩⟩, grey) for: (a) alpha, (b) transmission, (c) PS Utility. This demonstrates the robustness of the parameters used within the model. As expected, HIV prevalence rates are closely tied to average b-values amongst the population.
Figure 2.5: Average b-value for HIV- (⟨b−⟩, dashed black) and HIV+ (⟨b+⟩, dashed grey) individuals for: (a) alpha, (b) transmission, (c) PS Utility. This also shows the robustness of the parameters by indicating the cluster separation remains for varying parameter values.
2.3.2 Scenario $\beta < 1$

Our baseline assumption is $\beta = 1$, meaning that individuals do not have access to a global source of accurate information on HIV prevalence. When $\beta < 1$, individuals base their b-value partly on global HIV prevalence (Equation (2.6)). Average HIV prevalence at the pseudo-equilibrium $\bar{I}$ and the average b-value $\langle b \rangle$ are relatively unaffected by changes in $\beta$, however, the divergence between $\langle b^- \rangle$ and $\langle b^+ \rangle$ disappears as $\beta$ decreases, since individuals increasingly base their perception of HIV prevalence on actual prevalence in the population, rather than on their interactions with others (Figures 2.6, 2.7). This is robust to changes in $\alpha$, $u_{PS}$ and $\tau$ (Figures 2.8, 2.9, Table 2.4). We speculate that higher values of $\beta$ close to 1 are most realistic, since low values of $\beta$ correspond to having accurate information on global HIV prevalence on a weekly basis, which is not realistic for most populations. We also note that the rise in $\langle b \rangle$, $\langle b^- \rangle$, and $\langle b^+ \rangle$ is more gradual than the baseline scenario, indicating that Unprotected Sex will be preferred by both types for a longer amount of time.

2.3.3 Scenario $\omega < 1$

Our baseline assumption is $\omega = 1$, meaning that actors play the Risky Sex Game regardless of the previous sexual history of those they are paired with (Equation (2.1)). The divergence between $\langle b^- \rangle$ and $\langle b^+ \rangle$ persists when $\omega < 1$, and $\bar{I}$ and $\langle b \rangle$ are likewise relatively unaffected (Figures 2.10, 2.11, 2.12). The population still evolves into two groups characterized by divergent HIV status and sexual behaviour (Table 2.5). The main impact of decreasing $\omega$ is to cause system evolution to slow down on account of a larger number
Figure 2.6: (a) HIV Prevalence ($\langle I \rangle$, black) and average b-value ($\langle b \rangle$, grey for beta, (b) average b-value by type, average HIV negative ($\langle b^- \rangle$, black dashed), average HIV positive, ($\langle b^+ \rangle$, grey dashed). This illustrates the effect of increasing population HIV awareness in the population. As expected clustering rapidly disappears when individuals are made more aware of actual HIV prevalence in the population.
Figure 2.7: (a) HIV Spread over time ($I$ black), and (b) average b-values over time by type, average HIV negative ($b^-$, black dashed), average HIV positive, ($b^+$, grey dashed), $\beta = 0.9$. Results are similar to the baseline, with a significant reduction in clustering.
Figure 2.8: HIV % prevalence ($\langle I \rangle$, black), and total average $b$ ($\langle b \rangle$, grey) for: (a) alpha, (b) transmission, (c) PS Utility, for Beta = 0.9
Figure 2.9: Average b-value for HIV - $(\langle b^- \rangle$, dashed black) and HIV + $(\langle b^+ \rangle$, dashed grey) individuals for: (a) alpha, (b) transmission, (c) PS Utility, for Beta = 0.9
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<th>-/-</th>
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<td>5.31</td>
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<td>10.24</td>
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Table 2.4: Normalized sex acts for type, $t = 300:4500$ Beta = 0.9. First three rows show total number of sex acts between $t = 0$ and $t = 300$, second three rows show total number of sex acts between $t = 300$ and $t = 600$, etc. $t = 4500$ represents cum sex acts between $t = 4200$ and $t = 4500$ at equilibria.
of rejected pairings due to lack of a previous history between actors. However, long-term dynamics are unchanged. We expect larger values of $c$ to apply in populations that are smaller, where individuals are more likely to be known to one another.

Figure 2.10: (a) HIV Spread over time ($\langle I \rangle$ black), and (b) average b-values over time by type, average HIV negative ($\langle b^- \rangle$, black dashed), average HIV positive, ($\langle b^+ \rangle$, grey dashed), Omega = 0.2. This shows the effect of increasing the omega parameter, and delaying the initiation of a risky sex game between two strangers. Here we see similar results to the baseline with the exception that more time was required for the events to transpire.
Figure 2.11: HIV % prevalence ($\langle I \rangle$, black), and total average $b$ ($\langle b \rangle$, grey) for: (a) alpha, (b) transmission, (c) PS Utility. Omega = 0.2
Figure 2.12: Average b-value for HIV - (⟨$b^-$⟩, dashed black) and HIV + (⟨$b^+$⟩, dashed grey) individuals for: (a) alpha, (b) transmission, (c) PS Utility. Omega = 0.2
Table 2.5: Normalized sex acts for type, $t = 300:15000$ Omega = 0.2. First three rows show total number of sex acts between $t = 0$ and $t = 300$, second three rows show total number of sex acts between $t = 300$ and $t = 600$, etc. $t = 4500$ represents cum sex acts between $t = 4200$ and $t = 4500$. $t = 15000$ represents cum sex acts between $t = 14700$ and $t = 15000$ at equilibria.

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<th>+/-</th>
<th>+/-</th>
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<td>0.19</td>
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<tr>
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<td>0.48</td>
<td>10.10</td>
<td>76.32</td>
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<tr>
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<td>0.82</td>
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<td>0</td>
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2.3.4 Sensitivity analysis

We analyzed a variant of the model where individuals do not immediately know whether they have been infected, and only discover it if they are tested. Testing occurs with probability $t$ per timestep and we assume 100% accuracy. HIV+ individuals only change their utility from HIV- to HIV+ once they become aware of their changed HIV status. When the testing probability $t$ is sufficiently high, then the predictions of this variant model agree with those of the baseline model (Figures 2.13, 2.14). As $t$ decreases, some differences begin to emerge: total HIV prevalence is higher when the testing probability is very low (Figure 2.13). This occurs because there are more individuals in the population who are HIV+ and yet make decisions according to HIV- utilities, unwittingly spreading infection in cases where the outcome of the interaction is unprotected sex with an HIV- individual. Also, as $t$ decreases, the separation in b-values between HIV+ and HIV- individuals persists even as $t$ approaches zero (Figure 2.14). However, when $t$ is high, the b-value of HIV+ individuals who are not aware of their status aligns with the b-value of HIV+ individuals who are aware of their status, whereas when $t$ is low, the b-value of HIV+ individuals who are not aware of their status aligns with the b-value of HIV- individuals (Figure 2.14).

We assumed a population size of 1,000 because the number of clientele of a typical urban bathhouse is on this order of magnitude [29, 30]. However, we also experimented with varying $N$ from 500 to 10,000, finding that model predictions are close to our baseline population of $N = 1,000$ (the $N = 5,000$ case is shown in Figure 2.15).

We also conducted a probabilistic sensitivity analysis, where distributions are defined around certain input parameters based on lowest and highest plausible values, repeated
model simulations are conducted after sampling each input parameter from the distribution independently for each simulation, and mean and standard deviation of the resulting outputs are reported. This was conducted on $I_{initial}$, $\tau$, $\alpha$, and $b_0$. Results can be seen in Tables 2.6, 2.7, and indicate a continued separation between average b-values for HIV+ and HIV - individuals. These data demonstrates the robustness of the model with respect to uncertainty in those four parameters.

Figure 2.13: Prevalence of HIV ( % infected) among those who are aware of their HIV+ status (dark grey), those who are not aware of their HIV+ status (black dashed), and total HIV prevalence in the whole population (black).

<table>
<thead>
<tr>
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<th>Distribution</th>
<th>Mean, SD</th>
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</tr>
<tr>
<td>$\tau$</td>
<td>Normal distribution</td>
<td>0.01, 0.0025</td>
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<tr>
<td>$I_{initial}$</td>
<td>Normal distribution</td>
<td>0.05, 0.015</td>
</tr>
<tr>
<td>$b_0$</td>
<td>Normal distribution</td>
<td>0.05, 0.015</td>
</tr>
</tbody>
</table>

Table 2.6: Parameters adjusted in sensitivity analysis. Values recorded from normal distribution, with probabilities less than 0 or greater than 1 discarded.
Figure 2.14: Average b-value among HIV- individuals (black dashed), HIV+ not aware of their status (black), and HIV+ individuals aware of their status (dashed grey).

<table>
<thead>
<tr>
<th></th>
<th>Average</th>
<th>2SD</th>
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<tr>
<td>HIV Prevalence %</td>
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<td>0.1081</td>
</tr>
<tr>
<td>Average b-value</td>
<td>0.5489</td>
<td>0.0439</td>
</tr>
<tr>
<td>HIV - average b-value</td>
<td>0.7403</td>
<td>0.0882</td>
</tr>
<tr>
<td>HIV + average b-value</td>
<td>0.4171</td>
<td>0.0609</td>
</tr>
<tr>
<td>Average separation in b-value</td>
<td>0.3232</td>
<td>0.0343</td>
</tr>
</tbody>
</table>

Table 2.7: Parameters adjusted in sensitivity analysis. Results continue to demonstrate significant divergence between average b-values between HIV+ and HIV- population.
Figure 2.15: (a) HIV prevalence over time (% infected, \( I \), black). (b) Average b-values over time by type, HIV- (black dashed \( b^- \)), HIV+ (grey dashed \( b^+ \)), for a larger population, \( N = 5,000 \). Results shown are similar to the baseline \( N = 1,000 \) (Figure 1).
2.4 Discussion

Here we have explored a potential mechanism for how distinct groups—as defined by risk perception, HIV status, and sexual behaviour—can emerge out of the coevolution of HIV transmission and risk perception through sexual partner dynamics. The changing patterns of risk perception and sexual behaviour are plausible: the perceived level of HIV prevalence in the population rises along with the actual HIV prevalence, and as HIV spreads, more HIV- individuals opt for protected sex.

We observed that the actors’ b-values (the perceived probability that a randomly chosen individual in the population is HIV positive) diverged according to HIV status, with HIV- actors developing higher b-values and HIV+ actors developing lower b-values. This divergence was robust to changes in all model parameters except for $\beta$, which controlled the extent to which information on HIV prevalence is taken from global sources versus being based on their interactions with others. However, divergence was found to be less pronounced if actors were allowed to update their b-values not only when a counter-offer is discordant but also when the other actor agrees to what has been offered.

In at least one population, patterns of risk perception and sexual behaviour similar to those predicted by our model have been found. In a study of MSM in the United States, it was found that study participants with unrecognized HIV infection perceived themselves to have a low lifetime risk for acquiring HIV (i.e., they had low b-values), and also engaged in riskier sex [26]. This is consistent with our model prediction that HIV+ individuals have a lower perceived risk of being infected than HIV- individuals.

Because our objective was to identify a potential mechanism for how coevolution of
risk perception and HIV transmission could lead to the emergence of groups, and because our focus was on a small, relatively homogeneous core group population over a relatively short timescale, we did not include important heterogeneities in transmission, population structure, or risk perception, although some of these could influence our results quantitatively or qualitatively. For example, we neglected age structure, gender structure, vital dynamics (birth and death) and the details of HIV natural history in infected hosts. Future work could explore whole-population models and also build greater realism into the decision-making process. Our assumption that each actor knows whether or not they carry HIV is an idealization; in fact, there may be a significant lag between contracting HIV and becoming aware of HIV status, even in industrialized countries [31]. However, we explored the impact of this assumption in sensitivity analysis.

The model predicted that, at the pseudo-equilibrium, unprotected sex will usually be practiced in HIV+/HIV+ pairs, and protected sex in HIV+/HIV- or HIV-/HIV- pairs. This mixing pattern is the outcome of our assumed mechanisms of interaction between risk perception, partner selection, and infection transmission. Similar patterns of assortative mixing are observed in real populations. We do not claim that such assortative mixing patterns are sufficiently explained by this mechanism, however, we hypothesize that this mechanism can contribute to these mixing patterns.

HIV prevalence is not the only determinant of an individual’s perception of HIV infection risks, and many studies consider correlates for perceived risk such as gender, socioeconomic status and age, which are also influential. These previous studies are generally cross-sectional in nature, whereas longitudinal studies would be better suited to quantify factors of a dynamic nature such as feedback from evolving HIV prevalence during an out-
break. We suggest efforts should be made to conduct longitudinal population surveys to better gauge how risk perception and sexual partner practices evolve in response to changes in HIV prevalence and through the partner selection process, since our model indicates that it plays a central role in whether the b-values of HIV+ and HIV- individuals diverge or not.

Previous modelling approaches have not always considered how risk perception and transmission dynamics coevolve in the case of HIV. Our model highlights how individual perception of personal HIV infection risk can coevolve with HIV population prevalence in the course of an epidemic. This implies that risk perception is not a fixed, unchanging quantity that can be adequately described out of the context of HIV prevalence in the study population. Rather, risk perception influences HIV prevalence, and HIV prevalence in turn influences risk perception, so that they form a single, coupled system. It is difficult for cross-sectional studies to capture this effect, which plays out over time. However, future longitudinal studies could test this by attempting to correlate perceived HIV infection risk with actual HIV prevalence at different time points in an HIV epidemic, as well as monitor how perception of personal risks and local or global HIV prevalence changes before and after infection with HIV. This will become increasingly important as HIV vaccines become a reality over the next decade, since HIV vaccines might change how HIV infection risk and/or severity are perceived, and thus might change behaviour as well. We suggest that more attention needs to be given to this potential interaction, and more generally to the issue of the dynamics of core group formation and maintenance in the context of sexually-transmitted infections.
2.5 Acknowledgements

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Bibliography


Chapter 3

Sexual behaviour, risk perception, and HIV transmission can respond to HIV antiviral drugs and vaccines through multiple pathways

Abstract

There has been widening use of highly active antiretroviral treatment (HAART) and significant progress in developing prophylactic HIV vaccines. The simplest theories of problematic behavioural responses to such interventions tend to focus on single feedback mechanisms: HAART optimism makes infection less scary and thus promotes risky sexual behaviour, for example. Here, we develop an agent based, age-structured model of HIV transmission, risk perception, and partner selection in a core group to explore behavioural responses to interventions. We find that interventions can activate not one, but several feedback mechanisms that could potentially influence decision-making and HIV prevalence. In the model, HAART increases the attractiveness of unprotected sex, but it also increases perceived risk of infection and, on longer timescales, causes demographic impacts that partially counteract HAART optimism. Both HAART and vaccination usually lead to lower rates of unprotected sex on the whole, but intervention effectiveness depends strongly on whether individuals over- or under-estimate intervention coverage. Age cohort-specific effects cause sexual behaviour and HIV prevalence to change in opposite ways in old and young age groups. We conclude that complex infections like HIV—where interventions influence transmission, demography, sexual behaviour and risk perception—evaluations of behavioural responses should consider multiple feedback mechanisms.

3.1 Introduction

Over the past few decades, our growing understanding of factors contributing to HIV transmission has improved HIV control efforts. Partner selection and safe sex practices are
now recognized as major determinants of HIV prevalence ([1, 2]) and have been analyzed through mathematical models focussing on behavioural aspects of sexually infectious diseases such as HIV [3, 4, 5, 6]. This remains an important issue, particularly with data indicating that, despite greater public awareness, HIV incidence rates are once again increasing in men who have sex with men (MSM) within the United States [7]. Fortunately, treatment options such as Highly Active AntiRetroviral Treatment (HAART), are becoming more readily available, and an effective prophylactic HIV vaccine is within reach [8].

However, implementing treatment and prevention programs may have unintended consequences. Interventions like HAART that delay progression to AIDS may reduce the fear of living with HIV/AIDS (so-called ‘HAART optimism’). This in turn may cause individuals to choose riskier sexual behaviours, thereby increasing HIV transmission more than would have been the case if sexual behaviour did not change after HAART [9, 10]. Alternatively, both prophylactic vaccines and HAART may reduce HIV prevalence, which in turn may also cause some individuals to become complacent about their infection risk and thus increase their risky sexual behaviour, thereby also increasing HIV transmission. Both responses are examples of ‘policy resistance’, where the population’s response to an intervention tends to undermine the intervention [11]. This has become a particular concern for members of the population who are at higher risk for contracting HIV, such as MSM.

As such, it is important to assess a population’s perception of how the risks associated with contracting HIV might evolve with the introduction of treatment and the resulting changes in disease dynamics. Surveys can provide valuable information on what a population perception and behaviour at a specific time. However, it is difficult to extrapolate from surveys to determine how perception and behaviour might evolve under different circum-
stances (indeed, it is only possible to gauge how they think they would think under different circumstances). In contrast, mathematical models can be used to extrapolate to different circumstances, although by necessity, they also make simplifying assumptions. Using both mathematical models and surveys may provide a richer understanding of how policy resistance can emerge, and more broadly, the interplay between individual risk perception and sexual risk behaviour, population disease dynamics, and the effects of interventions, than either methodology on its own.

Numerous studies investigate HAART optimism and define it as a consequence of HAART that may lead to a change in behaviour. HAART optimism may cause an increase in unprotected sex, or a decreased likelihood to remain on medication. One such study comprising of a mass questionnaire found that 57% of optimists reported not always taking their HAART, compared to 29% of the individuals characterized as pessimistic[12]. The authors concluded that treatment centres should more closely monitor patients’ prognostic beliefs.

Some studies have found an increased level of risky behaviour in HAART patients[9, 10], as well as no change [13] and decreased risky behaviour,[14]. For example, Huebner et al conducted a mass survey to better understand the relation between gay and bisexual men’s beliefs about HAART and sexual risk behaviour. Using the participants data, Huebner found evidence of risk perception changing due to treatment. Men who believed that HAART decreased the risk of HIV transmission expressed reduced intentions to use condoms for anal sex and were also more likely to have engaged in unprotected anal intercourse with a casual partner. Similarly, with respect to potential HIV vaccines, Lee et al developed an HIV attitudes scale to predict vaccine acceptability. The survey consisted of
random individuals attending STD clinics and needle exchange sites. Risk compensation was found to be positively and significantly associated with vaccine acceptability, indicating individuals open to adopting the HIV vaccine perceived less of a need for protection through condom use [15].

However, other studies have found differing results. Remien et al’s cross-sectional study pertaining to MSM found no increased risk behaviour associated with HIV positive individuals being on HAART. Stephenson et al al conducted a cross-sectional study regarding HIV positive homosexual men, finding that men on HAART had fewer sexual partners, less unprotected anal intercourse and fewer acute sexually transmitted infections than men not on HAART, and thus a decreased level of risky behaviour amongst the HIV positive population. These studies further illuminate the complexity of perceptual and behavioural responses to interventions.

In order to better understand these phenomena, mathematical models have been developed to study how risk perception evolves, and how these behavioural changes impact the dynamics of the spread of HIV. Game theoretical and other behavioural frameworks formalize how individuals make decisions in a strategic environment. Schroeder et al used a signalling game to investigate sexually transmitted disease epidemics. Their results predict that, in the case where behaviour does not distinguish infected from uninfected partners, uninfected individuals engage in high-risk sex with potentially infected partners if the perceived rate of infection is sufficiently low [16]. Applying a decision-making model to infectious diseases, Auld investigated how a population’s choices and beliefs impact infectious diseases and the spread of HIV. Using a dynamical model, he showed that the success of an intervention is highly dependent on whether the population anticipates the presumed
changes and adjusts their behaviour. This demonstrated that a population’s behaviour leading up to and centring around an intervention could have an impact on its spread, and thus is important to consider [17].

Other models capture the impact of interventions like HAART. For example, Ramadanovic et al focus on changing risk behaviours in the context of HIV treatment as prevention. The authors create a deterministic compartmental model that treats HIV risk behaviour and infection as linked processes wherein the individual increases risk behaviour as a precursor to contracting HIV. Ramadanovic et al demonstrate that HIV incidence and prevalence only decline above threshold levels of HAART coverage, indicating a strong connection that is dependent on risk behaviour parameter values. Final results indicated that expanding HAART coverage combined with interventions aimed to reduce risky behaviours would amplify the preventative impact and possibly eliminate the HIV epidemic [3]. In their model of HIV and vaccination, Smith et al, define a fitness ratio as the average number of secondary HIV infections caused by an infected vaccinated individual, divided by the basic reproduction number [18]. By holding risk behaviour constant, they were able to determine thresholds at which HIV prevalence would increase instead of decrease due to the vaccine, in the case that disease modifying vaccines provide only a low degree of protection against infection and/or generate high fitness ratios. Their findings report that the success of a vaccination campaign hinges upon the fitness ratio, the proportion of the population that were vaccinated, and the degree of change of risk behaviour in unvaccinated infected individuals [18].

Much of the previous literature on HIV transmission modelling uses compartmental models [3, 4, 5, 6, 19, 20]. Here, we develop an agent-based model of the interaction be-
tween sexual partner selection processes (as they depend upon a time-evolving individual risk perception) and HIV disease dynamics, and how both respond to the introduction of HAART and prophylactic vaccines. Our objective is to explore potential mechanistic pathways that may lead to, or prevent, the development of policy resistance against those interventions. Each individual uses a utility function to decide whether to practice protected sex (PS), unprotected sex (US), or no sex (NS) with the other individual they are interacting with. This approach helps identify how decisions are formed, and how interactive decision-making between HIV+ and HIV- individuals helps determine spread of HIV. We introduce heterogeneity into the model in the form of age structure, allowing us to explore age cohort effects. With a more informed understanding of how risk perception evolves, and how it reacts to the introduction of HAART and prophylactic vaccines, we can better understand the changes in behaviour associated with new treatment options. We use the model to shed light on the complex nuances of HAART optimism and vaccine policy resistance.

3.2 Results

The partner selection model is based on a previous agent-based model used to explore the coevolution of risk perception, partner selection, and HIV transmission [21]. In the present model, individuals in an age-structured core group population (1) engage with others, (2) decide whether to have protected or unprotected sex based on their own status, the perceived probability that the other person is HIV+, and utilities, as modified by the presence of HAART and vaccines, and (3) may transmit the infection if they have
unprotected sex. The model is outlined in the Methods Section.

We investigate changes in the population caused by HAART or prophylactic vaccines by comparing the dynamics with and without the interventions. Because the model is necessarily complicated on account of exploring multiple potential feedbacks on perception and behaviour, we focus on the impact of these interventions separately and do not investigate scenarios where both are applied, leaving this to future work.

We explore how these changes depend on model parameters governing vaccine and treatment coverage, utilities, vaccine efficacy, duration of protection, risk perception parameters, and transmission rates. Model outcomes include population sizes, HIV prevalence, the perceived probability that the other person is HIV+ (which we hereafter refer to simply as “perceived infection risk”), and per capita number of unprotected sex acts (US) (i.e. US acts per HIV- individuals, providing a gauge of risky behaviour before and after interventions), broken down by age and HIV status. Baseline parameter values appear in Table 3.1. We use these parameter values in all simulations except when stated otherwise.

3.2.1 Baseline scenario: no HAART or vaccines

In the absence of interventions such as HAART or vaccines, the population converges to equilibrium levels of population size, HIV prevalence, and perceived infection risk ($b$) (Figure 3.1). HIV prevalence is highest in 20-29 and 30-39 year olds. The average perceived infection risk $b_t$ is similar to the HIV prevalence, although HIV- individuals tend to underestimate HIV infection risk and HIV+ individuals tend to slightly overestimate it. The perceived infection risk tends to be lowest in 15-19 year olds.
<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
<th>Baseline value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$b_0$</td>
<td>Initial $b_t$-value: Initial probability value individually chosen from a beta distribution of mean 0.05 and a standard deviation of 0.1.</td>
<td>0.05</td>
</tr>
<tr>
<td>$\alpha$</td>
<td>Historical influence parameter: Measures how much of the $b_t$-value will be based on past experience.</td>
<td>0.015</td>
</tr>
<tr>
<td>$\tau$</td>
<td>Transmission probability: Probability of HIV spread from an HIV+ actor to an HIV- actor through RS</td>
<td>0.02 [31]</td>
</tr>
<tr>
<td>$PS_{Utility}$</td>
<td>Protected sex utility.</td>
<td>50</td>
</tr>
<tr>
<td>$\zeta$</td>
<td>Chance an individual who identifies as HIV- will check to determine if they are infected.</td>
<td>0.1 per timestep</td>
</tr>
</tbody>
</table>

Table 3.1: Parameter definitions and values for baseline scenario.

As expected, increasing the transmission rate $\tau$ increases HIV prevalence, as well as the average $b_t$-value (perceived infection risk) (Figure 3.2). Increasing the utility for protected sex ($PS_{Utility}$) decreases both the HIV prevalence and the average perceived infection risk (Figure 3.3). This occurs because having a more attractive utility for PS reduces the spread of HIV and hence the perceived risk of contracting HIV.

### 3.2.2 Impact of HAART on risk perception, sexual behaviour, and HIV prevalence

Parameters for the baseline HAART scenario appear in Table 3.2. HAART decreases the transmission rate and thus reduces the incidence of new HIV cases. However it also increases the lifespan of HIV+ individuals, such that the net impact of HAART is a small net increase in the number of HIV+ individuals in the population (Figure 3.4a). Significant
Figure 3.1: Baseline scenario with no interventions. (a) number of HIV– (green) and HIV+ (red) individuals in the population; (b) average $b_t$-value for HIV– individuals by age, 15-20-year-olds (red), 20-30 (orange), 30-40 (yellow), 40-50 (green), and 50+ year-olds (blue); (c) average $b_t$-values for HIV+ individuals by same age groups; (d) number of HIV+ individuals by the same age groups, and with black representing the total number of HIV+ individuals; (e) total average $b_t$-value for HIV+ (red) and HIV– (green) populations; (f) HIV prevalence (percentage of the population currently infected).
Figure 3.2: No intervention, varying $\tau$. (a) HIV prevalence as a percentage of the population (black), total average $b_t$-value (grey); (b) average $b_t$-value for HIV− (black dotted) and HIV+ (grey dotted) populations.
Figure 3.3: No intervention, varying $P_{S_{Utility}}$. (a) HIV prevalence as a percentage of the population (black), total average $b_t$-value (grey); (b) average $b_t$-value for HIV− (black dotted) and HIV+ (grey dotted) populations.
reductions in the number of HIV+ individuals in the 15-39 year old age range due to reduced incidence are offset by significant increases in the number of HIV+ individuals in the 40+ age range due to longer lifespans and delayed age at infection (Figure 3.4d). As a result of reduced transmission rates, the number of HIV- individuals grows considerably, causing a decrease in overall HIV prevalence (Figure 3.4a,f).

In the short-term, HAART optimism causes a transient spike in the per capita rate of unprotected sex (US) between HIV+ and HIV- individuals in all age groups (Figure 3.5a versus Figure 3.6a). There is a corresponding increase in the total number of US acts, driven primarily by older age groups where the HIV+ population is expanding (Figure 3.5b versus Figure 3.6b). HAART makes unprotected sex more attractive to HIV- individuals by increasing the utility of US through the parameter \( d \), which in turn increases the number of US offers.

However, two other pathways partially counteract the effect of HAART optimism. The increase in the number of US offers also increases in the average value of \( b_t \) representing the perceived infection risk, across most age groups, and for both HIV+ and HIV- individuals (Figure 3.4b, c, e versus Figure 3.1). The increase in perceived infection risk has a protective effect on the population, by making HIV- individuals more likely to believe the other actor is HIV+ (since more US offers are being made). Additionally, a gradual but significant expansion of the HIV- population occurs over time (Figure 3.5 (c) versus Figure 3.6 (c)), which exceeds the expansion of the HIV+ population (Figure 3.5 (d) versus Figure 3.6 (d)), resulting in a net reduction in HIV prevalence. This means that any given encounter is more likely to be with an HIV- person than an HIV+ person. As a result, for younger age classes, and across all age classes on average, the per capita rate of US between HIV+ and HIV-
<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\eta_{HAART}$</td>
<td>HAART coverage</td>
<td>0.75</td>
</tr>
<tr>
<td>d</td>
<td>adjustment to $US_{Utility}$ due to HAART</td>
<td>20</td>
</tr>
<tr>
<td>k</td>
<td>parameter determining over- or under-confidence in coverage</td>
<td>1</td>
</tr>
<tr>
<td>$\eta_{Vac}$</td>
<td>vaccine coverage</td>
<td>0.75</td>
</tr>
<tr>
<td>$l_{Vac}$</td>
<td>duration of vaccine protection</td>
<td>10 years (normal dist. 10, 3)</td>
</tr>
<tr>
<td>$I_{test}$</td>
<td>times at which individuals are tested for remaining protection, post-</td>
<td>5, 10, and 15 years</td>
</tr>
<tr>
<td></td>
<td>vaccination</td>
<td></td>
</tr>
<tr>
<td>$\epsilon_{Vac}$</td>
<td>vaccine efficacy</td>
<td>0.9</td>
</tr>
<tr>
<td>$US(-,+)_\text{NoVac}$</td>
<td>utility for a HIV- individual to have US with a HIV+ individual, in absence of protection from the vaccine</td>
<td>-50</td>
</tr>
<tr>
<td>$US(-,+)_\text{Vac}$</td>
<td>utility for a HIV- individual to have US with a HIV+ individual.</td>
<td>100</td>
</tr>
</tbody>
</table>

Table 3.2: Parameter definitions and parameter values corresponding to HAART and vaccination scenarios.
Figure 3.4: Baseline scenario for HAART intervention introduced at year 50. (a) number of HIV- (green) and HIV+ (red) in the population; (b) average $b_t$-value for HIV- individuals by age; 15-20-year-olds (red), 20-30 (orange), 30-40 (yellow), 40-50 (green), and 50+ year-olds (blue); (c) average $b_t$-values for HIV+ individuals by same age groups; (d) number of HIV+ individuals by the same age groups, and with black representing the total number of HIV+ individuals; (e) total average $b_t$-value for HIV+ (red) and HIV- (green) populations; (f) HIV prevalence (percentage of population currently infected).
Figure 3.5: Baseline scenario for HAART intervention introduced at year 50. (a) total number of -/+ US acts per year divided by number of HIV- individuals in that age cohort at the end of the year, for age groups 15-20-year-olds (red), 20-30 (orange), 30-40 (yellow), 40-50 (green), and 50+ year-olds (blue), and cumulative number of individuals across all age groups (black); (b) total number of -/+ US acts per year, for same age groups; (c) number of HIV- individuals in each age cohort at the end of the year, for same age groups.
Figure 3.6: Baseline scenario with no interventions. (a) total number of -/+ US acts per year divided by number of HIV– individuals in that age cohort at the end of the year, for age groups 15-20-year-olds (red), 20-30 (orange), 30-40 (yellow), 40-50 (green), and 50+ year-olds (blue), and cumulative number of individuals across all age groups (black); (b) total number of -/+ US acts per year, for same age groups; (c) number of HIV– individuals in each age cohort at the end of the year, for same age groups.
actors falls to an equilibrium value that is below the baseline scenario with no HAART, although in older age groups it falls to a level that remains above the baseline scenario with no HAART. Hence, in the long run, HAART results in less US being practiced by HIV- individuals on average, but not for older individuals. Both protective pathways tend to decrease the per capita number of risky sex acts between HIV+ and HIV- individuals in the long term, so that the transient spike in the per capita rate of US between HIV+ and HIV- actors due to HAART optimism is followed by a gradual decrease.

In summary, HAART causes HAART optimism in the short term along with a transient spike in unprotected sex acts between HIV+ and HIV- individuals, but in the longer term it activates feedbacks through other pathways that confer protective effects by modifying risk perception and population composition. The effect of HAART on multiple pathways, some of which are protective and some of which are not, illustrates the complex nature of interactions between interventions, individual risk perception and behaviour, and population dynamics, and suggests one reason why different surveys of HAART effects conducted at different times in different populations might provide different results [9, 10, 13, 14]. These results also illustrate how the impact of HAART can evolve over time, and change from net negative to net positive as the population dynamics unfold.

Univariate sensitivity analysis for the impact of HAART on the utility for unprotected sex ($d$)

At baseline parameter values, the benefits of HAART in reducing transmission and increasing the perceived infection risk are strong enough to counteract how HAART optimism
makes US more attractive, resulting in a net reduction in HIV prevalence and incidence. HAART optimism operates through the model parameter $d$, which increases the utility of unprotected sex (Equation 3.3).

As the value of $d$ is increased above the baseline value $d = 20$, US becomes increasingly attractive, which increases actual post-treatment HIV prevalence as well as the average perceived infection risk (Figure 3.7). For $d > 60$, the post-treatment HIV prevalence exceeds the pre-treatment HIV prevalence: for these parameter values, the effects of HAART optimism cause a net increase in HIV in the population. At $d = 60$ for an HIV- actor, US with an HIV+ actor still provides a lower utility than PS. Hence, sufficiently strong HAART optimism could actually cause a net increase in HIV prevalence.

Decreasing $d$ has the opposite effect, making US under HAART less attractive to HIV-individuals and thus decreasing HIV prevalence (with an accompanying decrease in perceived infection risk) (Figure 3.8, and 3.9).

**Univariate sensitivity analysis for amount of over- or under-estimation of population HAART coverage ($k$)**

The parameter $k$ controls whether individuals over-estimate or under-estimate the amount of HAART coverage in the population. When $k > 1$ (respectively $k < 1$), individuals underestimate (respectively, over-estimate) the amount of coverage. This has implications for whether they think the other actor is HIV+ or not. If individuals underestimate HAART coverage ($k > 1$), then offers of US are more likely to be interpreted as meaning the other actor is HIV+, rather than being an HIV- person exhibiting HAART optimism,
Figure 3.7: HAART intervention, varying $d$. (a) HIV prevalence as a percentage of the population (black), total average $b_t$-value (grey); (b) average $b_t$-value for HIV– (black dotted) and HIV+ (grey dotted) populations. (c) total number of -$+$ US acts per year divided by number of HIV– individuals at the end of the year; (d) total number of -$+$ US acts per year; (e) number of HIV– individuals; (f) number of HIV+ individuals at end of simulation.
Figure 3.8: HAART intervention introduced at year 50, \(d=0\). (a) number of HIV– (green) and HIV+ (red) individuals in the population; (b) average \(b_t\)-value for HIV– individuals by age, 15-20-year-olds (red), 20-30 (orange), 30-40 (yellow), 40-50 (green), and 50+ year-olds (blue).
Figure 3.9: HAART intervention introduced at year 50, $d=-20$. (a) number of HIV− (green) and HIV+ (red) individuals in the population; (b) average $b_t$-value for HIV− individuals by age, 15-20-year-olds (red), 20-30 (orange), 30-40 (yellow), 40-50 (green), and 50+ year-olds (blue).
meaning their perceived prevalence of HIV will increase. Hence, they opt for protected
sex, causing a decrease in HIV prevalence. This is indeed what is observed in simulations:
as $k$ increases, HIV prevalence decrease (Figure 3.10). However, the average $b_t$-value also
decreases, since a decrease in HIV prevalence also causes a decrease in US offers. Hence, the
decrease in US offers is offset by an increase in the likelihood that they are interpreted as
evidence of HIV+ status, if individuals under-estimate HAART coverage in the population.
The opposite happens for $k < 1$.

**Univariate sensitivity analysis for coverage ($\eta$), the transmission rate ($\tau$) and
the utility for protected sex ($PS_{Utility}$)**

Increasing the population coverage of HAART ($\eta$) decreases HIV prevalence, while the
average perceived infection risk, $b_t$, increases slightly, at baseline parameter values (Fig-
ure 3.11). Increasing the transmission rate ($\tau$) increases the HIV prevalence, and the per-
ceived infection risk among HIV+ individuals, but has no effect on the perceived infection
risk among HIV- individuals (Figure 3.12) This occurs due to the structure of the game and
the utilities assigned to the available actions (See Supplementary Section 3.5.2). Finally,
increasing the utility associated with protected sex ($PS_{Utility}$) makes it more attractive,
and decreases HIV prevalence as well as perceived infection risk among both HIV+ and
HIV- individuals (Figure 3.13).
Figure 3.10: HAART intervention varying $k$: (a) HIV prevalence as a percentage of the population (black), total average $b_t$-value (grey); (b) average $b_t$-value for HIV− (black dotted) and HIV+ (grey dotted) populations.
Figure 3.11: HAART varying $\eta$. (a) HIV prevalence as a percentage of the population (black), total average $b_t$-value (grey); (b) average $b_t$-value for HIV− (black dotted) and HIV+ (grey dotted) populations.
Figure 3.12: HAART intervention, varying $\tau$. (a) HIV prevalence as a percentage of the population (black); total average $b_t$-value (grey); (b) average $b_t$-value for HIV– (black dotted) and HIV+ (grey dotted) populations. (c) total number of -/+ US acts per year divided by number of HIV– individuals at the end of the year; (d) total number of -/+ US acts per year; (e) number of HIV– individuals; (f) number of HIV+ individuals at end of simulation.
Figure 3.13: HAART intervention, varying $PS_{Utility}$, (a) HIV prevalence as a percentage of the population (black), total average $b_t$-value (grey); (b) average $b_t$-value for HIV− (black dotted) and HIV+ (grey dotted) populations.
3.2.3 Impact of prophylactic vaccination

The baseline parameters for prophylactic vaccination appear in Table 3.2. Whereas HAART is provided to HIV+ individuals, prophylactic vaccination is provided to HIV- individuals. We assume an efficaciously vaccinated HIV- individual adopts the same utility for US as an HIV+ individual, since they cannot acquire the infection while protected, which makes US offers attractive to vaccinated individuals.

Implementation of a vaccination program at year 50 covering 75 % of entering 15-year-olds, and providing protection for approximately 10 years, causes a rapid decrease in infected 15-29-year-olds (Figure 3.14d). A delayed and more moderate decrease occurs in infected 30-39 year-olds, but the number of infected individuals actually increases in 40+ year-olds (Figure 3.14d). This occurs because individuals who normally would have been infected when young, are no longer becoming infected due to the vaccine, but instead they become infected when they are older and vaccine protection has worn off. As a result, the total number of infected individuals remains relatively constant after vaccination is introduced, although the number of HIV-individuals increases, which reduces the HIV prevalence (Figure 3.14a,f).

Individuals have some awareness of the age at which the vaccine is administered, the vaccine overage, and the duration of protection, although they may overestimate or underestimate the actual vaccine coverage (again, this is controlled through the parameter $k$). The vaccine program decreases the perceived prevalence of HIV among HIV- individuals under 29 years of age, causes a slight increase in perceived prevalence in 30-39 year olds, and has no effect in 40+ year olds (Figure 3.14b). The slight increase in 30-39 year olds
Figure 3.14: Baseline scenario for vaccine intervention introduced at year 50. (a) Number of HIV- (green) and HIV+ (red) in the population; (b) average $b_t$-value for HIV- individuals by age: 15-20-year-olds (red), 20-30 (orange), 30-40 (yellow), 40-50 (green), and 50+ year-olds (blue); (c) average $b_t$-values for HIV+ individuals by same age groups; (d) number of HIV+ individuals by the same age groups, and with black representing the total number of HIV+ individuals; (e) total average $b_t$-value for HIV+ (red) and HIV- (green) populations; (f) HIV prevalence (percentage of population currently infected).
occurs because some of those individuals mix with individuals in younger age classes who are still protected by the vaccine and hence have a preference for US.

Results are similar among HIV+ individuals, except the perceived prevalence decreases slightly in 30+ year olds (Figure 3.14c). The decrease in perceived prevalence in younger age categories occurs due to awareness of the vaccine program, meaning that individuals are more likely to interpret an offer of US as evidence of vaccinated status. Hence, perceived prevalence tracks the decline in actual prevalence, even though US is still practiced and offered.

After the vaccine program is implemented, the rate of US acts between HIV+ and HIV- individuals, per HIV- individual, decreases in individuals below 39 years of age, remains constant in individuals 40-49 years old, and increases significantly in individuals 50+ (Figure 3.15a). The decline in younger age categories reflects the significantly diminished number of HIV+ individuals in those age categories: there are simply not enough HIV+ individuals, for there to be an increase in the per capita rates of US between HIV+ and HIV- actors. In older age categories, the increase in per capita risky sex by HIV- individuals is caused by the increased population of HIV+ individuals, due to the waning of protection from the vaccine.

Because perceived infection risk tracks HIV prevalence (Figure 3.14b,c) and because the per capita rates of risky sex are driven by changes in the numbers of HIV+ individuals in the age cohorts rather than behavioural changes stemming from altered utility functions \textit{per se}, the negative feedbacks stimulated by prophylactic vaccination are limited. Although vaccine-protected individuals practice more US than without the vaccine, this does not
Figure 3.15: Baseline scenario for vaccine intervention introduced at year 50. (a) total number of -/+ US acts per year divided by number of HIV- individuals in that age cohort at the end of the year, for age groups 15-20-year-olds (red), 20-30 (orange), 30-40 (yellow), 40-50 (green), and 50+ year-olds (blue), and cumulative number of individuals across all age groups (black); (b) total number of -/+ US acts per year, for same age groups; (c) number of HIV- individuals in each age cohort at the end of the year, for same age groups.
translate into higher HIV prevalence, and because the vaccinated individuals are HIV-, the
direct impact on the other actor is minimal.

However, these results suggest that a booster program may be beneficial in older age
categories, if vaccine protection wanes. Moreover, we did not explore the possibility of
vaccine exemption due to vaccine-generated herd immunity, which could reduce vaccine
coverage below socially optimal levels. These results also assume that individuals know
that the vaccine wanes, and know their immuno-protection status, which may not occur
in real populations where testing is not available or not adhered to.

Univariate sensitivity analysis for the over- or under-estimation of population
vaccine coverage ($k$)

For higher values of $k$, such that individuals under-estimate population vaccine coverage,
the perceived infection risk drops since individuals interpret US offers as evidence of HIV+
status. This causes HIV prevalence to decrease significantly compared to baseline, since PS
becomes more attractive than US under such circumstances (Figure 3.16). On the other
hand, lower values of $k$ mean individuals over-estimate population vaccine coverage, such
that perceived infection risk decreases instead of increasing, and HIV prevalence declines
only slightly compared to pre-vaccine prevalence (Figure 3.17). Hence, underestimation of
population vaccine coverage can significantly reduce the effectiveness of prophylactic HIV
vaccination programs, due to the tendency to accept US more often. These observations
are borne out across a range of value for $k$ (Figure 3.18). Also, changes in $k$ have a greater
effect for prophylactic vaccination (Figure 3.18) than for HAART (Figure 3.10).
Figure 3.16: Vaccination intervention introduced at year 50, $k=8$. (a) number of HIV− (green) and HIV+ (red) individuals in the population; (b) average $b_t$-value for HIV− individuals by age, 15-20-year-olds (red), 20-30 (orange), 30-40 (yellow), 40-50 (green), and 50+ year-olds (blue).
Figure 3.17: Vaccination intervention introduced at year 50, $k=0.125$. (a) number of HIV− (green) and HIV+ (red) individuals in the population; (b) average $b_t$-value for HIV− individuals by age, 15-20-year-olds (red), 20-30 (orange), 30-40 (yellow), 40-50 (green), and 50+ year-olds (blue).
Figure 3.18: Vaccine intervention, varying $k$, (a) HIV prevalence as a percentage of the population (black), total average $b_t$-value (grey); (b) average $b_t$-value for HIV− (black dotted) and HIV+ (grey dotted) populations.
Univariate sensitivity analysis for vaccine coverage ($\eta$), vaccine efficacy ($\epsilon$), transmission rate ($\tau$) and utility for protected sex ($PS_{Utility}$)

Increasing the vaccine coverage $\eta$ or the utility for protected sex $PS_{Utility}$ decreases both actual and perceived infection risk, as expected (Figures 3.19, 3.22). In contrast, increasing the vaccine efficacy $\epsilon$ decreases the HIV prevalence but slightly increases the perceived infection risk (Figure 3.20). This occurs because a higher vaccine efficacy protects more vaccinated individuals and thus leads to more US offers, however, individuals do not take vaccine efficacy into account in their risk perception, only vaccine coverage. Increasing the transmission rate $\tau$ increases the HIV prevalence (Figure 3.21) similar to the observations found in the no intervention scenario.

3.3 Discussion

This model illustrates how interventions, such as HAART and prophylactic HIV vaccines, can influence individual risk perception and behaviour through multiple pathways. These interventions may result directly in HAART or vaccine optimism, since they may alter the utilities or perceived risks for an HIV- person interacting with someone who is offering unprotected sex. However, they also confer protective effects through other pathways. The first pathway is that optimism itself may increase the offers of unprotected sex, which can increase the perceived infection risk in the population and make some HIV- individuals more cautious than they would otherwise be. A second pathway occurs through disease dynamics: interventions reduce HIV transmission and prevalence, which increases the pro-
Figure 3.19: Vaccine intervention, varying $\eta$, (a) HIV prevalence as a percentage of the population (black), total average $b_t$-value (grey); (b) average $b_t$-value for HIV− (black dotted) and HIV+ (grey dotted) populations.
Figure 3.20: Vaccine intervention, varying $\epsilon$, (a) HIV prevalence as a percentage of the population (black), total average $b_t$-value (grey); (b) average $b_t$-value for HIV− (black dotted) and HIV+ (grey dotted) populations.
Figure 3.21: Vaccine intervention, varying $\tau$, (a) HIV prevalence as a percentage of the population (black), total average $b_t$-value (grey); (b) average $b_t$-value for HIV– (black dotted) and HIV+ (grey dotted) populations.
Figure 3.22: Vaccine intervention, varying $PS_{Utility}$, (a) HIV prevalence as a percentage of the population (black), total average $b_t$-value (grey); (b) average $b_t$-value for HIV− (black dotted) and HIV+ (grey dotted) populations.
portion of HIV- individuals in the population. This, in itself, protects HIV- individuals since any given sexual encounter is more likely to be with another HIV- individual, and hence the number of unprotected sex acts with HIV+ actors per HIV- individual decreases. At baseline parameter values, the decrease in per capita unprotected sex acts due to a changing composition of the population is a net decrease, i.e. the effects of changing population composition are outweighed by any increase due to optimism. We note that this is not a simple outcome of herd immunity, since individuals can choose protected sex or unprotected sex.

As a result of these other feedback loops, both HIV prevalence and the rate of unprotected sex acts with HIV+ actors, per HIV- individual decrease under both HAART and prophylactic vaccines, despite the effects of HAART and vaccine optimism. However, the decline is not as significant as it would have been if compensatory behaviour did not emerge after the interventions. At other parameter values, HIV prevalence can increase as a result of the interventions. For example, we observed that when the effect of HAART optimism is sufficiently high, making the utility of unprotected sex sufficiently attractive, then HIV prevalence could actually rise under HAART (Figure 3.7). Also, for both HAART and the vaccine, if individuals over-estimate the population coverage of the intervention, they will tend to interpret unprotected sex offers as evidence of HAART optimism or vaccine protection, rather than HIV+ status, which can have damaging consequences (Figures 3.18, 3.10). Finally, if vaccine protection wanes after 10 years, then the burden of HIV incidence may simply be shifted to older age groups, which would necessitate booster programs.

This model makes several assumptions due to need for simplification or lack of data. Parameter values concerning prophylactic vaccines are based on preliminary assumptions.
since the effectiveness and duration of protection of such a vaccine were not known at the
time of publication. In addition, the game theoretical model is a simplified representation
of how individuals weigh their preferences; additional factors may influence the decision
making process in real populations. The model does not include memory of past sexual
counters, or sexual network structure. Although the model includes age structure, there
may be other heterogeneities that could influence results such as variable sexual activity
levels, or social and cultural group identification. Further work could improve the realism
of the model with respect to decision making processes and population structure; use more
empirical data; or attempt to replicate specific empirical findings concerning HAART.
Future work could also better assess how prophylactic HIV vaccines could best be used,
including optimal design of booster programs.

We conclude that the behavioural pathways that are activated by introducing interven-
tions are more complicated and numerous than the simple picture of potentially problem-
atic behavioural responses usually suggests, and the pathways could be beneficial as well
as harmful. Evaluations of the impact of HAART and potential prophylactic vaccines on
risk perception and behaviour should adopt a whole-population viewpoint regarding the
effects of the intervention. This includes considering feedbacks that the interventions may
introduce by altering dynamics of interaction between actors and their risk perception,
population demographics (HIV prevalence), how these factors interact, and how they vary
over time and across different age groups.
3.4 Methods

The model represents HIV transmission and partner selection dynamics in a core group of individuals with higher partnership turnover, such as a core group of MSM. The model is based on a previous agent-based partner selection model [21]. The previous model is a simplified representation of the co-evolution between risk perception and HIV prevalence, within a homogeneous population of MSM over a relatively short amount of time. Individuals are randomly paired and, while aware of their own status, are unaware of their partner’s status. The game they play represents a strategic interaction between the individuals, wherein utilities are weighed and an outcome, dependent on how an interaction has progressed, is chosen.

The previous model was modified to incorporate: (1) age structure, including age-specific sexual activity levels and mixing patterns, (2) vital dynamics, including recruitment, death and aging, (3) a modified representation of partner selection, (4) modifications to utility functions and risk perception dynamics to accommodate the presence of HAART and/or vaccine programs in the population, and (5) the impact of HAART and prophylactic vaccines on HIV infection probabilities and HIV natural history.

3.4.1 Vital Dynamics and Partner selection

Every time-step represents one month, after which each individual’s age counter is advanced by one month. New individuals enter the sexually active population at age 15 years [22]. All individuals will exit the population through natural death at 79 years of
age, or preemptively by death due to AIDS.

In each time step, there is a probability that an individual engages in an encounter that may lead to sex (i.e., plays the ‘risky sex game’). The probability of engaging is highest in 20-year-olds and declines with age (see Table 3.3)[23]. If an individual engages, they engage with a randomly selected individual who is within 8 years of their own age [22]. There is a random chance that any given actor will be assigned to be “Actor 1” in an interaction. Actor 2 represents the randomly chosen individual fitting the age requirement, and must not be engaged in a current interaction. Actor 2 must interact with Actor 1, if Actor 1 decides to interact with Actor 2 (although they do not have to choose sex). Individuals decide by calculating utilities based on the value of sex (protected or unprotected), the risk of contracting HIV (which depends on behaviour of the other individual, perceived , and perceived vaccine coverage), the health impact of contracting HIV, and how the impact might be modified by HAART (see following subsection on HAART). A detailed description of the interaction between individuals in an encounter appears in the Supplementary material.

<table>
<thead>
<tr>
<th>Age</th>
<th>Prob. of overall activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>15-19</td>
<td>$\delta = 0.5$</td>
</tr>
<tr>
<td>20-29</td>
<td>$\delta = 1$</td>
</tr>
<tr>
<td>30-39</td>
<td>$\delta = 0.8$</td>
</tr>
<tr>
<td>40-49</td>
<td>$\delta = 0.6$</td>
</tr>
<tr>
<td>50-59</td>
<td>$\delta = 0.3$</td>
</tr>
<tr>
<td>60-69</td>
<td>$\delta = 0.1$</td>
</tr>
<tr>
<td>70-79</td>
<td>$\delta = 0$</td>
</tr>
</tbody>
</table>

Table 3.3: Multiplicative factor $\delta$ controlling overall sexual activity level relative to 20-29-year-olds, by age.
3.4.2 Risk perception dynamics

In order to model risk perception evolution, we define $b_t$ to be an individual’s personal risk assessment at time $t$. Each actor has a specific $b_t$ value. This value varies over the course of the simulation as actors update their $b_t$-value based on their encounters. Each actor draws their initial $b_t$-value $b_0$ randomly from a normal distribution of mean $\mu = 0.05$ and standard deviation $\sigma = 0.1$; sampled values less than 0 or greater than 1 are discarded. We chose a relatively small value for the initial $b_t$-value because recruited individuals in the model are younger, and both the perceived prevalence of HIV in a population as well as the perceived risk of contacting HIV or other STIs are less within younger age groups [24, 25, 26]. During an interaction, an individual will either increase their risk assessment or decrease it depending on the offers they are receiving. If Actor 1 offers US, Actor 2 increases their $b_t$-value according to

$$b_t = \alpha + (1 - \alpha) \times b_{t-1} \quad (3.1)$$

where $\alpha$ is called the “historical influence parameter”, since it measures how much of $b_t$ is from past encounters versus the current offer. If Actor 1 offers PS, then Actor 2 decreases their $b_t$-value according to

$$b_t = (1 - \alpha) \times b_{t-1} \quad (3.2)$$

Risk perception changes by adjusting the assigned utilities as well as $b_t$-value. Utilities are assigned to possible actions, and an Actor’s decision is dependent on the weight of the utility and their risk perception. The formulation for utilities and calculating the expected
utility is similar to that described in the previous paper [21] and is described further in the supplementary material. Prior to intervention, the utility for US for an HIV- individual engaging with an HIV+ individual is -50. However, with the introduction of HAART and its effects on lowering transmission and increasing life span, the $U_{S\text{Utility}}$ is adjusted to account for this. Depending on the HAART coverage ($\eta$), and $k$ influencing the over or under confidence of coverage in the population, the resulting $U_{S\text{Utility}}$ can become more appealing than NS.

$$U_i(US, -, +) = \eta^k * (U_{S\text{Utility}} + d) + (1 - \eta^k) * (-50)$$

(3.3)

By adjusting the utility, the choices made by individuals are altered, and subsequently the risk perception is changed. The introduction of an HIV vaccine also changes the risky sex game. An HIV- individual that has been vaccinated and has acquired immunity will then alter how they update their $b_t$-value as well as the $U_{S\text{Utility}}$ for engaging with an HIV+ individual, by changing this to be the same utility as interacting with an HIV- person. Once the Actor however realizes that they are no longer protected, they will revert back to an HIV- utility set (See Table 3.2). Once the vaccine is introduced, the method by which an individual updates their $b_t$-value will change. Updating when someone offers US will now also be dependent on how the individual perceives the current vaccination coverage of the individual they are interacting with. When an individual is offered US, they will update their $b_t$-value as shown

$$b_t = \alpha * (1 - \eta^k) + (1 - \alpha) * b_{t-1}$$

(3.4)
We assume individuals have perfect knowledge of the age of an individual they are engaging with. Actor 1 will assign the appropriate $\eta$ value based on the assigned $\eta$ values taken from Table 3.2. We can again adjust $k$ to reflect an individual’s belief of the prevalence of the vaccine in the population. Adjusting utilities, and how an individual updates their risk assessment imitates the possible response in the population due to HAART and vaccine options. Analysis of the population’s individualized risk assessment over time aids in understanding risk perception dynamics.

### 3.4.3 HIV transmission and natural history

A person infected with HIV passes through the acute, latent, pre-AIDS, and AIDS stages. The duration of each stage is a fixed time interval (Table 3.4). Individuals die at the end of the AIDS stage (or the AIDS with treatment stage, see subsection on HAART below). The different stages of infection are illustrated by Figure 3.23. During unprotected sex, an infected person infects a susceptible person with a probability dependent on their current infection stage, with the relative infectivity during the various stages being highly variable (Table 3.5). However, individuals in the AIDS stage are assumed not to engage in sexual encounters at all, due to symptomaticity.

### 3.4.4 HAART

There is considerable debate as to when HAART should be initiated, since the benefits of early treatment can be counteracted by antiviral drug toxicity [27]. Here, we assume that at the end of the latent stage, an individual enters HAART with probability $\eta$, where
<table>
<thead>
<tr>
<th>Stage</th>
<th>Definition</th>
<th>Value</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\delta_{Age}$</td>
<td>age of the individual. This stage ends after 60 years or age 79</td>
<td>15-79 years</td>
<td>[27]</td>
</tr>
<tr>
<td>$\delta_{Acute}$</td>
<td>duration of time in acute stage. Once infected an individual will begin to age in the acute stage while exhibiting $\tau_{RS_{Acute}}$ level of infectiveness. This will last for 5 months unless their age reaches 79.</td>
<td>5 months</td>
<td>[27]</td>
</tr>
<tr>
<td>$\delta_{Latent}$</td>
<td>duration of time in latent stage. After Acute stage an individual will begin to age in the latent stage while exhibiting $\tau_{RS_{Latent}}$ level of infectiveness. This will last for 90 months unless total age reaches 79.</td>
<td>90 months</td>
<td>[27]</td>
</tr>
<tr>
<td>$\delta_{pre-aids}$</td>
<td>duration of time in pre-AIDS stage. After Latent stage an individual will begin to age in the pre-aids stage while exhibiting $\tau_{RS_{pre-AIDS}}$ level of infectiveness. This will last for 24 months unless total age reaches 79.</td>
<td>24 months</td>
<td>[27]</td>
</tr>
<tr>
<td>$\delta_{AIDS}$</td>
<td>duration of time in AIDS stage. After Pre-AIDS an individual will begin to age in the AIDS stage while exhibiting $\tau_{RS_{AIDS}}$ level of infectiveness. This will last for 60 months unless total age reaches 79. If individual reaches end of this stage, it will die.</td>
<td>60 months</td>
<td>[27]</td>
</tr>
<tr>
<td>$\delta_{pre-aidswtreatment}$</td>
<td>duration of time in pre-AIDS stage, with HAART. After Latent stage, if individual is selected for treatment the individual will begin in the pre-aids with treatment stage while exhibiting $\tau_{RS_{pre-AIDSwtreatment}}$ level of infectiveness. This will last for 2 months unless total age reaches 79.</td>
<td>2 months</td>
<td>[27]</td>
</tr>
<tr>
<td>$\delta_{AIDSwtreatment}$</td>
<td>duration of time in AIDS stage, with HAART. After pre-AIDS with treatment stage an individual will begin in the AIDS with treatment stage while exhibiting $\tau_{RS_{AIDSwtreatment}}$ level of infectiveness. This will last for 288 months unless total age reaches 79. If individual reaches end of this stage, it will die.</td>
<td>288 months</td>
<td>[32]</td>
</tr>
</tbody>
</table>

Table 3.4: Duration of HIV infection stages with and without HAART.
Figure 3.23: Flow diagram outlining how individuals progress to AIDS once infected, both with and without treatment.
<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
<th>Relative reduction in transmission</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\gamma_{USAcute}$</td>
<td>Relative reduction in transmission probability from an HIV+ actor to an HIV- actor through US during the acute stage.</td>
<td>11</td>
<td>[27]</td>
</tr>
<tr>
<td>$\gamma_{USLatent}$</td>
<td>Relative reduction in transmission probability from an HIV+ actor to an HIV- actor through US during the latent stage.</td>
<td>1</td>
<td>[27]</td>
</tr>
<tr>
<td>$\gamma_{USPre-Aids}$</td>
<td>Relative reduction in transmission probability from an HIV+ actor to an HIV- actor through US during the pre-AIDS stage.</td>
<td>3.3</td>
<td>[27]</td>
</tr>
<tr>
<td>$\gamma_{USAIDS}$</td>
<td>Relative reduction in transmission probability from an HIV+ actor to an HIV- actor through US during the AIDS stage.</td>
<td>6.1</td>
<td>[27]</td>
</tr>
<tr>
<td>$\gamma_{USPre-AidsWHAART}$</td>
<td>Relative reduction in transmission probability from an HIV+ actor to an HIV- actor through US during the pre-AIDS with HAART stage.</td>
<td>0.5</td>
<td>[33]</td>
</tr>
<tr>
<td>$\gamma_{USAIDSWHAART}$</td>
<td>Relative reduction in transmission probability from an HIV+ actor to an HIV- actor through US during the AIDS with HAART stage.</td>
<td>0.1</td>
<td>[27]</td>
</tr>
</tbody>
</table>

Table 3.5: Relative reduction in transmission probability depending on stage of infection.
\( \eta \) represents treatment coverage. HAART lengthens life, facilitates relative reduction in transmission, and improves the utility that an HIV- individual associates with unprotected sex, by an additive factor \( d \). Since HAART availability improves the \( U_{Utility} \), it affects whether individuals offer, or accept, unprotected sex, and hence it may influence the perceived risk parameter, \( b \).

The proportion of people living with AIDS who were receiving HAART increased from 74% in 2005 to 90% in 2008 in San Francisco [28]. In lower-income countries, the coverage is much lower but is rapidly increasing [29]. Here we consider values of \( \eta \) with a baseline of 75% and simulate ranging from 0 to 100% coverage. In simulations, we allow the population to come to an epidemiological and demographic equilibrium before introducing HAART into the population.

### 3.4.5 Prophylactic HIV Vaccine

Drawbacks of HAART include drug resistance, drug toxicity, and need to know HIV status and CD4 count before offering intervention. As a result, more than 30 HIV vaccines are being tested in human clinical trials worldwide [8], including at least one based on a genetically modified killed whole virus [30]. A prophylactic vaccine would mean that a certain percentage of vaccinated HIV- individuals are protected from infection, even if they engage in unprotected sex. As a result, prophylactic vaccines could impact how individuals update their risk perception based on their partner actions, and knowledge of vaccine coverage in the population.

A randomly chosen proportion \( \eta \) of 15-year-olds entering the sexually active population
receive the vaccine, which has all-or-none efficacy $\epsilon_V = 90\%$. Similar to the practice with hepatitis B vaccine in some jurisdictions, we assume that individuals are tested immediately after vaccination, and thus are aware if the vaccine worked for them. Individual who were not vaccinated, or in whom the vaccine was ineffective, do not change their utilities. However, those who are efficaciously protected increase their utility for unprotected sex, since they cannot be infected (see Supplementary Material for details).

The duration of protection for an efficaciously vaccinated individual is taken from a normal distribution with a mean 10 years and a standard deviation of 3 years. Vaccines are tested 5 and 10 years after being vaccinated and if the test indicates that their vaccine protection has ceased, the individual will change their utility back to that of an HIV- individual, otherwise they will continue with the utility of a vaccine-protected HIV- individual. At 15 years post-vaccination, individuals assume they are no longer protected and revert to the utility function of an unprotected HIV- individual.
Bibliography


[14] JM Stephenson, John Imrie, MMD Davis, C Mercer, S Black, AJ Copas, GJ Hart, OR Davidson, and IG Williams. Is use of antiretroviral therapy among homosex-


[29] Averting HIV and AIDS. Universal access to HIV treatment, July 2013.


3.5 Supplementary Material

3.5.1 Utilities assigned in the risky sex game

The utility of an actor describes how an individual ranks their preferences. The formulation for utilities and calculating the expected utility is similar to that described in a previous paper [21]. The utility value $U_i(k, s_i, s_j)$ for actor $i$ (1 or 2) of outcome $k$, unprotected sex, protected sex, and no sex, ($k=$US, PS, NS) and the HIV status of actor $i$ is $s_i$ (HIV+ or -) appear in Table 4.1. These values are used in calculating the expected utility (See Equation 3.5) which depends on $b_t$, an individual’s a priori belief at time $t$ of the probability that the person they are engaging with is HIV+ (we equate this with the perceived infection risk in the population).

$$E_i(b_t, s_i, k) = b_t U_i(k, s_i, +) + (1 - b_t)U_i(k, s_i, -)$$ (3.5)

The actor chooses between US and PS according to a Fermi-Dirac equation, such that the probability of choosing US is:

$$f(\Delta E) = \frac{1}{1 + e^{-(\Delta E)}}$$ (3.6)

$\Delta E$ represents the difference between expected utilities. Actor 1 formulates $\Delta E$ as $\Delta E = E_i(b_t, s_i, US) - E_i(b_t, s_i, PS)$, representing the difference in expected utilities calculated for US and PS. For every decision made, a random value is created between 0 and 1. If $f(\Delta E)$ is greater than this value, the individual’s choice becomes US, if it is less than
this, PS is the action chosen. For Actor 2, they choose between the offer given to them by Actor 1 and NS, meaning their $\Delta E = E_i(b_i, s_i, US) - E_i(b_i, s_i, NS)$ or $\Delta E = E_i(b_i, s_i, PS) - E_i(b_i, s_i, NS)$.

<table>
<thead>
<tr>
<th>Actor 1 Status</th>
<th>Actor 2 Status</th>
<th>Utility for US</th>
<th>Utility for PS</th>
<th>Utility for NS</th>
<th>Preferences of Actor 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>HIV+</td>
<td>HIV+</td>
<td>100</td>
<td>50</td>
<td>0</td>
<td>US &gt; PS &gt; NS</td>
</tr>
<tr>
<td>HIV+</td>
<td>HIV-</td>
<td>100</td>
<td>50</td>
<td>0</td>
<td>US &gt; PS &gt; NS</td>
</tr>
<tr>
<td>HIV-</td>
<td>HIV+</td>
<td>-50</td>
<td>50</td>
<td>0</td>
<td>PS &gt; NS &gt; US</td>
</tr>
<tr>
<td>HIV-</td>
<td>HIV-</td>
<td>100</td>
<td>50</td>
<td>0</td>
<td>US &gt; PS &gt; NS</td>
</tr>
</tbody>
</table>

Table 3.6: Utilities for Actor 1, given status of Actor 2, in absence of interventions. This outlines the preferences for different sexual acts given an individual’s status.

### 3.5.2 Understanding the evolution of $b_t$-values

This section describes the evolution of $b_t$-values through gameplay. Table 3.7 visualizes how the game is played. Randomly selected Actor 1 will weigh their expected utilities to offer either US or PS. Actor 2 either increases or decreases their $b_t$-value according to Equations 3.1 and 3.2, then chooses their option between what was offered to them or NS. After Actor 2 has made their offer, Actor 1 will either increase their $b_t$-value if offered US or decrease it and accept the choice.

**Choice threshold according to assigned utilities (No intervention)**

An HIV+ person will always prefer US to all other options, and PS when deciding between PS and NS. The HIV- individuals’ choice varies depending on what their $b_t$-value is. According to baseline utilities, HIV- individuals with $b_t$-value $< 0.3$ prefer US to PS. When
choosing between US and NS, HIV- individuals with $b_t$-value $< 0.6$ prefer US to NS. HIV-individuals will always prefer PS to NS under baseline utilities.

This helps explain why the $b_t$-values of HIV- individuals reach a ceiling in many simulations. When their values are $< 0.3$ they prefer US and will subsequently increase their $b_t$-value when they are Actor 1, or Actor 2 when being offered US. However, when their $b_t$-value surpasses 0.3 they will choose PS when they are Actor 1 and subsequently decrease their $b_t$-value when Actor 2 inevitably accepts. Since every actor is randomly assigned to be Actor 1 or 2 at every instance of the game, their $b_t$-value continues to oscillate between this value. The overall average $b_t$-value may appear slightly higher as individuals who dip below $< 0.3$ and choose US may contract HIV and be removed from the average resulting in a slightly higher overall average. Under the current utilities assigned, when choosing between PS and NS, no individual has incentive to choose NS, as we would expect. HIV-individuals choosing between US and NS will choose US whenever their $b_t$-value $< 0.6$, according to the baseline utilities. Because of the ceiling occurring at 0.3 the choice for NS would only occur by either adjusting the utilities or the parameters for the Fermi-Dirac equation. For HIV+ individuals, since US is always the favoured option, increased prevalence increases their overall average $b_t$-value, see Figure 3.2.

**Choice threshold according to assigned utilities (HAART)**

Upon introducing HAART into the population, the $US_{Utility}$ for an HIV- individual interacting with an HIV+ individual changes to Equation 3.3. Under the baseline settings, the threshold for an HIV- individual deciding between US and PS increases to 0.37, and the
threshold between US and NS increases to 0.74. This explains why we see an increase in
the overall average HIV- \( b_t \)-value threshold when compared to the no intervention option.
It also explains why increasing \( \tau \) which increases prevalence, does not increase the average
overall \( b_t \)-value beyond the established threshold as seen in Figure 3.12, 3.24, and 3.25.

**Choice threshold according to assigned utilities (Vaccine intervention)**

The results for introducing HIV vaccine are more diverse since the duration of vaccine pro-
tection has a specified length, which may also differ from an individual’s belief that they
are protected by the vaccine. The utility assigned for an HIV- individual that believes
they are protected changes from -50 to a value of 100, this means that they always prefer
US as long as they believe they are protected, even if the protection of the vaccine has
ended. A vaccinated individual checks their protection status at 5 and 10 years into the
program, and stops assuming protection after 15 years. The protection is assigned through
a random-normal distribution with a mean of 10 years, and standard deviation of 3 years.
When offered US, the \( b_t \)-value of an HIV- individual adjusts using Equation 3.4, where \( \eta \)
is the vaccine coverage. For this model, we assume individuals have perfect knowledge of
the age of the person they are interacting with. As the mean length of the vaccine is 10
years, individuals will formulate Equation 3.4 with \( \eta \) as the chosen coverage level when
interacting with individuals less than 25 years of age. When interacting with individuals
over 25 years of age, \( \eta \) will be set to 0 within this equation. This creates a number of
situations.
1. For young individuals, the $b_t$-value is slower to increase under US requests according to Equation 3.4 and our baseline settings.

2. In addition to reducing the incremental increase when offered US, the new equation creates a threshold of 0.25 for these young individuals when deciding between US and PS. An HIV- individual’s $b_t$-value will decrease when offered US according to our equation if the individuals $b_t$-value is $> 0.25$. This fact, combined with 1) explains why the average $b_t$-value is lower for the youngest age groups, (see Figure 3.14).

3. However, as an individual ages and begins to interact with individuals older than 25, the $\eta$ value in Equation 3.4 drops to 0. Leaving HIV- individuals with a preference for US and an sharply increasing $b_t$-value. What is interesting is that we also encounter individuals who still believe they are protected even though their vaccine protection has expired and they are between check-ups. This creates a group with a preference for US despite not having protection, even though they assume individuals over 25 to no longer be protected. This rapidly increases their $b_t$-value as these individuals are always preferring US and continue to increase their $b_t$-value when interacting with people over 25 years of age.

4. As HIV- individuals continue to age, their their $b_t$-value continues to rise which is why we see a spike in the average $b_t$-value for 30-40 year-olds. All vaccinated individuals have a final check-up after 15 years from vaccination where an HIV- individual
would then revert back to their original utility settings. Through interactions, their average $b_t$-value eventually returns to the threshold we have seen in the no intervention option as seen in the older age groups (see Figure 3.14).

**Interesting points**

We make the following observations about the evolution of the $b_t$-values.

1. The threshold found in the no intervention and HAART option is arguably a realistic portrayal of how an HIV- individual who randomly alternates between proposing and being propositioned would view their risk-assessment. An increase in threshold through HAART is also realistic since HAART aims to reduce the risk of spread, allowing HIV- individuals for an increased adjustment in their utility.

2. For the vaccination program, it is very interesting to see the effects of a population that understands the limitations of the length of the vaccine (assumes anyone older than 25 is no longer protected), but may overestimate their coverage between check-ups. The increase in average $b_t$-value for HIV- 30-40 year-olds reflects the consequences of individuals that prefers US, believing they are vaccinated while conservatively assuming the vaccination of others ended after 10 years. 30-40 year-olds having an increased $b_t$-value and thus preferring PS is beneficial as this results in less chances to contract HIV or other sexually transmitted infections.
3. A booster program or catch-up vaccination scenario would likely shift the average increased $b_t$-value average from 30-40 year-old’s to a higher age group. Since these age groups are still sexually active, it would likely be beneficial to implement such a program.

<table>
<thead>
<tr>
<th>Actor 1</th>
<th>Action</th>
<th>US</th>
<th>PS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actor 1</td>
<td>First offer</td>
<td>US</td>
<td>PS</td>
</tr>
<tr>
<td>Actor 2</td>
<td>$b_t$ update</td>
<td>$\uparrow b$</td>
<td>$\downarrow b$</td>
</tr>
<tr>
<td>Second offer</td>
<td>US</td>
<td>NS</td>
<td>PS</td>
</tr>
<tr>
<td>Actor 1</td>
<td>$b_t$ update</td>
<td>$\uparrow b$</td>
<td>$\downarrow b$</td>
</tr>
<tr>
<td>Result</td>
<td>US</td>
<td>NS</td>
<td>PS</td>
</tr>
</tbody>
</table>

Table 3.7: Layout of risky sex game between randomly selected actors. Actor 1 makes the first offer between US and PS. Actor 2 updates their $b_t$-value using equation 3.1 or 3.2. Actor 2 then makes an offer consisting of either Actor 1’s offer or NS. Actor 1 then updates their $b_t$-value and the resulting action occurs.
Figure 3.24: HAART intervention introduced at year 50, $\tau=0.03$. (a) number of HIV– (green) and HIV+ (red) individuals in the population; (b) average $b_t$-value for HIV– individuals by age, 15-20-year-olds (red), 20-30 (orange), 30-40 (yellow), 40-50 (green), and 50+ year-olds (blue); (c) average $b_t$-values for HIV+ individuals by same age groups; (d) number of HIV+ individuals by the same age groups, and with black representing the total number of HIV+ individuals; (e) total average $b_t$-value for HIV+ (red) and HIV– (green) populations; (f) HIV prevalence (percentage of the population currently infected).
Figure 3.25: HAART intervention introduced at year 50, \( \tau = 0.03 \). (a) total number of -/+ US acts per year divided by number of HIV– individuals in that age cohort at the end of the year, for age groups 15-20-year-olds (red), 20-30 (orange), 30-40 (yellow), 40-50 (green), and 50+ year-olds (blue), and cumulative number of individuals across all age groups (black); (b) total number of -/+ US acts per year, for same age groups; (c) number of HIV– individuals in each age cohort at the end of the year, for same age groups.
Chapter 4

Multiplayer games and HIV prevalence via casual encounters

Abstract

Population transmission models have been helpful in studying the spread of HIV. They assess changes made at the population level for different intervention strategies. To further understand how changes affecting an individual can impact the population as a whole, game theoretical models are used to quantify the decision making process. Investigating multiplayer nonlinear games modelling HIV transmission represents a unique approach in epidemiological research. We present here two-player and multiplayer noncooperative games where players are defined by HIV status and age and may engage in casual (sexual) encounters. Each player’s HIV status is kept private, and players have personal preferences ranked via utility values of unprotected and protected sex outcomes. We model a player’s strategy as their probability of being engaged in a casual unprotected sex encounter (US), which may lead to HIV transmission. We study the sensitivity of Nash strategies with respect to varying preference rankings and beliefs, and the impact of a prophylactic vaccine introduced in players of youngest age groups. We study the effect of these changes on the overall infection level; we conclude that the biggest impacts on increasing the infection levels are given by adjusting the utility afforded to HIV- individuals for US.

4.1 Introduction

Since the beginning of the HIV epidemic, it is estimated that 75 million people have been infected with HIV and 36 million have died[1]. HIV spans the globe affecting every country, although some have fared worse than others. This is especially apparent in Sub-Saharan Africa, with an estimated 5% of all adults infected[1]. HIV is not restricted to certain
age groups, and despite prevention programs and awareness campaigns, HIV incidence continues to increase, particularly amongst MSM.

Fortunately, there have been numerous medical advancements since AIDS was defined in 1982 and HIV subsequently defined as the cause in 1985. In 1986, antiretroviral drugs were introduced to prolong the life of individuals affected with HIV and reduce its spread. Highly Active Anti-retroviral Treatment was later introduced, allowing even further decrease in transmission and increased overall life span. Research continues to this day with current HAART allowing significantly decreased chance of spread, and allowing an infected individual to live to up to full life expectancy. In high income countries, the advent of this treatment has reduced the social stigma associated with HIV and alleviated to some degree the disease burden associated with HIV. While treatment availability varies by country, those with the option have begun to experience a positive social change.

With HAART beginning to change the perspective of HIV to that of a chronic disease, questions are being raised as to why the incidence rate continues to increase amongst certain groups, as well as how shifting perspectives may affect lower-income countries with fewer resources. Numerous surveys attempt to explain an individuals' reasoning, but the results have been varied. To further motivate our need for understanding, is the progress related to prophylactic HIV vaccines. The University of Western Ontario has promising results in their development of an HIV vaccine. Phase 1 clinical trial, testing safety and immune response ended late 2013 showing promising results. It is currently undergoing phase 2 trials to assess immune response in over 600 HIV− individuals in high risk categories, such as MSM and commercial sex employees. Without a doubt an HIV vaccine would have an enormous impact worldwide, but raises some interesting questions that need to
be addressed. Primarily, How can we better understand the individual decision making process as it relates to individuals choosing to engage in sex. How do these choices impact the spread of HIV, and what factors affect change in this decision making process.

Population models have been useful in understanding and predicting the spread of HIV. These models help assess changes made at the population level for varying interventions, and often employ a probability to confer the decision making process in relation to unprotected sex (US). However, to better understand how changes affecting the individual can impact the population as a whole, game theoretical models have been used. These models help to quantify the decision making process, and illuminates a feedback mechanism where individual’s choices may affect the population which in turn impacts the choices an individual is likely to make. Incorporating human behaviour and interaction in a mathematical model means finding ways to incorporate an individual's strategies and beliefs. For instance one may want to account for an individual’s disease awareness, which may or may not relate to the population views, and their personal opinions about others’ status with respect to a certain disease. To better understand how changes affecting the individual can impact the population as a whole, game theoretical models have been used [2]. Schroeder et al, construct a theoretical model that investigates the spread of HIV using a sequential game. Their model demonstrates how HIV transmission may be investigated on an individual level using a game theoretical approach [2].

In this paper, we model casual (sexual) encounters as a noncooperative game, where each player’s HIV status is known only to one’s self, and where the other players make assumptions on other players’ statuses. All players have personal preferences ranked in utility of unprotected and protected sex outcomes, and they are given expected utilities of
the casual encounter, depending on possible outcomes (unprotected sex – US, protected or no sex-notUS). We specifically model a player’s strategy as their probability of being engaged in US in an encounter, as this is the mechanism by which the HIV transmission occurs.

Game theory is a mathematical area of research developed since late 1940’s with the works of von Neumann and Morgenstern [3] and later those of Nash [4] in the early 1950’s. A game is a mathematical framework to describe decision-making by individuals engaged in competitive situations, where they can behave non-cooperatively or cooperatively. Non-cooperative game theory is nowadays widely used in applied areas such as economics, engineering, operations research, evolutionary biology and social sciences (psychology and cognitive sciences) [5][6].

It is often the case that applications of game theory in areas other than mathematics use classes of games which are generally well studied, and for which the concept of a (Nash) equilibrium point is well-defined. These classes of games are those with linear payoff functions (2-player or multiplayer matrix games), be it zero- or non-zero-sum games [7] [8]. More advanced modelling requires nonlinear payoffs and multiplayer contexts, in which case the methods of finding Nash equilibrium points of such games varies depending on the complexity of the game in question: it can be a reaction curves method, or an optimization type problem, a variational inequality problem, a computational method (such as genetic algorithms, evolutionary computation), or a replicator dynamics equilibrium, etc.. [9] [10].

In this paper, we focus on both 2-player and multiplayer nonlinear games where the players are defined as belonging to differing age groups, as opposed to modelling population-
level transmission processes. We consider an age stratified interaction in casual encounters as we are investigating the sexual transmission of HIV. Since partner choice is closely tied to an individual's age, it is beneficial to incorporate age structure in an HIV transmission model. As a prophylactic HIV vaccine would likely be offered to individuals before they become sexually active, it is important to observe the effects on transmission where different age groups have access to treatment options.

In our previous work on the topic, we modelled a similar setup of casual encounters with an agent-based model of the population [11] [12], and we analyzed how groups can emerge from coevolution of HIV spread with partner choices and risk perception. This was expanded to investigate the potential effects of policy resistance on intervention strategies such as highly retroactive antiretroviral treatment and prophylactic vaccines. Through an age-structured model we observed cohort effects amongst different age groups.

In this model, unlike our previous simulation based work, we construct a theoretical model to identify and analyze Nash equilibria with respect to the decisions players make. This allows us to better understand: a) the impact of personal preferences for unprotected sex; b) the impact of the weight each player places to construct their personal belief on the HIV status of the other players; c) the impact of heterogeneity of players (division in age groups) and initial HIV age group composition, both in presence and absence of a prophylactic vaccine. To the best of our knowledge, multiplayer nonlinear games solved with variational analysis techniques are quite few in the epidemiological literature (see [13],[9]) and the modelling of HIV transmission by such a class of games is novel.

The structure of the paper is as follows: In Section 2, we present a 2-player game and
its sensitivity analysis. In Sections 3 and 4 we formulate a multiplayer game of casual encounters between players in varying age groups. Throughout, we investigate the sensitivity of Nash strategies of players (defined as probability of having unprotected sex with another player) with respect to variation of their preferences and beliefs. Last but not least, we study throughout the variation of HIV transmission when age groups, prophylactic treatment and group-specific initial HIV age group composition are taken into account. Our most interesting conclusions are that preferences of HIV− players, and beliefs of HIV+ players have the largest impact on transmission. As well, in the presence of age group interactions and treatment introduction for the youngest group, we see that areas with high proportion of youth in the population, could stand to see more dramatic effects through implementation of a prophylactic vaccine. We close with a few conclusions and future work.

4.2 Casual encounter games

4.2.1 Brief introduction to nonlinear games

In general, a multiplayer game involves a finite number of players, denoted here by $N > 0$. A generic player $i \in \{1, \ldots, N\}$ is thought to have a strategy set $S_i \subset \mathbb{R}^{n_i}$, whose strategies are vectors $x_i \in S_i$, and a payoff function $f_i : S_i \to \mathbb{R}$. A Nash equilibrium of a multiplayer game is defined as follows:

**Definition 7** Assume each player is rational and wants to maximize their payoff. Then a
Nash equilibrium is a vector $x^* \in K := S_1 \times \ldots \times S_N$ which satisfies the inequalities:

$$\forall i, f_i(x^*_i, x^*_{-i}) \geq f_i(x_i, x^*_{-i}), \forall x_i \in S_i$$

where $x_{-i} := (x_1, \ldots, x_{i-1}, x_{i+1}, \ldots, x_N)$.

We can also think of a game as a set of coupled optimization problems as below:

**Definition 8** Given a multiplayer game as in Definition 7, for each player $i \in 1, \ldots, N$, its problem is:

$$\max f_i(x_i, x^*_{-i})$$

subject to

$x_i \in S_i$

There are many results regarding the existence of Nash equilibria, in either pure or mixed strategies [14]. One approach for finding criteria of existence for Nash equilibria of multiplayer games as well as devising computational methods is that of variational analysis [15] [16] [17]. This consists of equivalently reformulating the Nash game of Definition 7 into a variational problem of the type:

**Definition 9** Given a set $K \subset \mathbb{R}^n$, closed and convex, and given $F : K \rightarrow \mathbb{R}^n$ a continuous function, the variational inequality (VI) problem is to find a vector $x^* \in K$ such that

$$\langle F(x^*), y - x^* \rangle \geq 0, \forall y \in K.$$
It is known that there exists a way to equivalently reformulate some classes of games into variational inequality problems as in Definition 9. The advantages are two-fold: one can assert existence of solutions to the VI problem, as well as one can use computational methods developed in the VI theory, to analyze and compute Nash equilibria for the game. One such equivalence result is the one below (see [18]):

**Theorem 4** Assume a multiplayer game as defined above. Provided for each player $i$ assumed to maximize its payoffs, its payoff function $f_i$ is of class $C^1$ and is concave with respect to the variable $x_i \in S_i$, then $x^* \in K$ is a Nash equilibrium if and only if it satisfies the VI

$$\langle F(x^*), y - x^* \rangle \geq 0 \quad \forall y \in K$$

where $F(x) := (-\nabla x_1 f_1, ..., -\nabla x_N f_N)$.

We will be using Theorem 4 to assert existence of Nash equilibria for our multiplayer games in this Section and in Section 3. We also use the VI formulation of the games for computing the equilibria and conducting sensitivity analyses of the Nash strategies and overall HIV transmission.

### 4.2.2 Two-player casual encounter game

Let us consider now a casual encounter between 2 individuals. A player can have one of two statuses: HIV negative ($HIV-$) or HIV positive ($HIV+$). Let us then denote by $\epsilon_-$, respectively $\epsilon_+$, the proportion of HIV negative, respectively HIV positive, individuals so that $\epsilon_- + \epsilon_+ = 1$. Now, let us define by $P_1$ and $P_2$ respectively two players such that their
statuses are $s_1 := HIV^+$ and $s_2 := HIV^-$. We try to find out, via a game model, what are their probabilities of having unprotected sex (US) as a result of the casual encounter. To this end, we define a vector of two variables for each player:

$$x^i \in [0, 1]^2, x^i = (x^-_i, x^+_i), i \in \{1, 2\}$$

where $x^-_i$ = probability of $P_i$ having US with an HIV− player and $x^+_i$ = probability of $P_i$ having US with an HIV+ player.

Let us define the expected utilities for $P_i$, $i \in \{1, 2\}$ out of a casual encounter as: $E^-_i$: expected utility from interacting with an HIV− player and $E^+_i$: expected utility from interacting with an HIV+ player. For $P_1$, who is HIV+, these are:

$$E^-_1 = \rho [x^-_1 U(US, +, -) + (1 - x^-_1) U(notUS, +, -)]$$

and

$$E^+_1 = \rho [x^+_1 U(US, +, +) + (1 - x^+_1) U(notUS, +, +)]$$

where $\rho$ is the activity parameter of $P_1$. Section 4.3 will outline the different activity parameters for varying age groups, reflecting each age group’s propensity for engaging in casual sex. Then the overall expected utility of the encounter for $P_1$ is:

$$E^1(x^-_1, x^+_1) = (1 - b^+_1) E^-_1 + b^+_1 E^+_1,$$

where $b^+_1$ represents the HIV+’s risk assessment of the status of individuals they are
engaging casual sex with.

Similarly, for $P2$, whose status is $HIV^-$, we have:

\[
E_2^2 = \rho[x_2^2 U(US, -, -) + (1 - x_2^2)U(notUS, -, -)],
\]

\[
E_2^2 = \rho[x_2^2 U(US, -, +) + (1 - x_2^2)U(notUS, -, +)]
\]

and thus

\[
E^2(x_-, x_+) = (1 - b_-)E_-^2 + b_-E_+^2,
\]

where $b_-$ represents the HIV-'s risk assessment of the status of individuals they are engaging casual sex with. The values of the preferences used above are given in Table 4.1

<table>
<thead>
<tr>
<th>Actor 1 Status</th>
<th>Actor 2 Status</th>
<th>Utility for US</th>
<th>Utility for notUS</th>
<th>Preferences of Actor 1 given status of Actor 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>HIV+</td>
<td>HIV+</td>
<td>1</td>
<td>0.25</td>
<td>$US &gt; notUS$</td>
</tr>
<tr>
<td>HIV+</td>
<td>HIV-</td>
<td>0.75</td>
<td>0.25</td>
<td>$US &gt; notUS$</td>
</tr>
<tr>
<td>HIV-</td>
<td>HIV+</td>
<td>-0.5</td>
<td>0.25</td>
<td>notUS $&gt;$ US</td>
</tr>
<tr>
<td>HIV-</td>
<td>HIV-</td>
<td>1</td>
<td>0.25</td>
<td>notUS $&gt;$ notUS</td>
</tr>
</tbody>
</table>

Table 4.1: Utilities for Actor 1, given status of Actor 2. This outlines the preferences for different sexual acts given an individual’s status.

Now, let us further discuss the parameters $b_-, b_+$. We note that

\[
b_- = \beta_- b_-^{self} + (1 - \beta_-)\epsilon_+ \quad \text{and} \quad b_+ = \beta_+ b_+^{self} + (1 - \beta_+)\epsilon_+ \quad (4.1)
\]

where $b_-^{self}, b_+^{self}$ represent an individual’s risk assessment, varied between 0 and 1,
with 1 representing an individual who assumes everyone is HIV+. $\beta_-$ and $\beta_+$ are the local information parameters, varied between 0 and 1, i.e., they determine the weight a player places on personal assumptions of HIV prevalence versus true information on HIV prevalence.

At this point, let us recall that $\epsilon_+$ depends on the probabilities of players $P_1$ and $P_2$ to have US. Consequently, the expression of $\epsilon_+$ is:

$$\epsilon_+ = \epsilon_+(0) + \left[ x_1 \epsilon_+(0) + x_2 \epsilon_-(0) \right] \tau$$

(4.2)

where $\epsilon_+(0)$ is the initial (before the game) fraction of HIV+ in the population, which we take to be 0.05, and where $\tau = 0.02$ is the known transmission probability of HIV [19]. Using this observation on $\epsilon_+$ in equations (4.1) and (4.2) above, we see that

$$b_- = \beta_- b_-^{self} + (1 - \beta_-) [\epsilon_+(0) + \left[ x_1 \epsilon_+(0) + x_2 \epsilon_-(0) \right] \tau]$$

$$b_+ = \beta_+ b_+^{self} + (1 - \beta_+) [\epsilon_+(0) + \left[ x_1 \epsilon_+(0) + x_2 \epsilon_-(0) \right] \tau]$$

Players $P_1$ and $P_2$ want to maximize their expected utilities $E_1(x_1, x_2)$ and $E_2(x_1, x_2)$. Due to expression (4.2) we see that these utilities have actual dependencies on the other player’s choices, so our model is a 2-player game with nonlinear payoffs.

Each player needs to optimize their payoffs subject to constraints and the other player’s
choices, namely for each \( i \in \{1, 2\} \):

\[
P_i = \begin{cases} 
\max E^i := E^i(x^1, x^2) \\
\text{s.t } (x^1, x^2) \in K := S_1 \times S_2 \text{ and } S_i = \{ x^i \in [0,1]^2 | x^i_- + x^i_+ = 1, \ i = 1, 2 \} 
\end{cases}
\]

To solve our game we use Theorem 4 above. Each of \( S_1, S_2 \) are closed, convex, compact sets in \( \mathbb{R}^2 \), and \( E^1 \) is \( C^1 \). Then \( E^1 \) is concave w.r.t. the variable \( x^1 \) if:

\[
E^1(\lambda x^1 + (1 - \lambda)\bar{x}^1, x^2) \geq \lambda E^1(x^1, x^2) + (1 - \lambda)E^1(\bar{x}^1, x^2) \forall \lambda \in [0,1], \forall x^1, \bar{x}^1 \in K
\]

So let’s check the concavity for \( E^1 \). We see that \( E^1 \) is a polynomial function of degree 2, of the form (generically lumping constants in):

\[
E^1(x^1_-, x^1_+, x^2_-, x^2_+) = \alpha_1 x^1_- x^1_+ + \alpha_2 x^1_- x^2_- + \alpha_3 x^1_- + \alpha_4 x^1_+ + \alpha_5 x^2_- + \text{free} + \alpha_6(x^1_+)^2
\]

\[+ \alpha_7 x^1_+ x^2_- + \alpha_8 x^1_+ + \alpha_9 x^1_- + \alpha_{10} x^2_-]

\[
E^1(x^1_-, x^1_+, x^2_-, x^2_+) = \alpha_1 x^1_- x^1_+ + \alpha_2 x^1_- x^2_- + \alpha_3 x^1_- + \text{terms free of } x^1_-
\]

Here we see that this is clearly \( C^1 \) in all variables. Letting \( \lambda \in [0,1], \ x^1_-, x^1_+ \) we then
compute:

\[ E^1((\lambda x_1^- + (1 - \lambda)x_1^+), x_1^+, x_2^-, x_2^+) = \alpha_1(\lambda x_1^- + (1 - \lambda)x_1^-)x_1^+ + \alpha_2(\lambda x_1^- + (1 - \lambda)x_1^-)x_2^- + \alpha_3(\lambda x_1^- + (1 - \lambda)x_1^-) + A, \text{ where} \]

\[ A := \text{ terms free of } x_1^- \]. This gives further

\[ E^1((\lambda x_1^- + (1 - \lambda)x_1^+), x_1^+, x_2^-, x_2^+) = \lambda\alpha_1 x_1^- x_1^+ + (1 - \lambda)\alpha_1 x_1^- x_1^+ + \lambda\alpha_2 x_2^- x_2^- + (1 - \lambda)\alpha_2 x_2^- x_2^- + \lambda\alpha_3 x_1^- + (1 - \lambda)\alpha_3 x_1^- + A \]

Note that: \( A = \lambda A + (1 - \lambda)A \), and gathering like terms with a factors of \( \lambda \), respectively \( 1 - \lambda \) we get

\[ E^1((\lambda x_1^- + (1 - \lambda)x_1^+), x_1^+, x_2^-, x_2^+) = \lambda E^1(x_1^-, x_1^+, x_2^-, x_2^+) + (1 - \lambda)E^1(x_1^-, x_1^+, x_2^-, x_2^+) \]

The same computation can be shown for \( E^1 \) with respect to \( x_1^+ \) and for \( E^2 \) w.r.t the variables \( x_2^-, x_2^+ \).

### 4.2.3 Computation and uniqueness of Nash equilibria

In general it is expected that a Nash game have multiple equilibrium solutions, however uniqueness of solutions is always welcome. In order to establish whether uniqueness should be expected in the above encounter game, we checked known criteria (such as monotonicity
of $F(x^1, x^2) := (\nabla_{x_1} E^1, \nabla_{x_2} E^2)$, but these do not apply to our expected payoffs. Thus we took a numerical approach to investigate the type of Nash equilibria we get in the game above: we look at the Nash points $(x^1, x^2) \in K$ as critical points of a set of differential equations driven by the vector field $F$ and constrained to the set $K$ ([9, 20, 21]):

$$\frac{dx}{d\tau} = P_{T_K(x(\tau))}(-F(x(\tau))), \quad x(0) = (x^1_-(0), x^1_+(0), x^2_-(0), x^2_+(0)) \in K. \quad (4.3)$$

This allows us to explore the set of initial conditions of the differential equations and look at how many (and what values of) Nash equilibria we uncover. We first set our model parameters as described in the Table 4.2 below:

We vary the initial conditions using random uniformly distributed points from $K$. Figure 4.1 shows a (unique) Nash point $(1, 0, 1, 0)$ regardless of the initial conditions.

We ran 100 simulations each starting with 40 uniformly distributed initial strategy values, $x(0) = (x^1_-(0), x^1_+(0), x^2_-(0), x^2_+(0))$ where strategies are in the set $K$. Regardless of the initial strategy, the Nash equilibrium strategy vector is the same. This shows that for a given set of parameters, the initial strategy has no impact on the solution of the system. This demonstrates the uniqueness of the solution as shown in Figure 4.1. In the next section we will investigate the sensitivity of these results with respect to parameter changes.
Figure 4.1: Heat map for 2-player game showing $x^2_-, x^2_+, x^1_-$, and $x^1_+$ equilibrium values for the respective initial conditions. The parameters here are set according to the baseline values outlined in Table 4.2.
\begin{table}
\centering
\begin{tabular}{|c|p{10cm}|c|}
\hline
Term & Definition & Baseline value \\
\hline
\(P_i\) & Player \(i, i \in \{1, 2\}\) & \\
\hline
\(x_{i-}, x_{i+}\) & Probability of US for Player \(i\) engaging with an HIV– or HIV+ individual & [0,1] \\
\hline
\(b_\cdot\) & Risk perception amongst HIV– individuals & 0.3 \\
\hline
\(b_+\) & Risk perception amongst HIV+ individuals & 0.6 \\
\hline
\(\tau\) & Probability of HIV spread from an HIV+ player to an HIV– player through US & 0.02 \\
\hline
\(\beta_\cdot\) & Local information parameter: Proportion of the \(b_\cdot\)-value that is a combination of an HIV–’s interpretation of risk, and an accurate value of the actual proportion of infected individuals in the population & 0.5 \\
\hline
\(\beta_+\) & Local information parameter: Proportion of the \(b_+\)-value that is a combination of an HIV+’s interpretation of risk, and an accurate value of the actual proportion of infected individuals in the population & 0.5 \\
\hline
\(\epsilon_+(0)\) & Initial proportion of HIV+ individuals in the population. & 0.05 \\
\hline
\(\epsilon_-(0)\) & Initial proportion of HIV– individuals in the population. & 0.95 \\
\hline
\end{tabular}
\caption{Parameter definitions and values for baseline scenario.}
\end{table}

\subsection*{4.2.4 Sensitivity analysis of the 2-player encounter game}

In this section we are interested in the impact of varying payoff utilities has on the strategy vector for both players to have unprotected sex in a casual encounter. This is a question that has not been investigated thoroughly in previous works \cite{11}. We then track the effect these changes in probabilities of US have on the overall size of the fraction of infected individuals, \(\epsilon_+\). We use Table 4.2 to describe the values we used for our parameters. We choose to compute the Nash equilibrium points as in the previous Section 2.3, along the
trajectory of the system shown in equation 4.3 starting at \( x(0) = (x_1^1, x_1^2, x_2^2, x_2^1) := (0.5, 0.5, 0.5, 0.5) \).

Figure 4.2 shows the impact of changing the US negative utilities has on \( x_2^2 \) as this probability relates to the spread in HIV. To have a clearer image of the impact for changing these utilities, we plotted a 3-dimensional image that observes the change in these probabilities while altering both \( U(US, -, +) \) and \( U(US, -, -) \). Under the baseline values, \( x_1^1 \) remained at 1 while varying US negative utilities. Using the results, we also plotted the change in \( \epsilon_+ \) according to the same changes in utilities. We see a change in the equilibrium solution for \( x_2^2 \) as we vary the US utilities, and how this impacts \( \epsilon_+ \). As we expect, increasing \( U(US, -, -) \), lowers \( \epsilon_+ \) and \( x_2^2 \), while increasing \( U(US, -, +) \) increases \( \epsilon_+ \) and \( x_2^2 \). The results are unchanged for Player 1. In Figure 4.3 we see the impact of varying \( \beta_+ \) and \( \beta_- \). This appears to have no change on \( x_2^2 \), while \( x_1^1 \) appeared to increase with \( \beta_+ \). As \( \beta_+ \) increased, the \( b_+ \) value increased further with respect to the HIV prevalence in the population as opposed to Player 1’s initial risk assessment. This increase in \( x_1^1 \) is paired with an increase in \( \epsilon_+ \) as expected. The results show that variation of \( \epsilon_+ \) is statistically small, however, this is a result of investigating a one-off game. In a repeated structure, the several variations would likely compound into larger ones.

In Figure 4.4 we vary the \( b_-^{self} \) and \( b_+^{self} \) terms. We see that as \( b_+^{self} \), or as an HIV+ individual has a high initial level of risk perception, \( x_1^1 \) drops to 0 and there is no change in \( \epsilon_+ \). When \( b_-^{self} \) is reduced, the opposite occurs. When we increase \( \beta_+ \), \( b_+ \) increases further as \( b_+ = \beta_+(0.6)+(1-\beta_+)\epsilon_+ \), where \( \epsilon_+ \) is a smaller term. Then the formulation of

\[1\]We tested numerically the uniqueness of Nash equilibrium values over the varying ranges of utility parameters. The uniqueness property holds true, thus our choice of initial values in system shown in equation 4.3 is not important.
Figure 4.2: 3-dimensional results for 2-player game showing $x_2^+$ and $\epsilon_+$ varying $U(\text{US}, -, -)$ and $U(\text{US}, -, +)$. Results for $x_1^-$ remained at 1 across varying US negative utilities.
Figure 4.3: 3-dimensional results for 2-player game showing $x_1^+$ varying $\beta_+$ and $\beta_-$. Results for $x_2^+$ remained at 0 varying $\beta$ values.
Figure 4.4: 3-dimensional results for 2-player game showing $x_+^1$ and $\epsilon_+$ varying $b_-^\text{self}$ and $b_+^\text{self}$. Results for $x_+^2$ remained at 0 varying $b_-^\text{self}$ and $b_+^\text{self}$ values.
\[ E^1 = (1 - b_+) E^1_- + b_+ E^1_+ \], would weigh towards \( E^1_+ \), increasing \( x^1_+ \) over \( x^1_- \), and decreasing the overall \( \epsilon_+ \). It is somewhat interesting to see that there are levels of risk perception for HIV+'s where \( x^1_- \) decreases to 0, and likewise, more likely to engage in US when the perception is low.

### 4.3 Multiplayer game

We extend next the 2-player game presented in the previous section, to a multiplayer game to capture interactions between players belonging to different age groups. We consider here a population with 5 age cohorts, 15-20, 20-30, 30-40, 40-50 and 50+. Age group 1 (\( G_1 \)), representing 15-20 year-old individuals interacts with individuals from their age group plus with individuals of the 20-30 age cohort (\( G_2 \)). Age group 2 (\( G_2 \)), representing 20-30 year-old individuals interacts with individuals from their own age cohort, plus with individuals in their adjacent age groups, i.e. \( G_1 \) and 30-40 year-olds (\( G_3 \)). This continues for the 3rd and 4th age groups, with the 5th age group (\( G_5 \)) interacting with themselves and the 40-50 (\( G_4 \)) age cohort.

A game is defined by choosing one HIV positive player (always taken to be player 1) in one of the groups at a time; the other players in a game will have an HIV- status and will belong to the age cohorts allowed to interact with the age cohort \( P_1 \) belongs to. Following the age group interactions allowed above, if \( P_1 \) belongs to \( G_1 \) or \( G_5 \), then the HIV- players will be from the same or adjacent groups, thus we model a 3-player game. Whenever \( P_1 \) is chosen in one of the \( G_2, G_3, \) or \( G_4 \), then we model a 4-player game.
Let us denote by $game_i, i \in \{1, ..., 5\}$ one of the games described above, such that $P_1$ in $game_i$ belongs to $G_i$. We assume first that HIV+ individuals are spread among the five groups, thus each age group has a subgroup of HIV+ individuals of size $\epsilon_i^g(0), \ i \in \{1, ..., 5\}$ so that $\sum_{i=1}^{5} \epsilon_i^g(0) = \epsilon_+(0) = 5\%$ as in the previous section. We start first by assuming an even spread of HIV+ individuals among age groups, i.e. $\epsilon_i(0) = 0.01$.

Finally, each age group has a differing activity parameter $\rho_i, i \in \{1, ..., 5\}$ given by:

$\rho_1 = 0.5, \rho_2 = 1, \rho_3 = 0.8, \rho_4 = 0.6, \rho_5 = 0.3$. This represents a multiplicative factor controlling overall sexual activity level relative to the second age group, by age.

Each $P_i$ has an expected utility $E^i$ of unprotected sex in a casual encounter: $E^1 := b_+E^1_+(x) + (1 - b_+)E^1_-(x)$ and $E^i := b_-E^i_+(x) + (1 - b_-)E^i_-, \ \forall i \neq 1$, where $b_-, b_+$ are defined as before.

### 4.3.1 3-player game

We start by setting up the game concerning age cohort 15-20, where we choose $P_1$ to be HIV+ in $G_1$. Then $P_2$ and $P_3$ are HIV- players from age groups $G_1, G_2$ respectively. The vector of strategies of player $P_i$ is $x^i = (x^i_-, x^i_+, x^i_2)$ with $x^i_- + x^i_+ + x^i_2 = 1$, where by $x^i_j$ we denote the probability of $P_i$ to have unprotected sex with an HIV- individual in $G_j$, and by $x^i_j$ the probability of unprotected sex with an HIV+ individual in $G_j$. We define their expected utilities as:

$$E^1_- = \rho_1[(x^1_- + x^1_+)]U(US, +, -) +$$
(1 - (x_{1-}^1 + x_{2-}^1)U(notUS, +, -))

E_1^1 = \rho_1[(x_{1+}^1)U(US, +, +) + (1 - (x_{1+}^1)U(notUS, +, +)]

Similarly for \( P_2 \) an HIV– individual \( \in G_1 \), and \( P_3 \) an HIV– individual \( \in G_2 \), we get (for \( j = \{2, 3\} \)):

\[ E_j^1 = \rho_{j-1}[(x_{1-}^j + x_{2-}^j)U(US, -, -) + (1 - (x_{1-}^j + x_{2-}^j)U(notUS, -, -)] \]

\[ E_j^1 = \rho_{j-1}[(x_{1+}^j)U(US, -, +) + (1 - (x_{1+}^j)U(notUS, -, +)] \]

As a consequence of the interaction between players, the fractions of HIV+ individuals in \( G_1 \) and \( G_2 \) change now as follows (note that \( \epsilon_{gj}^0(game_1) = \epsilon_{gj}^1(0), j \in \{3, 4, 5\} \)):

\[ \epsilon_{gj}^0(game_1) = \epsilon_{gj}^0(0) + [x_{1-}^k \epsilon_{g1}^1(0) + x_{1+}^{j+1} \epsilon_{gj}^1(0)] \tau, \ j \in \{1, 2\} \]

Then we compute \( \epsilon_{+}(game_1) := \sum_{i=1}^{5} \epsilon_{gj}^0(game_1) \).

We investigate uniqueness of solutions as we did in Section 4.2.4. Figure 4.7 shows a (unique) Nash point \((0.5, 0.5, 0, 0.5, 0, 0.5, 0, 0.5, 0.5, 0)\) while varying initial conditions of system (4.3). The initial conditions for interacting with HIV– individuals across both age groups are taken the same as this multiplayer game is focused on interactions already within an individual’s age preferences.
Figure 4.5: Results for 3-player game. Figure (a) shows Choices for Player 1 varying \(U(US, -, -)\) which appear unchanging. Figure (b) shows choices for Player 2 dependent on \(U(US, -, -)\). Results for Player 3 are the same as Player 2. 2-dimensional results for varying \(U(US, -, +)\) remained unchanged when \(U(US, -, -)\) is set to baseline value.
4.3.2 Results & Discussion: 3-player game

Similar to studying the 2-player game, we study the effects of varying $U(US, -, -)$, $\beta_-, \beta_+$ on the choices of players and on the fraction $\epsilon_+$ of the population.

Figure 4.5(a) shows results similar to the 2-player scenario, where HIV- individuals favour engaging with HIV- individuals as $U(US, -, -)$ increases. Choices for $P_1$ do not change varying $U(US, -, -)$, with $x_{1+}^1$ remaining at 0, and $x_{1-}^1$, $x_{2-}^1$ both 0.5. The results for varying $U(US, -, +)$ remained unchanged when $U(US, -, -)$ is set to baseline value for each player. The respective results for $\epsilon_+(\text{game}_1)$ are shown in Figure 4.5(b), with low levels of $\epsilon_+(\text{game}_1)$ associated with high values of $U(US, -, -)$ in Figure 4.6.

Similarly, we see results for Figure 4.8 which investigates varying $\beta_+$. While varying
Figure 4.7: Heat map for 3-player game showing $x_{1-1}$, $x_{1-2}$, $x_{1+1}$, $x_{1+2}$, $x_{2-1}$, $x_{2-2}$, $x_{2+1}$, $x_{2+2}$, and $x_{3+1}$ equilibrium values for the respective initial conditions. The parameters here are set according to the baseline values outlined in Table 4.2.
β_ had no effect on the HIV− players at baseline parameters, we observed the range at which an HIV+ player switches their preference between interacting with HIV− and HIV+ players, and what effect this has on $\epsilon_+(game_1)$.

4.3.3 4-player game

We describe next the 4-player game arising from choosing for instance $P_1$ as an HIV+ player in $G_2$ (the game will be identical for a choice of $P_1$ in either $G_3$ or $G_4$).

We denote $P_1$ as HIV+ from $G_2$ and $P_2, P_3$ and $P_4$ HIV- players from $G_1, G_2$ and $G_3$ respectively. The expected utilities for these individuals are listed below, starting with $P_1$ representing HIV+ individuals from $G_2$:

\[
E_1^1 = \rho_2[(x_1^1 + x_2^1 + x_3^1)U(US, +, -)]
\]

\[
+ (1 - (x_1^1 + x_2^1 + x_3^1)U(notUS, +, -))
\]

\[
E_1^1 = \rho_2[(x_2^1)U(US, +, +) + (1 - (x_2^1)U(notUS, +, +))]
\]

Similarly for $P_2, P_4$, HIV- individuals $\in G_1, G_3$ respectively we have:

\[
E_j^j = \rho_{j-1}[(x_j^j + x_2^j)U(US, -, -)]
\]

\[
+ (1 - (x_j^j + x_2^j)U(notUS, -, -))
\]

\[
E_j^j = \rho_{j-1}[(x_2^j)U(US, -, +) + (1 - (x_2^j)U(notUS, -, +))]
\]
Figure 4.8: Results for 3-player game. Figure (a) showing choices for varying $\beta_+$ for Player 1. Results of Player 3 and Player 2 don’t vary for $\beta_-$ given the baseline utilities. Figure (b) shows a 3-dimensional results for 3-player game showing $\epsilon_+$ of population for varying $\beta$ values.
For $P_3$ an HIV– individual $\in G_2$:

$$E_3^- = \rho_2[(x_{1,-}^3 + x_{2,-}^3 + x_{3,-}^3)U(US, -, -)]$$

$$+(1 - (x_{1,-}^3 + x_{2,-}^3 + x_{3,-}^3)U(notUS, -, -)]$$

$$E_3^+ = \rho_2[(x_{2,+}^3)U(US, -, +) + (1 - (x_{2,+}^3)U(notUS, -, +))]$$

As a result of interactions allowed in this game, the fraction of the infected individuals changes in groups 1, 2, 3 (note that $\epsilon_{gj}^+(game_2) = \epsilon_{gj}^+(0)$, $j \in \{4, 5\}$):

$$\epsilon_{gj}^+(game_2) = \epsilon_{gj}^+(0) + [x_{1,-}^j \epsilon_{gj}^2(0) + x_{2,+}^{j+1} \epsilon_{gj}^-(0)]\tau, j \in \{1, 2, 3\}$$

Then we compute $\epsilon^+(game_2) := \sum_{i=1}^{5} \epsilon_{gj}^i$.

We again investigate uniqueness of solutions as we did in Section 4.2.4. Figure 4.9 shows a (unique) Nash point $(0.3, 0.3, 0.3, 0, 0.5, 0.5, 0, 0.3, 0.3, 0.3, 0, 0.5, 0.5, 0)$ while varying initial conditions of (4.3). The initial conditions for interacting with HIV– individuals across both age groups are the same as again this multiplayer game is focused on interactions already within an individual’s age preferences.
Uniformly distributed initial strategies

(a) Initial values for $x_1^1, x_2^1, x_3^1, x_1^2, x_2^2, x_3^2, x_1^3, x_2^3, x_3^3, x_1^{2+}, x_2^{2+}, x_3^{2+}$

Equilibrium value of strategy vector

(b) Equilibrium solutions for $x_1^1, x_2^1, x_3^1, x_1^2, x_2^2, x_3^2, x_1^3, x_2^3, x_3^3, x_1^{2+}, x_2^{2+}, x_3^{2+}$

Figure 4.9: Heat map for 4-player game showing $x_1^1, x_2^1, x_3^1, x_1^2, x_2^2, x_3^2, x_1^3, x_2^3, x_3^3, x_1^{2+}, x_2^{2+}, x_3^{2+}$ equilibrium values for the respective initial conditions. The parameters here are set according to the baseline values outlined in Table 4.2.
4.3.4 Results & Discussion: 4-player game

Similar to studying the 2-player and 3-player game, we vary $U(US, -, -)$ and $U(US, -, +)$ and study the Nash choices of players, as well as the $\epsilon_+(game_2)$ fraction. Figure 4.10 and 4.11 show results similar to the 2-player and 3-player scenario, where HIV– individuals favour engaging with HIV– individuals as $U(US, -, -)$ increases, although showing different thresholds across the different age groups. Figure 4.12 and 4.13 show the same set of plots while varying $U(US, -, +)$. Similarly, we see HIV– individuals preferring to engage with HIV+ individuals as $U(US, -, +)$ increases. The respective results for $\epsilon_+(game_2)$, in Figure 4.14, show low values of $\epsilon_+(game_2)$ associated with high values of $U(US, -, -)$ and low values of $U(US, -, +)$. Choices for $P_1$ do not change with $U(US, -, -)$ and $U(US, -, +)$, i.e., $x_{2+}^1 = 0, x_{1-}^1 = x_{2-}^1 = x_{3-}^1 = 0.(3)$.

4.3.5 Compounded effect of multiplayer games on HIV prevalence

Recall that by $game_i, i \in \{1, \ldots, 5\}$ we denoted the game where $P_i$ belongs to $G_i$. We let $p_i, i \in \{1, \ldots, 5\}$ be the size of the age group $G_i$ in the population (which was taken to be 0.2 for all groups in previous sections). So here we consider that $\epsilon_+^{gi}(0) := p_i \epsilon_+(0) = p_i \cdot 0.05, i \in \{1, \ldots, 5\}$. We denote by $\gamma_i$ the probability of $game_i$ taking place. Given that each game leads to possible unprotected sex among HIV+ and HIV- players, we estimate the infected fraction of individuals in each group, after interactions occur, to be described as follows:
Figure 4.10: 2-dimensional results for 4-player game showing choices for varying $U(US, -,-)$ utilities for Player 1 and 2.
Figure 4.11: 2-dimensional results for 4-player game showing choices for varying U(US,–,–) utilities for Player 3 and 4.
Figure 4.12: 2-dimensional results for 4-player game showing choices for varying $U(\text{US},-+,\text{+})$ utilities for Player 1 and 2.
Figure 4.13: 2-dimensional results for 4-player game showing choices for varying \(\text{U(US,\sim,+)}\) utilities for Player 3 and 4.
\[ \epsilon_{gi}^+ = \sum_{k=1}^{5} \gamma_k \epsilon_{gi}^+(game_k) \]

where for each \( i, k \in \{1, \ldots, 5\} \) we have that \( \epsilon_{gi}^+(game_k) \) are defined as in Section 3. The overall fraction of infected individuals in the population is obtained by adding the fractions above, after compiling the results for each game:

\[ \epsilon_+ = \left( \sum_{i=1}^{5} \epsilon_{gi}^+ \right) / 5. \]

We plot \( \epsilon_+ \) in Figure 4.15 using \( p = (0.086, 0.173, 0.159, 0.170, 0.412) \) the estimated size of the age groups according to U.S. census [23].
4.4 Prophylactic HIV vaccine and differentiated HIV group prevalence scenarios

In this section we investigate implementing a prophylactic vaccine, with efficacy $\mu$. Consequently we adjust some of the baseline utilities as follows: a) the utility for an unvaccinated HIV$^-$ individual interacting with an HIV$^+$ individual is increased due to the assumption unvaccinated individuals aware of a vaccination program would place higher utility for $US$ given an assumed increased level of protection through treatment optimism [22]; b) we define $U(US, -, +, vacc)$ as the utility for HIV$^-$ vaccinated individuals engaging in $US$ with HIV$^+$; c) we set a new baseline value for $U(US, -, +) = 0$ to reflect less worry amongst unvaccinated HIV$^-$ individuals; d) we increase $\beta_-$ to 0.8 as we assume
an HIV–individual shifts their risk assessment, $b_-$, closer to their personal belief; e) we lower $b_{self}$ to 0.1 to reflect less of a risk assumption upon implementation of a vaccination program. The population sizes are adjusted to fit $p = (0.086, 0.173, 0.159, 0.170, 0.412)$ with $p_i, i \in \{1, ..., 5\}$ the estimated size of the age group according to U.S. census [23] and $p = (0.21, 0.313, 0.18, 0.12, 0.18)$ using Zimbabwe census data [24].

We define $(1 - \mu)\tau$ to be the relative reduction in transmission. We investigate what impact these changes have if HIV-players in youngest age class are vaccinated.

Next we investigate the variation in $\epsilon_+$ in order to assess the overall impact of changing utilities and intervention strategies has on the overall transmission. We run the compounded game of Section 4.3.5 for both U.S. and Zimbabwe populations assuming that $\gamma_k = 1$ for all $k \in \{1, ..., 5\}$. Results presented are dependent on varying $\mu \in [0, 1]$ and $U(US, -, -) \in [...].$ Figure 4.16 shows that low values of $U(US, -, -)$ increases $\epsilon_+$, and high values of $\mu$ decrease $\epsilon_+$. Since $\mu$ is only relevant to the youngest age class, the impact across a compounded population is less observable. Figure 4.16 illustrates the compounded results for the U.S. and Zimbabwe data. $\epsilon_+$ for both populations show similar results with Zimbabwe a slightly lower overall prevalence.

### 4.5 Conclusion and future work

The previous sections outline a one-off game for 2, 3, and 4 players variations dependent on status and age. The results are focused on varying utilities with respect to an HIV–individuals as we also explored implementing prophylactic vaccines, which would be administered
Figure 4.16: Compound $\epsilon_+^+$ using U.S. census data comparing $\mu$ and $U(U S, - , - )$ with $U(U S, -, +, vacc) = 1$
to HIV– individuals resulting in a change in their decision making process. We demonstrated the sensitivity of Nash equilibria with respect to these utilities. We also showed how the strategies changed with respect to varying different parameters simultaneously, giving an appreciation for how decisions are impacted and how it may impact transmission. For some scenarios we showed that by adjusting the local information parameter for HIV+ players, preferences could be adjusted, having again an effect on transmission. As we go from 2 to 4 player games, we see players adopt similar strategies dependent on the assigned utilities. Compounding the age groups and adjusting for HIV composition, we show that transmission can have a greater impact in populations with a larger youth composition, as they are likely to receive a prophylactic vaccine. It would be interesting to include incorporation of HAART for HIV+ individuals which could show how adjusting their utilities may impact transmission. It would also be interesting conduct a repeated game in order to better see how transmission evolves and how this impacts the overall risk assessment and spread of HIV.
Bibliography


Chapter 5

Discussion
5.1 Discussion

The focus of this thesis was to analyze the dynamic interactions between risk perception, partner choice, HIV transmission, and HIV interventions. This thesis consisted of three projects:

1. Coevolution of risk perception, sexual behaviour, and HIV transmission in an agent based model.

2. Sexual behaviour, risk perception, and HIV transmission can respond to HIV antiviral drugs and vaccines through multiple pathways.

3. Multiplayer games and HIV prevalence via casual encounters.

The overall connection between these chapters is to explore the impact of individual behaviour with respect to HIV. The importance in understanding how behavioural response plays a role in safe sex practices is an important and necessary area to explore. With regards to the spread of HIV, this is becoming even more important as current treatments are changing and potential vaccines are approaching. The importance of behaviour and its connection to HIV has been stressed in numerous papers, however, many of these papers make assumptions on how behaviour should affect a population. This thesis offers a unique approach to understanding behaviour by instead creating a game theoretical framework through which we observe individual decision making. The scope of the thesis is not search for validation, but rather offer a novel approach to an often simplified problem. While this thesis centred around HIV, the unique approach to how individuals adopt
behavioural changes could be applicable to studying many of the over 30 different sexually transmissible bacteria, viruses and parasites [1].

In Chapter 2, we examined a highly active group of individuals who frequent a bath house over several years. The purpose was to see how behavioural dynamics could emerge given our interpretation of how individuals seek sex with casual partners. We were able to see different groups emerge based on status, as well as the level of perceived risk and behaviour. Choices made by individuals depended on their personal beliefs and were influenced by those they interacted with. We observed how HIV spread and risk assessment coevolve and showed how risk perception is not a fixed rate, but rather, risk perception influences prevalence and prevalence influences risk perception.

Group formation defined by HIV status, perceived risk, and sexual behaviour also helped us to understand this relationship. We observed how stabilization showed two groups, one being HIV+ which showed a lower perception of HIV prevalence in the population, and the other was HIV– and tended to have a higher perception of HIV prevalence in the population. We showed that this occurred when HIV prevalence increased. HIV+ individuals engaged in unprotected sex with other HIV+ individuals, but protected sex with HIV– actors, whereas HIV– individuals engage in protected sex with both HIV+ and HIV– individuals, or oftentimes no sex if the other individual is HIV+. The group formation is important as it shows groups are influenced by each other.

In Chapter 3, we adjusted how individuals engage in a risky sex game to imitate a possibly more realistic interaction, where the second player chooses between what they are propositioned with, or choosing not to engage with the individual. This also left the first
player to accept this choice. Additionally, the inclusion of age structure changes the activity levels of players, and allows new players with appropriately adjusted risk perceptions to enter the population. Infected players adjusted their activity levels and either exited the game through death or through old age along with aging HIV− players. This adjustment to the model changed the overall population risk assessment averages by type. We felt this model formulation would be appropriate for introducing intervention strategies in a age structured population.

Upon implementation of HAART and vaccine interventions, we observed multiple pathways emerging which demonstrated that policy resistance effects like HAART optimism may impact the population in different ways. While we adjusted for an increase in the attractiveness of US utilities, we saw an increase in the number of HIV+ individuals in the population. This led to increases in perceived risk, which in itself, counteracts HAART optimism. This is an important aspect for studying policy resistance, as these interventions lead to a lower per capita number of unprotected sex acts when compared to no intervention. We also examined the age stratified risk perception to search for any cohort effects that may occur. The vaccination strategy was aimed to be implemented within the youngest age class. This would be most appropriate as it would be targeted towards individuals prior to their first sexual experience through a mass and simultaneous vaccination the likes of which are usually obtained through a school setting to offer greater efficiency [2]. As the level of protection wains according to our model parameters, we see an increased level of risk assessment within the older age group. This may provided the benefit of protection to this age group by diminishing the likelihood of US through their subsequent active years.
In Chapter 4 we examined both two player and multiplayer nonlinear games where the players are defined as belonging to differing age groups in the population. The goal of this paper was to take a unique approach to understanding the impact of personal preferences ranking, the weight each players places to construct their personal belief on the HIV status of the other player, as well as heterogeneity of players though division of age groups. We were able to demonstrate these results while additionally incorporating the presence of a prophylactic vaccine. Implementing a prophylactic vaccine showed how further adjustments to the decision making process, as well as vaccine efficacy could impact HIV prevalence. The multiplayer nonlinear games were solved using variational analysis techniques which have few epidemiological papers to compare with. Incorporating the modelling of HIV transmission as well as an HIV vaccination treatment by such a class of games was a novel approach that aims to contribute to the ever expanding research area of sexual risk assessment and HIV transmission modelling.

In summary, these chapters outline a game theoretical framework for investigating how individual behaviour and risk assessment can impact HIV spread, how the decision process can be adjusted through varying utilities, and how these decisions consequently adjust HIV transmission. The approach using individualistic agent-based modelling as well as variational inequalities through projected dynamical systems demonstrates a novel method to studying a key aspect of HIV transmission. Our results highlight the complicated nature of the feedback mechanism between risk perception and HIV prevalence. We explored the sensitivity of Nash equilibria through varying utilities, HIV amongst a highly active closed group, as well as an age structured population. We further studied how incorporation of HAART and vaccines may adjust the decision making process, and observed how varying
influential parameters affected the success of such interventions.

## 5.2 Future Research

Chapter 2 discusses a closed group over short amount of time. Although we included a parameter that allowed individuals to remember past encounters, we ignored any social structure. Individuals remembering contact with greater detail, or possibly conveying information gathered about others and allowing that to spread would be an interesting approach. This aspect of sharing information could be introduced as a way of interacting with new people. Since the population is representative of highly active non-monogamous individuals, the model uses random pairing. However, information sharing could allow for individuals to seek new partners based on the contacts of their previous encounter, as a more realistic way of enacting how individuals may meet. Allowing individuals to retain more information from past partners and share information of previous contacts would be an interesting aspect, particularly for a relatively small and closed population model in order to study group dynamics.

Both Chapter 2 and 3 model HIV spread through highly active individuals. In Chapter 2 we studied some cases of variance in activity levels based upon an individual’s past correspondence, and in Chapter 3 we adjusted activity levels in individuals who vary by age and by status. The next approach would be to model a population where activity levels vary in more realistic terms between individuals. We would account for not just highly active people, but individuals who have a significantly greater amount of contacts over their lifetime. With regards to infectious diseases, these individuals are referred to as super
spreaders [3]. In infectious disease modelling of communicable diseases, this generally refers to people with a substantially greater amount of contacts through which an infection is spread [4]. Identifying these individuals depends on the nature through which the infection is transmitted. With respect to HIV, a super spreader represents an individual that engages in sexual acts more frequently. Whether or not they will actually spread HIV would depend on whether they choose protected or unprotected sex. A better understanding of the behaviour of super spreaders is important in order to be better prepared for HIV intervention programs.

Results for Chapter 3 could be further explored by implementing a catch-up program for young individuals that missed the initial vaccine. It would be worth investigating the effect of introducing a catch-up program for individuals who are still sexually active but were not part of the original vaccinated cohort. Additionally, it would be interesting to adopt a booster scenario, where individuals are able to become revaccinated after or before their current coverage ends. This would allow us to see what impact this could have on older generations, as well as overall HIV prevalence.

The game described in Chapter 4 demonstrated a one-off game for 2, 3, and 4 player variations dependent on status and age. It would be interesting to see changes in prevalence and decision making through a repeated game. Results of the previous encounter would be incorporated into the next game iteration representing population evolution over time. This would allow us to see how prevalence and risk assessment evolve and interact with each other. We would also be able to study how utility changing vaccine treatments would impact older generations. It would also be beneficial to incorporate HAART for HIV+ individuals as we studied in Chapter 3. Upon implementation of this it would be necessary
to vary the utilities with respect to HIV+ individuals to see how choices are made, as well as changes to the overall prevalence.

Bibliography


Chapter 6

Supplementary Material
6.1 Simulation Code: Chapter 2

;;;;The attached code was developed using Netlogo software.
;;;;Netlogo is an agent based programming language.
;;;;Parameter inputs are determined using the user interface.

;;;;Accessible variables to all agents
globals [layout? i j initialinfected infected prevalence choiceP1a choiceP2a choiceP1b
hivstatusP1 hivstatusP2 exnum1 exnum2 listturtlenum listinitialp listgen listgenlinks
tempnum1 tempnum2 tempturnum1 tempturnum2 hivnegavgp hivposavgp hivposdontknow
theposdontknow avgtotalp thenegp theposp theturtlep hivprevpercent totalhivpos
listtencount listencount hivprevpercentdontknow totalhivposdontknow
player0p player1p player2p player3p player4p player5p player6p player7p player8p
player9p player10p player11p player12p player13p player14p player15p player16p
player17p player18p player19p player20p player21p player22p player23p player24p
player25p player26p player27p player28p player29p player30p player31p player
32p player33p player34p player35p player36p player37p player38p player39p
origpvaluep1 origpvaluep2 cumsexactstemp temppnum3 temppnum4 temppnum5 temppnum6
temppnum7 temppnum8 temppnum9 temppnum10 temppnum11
totalRSpospos totalRSposneg totalRSnegneg totalPSpospos totalPSposneg totalPSnegneg
totalNSpospos totalNSposneg totalNSnegneg
temprencounterarraynumber temprencounterarraynumber2 temprencounterarraynumber3
rho c nointeractcionrho
cumsexactsum100 totalRSpospos100 totalRSposneg100 totalRSnegneg100
totalPSpospos100 totalPSposneg100 totalPSnegneg100
totalNSpospos100 totalNSposneg100 totalNSnegneg100
cumsexactsum200 totalRSpospos200 totalRSposneg200 totalRSnegneg200
totalPSpospos200 totalPSposneg200 totalPSnegneg200
cumsexactsum300 totalRSpospos300 totalRSposneg300 totalRSnegneg300
totalPSpospos300 totalPSposneg300 totalPSnegneg300
cumsexactsum400 totalRSpospos400 totalRSposneg400 totalRSnegneg400
totalPSpospos400 totalPSposneg400 totalPSnegneg400
cumsexactsum500 totalRSpospos500 totalRSposneg500 totalRSnegneg500
totalPSpospos500 totalPSposneg500 totalPSnegneg500
cumsexactsum1400 totalRSpospos1400 totalRSposneg1400 totalRSnegneg1400

204
totalPSpospos1400 totalPSposneg1400 totalPSnegneg1400 totalNSpospos1400
totalNSposneg1400 totalNSnegneg1400
cumsexactsum1500 totalRSpospos1500 totalRSposneg1500 totalRSnegneg1500
totalPSpospos1500 totalPSposneg1500 totalPSnegneg1500 totalNSpospos1500
totalNSposneg1500 totalNSnegneg1500
cumsexactsum4900 totalRSpospos4900 totalRSposneg4900 totalRSnegneg4900
totalPSpospos4900 totalPSposneg4900 totalPSnegneg4900 totalNSpospos4900
totalNSposneg4900 totalNSnegneg4900
cumsexactsum5000 totalRSpospos5000 totalRSposneg5000 totalRSnegneg5000
totalPSpospos5000 totalPSposneg5000 totalPSnegneg5000 totalNSpospos5000
totalNSposneg5000 totalNSnegneg5000
]
; directed-link-breed [red-links red-link]
; undirected-link-breed [blue-links blue-link]

; ; Defines variables belonging to each turtle, can only use these variables
; in turtle commands
 turtles-own [ own-status actual-status encounter-status action-list offer encounters RSencounters PSenounters NSencounters sextotalbytype print-self print-partner1 infection-length coupled?

205
partner1
self-action
self-action1
partner-action
EU20RS ;;Expected utility for player 2 who is HIV - ,0, for RS
EU20PS
EU20NS
EU21RS
EU21PS
EU21NS
EU10RS
EU10PS
EU10NS
EU11RS
EU11PS
EU11NS
updatepP2a ;;Temp variable to update P2's p-value on the first interaction a
updatepP2b
updatepP1a
updatepP1b
RStotal ;;variable that increases for each player after a RS event. This may be used to
assess on what level an actor feels they may unknowingly be infected.
PStotal
NStotal
RScounter ;;Temp variable to update each actors chance of infection belief
PScounter
NScounter
tempencount
]
;Extensions [matrix]

to setup ;;Creates number of turtles with appropriate list items
;; (for this model to work with NetLogo's new plotting features,
;; __clear-all-and-reset-ticks should be replaced with clear-all at
;; the beginning of your setup procedure and reset-ticks at the end
;; of the procedure.)
__clear-all-and-reset-ticks
reset-ticks
;set infection-chance 50
setup-network
setup-plot
setup-plot2
setup-plot3
update-plot

set i 0 ;Set i to 0
set initialinfected 0
set choiceP1a 0
set choiceP2a 0
set choiceP1b 0

;set sigma 0.5
;set lambda 0.9
while [i < num]
[
ask turtle i
[let p-level random-normal 0.05 0.1 ;; This is mean 0.3 and standard deviation 0.1
if (p-level > 0) and (p-level < 1)
[ set offer n-values 22 [0] ;;Creates list of 20 0's
set offer replace-item 0 offer "RS" ;;begins to replace items on list
set offer replace-item 1 offer "PS"
set offer replace-item 2 offer "NS"
set p-level precision p-level 3
set offer replace-item 3 offer p-level
;ifelse (i < count turtles * initialinfectpercent) ;;count reports number of agents in agent
set, this determines the initial infected turtles
[ set own-status 1 ;;HIV positive turtle (THINKS THEY ARE)
; set color red

207
; set offer replace-item 4 offer own-status
; set initialinfected initialinfected + 1]
;[ set own-status 0 ;; HIV negative (THINKS THEY ARE)
set own-status 0 ;; HIV negative
; set offer replace-item 4 offer own-status]
set offer replace-item 4 offer own-status
set offer replace-item 5 offer 100 ;; offer 5, 6, 7 are the utility function for an HIV positive actor, for RS, PS, and NS. It is assumed each player wants to maximize their expected utility. This is for an HIV + actor with the belief the other actor is HIV +
set offer replace-item 6 offer protectedsexutility
set offer replace-item 7 offer 0

set offer replace-item 8 offer 100 ;; offer 8, 9, 10 are the utility function for an HIV positive actor, for RS, PS, and NS. It is assumed each player wants to maximize their expected utility. This is for an HIV + actor with the belief the other actor is HIV -
set offer replace-item 9 offer protectedsexutility
set offer replace-item 10 offer 0

set offer replace-item 11 offer -50 ;; offer 11, 12, 13 are the utility function for an HIV negative actor, for RS, PS, and NS. It is assumed each player wants to maximize their utility. This is for an HIV - actor with the belief the other actor is HIV +
set offer replace-item 12 offer protectedsexutility
set offer replace-item 13 offer 0

set offer replace-item 14 offer 100 ;; offer 14, 15, 16 are the utility function for an HIV negative actor, for RS, PS, and NS. It is assumed each player wants to maximize their expected utility. This is for an HIV - actor with the belief the other actor is HIV -
set offer replace-item 15 offer protectedsexutility
set offer replace-item 16 offer 0

set offer replace-item 17 offer RStotal
set offer replace-item 18 offer PStotal
set offer replace-item 19 offer NStotal

set offer replace-item 20 offer i
set offer replace-item 21 offer 0 ;0 if not infected, 1 if infected, this is a marker that
we will use so that an individual with 1 will have a percentage chance of being tested
and determining they are infected. Own-status now only means whether they think they are infected

;print offer ;;This prints each turtles offer
set i i + 1
]
]
]

set j 0
set i 0
while [j < initialnuminfected]
[set i random num
;print i
ask turtle i
[
ifelse (own-status = 0)
[ set own-status 1
set offer replace-item 4 offer own-status
set color red
set initialinfected initialinfected + 1
set actual-status 1
set offer replace-item 21 offer actual-status
]
[
set j j - 1
]
]
]
set j j + 1
]
Each turtle has its own encounters array that stores the cumulative encounters it has with each turtle.

```
set i 0
while [i < num]
[
  ask turtle i
  [set encounters n-values num [0]
   ;print encounters
  ]
  set i i + 1
]

set i 0
while [i < num]
[
  ask turtle i
  [set RSenounters n-values num [0]
   ;print encounters
  ]
  set i i + 1
]

set i 0
while [i < num]
[
  ask turtle i
  [set PSenounters n-values num [0]
   ;print encounters
  ]
  set i i + 1
]
```

set i 0
while [i < num]
[ask turtle i
(set NSencounters n-values num [0]
 ;print encounters
 )
(set i i + 1
)]

(set i 0
(while [i < num]
[
(ask turtle i
(set sextotalbytype n-values 9 [0]
 ;print sextotalbytype
 )
(set i i + 1
)]

"0, 1, 2 RS ++ --, 3, 4, 5 PS ++ -- --, 6, 7, 8 NS ++ -- --"

many-encounters
;write-data-initial
;write-data-initial2
write-data7initial
write-data8initial
write-data9initial
update-plot
update-plot2
;update-plot3
findprevalence
getavgp
writecumsexactbytype
to make-traders ;;Begin command, places turtles randomly and determines shape
clear-turtles ;;kills all turtles
crt num ;;Create a number of turtles from button
[setxy (random-xcor * 0.95) (random-ycor * 0.95)
set size (world-width / 30)
set shape "circle"
if show-id-trader?
[
set label who ;;Set turtle ID number
set color green ]
]
end

to setup-network ;; Determine network type

;if network-type = "Random-generated" [
setup-random-network
;]
;if network-type = "Preferential-attachment-only-out-links" [
;setup-pa-network-only-out-links
;]
end

; this needs a chooser button on interface with the names on it as
; above in quotation marks
to setup-random-network  ;; This network creates random links between turtles
make-traders
;set i 0
;while [i < num]
[
;ask turtle i  ;; Creates a random number of links to other turtles that <= max
   links button, this can include 0 links (by itself)
   ; [ i
      ; ifelse (count out-link-neighbors >= 1) or (count in-link-neighbors >= 1)
      ; [ set i i + 1 ]
      ; ]; repeat random (max-links-per-node) [create-link-to one-of turtles
       with [self != myself]]
      ; ]; repeat random (max-links-per-node) [create-link-to one-of turtles
       with [self != myself and count out-link-neighbors = 0 and count in-link-neighbors = 0] ]
      ; set i i + 1 ]
; ]
;]
end

;;;;---------------------

;to setup-pa-network-only-out-links  ;; This network creates links based on preferential treatment
;clear-turtles
;make-node nobody  ;; first node, unattached
;make-node turtle 0
;; set-default-shape links "arrow"
;ask links [ set color grey ]
;repeat (num - 2) [make-node-only-out-links find-partner
; layout ] ;; Do not understand command
;
;if count turtles > num [stop]
;
;ask turtles[
;if show-id-trader?
; [ ]
; set label who
; set color green
; ]
;end

;to make-node [old-node]
; crt 1
; [ ]
; set shape "circle"
; set color red
; ;set label who
; set size (world-width / 50)
;
; if old-node != nobody
; [ if random-float 100 < 0
; [create-link-to old-node[ set color gray ]
; create-link-from old-node[ set color gray ]]
; move-to old-node
; fd 8 ;;forward by 8
; ]
; ]
; ]
;end
;
;to make-node-only-out-links [old-node]
; crt 1
; [ ]
; set shape "circle"
; set color red
; ;set label who
; set size (world-width / 50)
;
to-report find-partner
let partner nobody
ask turtle 0
[ ifelse (count in-link-neighbors > 0)
[ set partner one-of in-link-neighbors]
[ set partner nobody]
]
; Go through all the agents...
let turtle-number 1
while [turtle-number < count turtles]
[ ask turtle turtle-number
[ ifelse (count in-link-neighbors > 0)
[ set partner one-of in-link-neighbors]
[ set partner nobody]
]
set turtle-number turtle-number + 1
]
report partner
end

to layout
;; the number 3 here is arbitrary; more repetitions slows down the
;; model, but too few gives poor layouts
repeat 3 [
    ;; the more turtles we have to fit into the same amount of space,
    ;; the smaller the inputs to layout-spring we’ll need to use
    let factor sqrt count turtles
    ;; numbers here are arbitrarily chosen for pleasing appearance
    layout-spring turtles links (1 / factor) (7 / factor) (1 / factor)
    display ;; for smooth animation
]

;; don’t bump the edges of the world
let x-offset max [xcor] of turtles + min [xcor] of turtles
let y-offset max [ycor] of turtles + min [ycor] of turtles
;; big jumps look funny, so only adjust a little each time
set x-offset limit-magnitude x-offset 0.1
set y-offset limit-magnitude y-offset 0.1
ask turtles [ setxy (xcor - x-offset / 2) (ycor - y-offset / 2) ]
end

to-report limit-magnitude [number limit]
    if number > limit [ report limit ]
    if number < (- limit) [ report (- limit) ]
    report number
end

;;;;;;;;;;;;;;;;

to go ;;After setup, this begins with go button
print word "tick=" ticks
clear-links
;ask links with [color = red] [ die ]
;ask red-links [blue-links]
set i 0
while [i < num]
[ask turtle i ;;Creates a random number of links to other turtles
that <= max links button, this can include 0 links (by itself)
[ifelse (one-of turtles with [self != myself and
  count out-link-neighbors = 0 and count in-link-neighbors = 0] != nobody )
  [ifelse (count out-link-neighbors >= 1) or (count in-link-neighbors >= 1)
    ;;If this turtle already has in or out links, then i + 1.
    If it doesn't have any links, randomly either give it 0 or 1 link to
    a turtle not itself and already without in or out links.
    [set i i + 1 ]
    [repeat random (2) [create-link-to one-of turtles
      with [self != myself and count out-link-neighbors = 0 and count in-link-neighbors = 0] ]
      set i i + 1 ]
  ]
  [ set i i + 1 ]
]]
ask turtles [ interact ]
tick
update-plot
update-plot2
;update-plot3

set j 0
while [j < num]
[ask turtle j
[
  ;print offer
]
set j j + 1 ]
set j 0
while [j < num]
[ask turtle j
[ ;print encounters
;print sextotalbytype
]
set j j + 1
]

;getjustp
;;;;no createlist1 as this is in setup for initial p values before tick 0
;if (ticks = 1) [createlists2]
;if (ticks = 2) [createlists3]

;write-data
;write-data2
;write-data3
;write-data4
;write-data5
;write-data6
write-data7
write-data8
write-data9
;print prevalence
findprevalence
getavgp

writecumsexactbytype

if (ticks = 100)
[
print word "tick=" ticks
set cumsexactsum100 (totalRpospos + totalRposneg + totalRnegneg + totalPpospos +
totalPposneg + totalPnegneg + totalNpospos + totalNposneg + totalNnegneg)
]
set totalRSpospos100 totalRSpospos
set totalRSposneg100 totalRSposneg
set totalRSnegneg100 totalRSnegneg
set totalPSpospos100 totalPSpospos
set totalPSposneg100 totalPSposneg
set totalPSnegneg100 totalPSnegneg
set totalNSpospos100 totalNSpospos
set totalNSposneg100 totalNSposneg
set totalNSnegneg100 totalNSnegneg
print word "cumsexacts100" cumsexactsum100
print (totalRSpospos100 / cumsexactsum100) * 100
print (totalRSposneg100 / cumsexactsum100) * 100
print (totalRSnegneg100 / cumsexactsum100) * 100
print (totalPSpospos100 / cumsexactsum100) * 100
print (totalPSposneg100 / cumsexactsum100) * 100
print (totalPSnegneg100 / cumsexactsum100) * 100
print (totalNSpospos100 / cumsexactsum100) * 100
print (totalNSposneg100 / cumsexactsum100) * 100
print (totalNSnegneg100 / cumsexactsum100) * 100

print word "HIVprevalence " prevalence
; print totalRSpospos
; print totalRSposneg
; print totalRSnegneg
; print totalPSpospos
; print totalPSposneg
; print totalPSnegneg
; print totalNSpospos
; print totalNSposneg
; print totalNSnegneg
}

if (ticks = 200)
[print word "tick=" ticks
set cumsexactsum200 (totalRSpospos + totalRSposneg + totalRSnegneg + totalPSpospos + totalPSposneg + totalPSnegneg + totalNSpospos + totalNSposneg + totalNSnegneg)
set totalRSpospos200 (totalRSpospos )
set totalRSposneg200 (totalRSposneg )
set totalRSnegneg200 (totalRSnegneg )
set totalPSpospos200 (totalPSpospos )
set totalPSposneg200 (totalPSposneg )
set totalPSnegneg200 (totalPSnegneg )
set totalNSpospos200 (totalNSpospos )
set totalNSposneg200 (totalNSposneg )
set totalNSnegneg200 (totalNSnegneg )
print word "cumsexacts200" cumsexactsum200
print ((totalRSpospos200 - totalRSpospos100) / (cumsexactsum200 - cumsexactsum100)) * 100
print ((totalRSposneg200 - totalRSposneg100) / (cumsexactsum200 - cumsexactsum100)) * 100
print ((totalRSnegneg200 - totalRSnegneg100) / (cumsexactsum200 - cumsexactsum100)) * 100
print ((totalPSpospos200 - totalPSpospos100) / (cumsexactsum200 - cumsexactsum100)) * 100
print ((totalPSposneg200 - totalPSposneg100) / (cumsexactsum200 - cumsexactsum100)) * 100
print ((totalPSnegneg200 - totalPSnegneg100) / (cumsexactsum200 - cumsexactsum100)) * 100
print ((totalNSpospos200 - totalNSpospos100) / (cumsexactsum200 - cumsexactsum100)) * 100
print ((totalNSposneg200 - totalNSposneg100) / (cumsexactsum200 - cumsexactsum100)) * 100
print ((totalNSnegneg200 - totalNSnegneg100) / (cumsexactsum200 - cumsexactsum100)) * 100
print word "HIVprevalence " prevalence

; print totalRSpospos

220
if (ticks = 300)
[
print word "tick=" ticks
set cumsexactsum300 (totalRSpospos + totalRSposneg + totalRSnegneg + totalPSpospos + totalPSposneg + totalPSnegneg + totalNSpospos + totalNSposneg + totalNSnegneg)
set totalRSpospos300 (totalRSpospos)
set totalRSposneg300 (totalRSposneg)
set totalRSnegneg300 (totalRSnegneg)
set totalPSpospos300 (totalPSpospos)
set totalPSposneg300 (totalPSposneg)
set totalPSnegneg300 (totalPSnegneg)
set totalNSpospos300 (totalNSpospos)
set totalNSposneg300 (totalNSposneg)
set totalNSnegneg300 (totalNSnegneg)
print word "cumsexacts300" cumsexactsum300
print (((totalRSpospos300 - totalRSpospos200) / (cumsexactsum300 - cumsexactsum200)) * 100
print (((totalRSposneg300 - totalRSposneg200) / (cumsexactsum300 - cumsexactsum200)) * 100
print (((totalRSnegneg300 - totalRSnegneg200) / (cumsexactsum300 - cumsexactsum200)) * 100
print (((totalPSpospos300 - totalPSpospos200) / (cumsexactsum300 - cumsexactsum200)) * 100
print (((totalPSposneg300 - totalPSposneg200) / (cumsexactsum300 - cumsexactsum200)) * 100
print (((totalPSnegneg300 - totalPSnegneg200) / (cumsexactsum300 - cumsexactsum200)) * 100
}
\[
\text{print } \left( \frac{\text{totalPSnegneg300} - \text{totalPSnegneg200}}{\text{cumsexactsum300} - \text{cumsexactsum200}} \right) \times 100
\]
\[
\text{print } \left( \frac{\text{totalNSpospos300} - \text{totalNSpospos200}}{\text{cumsexactsum300} - \text{cumsexactsum200}} \right) \times 100
\]
\[
\text{print } \left( \frac{\text{totalNSposneg300} - \text{totalNSposneg200}}{\text{cumsexactsum300} - \text{cumsexactsum200}} \right) \times 100
\]
\[
\text{print } \left( \frac{\text{totalNSnegneg300} - \text{totalNSnegneg200}}{\text{cumsexactsum300} - \text{cumsexactsum200}} \right) \times 100
\]
\]
\text{print word "HIVprevalence " prevalence}

; print totalRSpospos
; print totalRSposneg
; print totalRSnegneg
; print totalPSpospos
; print totalPSposneg
; print totalPSnegneg
; print totalNSpospos
; print totalNSposneg
; print totalNSnegneg

if (ticks = 400)
[
\text{print word "tick=" ticks}
\text{set cumsexactsum400 (totalRSpospos + totalRSposneg + totalRSnegneg + totalPSpospos + totalPSposneg + totalPSnegneg + totalNSpospos + totalNSposneg + totalNSnegneg)}
\text{set totalRSpospos400 (totalRSpospos )}
\text{set totalRSposneg400 (totalRSposneg )}
\text{set totalRSnegneg400 (totalRSnegneg )}
\text{set totalPSpospos400 (totalPSpospos )}
\text{set totalPSposneg400 (totalPSposneg )}
\text{set totalPSnegneg400 (totalPSnegneg )}
\text{set totalNSpospos400 (totalNSpospos )}
\text{set totalNSposneg400 (totalNSposneg )}
\text{set totalNSnegneg400 (totalNSnegneg )}
print word "cumsexacts400" cumsexactsum400
print ((totalRSpospos400 - totalRSpospos300 )
/ (cumsexactsum400 - cumsexactsum300 )) * 100
print ((totalRSposneg400 - totalRSposneg300 )
/ (cumsexactsum400 - cumsexactsum300 )) * 100
print ((totalRSnegneg400 - totalRSnegneg300 )
/ (cumsexactsum400 - cumsexactsum300 )) * 100
print ((totalPSpospos400 - totalPSpospos300 )
/ (cumsexactsum400 - cumsexactsum300 )) * 100
print ((totalPSposneg400 - totalPSposneg300 )
/ (cumsexactsum400 - cumsexactsum300 )) * 100
print ((totalPSnegneg400 - totalPSnegneg300 )
/ (cumsexactsum400 - cumsexactsum300 )) * 100
print ((totalNSpospos400 - totalNSpospos300 )
/ (cumsexactsum400 - cumsexactsum300 )) * 100
print ((totalNSposneg400 - totalNSposneg300 )
/ (cumsexactsum400 - cumsexactsum300 )) * 100
print ((totalNSnegneg400 - totalNSnegneg300 )
/ (cumsexactsum400 - cumsexactsum300 )) * 100
print word "HIVprevalence " prevalence

; print totalRSpospos
; print totalRSposneg
; print totalRSnegneg
; print totalPSpospos
; print totalPSposneg
; print totalPSnegneg
; print totalNSpospos
; print totalNSposneg
; print totalNSnegneg
]

if (ticks = 500)
[
print word "tick=" ticks

223
set cumsexacts500 (totalRSpospos + totalRSposneg + totalRSnegneg + totalPSpospos + totalPSposneg + totalPSnegneg + totalNSpospos + totalNSposneg + totalNSnegneg)
set totalRSpospos500 (totalRSpospos )
set totalRSposneg500 (totalRSposneg )
set totalRSnegneg500 (totalRSnegneg )
set totalPSpospos500 (totalPSpospos )
set totalPSposneg500 (totalPSposneg )
set totalPSnegneg500 (totalPSnegneg )
set totalNSpospos500 (totalNSpospos )
set totalNSposneg500 (totalNSposneg )
set totalNSnegneg500 (totalNSnegneg )
print word "cumsexacts500" cumsexacts500
print ((totalRSpospos500 - totalRSpospos400 ) / (cumsexacts500 - cumsexacts400 ) ) * 100
print ((totalRSposneg500 - totalRSposneg400 ) / (cumsexacts500 - cumsexacts400 ) ) * 100
print ((totalRSnegneg500 - totalRSnegneg400 ) / (cumsexacts500 - cumsexacts400 ) ) * 100
print ((totalPSpospos500 - totalPSpospos400 ) / (cumsexacts500 - cumsexacts400 ) ) * 100
print ((totalPSposneg500 - totalPSposneg400 ) / (cumsexacts500 - cumsexacts400 ) ) * 100
print ((totalPSnegneg500 - totalPSnegneg400 ) / (cumsexacts500 - cumsexacts400 ) ) * 100
print ((totalNSpospos500 - totalNSpospos400 ) / (cumsexacts500 - cumsexacts400 ) ) * 100
print ((totalNSposneg500 - totalNSposneg400 ) / (cumsexacts500 - cumsexacts400 ) ) * 100
print ((totalNSnegneg500 - totalNSnegneg400 ) / (cumsexacts500 - cumsexacts400 ) ) * 100
print word "HIVprevalence " prevalence

; print totalRSpospos
; print totalRSposneg
; print totalRSnegneg

224
if (ticks = 1400) {
    print word "tick=" ticks
    set cumsexactsum1400 (totalRSpospos + totalRSposneg + totalRSnegneg + totalPSpospos + totalPSposneg + totalPSnegneg + totalNSpospos + totalNSposneg + totalNSnegneg)
    set totalRSpospos1400 (totalRSpospos)
    set totalRSposneg1400 (totalRSposneg)
    set totalRSnegneg1400 (totalRSnegneg)
    set totalPSpospos1400 (totalPSpospos)
    set totalPSposneg1400 (totalPSposneg)
    set totalPSnegneg1400 (totalPSnegneg)
    set totalNSpospos1400 (totalNSpospos)
    set totalNSposneg1400 (totalNSposneg)
    set totalNSnegneg1400 (totalNSnegneg)
}

if (ticks = 1500) {
    print word "tick=" ticks

225
set cumsexacts1500 (totalRSpospos + totalRSposneg + totalRSnegneg + totalPSpospos + totalPSposneg + totalPSnegneg + totalNSpospos + totalNSposneg + totalNSnegneg)
set totalRSpospos1500 (totalRSpospos )
set totalRSposneg1500 (totalRSposneg )
set totalRSnegneg1500 (totalRSnegneg )
set totalPSpospos1500 (totalPSpospos )
set totalPSposneg1500 (totalPSposneg )
set totalPSnegneg1500 (totalPSnegneg )
set totalNSpospos1500 (totalNSpospos )
set totalNSposneg1500 (totalNSposneg )
set totalNSnegneg1500 (totalNSnegneg )
print word "cumsexacts1500 " cumsexacts1500
print ((totalRSpospos1500 - totalRSpospos1400 )
/ (cumsexacts1500 - cumsexacts1400 )) * 100
print ((totalRSposneg1500 - totalRSposneg1400 )
/ (cumsexacts1500 - cumsexacts1400 )) * 100
print ((totalRSnegneg1500 - totalRSnegneg1400 )
/ (cumsexacts1500 - cumsexacts1400 )) * 100
print (totalPSpospos1500 - totalPSpospos1400 )
/ (cumsexacts1500 - cumsexacts1400 )) * 100
print (totalPSposneg1500 - totalPSposneg1400 )
/ (cumsexacts1500 - cumsexacts1400 )) * 100
print (totalPSnegneg1500 - totalPSnegneg1400 )
/ (cumsexacts1500 - cumsexacts1400 )) * 100
print (totalNSpospos1500 - totalNSpospos1400 )
/ (cumsexacts1500 - cumsexacts1400 )) * 100
print (totalNSposneg1500 - totalNSposneg1400 )
/ (cumsexacts1500 - cumsexacts1400 )) * 100
print (totalNSnegneg1500 - totalNSnegneg1400 )
/ (cumsexacts1500 - cumsexacts1400 )) * 100
print word "HIVprevalence " prevalence
; print totalRSpospos
; print totalRSposneg
; print totalRSnegneg
if (ticks = 4900)
[
    print word "tick=" ticks
    set cumsexactsum4900 (totalRSpospos + totalRSposneg + totalRSnegneg + totalPSpospos
        + totalPSposneg + totalPSnegneg + totalNSpospos + totalNSposneg + totalNSnegneg)
    set totalRSpospos4900 (totalRSpospos)
    set totalRSposneg4900 (totalRSposneg)
    set totalRSnegneg4900 (totalRSnegneg)
    set totalPSpospos4900 (totalPSpospos)
    set totalPSposneg4900 (totalPSposneg)
    set totalPSnegneg4900 (totalPSnegneg)
    set totalNSpospos4900 (totalNSpospos)
    set totalNSposneg4900 (totalNSposneg)
    set totalNSnegneg4900 (totalNSnegneg)
]

if (ticks = 5000)
[
    print word "tick=" ticks
    set cumsexactsum5000 (totalRSpospos + totalRSposneg + totalRSnegneg + totalPSpospos
        + totalPSposneg + totalPSnegneg + totalNSpospos + totalNSposneg + totalNSnegneg)
    set totalRSpospos5000 (totalRSpospos)
]
set totalRSposneg5000 (totalRSposneg)
set totalRSnegneg5000 (totalRSnegneg)
set totalPSpospos5000 (totalPSpospos)
set totalPSposneg5000 (totalPSposneg)
set totalPSnegneg5000 (totalPSnegneg)
set totalNSpospos5000 (totalNSpospos)
set totalNSposneg5000 (totalNSposneg)
set totalNSnegneg5000 (totalNSnegneg)
print word "cumsexacts5000" cumsexactsum5000
print ((totalRSpospos5000 - totalRSpospos4900) / (cumsexactsum5000 - cumsexactsum4900)) * 100
print ((totalRSposneg5000 - totalRSposneg4900) / (cumsexactsum5000 - cumsexactsum4900)) * 100
print ((totalRSnegneg5000 - totalRSnegneg4900) / (cumsexactsum5000 - cumsexactsum4900)) * 100
print ((totalPSpospos5000 - totalPSpospos4900) / (cumsexactsum5000 - cumsexactsum4900)) * 100
print ((totalPSposneg5000 - totalPSposneg4900) / (cumsexactsum5000 - cumsexactsum4900)) * 100
print ((totalPSnegneg5000 - totalPSnegneg4900) / (cumsexactsum5000 - cumsexactsum4900)) * 100
print ((totalNSpospos5000 - totalNSpospos4900) / (cumsexactsum5000 - cumsexactsum4900)) * 100
print ((totalNSposneg5000 - totalNSposneg4900) / (cumsexactsum5000 - cumsexactsum4900)) * 100
print ((totalNSnegneg5000 - totalNSnegneg4900) / (cumsexactsum5000 - cumsexactsum4900)) * 100
print word "HIVprevalence " prevalence

; print totalRSpospos
; print totalRSposneg
; print totalRSnegneg
; print totalPSpospos
; print totalPSposneg
; print totalPSnegneg
; print totalNSpospos
; print totalNSposneg
; print totalNSnegneg
]

;ask red-links [set color red]

ask turtles
[
  if (actual-status = 1) and (own-status = 0)
  [ ;print word "turtle is infected and doesnt know it " who
    let tempgetcheckup random-float 1 ;; less than 1 greater than or equal to zero
    if (tempgetcheckup < ChanceTested) ;if true then the individuals own-status will
    then change to 1 (HIV+) resulting in them choosing different utilities.
      Assume checkup is 100% effective
    [ ;print word "turtle received treatment, will change own-status " who
      set own-status 1
      set offer replace-item 4 offer own-status
      ;print offer
    ]
  ]
]
]
end
; to color-collaborations
; ask links with [[in-team?] of end1 and [in-team?] of end2]
; [ ifelse new-collaboration?
; [ ifelse ([incumbent?] of end1) and ([incumbent?] of end2)
; [ set color yellow ;; both members are incumbents
; ] ]
; [ ifelse ([incumbent?] of end1) or ([incumbent?] of end2)
; [ set color green ] ;; one member is an incumbent
; [ set color blue ] ;; both members are newcomers
; ] ]
; [ set color red ;; members are previous collaborators
; ] ]
;end

;--------------------
to many-encounters ;; Set nodes to blue if they have a pre-determined number of links.
This could be useful later.
ask turtles
[if (count out-link-neighbors >= 4)
[ set color blue ]
]
end

to couple ;; turtle procedure - they couple along the incoming links
;;This is a directed graph. If no arrow point to an actor,
it is regarded as alone despite having outward links.
set coupled? false ;;Initialize as with nobody
set partner1 nobody
let potential-partner one-of (in-link-neighbors)
;with [not coupled? ]
ifelse potential-partner != nobody
[ set partner1 potential-partner
set coupled? true
ask partner1 [ set coupled? true ]
ask partner1 [ set partner1 myself ]
;;;;;print word "Origin node = actor 1" partner1
;;;;;print word " Destination node = actor 2" self
]
;;;;;print "No mate (alone or no incoming links):"
]
end
;;;each person makes an offer of sex in this procedure

;;;each person makes an offer of sex in this procedure
to interact ;; turtle procedure

set updatepP2a 0
set updatepP2b 0
set updatepP1a 0
set updatepP1b 0

couple

if coupled?
[ ask partner1
[ ;print self
;print (item 20 offer)
;get id from offer
]
ask self
[ ;print self
;print (item 20 offer)
set tempencounterarraynumber (item 20 offer)
;print tempencounterarraynumber
;get id from offer, set as a temp var. use this temp var below as a reference
for thr RSencounters array to get that info
]
ask partner1
[ ;print self
;print word "now the array number " tempencounterarraynumber
;print "P1's RS encounter number "
;print RSencounters
;print (item tempencounterarraynumber RSencounters)
set tempencounterarraynumber2 (item tempencounterarraynumber RSencounters)
;print word "tempencounterarraynumber2 " tempencounterarraynumber2
set tempencounterarraynumber3 (item tempencounterarraynumber PSencounters)
;print word "tempencounterarraynumber3 " tempencounterarraynumber3
set c (tempencounterarraynumber2 + tempencounterarraynumber3)
;print word "c " c
let randomrho random-float 1 ;; less than 1 grater than or equal to zero
;print word "randomrho " randomrho
set rho (((omega + c)/(1 + c)))
;print word "rho " rho
ifelse (rho < randomrho)
[ ;print "P1 is gonna say NS"
set nointeratcionrho 0
]
[ set nointeratcionrho 1
]
ifelse ( (coupled?) and (nointeractionrho = 1) )
[ ask partner1
[ ;print self
;print word " HIV status of actor1 = " (item 4 offer)
ifelse ( (item 4 offer) != 0) ;;item 4 offer 0 is HIV-, 1 is HIV+
[set EU11RS (item 3 offer)*(item 5 offer) + (1 + (-1)*(item 3 offer))* (item 8 offer)
set EU11PS (item 3 offer)*(item 6 offer) + (1 + (-1)*(item 3 offer))* (item 9 offer)
set EU11NS (item 3 offer)*(item 7 offer) + (1 + (-1)*(item 3 offer))* (item 10 offer)

if ( (EU11RS >= EU11PS) and (EU11RS >= EU11NS))
[set partner-action (item 0 offer)] ;;0 is RS
if ( (EU11PS > EU11RS) and (EU11PS >= EU11NS))
[set partner-action (item 1 offer)] ;;1 is PS
if ( (EU11NS > EU11RS) and (EU11NS > EU11PS))
[set partner-action (item 2 offer)] ;;2 is NS

set print-partner1 n-values 6 [0]
set print-partner1 replace-item 0 print-partner1 self
set print-partner1 replace-item 1 print-partner1 partner-action
set print-partner1 replace-item 2 print-partner1 (item 4 offer)
set print-partner1 replace-item 3 print-partner1 EU11RS
set print-partner1 replace-item 4 print-partner1 EU11PS
set print-partner1 replace-item 5 print-partner1 EU11NS]
[set EU10RS (item 3 offer)*(item 11 offer) + (1 + (-1)*(item 3 offer))* (item 14 offer)]
set EU10PS (item 3 offer)*(item 12 offer) + (1 + (-1)*(item 3 offer))* (item 15 offer)
set EU10NS (item 3 offer)*(item 13 offer) + (1 + (-1)*(item 3 offer))* (item 16 offer)
if ( (EU10RS >= EU10PS) and (EU10RS >= EU10NS))
[set partner-action (item 0 offer)] ;;0 is RS
if ( (EU10PS > EU10RS) and (EU10PS >= EU10NS))
[set partner-action (item 1 offer)] ;;1 is PS
if ( (EU10NS > EU10RS) and (EU10NS > EU10PS))
[set partner-action (item 2 offer)] ;;2 is NS

set print-partner1 n-values 6 [0]
set print-partner1 replace-item 0 print-partner1 self
set print-partner1 replace-item 1 print-partner1 partner-action
set print-partner1 replace-item 2 print-partner1 (item 4 offer)
set print-partner1 replace-item 3 print-partner1 EU10RS
set print-partner1 replace-item 4 print-partner1 EU10PS
set print-partner1 replace-item 5 print-partner1 EU10NS]
 (;; ; print word " Actor1=" print-partner1
 ; print print-partner1

set choiceP1a partner-action
set tempnum1 (item 0 print-partner1)
set tempturnum1 (item 20 offer)
set origpvaluep1 (item 3 offer)
;print word "this is tempnum1" tempnum1
set hivstatusP1 (item 21 offer)

]
Should there be a separate p-value in their array for updating? Should they always have access to the original p, or will that matter?

set origvaluep2 (item 3 offer)

; set updatepP2a ((item 3 offer) + ((1 - (item 3 offer))*(sigma))

; set updatepP2b ((lambda)*(item 3 offer)) + ((1 - lambda)*(updatepP2a))

; print " actor2 updated perceived p " updatepP2b

set updatepP2a ( beta *((alpha) + ((1 - (alpha))*(item 3 offer)))

+ (1 - beta) * prevalence )

set offer replace-item 3 offer updatepP2a

ifelse ((item 4 offer) != 0 ) ;;item 4 offer 0 is HIV-, 1 is HIV+

;; player is HIV+

[ set EU21RS (item 3 offer)*(item 5 offer) + (1 + (-1)*(item 3 offer))*(item 8 offer)

set EU21PS (item 3 offer)*(item 6 offer) + (1 + (-1)*(item 3 offer))*(item 9 offer)

set EU21NS (item 3 offer)*(item 7 offer) + (1 + (-1)*(item 3 offer))*(item 10 offer)

if ( (EU21RS >= EU21PS) and (EU21RS >= EU21NS))

[ set self-action (item 0 offer) ] ;;0 is RS

if ( (EU21PS > EU21RS) and (EU21PS >= EU21NS))

[ set self-action (item 1 offer) ] ;;1 is PS

if ( (EU21NS > EU21RS) and (EU21NS > EU21PS))

[ set self-action (item 2 offer) ] ;;2 is NS

set print-self n-values 6 [0]

set print-self replace-item 0 print-self self

set print-self replace-item 1 print-self self-action

set print-self replace-item 2 print-self (item 4 offer)

set print-self replace-item 3 print-self EU21RS

set print-self replace-item 4 print-self EU21PS

set print-self replace-item 5 print-self EU21NS ]

;; player is HIV-

[ set EU20RS (item 3 offer)*(item 11 offer) + (1 + (-1)*(item 3 offer))*(item 14 offer)

set EU20PS (item 3 offer)*(item 12 offer) + (1 + (-1)*(item 3 offer))*(item 15 offer)

set EU20NS (item 3 offer)*(item 13 offer) + (1 + (-1)*(item 3 offer))*(item 16 offer)

if ( (EU20RS >= EU20PS) and (EU20RS >= EU20NS))

[ set self-action (item 0 offer) ] ;;0 is RS

if ( (EU20PS > EU20RS) and (EU20PS >= EU20NS))

[ set self-action (item 0 offer) ] ;;0 is RS

if ( (EU20PS > EU20RS) and (EU20PS >= EU20NS))
[set self-action (item 1 offer)] ;;1 is PS
if ( (EU20NS > EU20RS) and (EU20NS > EU20PS))
[set self-action (item 2 offer)] ;;2 is NS
set print-self n-values 6 [0]
set print-self replace-item 0 print-self self
set print-self replace-item 1 print-self self-action
set print-self replace-item 2 print-self (item 4 offer)
set print-self replace-item 3 print-self EU20RS
set print-self replace-item 4 print-self EU20PS
set print-self replace-item 5 print-self EU20NS]

;print word " Actor2=" print-self
;print print-self
set choiceP2a self-action
set tempnum2 (item 0 print-self)
set tempturnum2 (item 20 offer)
set hivstatusP2 (item 21 offer)
;print word "this is tempnum2" tempnum2
]

;;;;;;;;;;;;;;;;;;;If choiceP1a is PS
[
;set updatepP2a (((item 3 offer)- (( (item 3 offer) - 0)\*(sigma))))
;set updatepP2b (((lambda)*((item 3 offer)) + ((1 - lambda)*updatepP2a) )
;print word " actor2 updated perceived p " updatepP2b
set updateP2a ( beta * ((1 - alpha)*((item 3 offer)) + ((1 - beta) * prevalence) )
set offer replace-item 3 offer updateP2a
ifelse ((item 4 offer) != 0 ) ;;item 4 offer 0 is HIV-, 1 is HIV+
;;player is HIV+
[ set EU21RS (item 3 offer)*((item 5 offer) + (1 + (-1)\*(item 3 offer))* (item 8 offer)
set EU21PS (item 3 offer)*((item 6 offer) + (1 + (-1)\*(item 3 offer))* (item 9 offer)
set EU21NS (item 3 offer)*((item 7 offer) + (1 + (-1)\*(item 3 offer))* (item 10 offer)
if ( (EU21RS >= EU21PS) and (EU21RS >= EU21NS))

236
[set self-action (item 0 offer)] ;;0 is RS
if (EU21PS > EU21RS and (EU21PS >= EU21NS))
[set self-action (item 1 offer)] ;;1 is PS
if (EU21NS > EU21RS and (EU21NS > EU21PS))
[set self-action (item 2 offer)] ;;2 is NS

set print-self n-values 6 [0]
set print-self replace-item 0 print-self self
set print-self replace-item 1 print-self self-action
set print-self replace-item 2 print-self (item 4 offer)
set print-self replace-item 3 print-self EU21RS
set print-self replace-item 4 print-self EU21PS
set print-self replace-item 5 print-self EU21NS ]
;;player is HIV-
[ set EU20RS (item 3 offer)*(item 11 offer) + (1 + (-1)*(item 3 offer))* (item 14 offer)
set EU20PS (item 3 offer)*(item 12 offer) + (1 + (-1)*(item 3 offer))* (item 15 offer)
set EU20NS (item 3 offer)*(item 13 offer) + (1 + (-1)*(item 3 offer))* (item 16 offer)
if (EU20RS >= EU20PS and (EU20RS >= EU20NS))
[set self-action (item 0 offer)] ;;0 is RS
if (EU20PS > EU20RS and (EU20PS >= EU20NS))
[set self-action (item 1 offer)] ;;1 is PS
if (EU20NS > EU20RS and (EU20NS > EU20PS))
[set self-action (item 2 offer)] ;;2 is NS
set print-self n-values 6 [0]
set print-self replace-item 0 print-self self
set print-self replace-item 1 print-self self-action
set print-self replace-item 2 print-self (item 4 offer)
set print-self replace-item 3 print-self EU20RS
set print-self replace-item 4 print-self EU20PS
set print-self replace-item 5 print-self EU20NS ]

;print word " Actor2=" print-self
;print print-self
set choiceP2a self-action
set tempnum2 (item 0 print-self)
set tempturnnum2 (item 20 offer)
set hivstatusP2 (item 21 offer)
]
]
;;Now Player 1 reevaluates what it wants...

;;The game progresses. If same choices, that type of sex will occur, if not, another round of questions.
;print word " " choiceP1a
;print word " " choiceP2a
ifelse choiceP1a = choiceP2a
[
ifelse choiceP1a = "RS"
[ ;print word " Players will have " choiceP1a
;print word " " hivstatusP1
;print word " " hivstatusP2

if (hivstatusP1 = 1 and hivstatusP2 = 1) ;;1 is HIV pos
[ set cumsexactstemp ((item 0 sextotalbytype)+ 1)
set sextotalbytype replace-item 0 sextotalbytype cumsexactstemp
]
if (hivstatusP1 = 1 and hivstatusP2 = 0) or (hivstatusP1 = 0 and hivstatusP2 = 1) ;;1 is HIV pos
[ set cumsexactstemp ((item 1 sextotalbytype)+ 1)
set sextotalbytype replace-item 1 sextotalbytype cumsexactstemp
]
if (hivstatusP1 = 0 and hivstatusP2 = 0) ;;1 is HIV pos
[ set cumsexactstemp ((item 2 sextotalbytype)+ 1)
set sextotalbytype replace-item 2 sextotalbytype cumsexactstemp
]
;set tempnum2 item 0 print-partner1
;ask link (item 0 print-self) (item 0 print-partner1)
;ask link tempnum1 tempnum2
;ask links with [[self] of end1 and [partner1] of end2]
;[set color red]
;ask self [create-blue-link-to partner1]
;print word " tempnum1=" tempnum1
;create-blue-link-with tempnum1
;[set color blue]
;;Here probability of spread for RS
set exnum1 1
;set spreadRS 0.85
set exnum1 random-float exnum1 ;;random number between 0 and exnum1
ifelse exnum1 < spreadRS
[

ifelse (hivstatusP1 != hivstatusP2) ;;one player is HIV + and one is not
and HIV WILL spread
[ask partner1
 [ ;set own-status 1
 set actual-status 1
 set offer replace-item 21 offer actual-status
 set RScounter ((item 17 offer)+ 1)
 ;set offer replace-item 4 offer own-status
 set offer replace-item 17 offer RScounter
 set color red
 set tempencount ((item tempturnum2 encounters)+ 1)
 set encounters replace-item tempturnum2 encounters tempencount
 set tempencount ((item tempturnum2 RSencounters)+ 1)
 set RSencounters replace-item tempturnum2 RSencounters tempencount
 ;;;;print word " RScounter
;set updateP1b ( ((lambda)*item 3 offer)) + ((1 - lambda)*(updateP1a))
;set updateP1b ( ((lambda)*origpvaluep1)) + ((1 - lambda)*(updateP1a))
;set offer replace-item 3 offer updateP1b
]
ask self
[
  ;set own-status 1
  set actual-status 1
  set offer replace-item 21 offer actual-status
  set RScounter ((item 17 offer)+ 1)
  ;set offer replace-item 4 offer own-status
  set offer replace-item 17 offer RScounter
  set color red
  set tempencount ((item tempturnum1 encounters)+ 1)
  set encounters replace-item tempturnum1 encounters tempencount
  set tempencount ((item tempturnum1 RSencounters)+ 1)
  set RSencounters replace-item tempturnum1 RSencounters tempencount

  ;set updateP2b ( ((lambda)*(origpvaluep2)) + ((1 - lambda)*(updateP2a)) )
  ;set offer replace-item 3 offer updateP2b
  ;;;print word " " RScounter
]
]

;;If players have same HIV status, meaning no spread
[ask partner1
[
  set RScounter ((item 17 offer)+ 1)
  set offer replace-item 17 offer RScounter
  set tempencount ((item tempturnum2 encounters)+ 1)
  set encounters replace-item tempturnum2 encounters tempencount
  set tempencount ((item tempturnum2 RSencounters)+ 1)
  set RSencounters replace-item tempturnum2 RSencounters tempencount
  ;;;print word " " RScounter
  ;set updateP1b ( ((lambda)*(origpvaluep1)) + ((1 - lambda)*(updateP1a)) )
  ;set offer replace-item 3 offer updateP1b
]
]

ask self
[
  set RScounter ((item 17 offer)+ 1)
set offer replace-item 17 offer RScounter
set tempencount ((item tempturnum1 encounters)+ 1)
set encounters replace-item tempturnum1 encounters tempencount
set tempencount ((item tempturnum1 RSencounters)+ 1)
set RSencounters replace-item tempturnum1 RSencounters tempencount
;;;;;print word " RScounter
;set updatepP2b ( ((lambda)*(origpvaluep2)) + ((1 - lambda)*(updatepP2a)) )
;set offer replace-item 3 offer updatepP2b
]
]
]
]
]

ifelse (hivstatusP1 != hivstatusP2) ;;one player is HIV + and one is not
and HIV WILL NOT spread
[ask partner1
[ set RScounter ((item 17 offer)+ 1)
set offer replace-item 17 offer RScounter
set tempencount ((item tempturnum2 encounters)+ 1)
set encounters replace-item tempturnum2 encounters tempencount
set tempencount ((item tempturnum2 RSencounters)+ 1)
set RSencounters replace-item tempturnum2 RSencounters tempencount
;;;;;print word " RScounter
;set updatepP1b ( ((lambda)*(origpvaluep1)) + ((1 - lambda)*(updatepP1a)) )
;set offer replace-item 3 offer updatepP1b
]

ask self
[ set RScounter ((item 17 offer)+ 1)
set offer replace-item 17 offer RScounter
set tempencount ((item tempturnum1 encounters)+ 1)
set encounters replace-item tempturnum1 encounters tempencount
set tempencount ((item tempturnum1 RSencounters)+ 1)
set RSencounters replace-item tempturnum1 RSencounters tempencount
;;;;;print word " RScounter

241
;;;If players have same HIV status, meaning no spread
[ask partner1
[ set RScounter ((item 17 offer)+ 1)
set offer replace-item 17 offer RScounter
set tempencount ((item tempturnum2 encounters)+ 1)
set encounters replace-item tempturnum2 encounters tempencount
set tempencount ((item tempturnum2 RSencounters)+ 1)
set RSencounters replace-item tempturnum2 RSencounters tempencount
;;;;;print word " " RScounter
;set updateP1b ( ((lambda)*(origpvaluep1)) + ((1 - lambda)*(updateP1a)) )
;set offer replace-item 3 offer updateP1b
]

ask self
[ set RScounter ((item 17 offer)+ 1)
set offer replace-item 17 offer RScounter
set tempencount ((item tempturnum1 encounters)+ 1)
set encounters replace-item tempturnum1 encounters tempencount
set tempencount ((item tempturnum1 RSencounters)+ 1)
set RSencounters replace-item tempturnum1 RSencounters tempencount
;;;;;print word " " RScounter
;set updateP2b ( ((lambda)*(origpvaluep2)) + ((1 - lambda)*(updateP2a)) )
;set offer replace-item 3 offer updateP2b
]
If Both players engage in PS

Players will have choiceP1b

hivstatusP1

hivstatusP2

ask links [set color blue]

print word " Players will have " choiceP1b

print word " hivstatusP1

print word " hivstatusP2

;create-blue-link-with tempnum1

if (hivstatusP1 = 1 and hivstatusP2 = 1) ;;1 is HIV pos

[ set cumsexactstemp ((item 3 sextotalbytype)+ 1)

set sextotalbytype replace-item 3 sextotalbytype cumsexactstemp

]}

if (hivstatusP1 = 1 and hivstatusP2 = 0) or (hivstatusP1 = 0 and hivstatusP2 = 1) ;;1 is HIV pos

[ set cumsexactstemp ((item 4 sextotalbytype)+ 1)

set sextotalbytype replace-item 4 sextotalbytype cumsexactstemp

]}

if (hivstatusP1 = 0 and hivstatusP2 = 0) ;;1 is HIV pos

[ set cumsexactstemp ((item 5 sextotalbytype)+ 1)

set sextotalbytype replace-item 5 sextotalbytype cumsexactstemp

]}

;create-blue-link-with tempnum1

; [set color yellow]
ifelse (hivstatusP1 != hivstatusP2) ;;one player is HIV + and one is not and HIV WILL spread
[ask partner1
[ ;set own-status 1
set actual-status 1
set offer replace-item 21 offer actual-status
set PScounter ((item 18 offer)+ 1)
;set offer replace-item 4 offer own-status
set offer replace-item 18 offer PScounter
set color red
set tempencount ((item tempturnum2 encounters)+ 1)
set encounters replace-item tempturnum2 encounters tempencount
set tempencount ((item tempturnum2 PSencounters)+ 1)
set PSencounters replace-item tempturnum2 PSencounters tempencount
;;;;;print word " " PScounter
;set updateP1b ( ((lambda)*(origpvaluep1)) + ((1 - lambda)*(updateP1a)) )
;set offer replace-item 3 offer updateP1b
]

ask self
[ ;set own-status 1
set actual-status 1
set offer replace-item 21 offer actual-status
set PScounter ((item 18 offer)+ 1)
;set offer replace-item 4 offer own-status
set offer replace-item 18 offer PScounter
set color red
set tempencount ((item tempturnum1 encounters)+ 1)
set encounters replace-item tempturnum1 encounters tempencount
set tempencount ((item tempturnum1 PSencounters)+ 1)
set PSencounters replace-item tempturnum1 PSencounters tempencount
;;;;;print word " " PScounter
;set updateP2b ( ((lambda)*(origpvaluep2)) + ((1 - lambda)*(updateP2a)) )
;set offer replace-item 3 offer updateP2b
]
one player is HIV + and one is not and HIV WILL NOT spread

[ask partner1
[ set PScounter ((item 18 offer)+ 1)
set offer replace-item 18 offer PScounter
set tempencount ((item tempturnum2 encounters)+ 1)
set encounters replace-item tempturnum2 encounters tempencount
set tempencount ((item tempturnum2 PSencounters)+ 1)
set PSencounters replace-item tempturnum2 PSencounters tempencount
;;;;;print word " " PScounter
;set updateP1b ( ((lambda)*(origpvaluep1)) + ((1 - lambda)*(updateP1a)) )
;set offer replace-item 3 offer updateP1b
]

ask self
[ set PScounter ((item 18 offer)+ 1)
set offer replace-item 18 offer PScounter
set tempencount ((item tempturnum1 encounters)+ 1)
set encounters replace-item tempturnum1 encounters tempencount
set tempencount ((item tempturnum1 PSencounters)+ 1)
set PSencounters replace-item tempturnum1 PSencounters tempencount
;;;;;print word " " PScounter
;set updateP2b ( ((lambda)*(origpvaluep2)) + ((1 - lambda)*(updateP2a)) )
;set offer replace-item 3 offer updateP2b
]
]

]

ifelse (hivstatusP1 != hivstatusP2)
[ask partner1
[ set PScounter ((item 18 offer)+ 1)
set offer replace-item 18 offer PScounter
set tempencount ((item tempturnum2 encounters)+ 1)
set encounters replace-item tempturnum2 encounters tempencount
set tempencount ((item tempturnum2 PSencounters)+ 1)
set PSencounters replace-item tempturnum2 PSencounters tempencount
;set color red
;;;;;print word " " PScounter
;set updateP1b ( ((lambda)*(origvalueP1)) + ((1 - lambda)*(updateP1a)) )
;set offer replace-item 3 offer updateP1b
]

ask self
[
set PScounter ((item 18 offer)+ 1)

set offer replace-item 18 offer PScounter
set tempencount ((item tempturnum1 encounters)+ 1)
set encounters replace-item tempturnum1 encounters tempencount
set tempencount ((item tempturnum1 PSencounters)+ 1)
set PSencounters replace-item tempturnum1 PSencounters tempencount
;set color red
;;;;;print word " " PScounter
;set updateP2b ( ((lambda)*(origvalueP2)) + ((1 - lambda)*(updateP2a)) )
;set offer replace-item 3 offer updateP2b
]
]

[ask partner1
[ set PScounter ((item 18 offer)+ 1)
set offer replace-item 18 offer PScounter
set tempencount ((item tempturnum2 encounters)+ 1)
set encounters replace-item tempturnum2 encounters tempencount
set tempencount ((item tempturnum2 PSencounters)+ 1)
set PSencounters replace-item tempturnum2 PSencounters tempencount

;;;;print word = " PScounter
;set updateP1b ( ((lambda)*(origpvaluep1)) + ((1 - lambda)*(updateP1a)) )
;set offer replace-item 3 offer updateP1b
[
]

ask self
[ set PScounter ((item 18 offer)+ 1)
set offer replace-item 18 offer PScounter
set tempencount ((item tempturnum1 encounters)+ 1)
set encounters replace-item tempturnum1 encounters tempencount
set tempencount ((item tempturnum1 PSencounters)+ 1)
set PSencounters replace-item tempturnum1 PSencounters tempencount
;;;;print word = " PScounter
;set updateP2b ( ((lambda)*(origpvaluep2)) + ((1 - lambda)*(updateP2a)) )
;set offer replace-item 3 offer updateP2b
[
]
]

] ;;;if choices are not same p1 makes new choice if it is then the same sex
will occur otherwise no sex
ask partner1
[ifelse (choiceP2a = (item 0 offer)) ;;If P2 counteroffers RS
[set updateP1a ((item 3 offer)* ((1 - (item 3 offer))*(sigma)))
;set updateP1b ( ((lambda)*(item 3 offer)) + ((1 - lambda)*(updateP1a)) )
;print word " actor1 updated perceived p " updateP1b
set updateP1a ( beta *((alpha) + (( 1 - (alpha))*(item 3 offer)))
+ (1 - beta) * prevalence )
set offer replace-item 3 offer updateP1a
ifelse ( (item 4 offer) != 0) ;;item 4 offer 0 is HIV-, 1 is HIV+
[set EU11RS (item 3 offer)*(item 5 offer) + (1 + (-1)*(item 3 offer))* (item 8 offer)
set EU11PS (item 3 offer)*(item 6 offer) + (1 + (-1)*(item 3 offer))* (item 9 offer)
set EU11NS (item 3 offer)*(item 7 offer) + (1 + (-1)*(item 3 offer))* (item 10 offer)

; if ( (EU11RS >= EU11PS) and (EU11RS >= EU11NS))
; [set partner-action (item 0 offer)] ;;0 is RS
; if ( (EU11PS > EU11RS) and (EU11PS >= EU11NS))
; [set partner-action (item 1 offer)] ;;1 is PS
; if ( (EU11NS > EU11RS) and (EU11NS > EU11PS))
; [set partner-action (item 2 offer)] ;;2 is NS
ifelse (EU11RS >= EU11NS)
[set partner-action (item 0 offer)] ;;0 is RS
[set partner-action (item 2 offer)] ;;2 is NS

set print-partner1 n-values 6 [0]
set print-partner1 replace-item 0 print-partner1 self
set print-partner1 replace-item 1 print-partner1 partner-action
set print-partner1 replace-item 2 print-partner1 (item 4 offer)
set print-partner1 replace-item 3 print-partner1 EU11RS

248
set print-partner1 replace-item 4 print-partner1 EU11PS
set print-partner1 replace-item 5 print-partner1 EU11NS

;print word " Actor1 (part2)=" print-partner1
set choiceP1b partner-action
set hivstatusP1 (item 21 offer)
]

[set EU10RS (item 3 offer)*(item 11 offer) + (1 + (-1)*(item 3 offer))% (item 14 offer)
set EU10PS (item 3 offer)*(item 12 offer) + (1 + (-1)*(item 3 offer))% (item 15 offer)
set EU10NS (item 3 offer)*(item 13 offer) + (1 + (-1)*(item 3 offer))% (item 16 offer)

; if ( (EU10RS >= EU10PS) and (EU10RS >= EU10NS))
; [set partner-action (item 0 offer)] ;0 is RS
; if ( (EU10PS > EU10RS) and (EU10PS >= EU10NS))
; [set partner-action (item 1 offer)] ;1 is PS
; if ( (EU10NS > EU10RS) and (EU10NS > EU10PS))
; [set partner-action (item 2 offer)] ;2 is NS

ifelse (EU10RS >= EU10NS)
[set partner-action (item 0 offer)]
[set partner-action (item 2 offer)]

set print-partner1 n-values 6 [0]
set print-partner1 replace-item 0 print-partner1 self
set print-partner1 replace-item 1 print-partner1 partner-action
set print-partner1 replace-item 2 print-partner1 (item 4 offer)
set print-partner1 replace-item 3 print-partner1 EU10RS
set print-partner1 replace-item 4 print-partner1 EU10PS
set print-partner1 replace-item 5 print-partner1 EU10NS

;print word " Actor1 (part2)=" print-partner1
set choiceP1b partner-action
set hivstatusP1 (item 21 offer)
]
; If Player 2 counteroffers PS
[
; set updateP1a ((item 3 offer) - ((item 3 offer) - 0)*sigma))
; set updateP1b (((lambda)*(item 3 offer)) + ((1 - lambda)*(updateP1a)))
; print word " actor1 updated perceived p " updateP1b
set updateP1a (beta * ((1 - alpha)*(item 3 offer)) + ((1 - beta) * prevalence))
set offer replace-item 3 offer updateP1a

ifelse (item 4 offer) != 0 ;; item 4 offer 0 is HIV-, 1 is HIV+... Assume he is HIV+
[ set EU11RS (item 3 offer)*(item 5 offer) + (1 + (-1)*(item 3 offer))* (item 8 offer)
set EU11PS (item 3 offer)*(item 6 offer) + (1 + (-1)*(item 3 offer))* (item 9 offer)
set EU11NS (item 3 offer)*(item 7 offer) + (1 + (-1)*(item 3 offer))* (item 10 offer)

; by setting item1 offer, player 1 is always choosing PS
; if (EU11RS >= EU11PS) and (EU11RS >= EU11NS)
; [set partner-action (item 0 offer)]; 0 is RS
; if (EU11PS > EU11RS) and (EU11PS >= EU11NS)
; [set partner-action (item 1 offer)]; 1 is PS
; if (EU11NS > EU11RS) and (EU11NS > EU11PS)
; [set partner-action (item 2 offer)]; 2 is NS

ifelse (EU11PS >= EU11NS)
[set partner-action (item 1 offer)]; 1 is PS
[set partner-action (item 2 offer)]; 2 is NS
set print-partner1 n-values 6 [0]
set print-partner1 replace-item 0 print-partner1 self
set print-partner1 replace-item 1 print-partner1 partner-action
set print-partner1 replace-item 2 print-partner1 (item 4 offer)
set print-partner1 replace-item 3 print-partner1 EU11RS
set print-partner1 replace-item 4 print-partner1 EU11PS
set print-partner1 replace-item 5 print-partner1 EU11NS

;print word " Actor1 (part2)=" print-partner1
set choiceP1b partner-action
set hivstatusP1 (item 21 offer)
]
[set EU10RS (item 3 offer)*(item 11 offer) + (1 + (-1)*(item 3 offer))* (item 14 offer)
set EU10PS (item 3 offer)*(item 12 offer) + (1 + (-1)*(item 3 offer))* (item 15 offer)
set EU10NS (item 3 offer)*(item 13 offer) + (1 + (-1)*(item 3 offer))* (item 16 offer)

; if ( (EU10RS >= EU10PS) and (EU10RS >= EU10NS))
; [set partner-action (item 0 offer)] ;;0 is RS
; if ( (EU10PS > EU10RS) and (EU10PS >= EU10NS))
; [set partner-action (item 1 offer)] ;;1 is PS
; if ( (EU10NS > EU10RS) and (EU10NS > EU10PS))
; [set partner-action (item 2 offer)] ;;2 is NS
ifelse (EU10RS >= EU10NS)
[set partner-action (item 0 offer)]
[set partner-action (item 2 offer)]

set print-partner1 n-values 6 [0]
set print-partner1 replace-item 0 print-partner1 self
set print-partner1 replace-item 1 print-partner1 partner-action
set print-partner1 replace-item 2 print-partner1 (item 4 offer)
set print-partner1 replace-item 3 print-partner1 EU10RS
set print-partner1 replace-item 4 print-partner1 EU10PS
set print-partner1 replace-item 5 print-partner1 EU10NS
\(\text{;print word " Actor1 (part2)=" print-partner1}\)

set choiceP1b partner-action

set hivstatusP1 (item 21 offer)
]
]

\(\text{;print word " Actor1 (part2)=" print-partner1}\)

set choiceP1b partner-action

set hivstatusP1 (item 21 offer)
]

ifelse choiceP1b = choiceP2a
[
ifelse choiceP1b = "RS"
[;print word " Players will have " choiceP1a
;print word " hivstatusP1
;print word " hivstatusP2

if (hivstatusP1 = 1 and hivstatusP2 = 1) ;;1 is HIV pos
[ set cumexactstemp ((item 0 sextotalbytype)* 1)
set sextotalbytype replace-item 0 sextotalbytype cumexactstemp
]
if (hivstatusP1 = 1 and hivstatusP2 = 0) or (hivstatusP1 = 0 and hivstatusP2 = 1) ;; 1 is HIV pos
[ set cumsexactstemp ((item 1 sextotalbytype)+ 1)
set sextotalbytype replace-item 1 sextotalbytype cumsexactstemp
]
if (hivstatusP1 = 0 and hivstatusP2 = 0) ;; 1 is HIV pos
[ set cumsexactstemp ((item 2 sextotalbytype)+ 1)
set sextotalbytype replace-item 2 sextotalbytype cumsexactstemp
]
; set tempnum2 item 0 print-partner1
; ask link (item 0 print-self) (item 0 print-partner1)
; ask link tempnum1 tempnum2
; ask links with [[self] of end1 and [partner1] of end2]
; [ set color red]
; ask self [create-blue-link-to partner1]
; print word " tempnum1=" tempnum1
; create-blue-link-with tempnum1
; [ set color blue]
; ; Here probability of spread for RS
set exnum1 1
; set spreadRS 0.85
set exnum1 random-float exnum1 ;; random number between 0 and exnum1
ifelse exnum1 < spreadRS
[

ifelse (hivstatusP1 != hivstatusP2) ;; one player is HIV +
and one is not and HIV WILL spread
[ ask partner1
[ ; set own-status 1
set actual-status 1
set offer replace-item 21 offer actual-status
set RScounter ((item 17 offer)+ 1)
; set offer replace-item 4 offer own-status
set offer replace-item 17 offer RScounter
]
set color red

set tempencount ((item tempturnum2 encounters)+ 1)
set encounters replace-item tempturnum2 encounters tempencount
set tempencount ((item tempturnum2 RSencounters)+ 1)
set RSencounters replace-item tempturnum2 RSencounters tempencount

;;;;;print word " RScounter
;set updatepP1b ( ((lambda)*(item 3 offer)) + ((1 - lambda)*(updatepP1a)) )
;set updatepP1b ( ((lambda)*(origpvaluep1)) + ((1 - lambda)*(updatepP1a)) )
;set offer replace-item 3 offer updatepP1b
]

ask self
[ ;set own-status 1
set actual-status 1
set offer replace-item 21 offer actual-status
set RScounter ((item 17 offer)+ 1)
;set offer replace-item 4 offer own-status
set offer replace-item 17 offer RScounter
set color red
set tempencount ((item tempturnum1 encounters)+ 1)
set encounters replace-item tempturnum1 encounters tempencount
set tempencount ((item tempturnum1 RSencounters)+ 1)
set RSencounters replace-item tempturnum1 RSencounters tempencount

;set updatepP2b ( ((lambda)*(origpvaluep2)) + ((1 - lambda)*(updatepP2a)) )
;set offer replace-item 3 offer updatepP2b
;;;;;print word " RScounter
]
]

;;;;;If players have same HIV status, meaning no spread
[ask partner1
[ set RScounter ((item 17 offer)+ 1)
set offer replace-item 17 offer RScounter
set tempencount ((item tempturnum2 encounters)+ 1)
set encounters replace-item tempturnum2 encounters tempencount
set tempencount ((item tempturnum2 RSencounters)+ 1)
set RSencounters replace-item tempturnum2 RSencounters tempencount

;;;;print word " RScounter
;set updatepP1b ( ((lambda)*(origpvaluep1)) + ((1 - lambda)*(updatepP1a)) )
;set offer replace-item 3 offer updatepP1b
]

ask self
[ set RScounter ((item 17 offer)+ 1)
set offer replace-item 17 offer RScounter
set tempencount ((item tempturnum1 encounters)+ 1)
set encounters replace-item tempturnum1 encounters tempencount
set tempencount ((item tempturnum1 RSencounters)+ 1)
set RSencounters replace-item tempturnum1 RSencounters tempencount

;;;;print word " RScounter
;set updatepP2b ( ((lambda)*(origpvaluep2)) + ((1 - lambda)*(updatepP2a)) )
;set offer replace-item 3 offer updatepP2b
]
]
]
]
]
[

ifelse (hivstatusP1 != hivstatusP2) ;;one player is HIV + and one is not
and HIV WILL NOT spread
[ask partner1
[ set RScounter ((item 17 offer)+ 1)
set offer replace-item 17 offer RScounter
set tempencount ((item tempturnum2 encounters)+ 1)
set encounters replace-item tempturnum2 encounters tempencount
set tempencount ((item tempturnum2 RSencounters)+ 1)
set RSencounters replace-item tempturnum2 RSencounters tempencount

;;;;print word " RScounter
;set updatepP1b ( ((lambda)*(origpvaluep1)) + ((1 - lambda)*(updatepP1a)) )
;set offer replace-item 3 offer updatepP1b

255
ask self
[ set RScounter ((item 17 offer)+ 1)
set offer replace-item 17 offer RScounter
set tempencount ((item tempturnum1 encounters)+ 1)
set encounters replace-item tempturnum1 encounters tempencount
set tempencount ((item tempturnum1 RSencounters)+ 1)
set RSencounters replace-item tempturnum1 RSencounters tempencount
;;;;;print word " " RScounter
;set updateP2b ( ((lambda)*(origpvaluep2)) + ((1 - lambda)*(updateP2a)) )
;set offer replace-item 3 offer updateP2b
]
]

;;;;If players have same HIV status, meaning no spread
[ask partner1
[ set RScounter ((item 17 offer)+ 1)
set offer replace-item 17 offer RScounter
set tempencount ((item tempturnum2 encounters)+ 1)
set encounters replace-item tempturnum2 encounters tempencount
set tempencount ((item tempturnum2 RSencounters)+ 1)
set RSencounters replace-item tempturnum2 RSencounters tempencount
;;;;;print word " " RScounter
;set updateP1b ( ((lambda)*(origpvaluep1)) + ((1 - lambda)*(updateP1a)) )
;set offer replace-item 3 offer updateP1b
]
]

ask self
[ set RScounter ((item 17 offer)+ 1)
set offer replace-item 17 offer RScounter
set tempencount ((item tempturnum1 encounters)+ 1)
set encounters replace-item tempturnum1 encounters tempencount
set tempencount ((item tempturnum1 RSencounters)+ 1)
set RSencounters replace-item tempturnum1 RSencounters tempencount
;;; print word " RScounter
; set updateP2b ( ((lambda)*(origpvalueP2)) + ((1 - lambda)*(updateP2a)) )
; set offer replace-item 3 offer updateP2b
]}
]
]
]
]

;; If Both players engage in PS
[; print word " Players will have " choiceP1b
; print word " HIV statusP1
; print word " HIV statusP2
; ask links [set color blue]
; print word " tempnum1= " tempnum1

if (hivstatusP1 = 1 and hivstatusP2 = 1) ;; 1 is HIV pos
[ set cumsexactstemp ((item 3 sextotalbytype)+ 1)
set sextotalbytype replace-item 3 sextotalbytype cumsexactstemp
]

if (hivstatusP1 = 1 and hivstatusP2 = 0) or (hivstatusP1 = 0 and hivstatusP2 = 1) ;; 1 is HIV pos
[ set cumsexactstemp ((item 4 sextotalbytype)+ 1)
set sextotalbytype replace-item 4 sextotalbytype cumsexactstemp
]

if (hivstatusP1 = 0 and hivstatusP2 = 0) ;; 1 is HIV pos
[ set cumsexactstemp ((item 5 sextotalbytype)+ 1)
set sextotalbytype replace-item 5 sextotalbytype cumsexactstemp
]
;Here probability of spread for PS
set exnum2 1
;set spreadPS 0.25
set exnum2 random-float exnum2 ;;random number between 0 and exnum2
ifelse exnum2 < spreadPS

[ ifelse (hivstatusP1 != hivstatusP2) ;;one player is HIV + and one is not and HIV WILL spread 
[ask partner1
[ ;set own-status 1
set actual-status 1
set offer replace-item 21 offer actual-status
set PScounter ((item 18 offer)+ 1)
;set offer replace-item 4 offer own-status
set offer replace-item 18 offer PScounter
set color red
set tempencount ((item tempturnum2 encounters)+ 1)
set encounters replace-item tempturnum2 encounters tempencount
set tempencount ((item tempturnum2 PSencounters)+ 1)
set PSencounters replace-item tempturnum2 PSencounters tempencount
;;;;print word " " PScounter
;set updateP1b ( ((lambda)*(origpvaluep1)) + ((1 - lambda)*(updateP1a)) )
;set offer replace-item 3 offer updateP1b
]

ask self
[ ;set own-status 1
set actual-status 1
set offer replace-item 21 offer actual-status

258
set PScounter ((item 18 offer)+ 1)
;set offer replace-item 4 offer own-status
set offer replace-item 18 offer PScounter
set color red
set tempencount ((item tempturn1 encounters)+ 1)
set encounters replace-item tempturn1 encounters tempencount
set tempencount ((item tempturn1 PSencounters)+ 1)
set PSencounters replace-item tempturn1 PSencounters tempencount
;;;;;print word " " PScounter
;set updatepP2b ((lambda)*(origpvaluep2)) + ((1 - lambda)*(updatepP2a))
;set offer replace-item 3 offer updatepP2b
]
]

;;one player is HIV + and one is not and HIV WILL NOT spread
[ask partner1
[ set PScounter ((item 18 offer)+ 1)
set offer replace-item 18 offer PScounter
set tempencount ((item tempturn2 encounters)+ 1)
set encounters replace-item tempturn2 encounters tempencount
set tempencount ((item tempturn2 PSencounters)+ 1)
set PSencounters replace-item tempturn2 PSencounters tempencount
;;;;;print word " " PScounter
;set updateP1b ((lambda)*(origpvaluep1)) + ((1 - lambda)*(updateP1a))
;set offer replace-item 3 offer updateP1b
]

ask self
[ set PScounter ((item 18 offer)+ 1)
set offer replace-item 18 offer PScounter
set tempencount ((item tempturn1 encounters)+ 1)
set encounters replace-item tempturn1 encounters tempencount
set tempencount ((item tempturn1 PSencounters)+ 1)
set PSencounters replace-item tempturn1 PSencounters tempencount
;;;;;print word " " PScounter

259
\[ \text{ifelse (hivstatusP1 != hivstatusP2)} \]
\[ \text{ask partner1} \]
\[ \text{set PScounter ((item 18 offer)+ 1)} \]

\[ \text{set offer replace-item 18 offer PScounter} \]
\[ \text{set tempencount ((item tempturnum2 encounters)+ 1)} \]
\[ \text{set encounters replace-item tempturnum2 encounters tempencount} \]
\[ \text{set tempencount ((item tempturnum2 PSencounters)+ 1)} \]
\[ \text{set PSencounters replace-item tempturnum2 PSencounters tempencount} \]
\[ \text{set color red} \]
\[ \text{;;;;print word " PScounter} \]
\[ \text{set updatepP2b ( ((lambda)*(origpvaluep2)) + ((1 - lambda)*(updatepP2a)) )} \]
\[ \text{set offer replace-item 3 offer updatepP2b} \]

\[ \text{ask self} \]
\[ \text{set PScounter ((item 18 offer)+ 1)} \]

\[ \text{set offer replace-item 18 offer PScounter} \]
\[ \text{set tempencount ((item tempturnum1 encounters)+ 1)} \]
\[ \text{set encounters replace-item tempturnum1 encounters tempencount} \]
\[ \text{set tempencount ((item tempturnum1 PSencounters)+ 1)} \]
\[ \text{set PSencounters replace-item tempturnum1 PSencounters tempencount} \]
\[ \text{set color red} \]
\[ \text{;;;;print word " PScounter} \]
;set updateP2b ( ((lambda)*(origpvalueP2)) + ((1 - lambda)*(updateP2a)) )
;set offer replace-item 3 offer updateP2b
]
]

[ask partner1

[ set PScounter ((item 18 offer)+ 1)
set offer replace-item 18 offer PScounter
set tempencount ((item tempturnum2 encounters)+ 1)
set encounters replace-item tempturnum2 encounters tempencount
set tempencount ((item tempturnum2 PSencounters)+ 1)
set PSencounters replace-item tempturnum2 PSencounters tempencount
;;;;;print word " PScounter
;set updateP1b ( ((lambda)*(origpvalueP1)) + ((1 - lambda)*(updateP1a)) )
;set offer replace-item 3 offer updateP1b
]

ask self
[ set PScounter ((item 18 offer)+ 1)
set offer replace-item 18 offer PScounter
set tempencount ((item tempturnum1 encounters)+ 1)
set encounters replace-item tempturnum1 encounters tempencount
set tempencount ((item tempturnum1 PSencounters)+ 1)
set PSencounters replace-item tempturnum1 PSencounters tempencount
;;;;;print word " PScounter
;set updateP2b ( ((lambda)*(origpvalueP2)) + ((1 - lambda)*(updateP2a)) )
;set offer replace-item 3 offer updateP2b
]
]
]
;print " Didn't agree again. Result NS"
ask partner1
[
if (hivstatusP1 = 1 and hivstatusP2 = 1) ;;1 is HIV pos
[ set cumsexactstemp ((item 6 sextotalbytype)+ 1)
set sextotalbytype replace-item 6 sextotalbytype cumsexactstemp
]
if (hivstatusP1 = 1 and hivstatusP2 = 0) or (hivstatusP1 = 0
and hivstatusP2 = 1) ;;1 is HIV pos
[ set cumsexactstemp ((item 7 sextotalbytype)+ 1)
set sextotalbytype replace-item 7 sextotalbytype cumsexactstemp
]
if (hivstatusP1 = 0 and hivstatusP2 = 0) ;;1 is HIV pos
[ set cumsexactstemp ((item 8 sextotalbytype)+ 1)
set sextotalbytype replace-item 8 sextotalbytype cumsexactstemp
]
set NScounter ((item 19 offer)+ 1)
set offer replace-item 19 offer NScounter
set tempencount ((item tempturnum2 NSencounters)+ 1)
set NSencounters replace-item tempturnum2 NSencounters tempencount
;;;;;print word " NScounter
;set updateP1b ( ((lambda)*(origpvaluep1)) + ((1 - lambda)*(updateP1a)) )
;set offer replace-item 3 offer updateP1b
]

ask self
[ set NScounter ((item 19 offer)+ 1)
set offer replace-item 19 offer NScounter
set tempencount ((item tempturnum1 NSencounters)+ 1)
set NSencounters replace-item tempturnum1 NSencounters tempencount
;;;;;print word " NScounter
;set updateP2b ( ((lambda)*(origpvaluep2)) + ((1 - lambda)*(updateP2a)) )
;set offer replace-item 3 offer updateP2b
]
]
[ set self-action (item 2 offer) ]
set print-self n-values 2 [0]
set print-self replace-item 0 print-self self
set print-self replace-item 1 print-self self-action
;;;;;print word = "actor1 alone = " print-self
]

;update-plot

;;;;Afterwards you can remove print statements
;;;;Need to implement next stage of interaction now that their preferences have been established.
;;;;Need to keep track of HIV pos players in game (infection)
;;;;How do we update p?
;;;;How do we accept or reject?
The Players HIV status will effect their utility function, with a different numerical value representing different sexual outcomes, with each player trying to optimize this outcome.

to findprevalence
set i 0 ;Set i to 0
set infected 0
while [i < num]
[ ask turtle i
[ if (color = red)
[ set infected infected + 1 ]
]
set i i + 1
]
set prevalence infected / num ;* 100
end
to setup-plot
  set-current-plot "Population"
  set-plot-y-range 0 (num + 10)
end

; to update-plot
  set-current-plot "Population"
  ; set-current-plot-pen "Uncoupled"
  ; plot count turtles with [not infected?]
  ; set-current-plot-pen "Coupled"
  ; plot count turtles with [infected?] -
  ; count turtles with [known?]
  set-current-plot-pen "HIV+
  plot count turtles with [actual-status = 1 and own-status = 1];
  ; own-status = 1 or
  set-current-plot-pen "HIV-
  plot count turtles with [actual-status = 0]
set-current-plot-pen "HIV+dontknow"
plot count turtles with [actual-status = 1 and own-status = 0]
end

; to getjustp
; set i 0
; while [i < num]
; [
;   ask turtle i
;     [ let theps (item 3 offer)
;       print theps
;       set i i + 1
;     ]
; ]
; end
to write-data-initial
file-delete "data-test.txt"
set i 0
set listturtlenum n-values num [0]
while [i < num]
  [set listturtlenum replace-item i listturtlenum i set i i + 1]
] ;print listturtlenum
file-open "data-test.txt"
file-print listturtlenum
file-close
file-open "data-test.txt"
set j 0
set listinitialp n-values num [0]
let temporaryp 100
while [j < num]
  [ask turtle j
   [set temporaryp (item 3 offer)]
   set listinitialp replace-item j listinitialp temporaryp
   set j j + 1]
] ;print listinitialp
file-print listinitialp
file-close
end

to write-data
  file-open "data-test.txt"
  set j 0
  set listgen n-values num [0]
  let temporaryp 100
  while [j < num]
  [  
    ask turtle j
    [ 
      set temporaryp (item 3 offer)
    ]
    set listgen replace-item j listgen temporaryp
    set j j + 1
  ]
  ;print listgen
  file-print listgen
  file-close
end

to write-data-initial2
  file-delete "data-test2.txt"
  set i 0
  set listturtlenum n-values num [0]
  while [i < num]
  [  
    set listturtlenum replace-item i listturtlenum i
    set i i + 1
  ]
  ;print listturtlenum
  file-open "data-test2.txt"
file-print listturtlenum
file-close
;file-open "data-test2.txt"
;set j 0
; set listinitialp n-values num [0]
; let temporaryp 100
; while [j < num]
 ; [     
 ;     ask turtle j
 ;     [     
 ;     set temporaryp (item 3 offer)
 ;     ]     
 ;     set listinitialp replace-item j listinitialp temporaryp
 ;     set j j + 1
 ; ]
; print listinitialp
;file-print listinitialp
;file-close
end

;to write-data2
;file-open "data-test2.txt"
;set j 0
; set listgen n-values num [0]
; let temporaryp 100
; while [j < num]
 ; [     
 ;     ask turtle j
 ;     [     
 ;     set temporaryp (item 3 offer)
 ;     ]     
 ;     set listgen replace-item j listgen temporaryp
 ;     set j j + 1

269
;;;print listgen
;file-print listgen
;file-close
;
; ;turtle 1 [ count my-blue-links ] to turtle 0
;; ask turtle 1
;;[
;; show my-blue-links ;; shows an agentset containing the link 0 1
;]
;end

;to write-data2
;file-open "data-test2.txt"
;set i 0
;set j 0
; set listgen n-values num [0]
;let temporaryp 100
; while [i < num]
; [  
;   ask turtle j
;    [  
;      ; set temporaryp (item 3 offer)
;    ]
; set listgen replace-item j listgen temporaryp
; set j j + 1
; ]
;;print listgen
;file-print listgen
;file-close
;
; println [ count my-blue-links ] of turtle 0
;
;end

270
to write-data2
file-open "data-test2.txt"
set i 0
set j 0
set listgenlinks n-values num [0]
let temporarylinks 100
while [j < num]
[ while [i < num]
[ ask turtle j
  [ set temporarylinks [ count my-blue-links ] of turtle j
  ]
  set listgenlinks replace-item i listgenlinks temporarylinks
  set i i + 1
  ]
set j j + 1
file-print listgenlinks
set i 0
] file-close
end

to write-data3
file-delete "data-test3.txt"
set i 0
set listturencount n-values num [0]
; while [i < num]
  [  
    set listturrencount replace-item i listturrencount i  
    set i i + 1  
  ]  
  ;print listturtlenum  
;file-open "data-test3.txt"  
;file-print listturrencount  
;file-close  
;file-open "data-test3.txt"  
;set j 0  
;set i 0  
;set listencount n-values num [0]  
;let temporaryencount 100  
; while [j < num]
  [  
    while [i < num]
      [  
        ask turtle j  
        [  
          set temporaryencount (item i encounters)  
        ]  
        set listencount replace-item j listencount temporaryencount  
        set i i + 1  
      ]  
    file-print listencount  
    print listencount  
    set j j + 1  
    set i 0  
  ]  
  ;;print listencount  
  ;file-close
end
to write-data3
  file-delete "data-test3.txt"
  file-open "data-test3.txt"
  set j 0
  ;set listencount n-values num [0]
  ;let temporaryencount 100
  while [j < num]
    [ask turtle j
     [file-print encounters
     ]
     set j j + 1
     ]
  ;print listencount
  file-close
end

to write-data4
  file-delete "data-test4.txt"
  file-open "data-test4.txt"
  set j 0
  ;set listencount n-values num [0]
  ;let temporaryencount 100
  while [j < num]
    [ask turtle j
     [file-print RSencounters
     ]
     set j j + 1
     ]
  ;print listencount
  file-close
end
to write-data5
file-delete "data-test5.txt"
file-open "data-test5.txt"
set j 0
;set listencount n-values num [0]
;let temporaryencount 100
while [j < num]
[     ask turtle j
[         file-print PSencounters
 ]
set j j + 1
]
;set listencount
file-close
drop
end

to write-data6
file-delete "data-test6.txt"
file-open "data-test6.txt"
set j 0
;set listencount n-values num [0]
;let temporaryencount 100
while [j < num]
[      ask turtle j
[         file-print NSencounters
 ]
set j j + 1
]
;set listencount
file-close

to write-data7
file-open "data-test7.txt"
file-print hivnegavgp
file-close
end

to write-data7initial
file-delete "data-test7.txt"
file-open "data-test7.txt"
file-print hivnegavgp
file-close
end

to write-data8
file-open "data-test8.txt"
file-print hivposavgp
file-close
end

to write-data8initial
file-delete "data-test8.txt"
file-open "data-test8.txt"
file-print hivposavgp
file-close
end

to write-data9
file-open "data-test9.txt"
file-print totalhivpos
file-close
end

to write-data9initial
file-delete "data-test9.txt"
file-open "data-test9.txt"
file-print totalhivpos
file-close
end
to write-data9
file-open "data-test9.txt"
file-print totalhivpos
file-close
end

to getavgp
set i 0
set hivposavgp 0
set hivnegavgp 0
set hivposdontknow 0
while [i < num]
[ ask turtle i
[ if (actual-status = 0)
[ set thenegp (item 3 offer)
set hivnegavgp (hivnegavgp + thenegp / (count turtles with [actual-status = 0]))
;print thenegp
]
if (actual-status = 1) and (own-status = 1) ;;meaning they are hiv+ and know they are
[ set theposp (item 3 offer)
set hivposavgp (hivposavgp + theposp / (count turtles with [own-status = 1 and
actual-status = 1] ))
;print theposp
]
if (actual-status = 1) and (own-status = 0) ;;meaning they are hiv+ and dont know they are
[ set thepospdontknow (item 3 offer)
set hivposdontknow (hivposdontknow + thepospdontknow / (count turtles with [own-status = 0 and actual-status = 1] ))
;print theposp
]
set i i + 1
]
;ask turtle i
;
; [  
; ifelse (own-status = 0)
 ;   [ set thenegp (item 3 offer)  
;       set hivnegavgp (hivnegavgp + thenegp / (count turtles with [own-status = 0])))  
;print thenegp
; ]
; [ set theposp (item 3 offer)
;   set hivposavgp (hivposavgp + theposp / (count turtles with [own-status = 1])))
;print theposp
; ]
; set i i + 1
; ]
]

set j 0
set avgtotalp 0
while [j < num]
[
ask turtle j

[ set theturtlep (item 3 offer)
set avgtotalp (avgtotalp + theturtlep / (count turtles))
]

set j j + 1
]
;print avgtotalp

set i 0
set hivprevpercent 0
set hivprevpercentdontknow 0
set totalhivpos 0
set totalhivposdontknow 0
while [i < num]
[
ask turtle i
[
if (actual-status = 1) and (own-status = 1)
[ set totalhivpos totalhivpos + 1
]
if (actual-status = 1) and (own-status = 0)
[ set totalhivposdontknow totalhivposdontknow + 1
]
]
set i i + 1
]
set hivprevpercent (totalhivpos / (count turtles))
set hivprevpercentdontknow (totalhivposdontknow / (count turtles))
;print hivprevpercent
end

to setup-plot2
set-current-plot "Average P"
;set-plot-y-range 0 (num + 1)
end

to update-plot2
set-current-plot "Average P"
set-current-plot-pen "hivnegavgp"
plot hivnegavgp
set-current-plot-pen "hivposavgp"
plot hivposavgp
set-current-plot-pen "hivposdontknow"
plot hivposdontknow
end

to setup-plot3
set-current-plot "Average P"
;set-plot-y-range 0 (num + 1)
end

to update-plot3
; set-current-plot "Individual P Values"
; set-current-plot-pen "Player 0"
; ask turtle 0
; [ set player0p (item 3 offer) ]
; plot player0p
;
; set-current-plot-pen "Player 1"
; ask turtle 1
; [ set player1p (item 3 offer) ]
; plot player1p
;
; set-current-plot-pen "Player 2"
; ask turtle 2
; [ set player2p (item 3 offer) ]
; plot player2p
;
; set-current-plot-pen "Player 3"
; ask turtle 3
; [ set player3p (item 3 offer) ]
; plot player3p
;
; set-current-plot-pen "Player 4"
; ask turtle 4
; [ set player4p (item 3 offer) ]
; plot player4p
;
; set-current-plot-pen "Player 5"
; ask turtle 5
; [ set player5p (item 3 offer) ]
; plot player5p
;
; set-current-plot-pen "Player 6"
; ask turtle 6
; [ set player6p (item 3 offer) ]
; plot player6p
;
; set-current-plot-pen "Player 7"
; ask turtle 7
; [ set player7p (item 3 offer) ]
; plot player7p
;
; set-current-plot-pen "Player 8"
; ask turtle 8
; [ set player8p (item 3 offer) ]
; plot player8p
;
; set-current-plot-pen "Player 9"
; ask turtle 9
; [ set player9p (item 3 offer) ]
; plot player9p
;
; set-current-plot-pen "Player 10"
; ask turtle 10
; [ set player10p (item 3 offer) ]
; plot player10p
;
; set-current-plot-pen "Player 11"
; ask turtle 11
; [ set player11p (item 3 offer) ]
; plot player11p
;
; set-current-plot-pen "Player 12"
; ask turtle 12
; [ set player12p (item 3 offer) ]
; plot player12p
;
; set-current-plot-pen "Player 13"
; ask turtle 13
; [ set player13p (item 3 offer) ]
; plot player13p
;
; set-current-plot-pen "Player 14"
; ask turtle 14
; [ set player14p (item 3 offer) ]
; plot player14p
;
; set-current-plot-pen "Player 15"
; ask turtle 15
; [ set player15p (item 3 offer) ]
; plot player15p
;
; set-current-plot-pen "Player 16"
; ask turtle 16
; [ set player16p (item 3 offer) ]
; plot player16p
;
; set-current-plot-pen "Player 17"
; ask turtle 17
; [ set player17p (item 3 offer) ]
; plot player17p
;
; set-current-plot-pen "Player 18"
; ask turtle 18
; [ set player18p (item 3 offer) ]
; plot player18p
;
; set-current-plot-pen "Player 19"
; ask turtle 19
;   [ set player19p (item 3 offer) ]
; plot player19p
;
; set-current-plot-pen "Player 20"
; ask turtle 20
;   [ set player20p (item 3 offer) ]
; plot player20p
;
; set-current-plot-pen "Player 21"
; ask turtle 21
;   [ set player21p (item 3 offer) ]
; plot player21p
;
; set-current-plot-pen "Player 22"
; ask turtle 22
;   [ set player22p (item 3 offer) ]
; plot player22p
;
; set-current-plot-pen "Player 23"
; ask turtle 23
;   [ set player23p (item 3 offer) ]
; plot player23p
;
; set-current-plot-pen "Player 24"
; ask turtle 24
;   [ set player24p (item 3 offer) ]
; plot player24p
;
; set-current-plot-pen "Player 25"
; ask turtle 25
;   [ set player25p (item 3 offer) ]
; plot player25p
;
; set-current-plot-pen "Player 26"
; ask turtle 26
;    [ set player26p (item 3 offer) ]
; plot player26p
;
; set-current-plot-pen "Player 27"
; ask turtle 27
;    [ set player27p (item 3 offer) ]
; plot player27p
;
; set-current-plot-pen "Player 28"
; ask turtle 28
;    [ set player28p (item 3 offer) ]
; plot player28p
;
; set-current-plot-pen "Player 29"
; ask turtle 29
;    [ set player29p (item 3 offer) ]
; plot player29p
;
; set-current-plot-pen "Player 30"
; ask turtle 30
;    [ set player30p (item 3 offer) ]
; plot player30p
;
; set-current-plot-pen "Player 31"
; ask turtle 31
;    [ set player31p (item 3 offer) ]
; plot player31p
;
; set-current-plot-pen "Player 32"
; ask turtle 32
;    [ set player32p (item 3 offer) ]
; plot player32p
;
; set-current-plot-pen "Player 33"
; ask turtle 33
; [ set player33p (item 3 offer) ]
; plot player33p
;
; set-current-plot-pen "Player 34"
; ask turtle 34
; [ set player34p (item 3 offer) ]
; plot player34p
;
; set-current-plot-pen "Player 35"
; ask turtle 35
; [ set player35p (item 3 offer) ]
; plot player35p
;
; set-current-plot-pen "Player 36"
; ask turtle 36
; [ set player36p (item 3 offer) ]
; plot player36p
;
; set-current-plot-pen "Player 37"
; ask turtle 37
; [ set player37p (item 3 offer) ]
; plot player37p
;
; set-current-plot-pen "Player 38"
; ask turtle 38
; [ set player38p (item 3 offer) ]
; plot player38p
;
; set-current-plot-pen "Player 39"
; ask turtle 39
; [ set player39p (item 3 offer) ]
; plot player39p
;
end
to writecumsexactbytype
set j 0
set tempnum3 0
set totalRSpospos 0
set totalRSposneg 0
set totalRSnegneg 0
set totalPSpospos 0
set totalPSposneg 0
set totalPSnegneg 0
set totalNSpospos 0
set totalNSposneg 0
set totalNSnegneg 0

while [j < num]
[ ask turtle j
[ set tempnum3 (item 0 sextotalbytype)
set totalRSpospos (totalRSpospos + tempnum3)
set tempnum4 (item 1 sextotalbytype)
set totalRSposneg (totalRSposneg + tempnum4)
set tempnum5 (item 2 sextotalbytype)
set totalRSnegneg (totalRSnegneg + tempnum5)
set tempnum6 (item 3 sextotalbytype)
set totalPSpospos (totalPSpospos + tempnum6)
set tempnum7 (item 4 sextotalbytype)
set totalPSposneg (totalPSposneg + tempnum7)
set tempnum8 (item 5 sextotalbytype)
set totalPSnegneg (totalPSnegneg + tempnum8)
set tempnum9 (item 6 sextotalbytype)
set totalNSpospos (totalNSpospos + tempnum9)
set tempnum10 (item 7 sextotalbytype)
set totalNSposneg (totalNSposneg + tempnum10)
set tempnum11 (item 8 sextotalbytype)
6.2 Simulation Code: Chapter 3

;; Attached Code was again developed using Netlogo software
;; Netlogo is an agent based programming language
;; A user interface needs to be created assign parameter inputs
;; This model builds upon the model outlined in the previous section

;; Accessible variables to all agents
globals [layout? i j initialinfected infected prevalence choiceP1a choiceP2a choiceP1b hivstatusP1 hivstatusP2 exnum1 exnum2 listturtlelist listinitialp listgen listgenlinks tempnum1 tempnum2 tempturnum1 tempturnum2 hivnegavgp hivposavgp hivposdontknow avgtotalp thenegp theposp thepospdontknow theturtlep hivprevpercent hivprevpercentdontknow totalhivpos totalhivposdontknow listturtlenum listencount listturtlenum0 listturtlenum1 listturtlenum2 listturtlenum3 listturtlenum4 listturtlenum5 listturtlenum6 listturtlenum7 listturtlenum8 listturtlenum9 listturtlenum10 listturtlenum11 listturtlenum12 listturtlenum13 listturtlenum14 listturtlenum15 listturtlenum16 listturtlenum17 listturtlenum18 listturtlenum19 listturtlenum20 listturtlenum21 listturtlenum22 listturtlenum23 listturtlenum24 listturtlenum25 listturtlenum26 listturtlenum27 listturtlenum28 listturtlenum29 listturtlenum30 listturtlenum31 listturtlenum32 listturtlenum33 listturtlenum34 listturtlenum35 listturtlenum36 listturtlenum37 listturtlenum38 listturtlenum39

set totalNSnegneg (totalNSnegneg + tempnum11)
]
set j j + 1
]
; print totalRSpospos
; print totalRSposneg
; print totalRSnegneg
; print totalPSpospos
; print totalPSposneg
; print totalPSnegneg
; print totalNSpospos
; print totalNSposneg
; print totalNSnegneg
end
origpvaluep1 origpvaluep2 cumsexactstemp tempnum3 tempnum4 tempnum5 tempnum6 tempnum7
tempnum8 tempnum9 tempnum10 tempnum11
totalRSpospos totalRSposneg totalRSnegneg totalPSpospos totalPSposneg totalPSnegneg
totalNSpospos totalNSposneg totalNSnegneg
tempencounterarraynumber tempencounterarraynumber2 tempencounterarraynumber3 rho c
nointeractionrho
cumsexactsum cumsexactsum100 totalRSpospos100 totalRSnegneg100 totalPSpospos100 totalNSpospos100
totalNSnegneg100
cumsexactsum200 totalRSpospos200 totalRSnegneg200 totalPSpospos200 totalNSpospos200
totalNSnegneg200
cumsexactsum300 totalRSpospos300 totalRSnegneg300 totalPSpospos300 totalNSpospos300
totalNSnegneg300
cumsexactsum400 totalRSpospos400 totalRSnegneg400 totalPSpospos400 totalNSpospos400
totalNSnegneg400
cumsexactsum500 totalRSpospos500 totalRSnegneg500 totalPSpospos500 totalNSpospos500
totalNSnegneg500
cumsexactsum1400 totalRSpospos1400 totalRSnegneg1400 totalPSpospos1400 totalNSpospos1400
totalNSnegneg1400
cumsexactsum1500 totalRSpospos1500 totalRSnegneg1500 totalPSpospos1500 totalNSpospos1500
totalNSnegneg1500
cumsexactsum4900 totalRSpospos4900 totalRSnegneg4900 totalPSpospos4900 totalNSpospos4900
totalNSnegneg4900
cumsexactsum5000 totalRSpospos5000 totalRSnegneg5000 totalPSpospos5000 totalNSpospos5000
totalNSnegneg5000
temptimearray0 temptimearray1 temptimearray2 temptimearray3 temptimearray4 temptimearray5
temptimearray6 temptimearray7 temptimearray8 temptimearray9 temptimearray10 temptimearray11
temptimearray12 temptimearray13
tempHAARTtreatment delta transSpreadP1 transSpreadP2 totalturtles totalturtlesaddedpermonth
plusminus8 totalturtlesEVER
ARTcoverage RSutilitypos HIVnegage hivposage age15 age20 age30 age40 age50 age60 age70
hivnegpop hivpospop incidenceHIV incidenceHIV1520 incidenceHIV2030 incidenceHIV3040
ingcidenceHIV4050 incidenceHIV50+
vacccoverage vacccoveragetheta vaccineefficacy tempvacceff tempinitvacc tempcatchupage
catchupvacc20 tempcatchup20 catchupvacc30 tempcatchup30 lengthofcatchupprogram
tempprovaccov tempprovackno ChanceTested fermidiraca fermidiracp fnctheta startvacc startART
P1theta P2theta thetadecision vacccatchupgroup
thenegp1520 hivnegavgp1520 theposp1520 hivposavgp1520 thepospdontknow1520 hivposdontknow1520
avgtotalp1520 theturtlep1520 hivprevpercent1520 hivprevpercentdontknow1520
totalhivpos1520 totalhivposdontknow1520
thenegp2030 hivnegavgp2030 theposp2030 hivposavgp2030 thepospdontknow2030 hivposdontknow2030
avgtotalp2030 theturtlep2030 hivprevpercent2030 hivprevpercentdontknow2030
totalhivpos2030 totalhivposdontknow2030
thenegp3040 hivnegavgp3040 theposp3040 hivposavgp3040 thepospdontknow3040 hivposdontknow3040
avgtotalp3040 theturtlep3040 hivprevpercent3040 hivprevpercentdontknow3040
totalhivpos3040 totalhivposdontknow3040
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avgtotalp4050 theturtlep4050 hivprevpercent4050 hivprevpercentdontknow4050
totalhivpos4050 totalhivposdontknow4050
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avgtotalp6070 theturtlep6070 hivprevpercent6070 hivprevpercentdontknow6070
totalhivpos6070 totalhivposdontknow6070
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avgtotalp7080 theturtlep7080 hivprevpercent7080 hivprevpercentdontknow7080
totalhivpos7080 totalhivposdontknow7080
thenegp50+ hivnegavgp50+ theposp50+ hivposavgp50+ thepospdontknow50+ hivposdontknow50+
avgtotalp50+ theturtlep50+ hivprevpercent50+ hivprevpercentdontknow50+ totalhivpos50+
totalhivposdontknow50+
avgthetalpha1520 avgthetalpha2030 avgthetalpha3040 avgthetalpha4050 avgthetalpha50+
theta1520 theta2030 theta3040 theta4050 theta50+
tempnum0hiv-3040 tempnum1hiv-3040 tempnum2hiv-3040 tempnum3hiv-3040 tempnum4hiv-3040
tempnum5hiv-3040 tempnum6hiv-3040 tempnum7hiv-3040 tempnum8hiv-3040 tempnum9hiv-3040
totalsumalltypesHIV-3040 totalRSposposHIV-3040 totalRSposnegHIV-3040 totalRSnegnegHIV-3040
totalPSposposHIV-3040 totalPSposnegHIV-3040 totalPSnegnegHIV-3040 totalNSposposHIV-3040
totalNSposnegHIV-3040 totalNSnegnegHIV-3040
totalRSposposHIV-3040percent totalRSposnegHIV-3040percent totalRSnegnegHIV-3040percent
totalPSposposHIV-3040percent totalPSposnegHIV-3040percent totalPSnegnegHIV-3040percent
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<tr>
<td>totalPSposnegHIV-4050</td>
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<td>totalPSnegnegHIV-4050</td>
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<tr>
<td>totalNSposposHIV-50+</td>
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<td>totalNSposnegHIV-50+</td>
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<tr>
<td>totalNSnegnegHIV-50+</td>
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<tr>
<td>Type</td>
<td>HIV-50+</td>
<td>HIV+1520</td>
<td>HIV+2030</td>
<td>HIV+4050</td>
<td>HIV+50+</td>
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<tr>
<td>Total Cumulative</td>
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<td>RS pos.pos.</td>
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<tr>
<td>RS pos.neg.</td>
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<td>RS neg.neg.</td>
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<td>PS pos.pos.</td>
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<td>PS pos.neg.</td>
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<td>PS neg.neg.</td>
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<td>NS pos.pos.</td>
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<td>NS pos.neg.</td>
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<td>NS neg.neg.</td>
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<tr>
<td>Total</td>
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<td>1520</td>
<td>2030</td>
<td>4050</td>
<td>50+</td>
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<tr>
<td>RS pos.pos. percent</td>
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<td>RS pos.neg. percent</td>
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<td>RS neg.neg. percent</td>
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<td>PS pos.pos. percent</td>
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<td>PS neg.neg. percent</td>
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<td>NS pos.pos. percent</td>
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<td>NS pos.neg. percent</td>
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<td>NS neg.neg. percent</td>
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</tbody>
</table>
totalRSposposHIV+50+percent totalRSposnegHIV+50+percent totalRSnegnegHIV+50+percent
totalPSposposHIV+50+percent totalPSposnegHIV+50+percent totalPSnegnegHIV+50+percent
totalNSposposHIV+50+percent totalNSposnegHIV+50+percent totalNSnegnegHIV+50+percent
HIV+turtles1520 HIV+turtles2030 HIV+turtles3040 HIV+turtles4050 HIV+turtles50+ HIV-turtles1520
HIV-turtles2030 HIV-turtles3040 HIV-turtles4050 HIV-turtles50+
numofHIV+temp totalsexactsbyage totalsexactstemp P1ageclass P2ageclass cumUS1520peryear
cumUS2030peryear cumUS3040peryear cumUS4050peryear cumUS50+peryear]

;directed-link-breed [red-links red-link]
;undirected-link-breed [blue-links blue-link]

;links-own[reds blues]

;;Defines variables belonging to each turtle, can only use these variables in turtle commands
turtles-own [  
  own-status  
  actual-status  
  encounter-status  
  action-list  
  offer  
  ;encounters  
  ;RSencounters  
  ;PSencounters  
  ;NSencounters  
  sextotalbytype  
  print-self  
  print-partner1  
  infection-length  
  coupled?  
  partner1  
  self-action  
  self-action1  
  partner-action  
EU20RS  ;;Expected utility for player 2 who is HIV - ,0, for RS
EU20PS
EU20NS
EU21RS
EU21PS
EU21NS
EU10RS
EU10PS
EU10NS
EU11RS
EU11PS
EU11NS
updateP2a ;; Temp variable to update P2's p-value on the first interaction a
updateP2b
updateP1a
updateP1b
RS\text{total} ;; Variable that increases for each player after a RS event. This may be used to assess on what level an actor feels they may unknowingly be infected.
P\text{total}
N\text{total}
RS\text{counter} ;; Temp variable to update each actor's chance of infection belief
PS\text{counter}
NS\text{counter}
temp\text{encount}
time\text{array}
]

; Extensions [matrix]

to setup ;; Creates number of turtles with appropriate list items
;; (for this model to work with NetLogo's new plotting features,
;; __clear-all-and-reset-ticks should be replaced with clear-all at
;; the beginning of your setup procedure and reset-ticks at the end
;; of the procedure.)
__clear-all-and-reset-ticks
reset-ticks
;set infection-chance 50
setup-network

setup-plot
setup-plot2
; setup-plot3
; setup-plotincidence
; update-plot
setup-plot-HIV+byage
setup-plot-HIV-byage
setup-plot-Average-b-value-HIV+--by-age
setup-plot-Average-b-value-HIV--by-age
setup-plot-HIV+prevpercent
; setup-plot-Average-theta-value-by-age
setup-plot-sex-act-percentHIV-3040
setup-plot-sex-act-percentHIV+3040
setup-plot-sex-act-percentHIV-1520
setup-plot-sex-act-percentHIV-2030
setup-plot-sex-act-percentHIV+4050
setup-plot-sex-act-percentHIV-50+
setup-plot-sex-act-percentHIV+1520
setup-plot-sex-act-percentHIV+2030
setup-plot-sex-act-percentHIV+4050
setup-plot-sex-act-percentHIV+50+

;setup-plot-sexactstotalbyageRSHIVnegpos
;setup-plot-sexactstotalbyageRSHIVnegneg
setup-plot-CumUSnegposperyear

;set i 0 ; Set i to 0
set initialinfected 0
set choiceP1a 0
set choiceP2a 0
set choiceP1b 0
set vacccoverage 0;.75;.75;0.75 this serves as current theta and actual coverage!
nee to split this up if you want to investigate differences
set vacccoveragetheta 0;.75;.75 ;0.75
set vacccatchupgroup 0;0.1 ;;0.1May need to change this variable!!!!
;set kdecision 1 ;;Changes results if left as zero when theta is zero!! CAREFUL!!
set startvacc 600 ;the time step the vaccine is introduced
set startART 600 ;the timestep the ART is introduced
set catchupvacc20 0;0.1 ;0.1 this is the percent that will receive coverage for that age class
set catchupvacc30 0;0.05 ;0.05
set lengthofcatchupprogram 120
set vaccineefficacy 0.9
;;; Now have length of theta value, after 15 years, it returns to zero!
;;; PAY attention to the turtles added per month!

;set sigma 0.5
;set lambda 0.9

set totalsexactsbyage n-values 5 [0]

ask turtles
[ set i 0
while [i < 1]
[let p-level random-normal 0.05 0.1;0.1 ;; This is mean 0.05 and standard deviation 0.1
if (p-level > 0) and (p-level < 1)
[ set offer n-values 22 [0] ;;Creates list of 21 O's
set offer replace-item 0 offer "RS" ;;begins to replace items on list
set offer replace-item 1 offer "PS"
set offer replace-item 2 offer "NS"
set p-level precision p-level 3
set offer replace-item 3 offer p-level
set own-status 0 ;;HIV negative (OWN-STATUS is BELIEF of status)

set offer replace-item 4 offer own-status
set offer replace-item 5 offer 100 ;;offer 5,6,7 are the utility function for an
HIV positive actor, for RS, PS, and NS. It is assumed each player wants to maximize
their expected utility. This is for an HIV+ actor with the belief the other actor is HIV+
set offer replace-item 6 offer protectedsexutility
set offer replace-item 7 offer 0

set offer replace-item 8 offer 100 ;;offer 8,9,10 are the utility function for an
HIV positive actor, for RS, PS, and NS. It is assumed each player wants to maximize
their expected utility. This is for an HIV+ actor with the belief the other actor is HIV-
set offer replace-item 9 offer protectedsexutility
set offer replace-item 10 offer 0

set offer replace-item 11 offer -50 ;;offer 11,12,13 are the utility function for an
HIV negative actor, for RS, PS, and NS. It is assumed each player wants to maximize
their utility. This is for an HIV- actor with the belief the other actor is HIV+
set offer replace-item 12 offer protectedsexutility
set offer replace-item 13 offer 0

set offer replace-item 14 offer 100 ;;offer 14,15,16 are the utility function for an
HIV negative actor, for RS, PS, and NS. It is assumed each player wants to maximize
their expected utility. This is for an HIV- actor with the belief the other actor is HIV-
set offer replace-item 15 offer protectedsexutility
set offer replace-item 16 offer 0

set offer replace-item 17 offer RStotal
set offer replace-item 18 offer PStotal
set offer replace-item 19 offer NStotal

set offer replace-item 20 offer who ;;Their ID

set offer replace-item 21 offer 0 ;(ACTUAL-STATUS) 0 if not infected, 1 if infected, this is a
marker that we will use so that an individual with 1 will have a percentage chance of
being tested and determining they are infected. Own-status now only means whether they
think they are infected

;print offer ;;This prints each turtles offer
set i i + 1
]
]
]

set j 0
set i 0
while [j < initialnuminfected]
[set i random num
;print i
ask turtle i
[
ifelse (own-status = 0)
[ set own-status 1
set offer replace-item 4 offer own-status
set color red
set initialinfected initialinfected + 1
set actual-status 1
set offer replace-item 21 offer actual-status
]
]
[ set j j - 1
]
]
set j j + 1
]

;;Each turtle has its own encounters array that stores the cumulative encounters it has with each turtle.

ask turtles
[;set encounters n-values 15000 [0];num [0]
;print encounters
]

ask turtles
[;set RSencounters n-values 15000 [0];num [0]
;print encounters
]

ask turtles
[;set PSencounters n-values 15000 [0];num [0]
;print encounters
]

ask turtles
[;set NSencounters n-values 15000 [0];num [0]
;print encounters
]

ask turtles ;;this is an individual log, not the total of all turtles, that is added at the bottom.
As well, the sex act is only recorded for actor 2, not actor 1 to prevent double counting.
[set sextotalbytype n-values 9 [0]
;print sextotalbytype
]

;;0, 1, 2 RS ++ --, 3,4,5 PS ++ --, 6,7,8 NS ++ --

ask turtles
[
set timearray n-values 26 [0]
set timearray replace-item 0 timearray who ;;their ID

;print word "this turtle is " who
set i who
if (i <= 780)
[ set timearray replace-item 1 timearray i ;; their age in months ]
if (i <= 1559) and (i > 780)
[ set timearray replace-item 1 timearray (i - 780) ]
if (i <= 2339) and (i > 1559)
[ set timearray replace-item 1 timearray (i - 1560) ]
if (i <= 3119) and (i > 2339)
[ set timearray replace-item 1 timearray (i - 2340) ]
if (i <= 3899) and (i > 3119)
[ set timearray replace-item 1 timearray (i - 3120) ]

set timearray replace-item 2 timearray 0
set timearray replace-item 3 timearray 0 ;; Age groups for the seven stages below
set timearray replace-item 4 timearray 0
set timearray replace-item 5 timearray 0
set timearray replace-item 6 timearray 0
set timearray replace-item 7 timearray 0
set timearray replace-item 8 timearray 0
set timearray replace-item 9 timearray 1 ; describes odds that you couple. Changes with age.
set timearray replace-item 10 timearray 0 ;; Age groups for the different infected stages below
set timearray replace-item 11 timearray 0
set timearray replace-item 12 timearray 0
set timearray replace-item 13 timearray 0
set timearray replace-item 14 timearray 0
set timearray replace-item 15 timearray 0
set timearray replace-item 16 timearray 1 ; describes infectivity, changes with stages.
set timearray replace-item 17 timearray 0 ;To determine if they will receive HAART
treatment, 0 is no treatment 1 is treatment.

set timearray replace-item 18 timearray 0 ; counter turns to 1 once infected individual reach
end of latent age, so that they are only deciding for treatment once.

set timearray replace-item 19 timearray 0 ;0, or 1 counter to determine if individual has
received vaccination. 1 means vaccinated.
set timearray replace-item 20 timearray 0 ;; counter for protection with vaccine, is
assigned and then counts down!
set timearray replace-item 21 timearray 0 ;; Individual BELIEVES they are
Vaccinated, 0 means they think they aren’t, 1 means they think they are.
set timearray replace-item 22 timearray 0 ;;Counter for when an individual will check to
see that they are still covered, begins as soon as they are vaccinated

set timearray replace-item 23 timearray 0 ;;Vaccination category, 0 - pre-vacc, 1, 15-29 after
initialization, 2 - in new age class
set timearray replace-item 24 timearray 0 ;;place holder for 16-30 age class for
vacccatchupgroup. 1 if they will be in this group. 0 otherwise
set timearray replace-item 25 timearray 0 ;;place holder for if they have been infected and
need to reset their cumsexactarray. 0 not infected, 1 if have been infected and
need to go through process, 2 if info has been reset.
;print timearray
]

; ask turtles ;; the initially infected turtles start in the latent stage
; [ if ( actual-status = 1)
;  [set timearray replace-item 10 timearray 5
;  ]
; ]
many-encounters
;write-data-initial
;write-data-initial2

; write-data7initial
; write-data8initial
; write-data9initial

;write-data10initial
;write-data11initial
;write-data12initial
;write-data13initial

update-plot
update-plot2
; update-plot3
; ;update-plotincidence
update-plot-HIV+byage
update-plot-HIV-byage
update-plot-Average-b-value-HIV+-by-age
update-plot-Average-b-value-HIV--by-age
update-plot-HIV+prevpercent
;update-plot-Average-theta-value-by-age

update-plot-sex-act-percentHIV-3040
update-plot-sex-act-percentHIV+3040
update-plot-sex-act-percentHIV-1520
update-plot-sex-act-percentHIV-2030
update-plot-sex-act-percentHIV-4050
update-plot-sex-act-percentHIV-50+
update-plot-sex-act-percentHIV+1520
update-plot-sex-act-percentHIV+2030
update-plot-sex-act-percentHIV+4050
update-plot-sex-act-percentHIV+50+
;update-plot-sexactstotalbyagerSHIVnegpos
;update-plot-sexactstotalbyagerSHIVnegneg
update-plot-CumUSnegposperyear

getavgp
writecumsexactbytype
set totalturtles num
set totalturtlesEVER num
set totalturtlesaddedpermonth 5
findprevalence
;print word "total turtles" totalturtles
set ARTcoverage 0 ;Set to 0 first then change it later!!! Find ARTcoverage
;set Artcoverd 90 ;;80 interesting oscilations THIS IS NOW ON INTERFACE
set ChanceTested 0.1
;print word "ticks before test 0 " ticks
set fermidiraca 1
set fermidiracp 0
end

to make-traders ;;Begin command, places turtles randomly and determines shape
clear-turtles ;;kills all turtles
crt num ;;Create a number of turtles from button
[setxy (random-xcor * 0.95) (random-ycor * 0.95)
set size (world-width / 30)
set shape "circle"
if show-id-trader?
[
set label who ;;Set turtle ID number
set color green ]
]
to setup-network ;; Determine network type

;if network-type = "Random-generated" [
setup-random-network
;]
;if network-type = "Preferential-attachment-only-out-links" [
;setup-pa-network-only-out-links
;]
end

to setup-random-network ;; This network creates random links between turtles
make-traders
;set i 0
;while [i < num]
;
;ask turtle i ;;Creates a random number of links to other turtles
that <= max links button, this can include 0 links (by itself)

; [;
; ifelse (count out-link-neighbors >= 1) or (count in-link-neighbors >= 1)
; [ set i i + 1 ]
; ];[ repeat random (max-links-per-node) [create-link-to one-of turtles with [self != myself]]
; ];[ repeat random (max-links-per-node) [create-link-to one-of turtles with [self != myself and count out-link-neighbors = 0 and count in-link-neighbors = 0] ]
; set i i + 1 ]
; ]
;
end

;; -------------------

302
;to setup-pa-network-only-out-links ;;This network creates links based on preferential treatment
;clear-turtles
;make-node nobody ;; first node, unattached
;make-node turtle 0
;;set-default-shape links "arrow"
;ask links [ set color grey ]
;repeat (num - 2) [make-node-only-out-links find-partner
;layout ] ;;Do not understand command
;
;if count turtles > num [stop]
;
;ask turtles[
;if show-id-trader?
;
;set label who
;set color green
;
]
;end

;to make-node [old-node]
;crt 1
;
;set shape "circle"
;set color red
;set label who
;set size (world-width / 50)
;
;if old-node != nobody
;
[ if random-float 100 < 0
;
[create-link-to old-node[ set color gray ]
;
create-link-from old-node[ set color gray ]]
;
move-to old-node
;
fd 8 ;;forward by 8

; ]
; ]
;
;end
;
;to make-node-only-out-links [old-node]
; crt 1
;
; set shape "circle"
; set color red
; ;set label who
; set size (world-width / 50)
;
; if old-node != nobody
; [  create-link-from old-node[ set color gray ]
;   move-to old-node
;   fd 8
; ]
;
;end

to-report find-partner
let partner nobody
ask turtle 0
[ ifelse (count in-link-neighbors > 0) [ set partner one-of in-link-neighbors] [ set partner nobody]]
]
; Go through all the agents...
let turtle-number 1
while [turtle-number < count turtles] [ ask turtle turtle-number
  [ ifelse (count in-link-neighbors > 0) ]
[ set partner one-of in-link-neighbors]
[ set partner nobody]
]
set turtle-number turtle-number + 1
]
report partner
end

to layout
    ;; the number 3 here is arbitrary; more repetitions slows down the
    ;; model, but too few gives poor layouts
    repeat 3 [  
    ;; the more turtles we have to fit into the same amount of space,
    ;; the smaller the inputs to layout-spring we'll need to use
    let factor sqrt count turtles
    ;; numbers here are arbitrarily chosen for pleasing appearance
    layout-spring turtles links (1 / factor) (7 / factor) (1 / factor)
    display ;; for smooth animation
    ]
    ;; don't bump the edges of the world
    let x-offset max [xcor] of turtles + min [xcor] of turtles
    let y-offset max [ycor] of turtles + min [ycor] of turtles
    ;; big jumps look funny, so only adjust a little each time
    set x-offset limit-magnitude x-offset 0.1
    set y-offset limit-magnitude y-offset 0.1
    ask turtles [ setxy (xcor - x-offset / 2) (ycor - y-offset / 2) ]
end

to-report limit-magnitude [number limit]
    if number > limit [ report limit ]
    if number < (- limit) [ report (- limit) ]
    report number
end

305
to go ;;After setup, this begins with go button
tick
print word "tick=" ticks
if (ticks = 2000)
[ stop ]
;print word "vacc cov " vaccoverage
clear-links
;ask links with [color = red] [ die ]
;ask red-links [blue-links]
;set i 0
;while [i < num]
;
[ ask turtles ;;Creates a random number of links to other turtles
that <= max links button, this can include 0 links (by itself)
[ set plusminus8 item 1 timearray
;show plusminus8
;ask one-of turtles [ print item 1 timearray ]
;show who
ifelse (one-of turtles with [self != myself and count out-link-neighbors = 0 and
count in-link-neighbors = 0 and abs(item 1 timearray - plusminus8) < 97] != nobody )
;;(97)if one-of turtles reports random turtle with such characterists (no outwrd links) and
is not nobody (dead) then move to next ifelse.... else do
nothing (ie there are no turtles left that aren’t paired up
[ ifelse (count out-link-neighbors >= 1) or (count in-link-neighbors >= 1)
;;If this turtle already has in or out links, then i + 1. If it doesn’t have any inward links,
randomly either give it 0 or 1 link to a turtle not itself and already without in or out links.
]
[; set i 0
; show one-of turtles with [self != myself]
; ask self [print item 1 timearray]
; ask self [print remainder item 1 timearray plusminus8]
; while [i < 1]
;
; ask one-of turtles with [self != myself]
; [print who
; print item 1 timearray
; print abs (item 1 timearray - plusminus8)
;]
;
; repeat random (2) [create-link-to one-of turtles with [self != myself and count out-link-neighbors = 0 and count in-link-neighbors = 0 and abs(item 1 timearray - plusminus8) < 97] ]
create-link-to one-of turtles with [self != myself and count out-link-neighbors = 0 and count in-link-neighbors = 0 and abs(item 1 timearray - plusminus8) < 97]

; create-link-to one-of turtles with [self != myself and count out-link-neighbors = 0 and count in-link-neighbors = 0 and abs(item 1 timearray - plusminus8) < 9]

; set i i + 1
;]
ask turtles [ interact ]

ask turtles
[ ;print offer
 ;print timearray
 ]

ask turtles
[ ;print encounters
 ;print sextotalbytype
 ]

ask turtles
[ ]

if ( item 25 timearray = 1 ) ;;if newly infected (has 1 )
[ 
 ;set sextotalbytype n-values 9 [0] ;;reset their sextotalbytype array.
 set sextotalbytype replace-item 0 sextotalbytype 0
 set sextotalbytype replace-item 1 sextotalbytype 0
 set sextotalbytype replace-item 2 sextotalbytype 0
 set sextotalbytype replace-item 3 sextotalbytype 0
 set sextotalbytype replace-item 4 sextotalbytype 0
 set sextotalbytype replace-item 5 sextotalbytype 0
 set sextotalbytype replace-item 6 sextotalbytype 0
 set sextotalbytype replace-item 7 sextotalbytype 0
 set sextotalbytype replace-item 8 sextotalbytype 0
 ]
set timearray replace-item 25 timearray 2 ; change item 25 timearray to 2 so it is not reset again.
]
]

ask turtles
[
; set timearray replace-item 1 timearray (item 1 timearray + 1)

set temptimearray0 (item 1 timearray)
set temptimearray1 (item 2 timearray)
set temptimearray2 (item 3 timearray)
set temptimearray3 (item 4 timearray)
set temptimearray4 (item 5 timearray)
set temptimearray5 (item 6 timearray)
set temptimearray6 (item 7 timearray)
set temptimearray7 (item 8 timearray)
set temptimearray8 (item 10 timearray)
set temptimearray9 (item 11 timearray)
set temptimearray10 (item 12 timearray)
set temptimearray11 (item 13 timearray)
set temptimearray12 (item 14 timearray)
set temptimearray13 (item 15 timearray)
; if ( temptimearray1 < 10)
; [ set temptimearray1 temptimearray1 + 1
; set timearray replace-item 2 timearray temptimearray1
; ]
ifelse ( temptimearray0 >= 61)
[
    ifelse ( temptimearray0 >= 181)
    [
        ifelse ( temptimearray0 >= 301)
        [
            ifelse ( temptimearray0 >= 421)
            [
                ifelse ( temptimearray0 >= 541)
                [
                    ifelse ( temptimearray0 >= 661)
                    [
                        ifelse ( temptimearray0 = 780)
                        [
                            ;print " Player reaches end of life here"
                            die
                        ]
                        [ set timearray replace-item 1 timearray (item 1 timearray + 1)
                            set timearray replace-item 9 timearray 0
                        ]
                    ]
                    [ set timearray replace-item 1 timearray (item 1 timearray + 1)
                        set timearray replace-item 9 timearray 0.1
                    ]
                ]
                [ set timearray replace-item 1 timearray (item 1 timearray + 1)
                    set timearray replace-item 9 timearray 0.3
                ]
            ]
            [ set timearray replace-item 1 timearray (item 1 timearray + 1)
                set timearray replace-item 9 timearray 0.6
            ]
        ]
    ]
]
if ( temptimearray9 = 90 ) and (item 18 timearray = 0)
[ set tempHAARTtreatment random-float 1
 ;print tempHAARTtreatment
 ifelse ( tempHAARTtreatment > ARTcoverage)
 [ set timearray replace-item 17 timearray 0 ;;not treated
 set timearray replace-item 18 timearray 1 ;;counter
 ;print item 17 timearray
 ;print item 18 timearray ]
 [ set timearray replace-item 17 timearray 1 ;;treated
 set timearray replace-item 18 timearray 1
 ;print item 17 timearray
 ;print item 18 timearray ]
]
]

if (actual-status = 1)
[;print word "infected" who

ifelse ( temptimearray8 > 4)

311
\[\text{ifelse ( temptimearray9 > 89)}\]
\[
\text{ifelse ( item 17 timearray = 0 )}\]
\[
\text{ifelse ( temptimearray10 > 23)}\]
\[
\text{ifelse ( temptimearray11 = 59)}\]
\[
\text{;print } "\text{Player reaches end of life here aids without treatment}"\]
\text{die}
\]
\[
\text{set temptimearray11 temptimearray11 + 1}\]
\text{set timearray replace-item 13 timearray temptimearray11}\]
\[
\text{;set timearray replace-item 8 timearray 0.3}\]
\text{set timearray replace-item 16 timearray 6.1}\]
\text{set timearray replace-item 9 timearray 0}\]
\]
\]
\[
\text{set temptimearray10 temptimearray10 + 1}\]
\text{set timearray replace-item 12 timearray temptimearray10}\]
\[
\text{;set timearray replace-item 8 timearray 0.6}\]
\text{set timearray replace-item 16 timearray 3.3}\]
\]
\]
\[
\text{ifelse ( temptimearray12 > 1)}\]
\[
\text{ifelse ( temptimearray13 = 287)}\]
\[
\text{;print } "\text{Player reaches end of life here aids with treatment}"\]
\text{die}
[ set temptimearray13 temptimearray13 + 1
set timearray replace-item 15 timearray temptimearray13
;set timearray replace-item 8 timearray 0
set timearray replace-item 16 timearray 0.1
]
]

[ set temptimearray12 temptimearray12 + 1
set timearray replace-item 14 timearray temptimearray12
;set timearray replace-item 8 timearray 0.1
set timearray replace-item 16 timearray 0.5
]
]
]

[ set temptimearray9 temptimearray9 + 1
set timearray replace-item 11 timearray temptimearray9
set timearray replace-item 16 timearray 1
]
]
]

[ set temptimearray8 temptimearray8 + 1
set timearray replace-item 10 timearray temptimearray8
set timearray replace-item 16 timearray 11
]
]

;print timearray
;set j j + 1
]
ask turtles
[if (item 19 timearray = 1) ;; if they are vaccinated
  ;print word "individuals that has been vaccinated;" who
  ;print timearray
]ifelse (item 20 timearray = 0) ;; if coverage is at zero, remove their vaccination status
  [set timearray replace-item 19 timearray 0
    ;print word "individuals pro-vacc level is over=" who
    ;print timearray
  ]
]set tempprovaccov (item 20 timearray) ;; otherwise remove another month
set tempprovaccov tempprovaccov - 1 ;; for every timestep remove one month of coverage
set timearray replace-item 20 timearray tempprovaccov
;print word "individuals pro-vacc level;" tempprovaccov
;print timearray
]
]
]
]

ask turtles
[if (item 22 timearray > 0) ;; if they are vaccinated, it starts at 1, and keeps increasing every iteration.
  ;set tempprovackno (item 22 timearray) ;; add another month
  ;set tempprovackno tempprovackno + 1 ;; for every timestep remove one month of coverage
  ;set timearray replace-item 22 timearray tempprovackno
  ;print word "individuals has been aware of vaccination;" who
  ;print word "individuals knows for this long;" item 22 timearray
  ;print timearray
]
if (item 22 timearray = 60) and (item 19 timearray = 0);; if knowledge of coverage is at 5 years, and that individual is no longer covered, then 1) they are now aware they are no longer covered, 2) reset knowledge of their coverage to 0
[ set timearray replace-item 21 timearray 0
set timearray replace-item 22 timearray 0
; print word "individuals pro-vacc and belief are over========================================" who
; print timearray
]
if (item 22 timearray = 120) and (item 19 timearray = 0);; if knowledge of coverage is at 10 years, and that individual is no longer covered, then 1) they are now aware they are no longer covered, 2) reset knowledge of their coverage to 0
[ set timearray replace-item 21 timearray 0
set timearray replace-item 22 timearray 0
; print word "individuals pro-vacc and belief are over========================================" who
; print timearray
]
if (item 22 timearray = 180) ; and (item 19 timearray = 0);; if knowledge of coverage is at 15 years, it doesn’t matter if the individual is still protected or not, then 1) they are now aware they are no longer covered, 2) reset knowledge of their coverage to 0
[ set timearray replace-item 21 timearray 0
set timearray replace-item 22 timearray 0
; print word "individuals pro-vacc and belief are over========================================" who
; print timearray
]

; if (item 22 timearray = 540) and (item 19 timearray = 0);; if knowledge of coverage is at 5 years, and that individual is no longer covered, then 1) they are now aware they are no longer covered, 2) reset knowledge of their coverage to 0
; [ set timearray replace-item 20 timearray 0
; set timearray replace-item 22 timearray 0
; ; print word "individuals pro-vacc and belief are
over========================================" who
; ; print timearray
}
if (item 22 timearray = 600) and (item 19 timearray = 0);; if knowledge of coverage is at 10 years, and that individual is no longer covered, then 1) they are now aware they are no longer covered, 2) reset knowledge of their coverage to 0

[ set timearray replace-item 20 timearray 0

set timearray replace-item 22 timearray 0

:print word "individuals pro-vacc and belief are over========================================" who

:print timearray

:]

if (item 22 timearray = 660); and (item 19 timearray = 0);; if knowledge of coverage is at 15 years, it doesn’t matter if the individual is still protected or not, then 1) they are now aware they are no longer covered, 2) reset knowledge of their coverage to 0

[ set timearray replace-item 20 timearray 0

set timearray replace-item 22 timearray 0

:print word "individuals pro-vacc and belief are over========================================" who

:print timearray

:]

if (ticks = 10)

[ ask turtle 4 [die]

]

if (ticks = 720)

[ ask turtles

[ if (actual-status = 0) and ((item 1 timearray) > 180) and ((item 1 timearray) <= 300)

[ :print (item 21 timearray)

;set thenegp3040 (item 3 offer)

:print thenegp3040

316
if (ticks = 900)
[ask turtles
  [ if (actual-status = 0) and ((item 1 timearray) > 180) and ((item 1 timearray) <= 300)
  [ ;print (item 21 timearray)
    ;set thenegp3040 (item 3 offer)
    ;print thenegp3040
  ]
  ]
;print hivnegavgp3040
]

if (ticks = 1200)
[ask turtles
  [ if (actual-status = 0) and ((item 1 timearray) > 180) and ((item 1 timearray) <= 300)
  [ ;print (item 21 timearray)
    ;set thenegp3040 (item 3 offer)
    ;print thenegp3040
  ]
  ]
;print hivnegavgp3040
]
;if (actual-status = 0) and ((item 1 timearray) > 180) and ((item 1 timearray) <= 300)
; [ set thenegp3040 (item 3 offer)
; set hivnegavgp3040 (hivnegavgp3040 + thenegp3040 / (count turtles with
[actual-status = 0 and ((item 1 timearray) > 180) and ((item 1 timearray) <= 300) ] ))
;print word "thenegp1520" thenegp1520

;if (ticks >= 920)
;[ ask turtles
; [ if ( item 1 timearray < 13)
; [ print word "age " item 1 timearray
; print word "b-value " item 3 offer
; print offer
; print timearray
; ]
; ]
;]
;

;ask turtles
;[
; if (who = 6)
;[ print timearray]
;]

;if (ticks = 20)
;[ ask turtle 0 [die]
;]

;getjustp
;;no createlist1 as this is in setup for initial p values before tick 0
;if (ticks = 1) [createlist2]
;if (ticks = 2) [createlist3]
; if (ticks = 100)
{
   ; print word "tick=" ticks
   ; set cumsexactsum100 ( totalRSpospos + totalRSposneg + totalRSnegneg + totalPSpospos +
      totalPSposneg + totalPSnegneg + totalPSpospos + totalNSpospos + totalNSposneg + totalNSnegneg )
   ; set totalRSpospos100 totalRSpospos
   ; set totalRSposneg100 totalRSposneg
   ; set totalRSnegneg100 totalRSnegneg
   ; set totalPSpospos100 totalPSpospos
   ; set totalPSposneg100 totalPSposneg
   ; set totalPSnegneg100 totalPSnegneg
   ; set totalNSpospos100 totalNSpospos
   ; set totalNSposneg100 totalNSposneg
   ; set totalNSnegneg100 totalNSnegneg
   ; print word "cumsexacts100" cumsexactsum100
   ; print (totalRSpospos100 / cumsexactsum100) * 100
   ; print (totalRSposneg100 / cumsexactsum100) * 100
   ; print (totalRSnegneg100 / cumsexactsum100) * 100
   ; print (totalPSpospos100 / cumsexactsum100) * 100
   ; print (totalPSposneg100 / cumsexactsum100) * 100
   ; print (totalPSnegneg100 / cumsexactsum100) * 100
   ; print (totalNSpospos100 / cumsexactsum100) * 100
   ; print (totalNSposneg100 / cumsexactsum100) * 100
   ; print (totalNSnegneg100 / cumsexactsum100) * 100

   ; print word "HIVprevalence " prevalence
   ; print totalRSpospos
   ; print totalRSposneg
   ; print totalRSnegneg
   ; print totalPSpospos
if (ticks = 200)
{
    print word "tick=" ticks
    set cumsexactsum200 (totalRSpospos + totalRSposneg + totalRSnegneg + totalPSpospos +
                           totalPSposneg + totalPSnegneg + totalNSpospos + totalNSposneg +
                           totalNSnegneg)
    set totalRSpospos200 (totalRSpospos)
    set totalRSposneg200 (totalRSposneg)
    set totalRSnegneg200 (totalRSnegneg)
    set totalPSpospos200 (totalPSpospos)
    set totalPSposneg200 (totalPSposneg)
    set totalPSnegneg200 (totalPSnegneg)
    set totalNSpospos200 (totalNSpospos)
    set totalNSposneg200 (totalNSposneg)
    set totalNSnegneg200 (totalNSnegneg)
    print word "cumsexacts200" cumsexactsum200
    print ((totalRSpospos200 - totalRSpospos100) / (cumsexactsum200 - cumsexactsum100)) * 100
    print ((totalRSposneg200 - totalRSposneg100) / (cumsexactsum200 - cumsexactsum100)) * 100
    print ((totalRSnegneg200 - totalRSnegneg100) / (cumsexactsum200 - cumsexactsum100)) * 100
    print ((totalPSpospos200 - totalPSpospos100) / (cumsexactsum200 - cumsexactsum100)) * 100
    print ((totalPSposneg200 - totalPSposneg100) / (cumsexactsum200 - cumsexactsum100)) * 100
    print ((totalPSnegneg200 - totalPSnegneg100) / (cumsexactsum200 - cumsexactsum100)) * 100
    print ((totalNSpospos200 - totalNSpospos100) / (cumsexactsum200 - cumsexactsum100)) * 100
    print ((totalNSposneg200 - totalNSposneg100) / (cumsexactsum200 - cumsexactsum100)) * 100
    print ((totalNSnegneg200 - totalNSnegneg100) / (cumsexactsum200 - cumsexactsum100)) * 100
    print word "HIVprevalence " prevalence
}
if (ticks = 300)
[
    print word "tick=" ticks
    set cumsexactsum300 (totalRSpospos + totalRSposneg + totalRSnegneg + totalPSpospos +
    totalPSposneg + totalPSnegneg + totalNSpospos + totalNSposneg + totalNSnegneg)
    set totalRSpospos300 (totalRSpospos)
    set totalRSposneg300 (totalRSposneg)
    set totalRSnegneg300 (totalRSnegneg)
    set totalPSpospos300 (totalPSpospos)
    set totalPSposneg300 (totalPSposneg)
    set totalPSnegneg300 (totalPSnegneg)
    set totalNSpospos300 (totalNSpospos)
    set totalNSposneg300 (totalNSposneg)
    set totalNSnegneg300 (totalNSnegneg)

    print word "cumsexacts300" cumsexactsum300
    print ((totalRSpospos300 - totalRSpospos200) / (cumsexactsum300 - cumsexactsum200)) * 100
    print ((totalRSposneg300 - totalRSposneg200) / (cumsexactsum300 - cumsexactsum200)) * 100
    print ((totalRSnegneg300 - totalRSnegneg200) / (cumsexactsum300 - cumsexactsum200)) * 100
    print ((totalPSpospos300 - totalPSpospos200) / (cumsexactsum300 - cumsexactsum200)) * 100
    print ((totalPSposneg300 - totalPSposneg200) / (cumsexactsum300 - cumsexactsum200)) * 100
    print ((totalPSnegneg300 - totalPSnegneg200) / (cumsexactsum300 - cumsexactsum200)) * 100
    print ((totalNSpospos300 - totalNSpospos200) / (cumsexactsum300 - cumsexactsum200)) * 100
    print ((totalNSposneg300 - totalNSposneg200) / (cumsexactsum300 - cumsexactsum200)) * 100
    print ((totalNSnegneg300 - totalNSnegneg200) / (cumsexactsum300 - cumsexactsum200)) * 100
    print word "HIVprevalence " prevalence
]
if (ticks = 400)
[
    print word "tick=" ticks
    set cumsexactsum400 (totalRSpospos + totalRSposneg + totalRSnegneg + totalPSpospos +
                          totalPSposneg + totalPSnegneg + totalNSpospos + totalNSposneg +
                          totalNSnegneg)
    set totalRSpospos400 (totalRSpospos )
    set totalRSposneg400 (totalRSposneg )
    set totalRSnegneg400 (totalRSnegneg )
    set totalPSpospos400 (totalPSpospos )
    set totalPSposneg400 (totalPSposneg )
    set totalPSnegneg400 (totalPSnegneg )
    set totalNSpospos400 (totalNSpospos )
    set totalNSposneg400 (totalNSposneg )
    set totalNSnegneg400 (totalNSnegneg )
    print word "cumsexacts400" cumsexactsum400
    print ((totalRSpospos400 - totalRSpospos300 ) / (cumsexactsum400 - cumsexactsum300 )) * 100
    print ((totalRSposneg400 - totalRSposneg300 ) / (cumsexactsum400 - cumsexactsum300 )) * 100
    print ((totalRSnegneg400 - totalRSnegneg300 ) / (cumsexactsum400 - cumsexactsum300 )) * 100
    print ((totalPSpospos400 - totalPSpospos300 ) / (cumsexactsum400 - cumsexactsum300 )) * 100
    print ((totalPSposneg400 - totalPSposneg300 ) / (cumsexactsum400 - cumsexactsum300 )) * 100
    print ((totalPSnegneg400 - totalPSnegneg300 ) / (cumsexactsum400 - cumsexactsum300 )) * 100
    print ((totalNSpospos400 - totalNSpospos300 ) / (cumsexactsum400 - cumsexactsum300 )) * 100
    print ((totalNSposneg400 - totalNSposneg300 ) / (cumsexactsum400 - cumsexactsum300 )) * 100
    print ((totalNSnegneg400 - totalNSnegneg300 ) / (cumsexactsum400 - cumsexactsum300 )) * 100
if (ticks = 500)
{
    ; print word "tick=" ticks
    ; set cumsexacts500 (totalRSpospos + totalRSposneg + totalRSnegneg + totalPSpospos +
        totalPSposneg + totalPSnegneg + totalNSpospos + totalNSposneg + totalNSnegneg)
    ; set totalRSpospos500 (totalRSpospos )
    ; set totalRSposneg500 (totalRSposneg )
    ; set totalRSnegneg500 (totalRSnegneg )
    ; set totalPSpospos500 (totalPSpospos )
    ; set totalPSposneg500 (totalPSposneg )
    ; set totalPSnegneg500 (totalPSnegneg )
    ; set totalNSpospos500 (totalNSpospos )
    ; set totalNSposneg500 (totalNSposneg )
    ; set totalNSnegneg500 (totalNSnegneg )
    ; print word "cumsexacts500" cumsexacts500
    ;print ((totalRSpospos500 - totalRSpospos400 ) / (cumsexacts500 - cumsexacts400 )) * 100
    ;print ((totalRSposneg500 - totalRSposneg400 ) / (cumsexacts500 - cumsexacts400 )) * 100
    ;print ((totalRSnegneg500 - totalRSnegneg400 ) / (cumsexacts500 - cumsexacts400 )) * 100
    ;print ((totalPSpospos500 - totalPSpospos400 ) / (cumsexacts500 - cumsexacts400 )) * 100
    ;print ((totalPSposneg500 - totalPSposneg400 ) / (cumsexacts500 - cumsexacts400 )) * 100
    ;print ((totalPSnegneg500 - totalPSnegneg400 ) / (cumsexacts500 - cumsexacts400 )) * 100
    ;print ((totalNSpospos500 - totalNSpospos400 ) / (cumsexacts500 - cumsexacts400 )) * 100
; ; print ((totalNSposneg500 - totalNSposneg400) / (cumsexactsum500 - cumsexactsum400)) * 100
; ; print ((totalNSnegneg500 - totalNSnegneg400) / (cumsexactsum500 - cumsexactsum400)) * 100
; ; print word "HIVprevalence " prevalence
;
; ; print totalRSpospos
; ; print totalRSposneg
; ; print totalRSnegneg
; ; print totalPSpospos
; ; print totalPSposneg
; ; print totalPSnegneg
; ; print totalNSpospos
; ; print totalNSposneg
; ; print totalNSnegneg
;
;if (ticks = 1400) [
; print word "tick=" ticks
; set cumsexactsum1400 (totalRSpospos + totalRSposneg + totalRSnegneg + totalPSpospos +
totalPSposneg + totalPSnegneg + totalNSpospos + totalNSposneg + totalNSnegneg)
; set totalRSpospos1400 (totalRSpospos )
; set totalRSposneg1400 (totalRSposneg )
; set totalRSnegneg1400 (totalRSnegneg )
; set totalPSpospos1400 (totalPSpospos )
; set totalPSposneg1400 (totalPSposneg )
; set totalPSnegneg1400 (totalPSnegneg )
; set totalNSpospos1400 (totalNSpospos )
; set totalNSposneg1400 (totalNSposneg )
; set totalNSnegneg1400 (totalNSnegneg )
;]

324
; if (ticks = 1500)
;
; print word "tick=" ticks
;
; set cumsexactsum1500 (totalRSpospos + totalRSposneg + totalRSnegneg + totalPSPospos +
totalPSPosneg + totalPSnegneg + totalNSpospos + totalNSposneg + totalNSnegneg)
;
; set totalRSpospos1500 (totalRSpospos )
;
; set totalRSposneg1500 (totalRSposneg )
;
; set totalRSnegneg1500 (totalRSnegneg )
;
; set totalPSpospos1500 (totalPSpospos )
;
; set totalPSposneg1500 (totalPSposneg )
;
; set totalPSnegneg1500 (totalPSnegneg )
;
; set totalNSpospos1500 (totalNSpospos )
;
; set totalNSposneg1500 (totalNSposneg )
;
; set totalNSnegneg1500 (totalNSnegneg )
;
; print word "cumsexacts1500 " cumsexactsum1500
;
; print ((totalRSpospos1500 - totalRSpospos1400 ) / (cumsexactsum1500 - cumsexactsum1400 )) * 100
;
; print ((totalRSposneg1500 - totalRSposneg1400 ) / (cumsexactsum1500 - cumsexactsum1400 )) * 100
;
; print ((totalRSnegneg1500 - totalRSnegneg1400 ) / (cumsexactsum1500 - cumsexactsum1400 )) * 100
;
; print ((totalPSpospos1500 - totalPSpospos1400 ) / (cumsexactsum1500 - cumsexactsum1400 )) * 100
;
; print ((totalPSposneg1500 - totalPSposneg1400 ) / (cumsexactsum1500 - cumsexactsum1400 )) * 100
;
; print ((totalPSnegneg1500 - totalPSnegneg1400 ) / (cumsexactsum1500 - cumsexactsum1400 )) * 100
;
; print ((totalNSpospos1500 - totalNSpospos1400 ) / (cumsexactsum1500 - cumsexactsum1400 )) * 100
;
; print ((totalNSposneg1500 - totalNSposneg1400 ) / (cumsexactsum1500 - cumsexactsum1400 )) * 100
;
; print ((totalNSnegneg1500 - totalNSnegneg1400 ) / (cumsexactsum1500 - cumsexactsum1400 )) * 100
;
; print word "HIVprevalence " prevalence
;
;
; print totalRSpospos
;
; print totalRSposneg
;
; print totalRSnegneg
;
; print totalPSpospos
;
; print totalPSposneg
;
; print totalPSnegneg
if (ticks = 4900)
{
  print word "tick=" ticks
  set cumsexactsum4900 (totalRSpospos + totalRSposneg + totalRSnegneg + totalPSpospos +
totalPSposneg + totalPSnegneg + totalNSpospos + totalNSposneg + totalNSnegneg)
  set totalRSpospos4900 (totalRSpospos )
  set totalRSposneg4900 (totalRSposneg )
  set totalRSnegneg4900 (totalRSnegneg )
  set totalPSpospos4900 (totalPSpospos )
  set totalPSposneg4900 (totalPSposneg )
  set totalPSnegneg4900 (totalPSnegneg )
  set totalNSpospos4900 (totalNSpospos )
  set totalNSposneg4900 (totalNSposneg )
  set totalNSnegneg4900 (totalNSnegneg )
}

if (ticks = 5000)
{
  print word "tick=" ticks
  set cumsexactsum5000 (totalRSpospos + totalRSposneg + totalRSnegneg + totalPSpospos +
totalPSposneg + totalPSnegneg + totalNSpospos + totalNSposneg + totalNSnegneg)
  set totalRSpospos5000 (totalRSpospos )
  set totalRSposneg5000 (totalRSposneg )
  set totalRSnegneg5000 (totalRSnegneg )
; set totalP_pospos5000 (totalP_pospos )
; set totalP_posneg5000 (totalP_posneg )
; set totalP_negneg5000 (totalP_negneg )
; set totalN_pospos5000 (totalN_pospos )
; set totalN_posneg5000 (totalN_posneg )
; set totalN_negneg5000 (totalN_negneg )

; print word "cumsexacts5000" cumsexactsum5000
; print ((totalR_pospos5000 - totalR_pospos4900 ) / (cumsexactsum5000 - cumsexactsum4900 )) * 100
; print ((totalR_posneg5000 - totalR_posneg4900 ) / (cumsexactsum5000 - cumsexactsum4900 )) * 100
; print ((totalR_negneg5000 - totalR_negneg4900 ) / (cumsexactsum5000 - cumsexactsum4900 )) * 100
; print ((totalP_pospos5000 - totalP_pospos4900 ) / (cumsexactsum5000 - cumsexactsum4900 )) * 100
; print ((totalP_posneg5000 - totalP_posneg4900 ) / (cumsexactsum5000 - cumsexactsum4900 )) * 100
; print ((totalP_negneg5000 - totalP_negneg4900 ) / (cumsexactsum5000 - cumsexactsum4900 )) * 100
; print ((totalN_pospos5000 - totalN_pospos4900 ) / (cumsexactsum5000 - cumsexactsum4900 )) * 100
; print ((totalN_posneg5000 - totalN_posneg4900 ) / (cumsexactsum5000 - cumsexactsum4900 )) * 100
; print ((totalN_negneg5000 - totalN_negneg4900 ) / (cumsexactsum5000 - cumsexactsum4900 )) * 100

; print word "HIVprevalence " prevalence

; ask red-links [set color red]
; show remainder ticks 12
ask turtles
[
if (actual-status = 1) and (own-status = 0)
[;print word "turtle is infected and doesn't know it" who
let tempgetcheckup random-float 1 ;; less than 1 greater than or equal to zero
if (tempgetcheckup < ChanceTested) ;if true then the individual's own-status will then
  change to 1 (HIV+) resulting in them choosing different utilities. Assume checkup is 100% effective
[;print word "turtle received treatment, will change own-status" who
set own-status 1
set offer replace-item 4 offer own-status
;print offer
]
]
]

;if (ticks = 60)
;print word "ticks before test 1" ticks
if (ticks >= 2) ;;(remainder ticks 12 = 0) every 12 months or 1 year do this.
Now every month add one starting after month 1
[
;print word "ticks before test 2" ticks
;print word "new individuals to population" totalturtlesaddedpermonth
;print word "the total turtles before adding 1" totalturtles
.crt totalturtlesaddedpermonth ;;Create a number of turtles
[setxy (random-xcor * 0.95) (random-ycor * 0.95)
set size (world-width / 30)
set shape "circle"
if show-id-trader?[
set label who ;;Set turtle ID number
set color green ]
]
ask turtles [
if who > totalturtlesEVER - 1 [
   ;print "test"
]
set i 0
while [i < 1] [
   ;let p-level random-normal prevalence 0.1
   let p-level random-normal 0.05 0.1;0.1 ;; This is mean 0.05 and standard deviation 0.1
   if (p-level > 0) and (p-level < 1) [
      ;print word "the p-level is " p-level
      set offer n-values 22 [0] ;;Creates list of 21 0's
      set offer replace-item 0 offer "RS" ;;begins to replace items on list
      set offer replace-item 1 offer "PS"
      set offer replace-item 2 offer "NS"
      set p-level precision p-level 3
      set offer replace-item 3 offer p-level
      set own-status 0 ;;HIV negative is 0
      set offer replace-item 4 offer own-status
      set offer replace-item 5 offer 100 ;;offer 5,6,7 are the utility function for an HIV positive actor, for RS, PS, and NS. It is assumed each player wants to maximize their expected utility. This is for an HIV + actor with the belief the other actor is HIV+
      set offer replace-item 6 offer protectedsexutility
      set offer replace-item 7 offer 0
      set offer replace-item 8 offer 100 ;;offer 8,9,10 are the utility function for an HIV positive actor, for RS, PS, and NS. It is assumed each player wants to maximize their expected utility. This is for an HIV + actor with the belief the other actor is HIV-
      set offer replace-item 9 offer protectedsexutility
      set offer replace-item 10 offer 0
      set offer replace-item 11 offer -50 ;;offer 11,12,13 are the utility function for an HIV
negative actor, for RS, PS, and NS. It is assumed each player wants to maximize their utility. This is for an HIV- actor with the belief the other actor is HIV+

set offer replace-item 12 offer protectedsexutility
set offer replace-item 13 offer 0

set offer replace-item 14 offer 100 ;;offer 14,15,16 are the utility function for an HIV negative actor, for RS, PS, and NS. It is assumed each player wants to maximize their expected utility. This is for an HIV- actor with the belief the other actor is HIV-

set offer replace-item 15 offer protectedsexutility
set offer replace-item 16 offer 0

set offer replace-item 17 offer RStotal
set offer replace-item 18 offer PStotal
set offer replace-item 19 offer NStotal

set offer replace-item 20 offer who

set offer replace-item 21 offer 0 ;0 if not infected, 1 if infected, this is a marker that we will use so that an individual with 1 will have a percentage chance of being tested and determining they are infected. Own-status now only means whether they think they are infected

;print offer ;;This prints each turtles offer
set i i + 1
]
]

;;Each turtle has its own encounters array that stores the cumulative encounters it has with each turtle.

;set encounters n-values 6000 [0];num [0]
;set RSencounters n-values 6000 [0];num [0]
; set PSencounters n-values 6000 [0]; num [0]
; set NSencounters n-values 6000 [0]; num [0]
set sextotalbytype n-values 9 [0]

; ; 0, 1, 2 RS ++ +−−, 3, 4, 5 PS ++ +−−, 6, 7, 8 NS ++ +−−

set timearray n-values 26 [0]
set timearray replace-item 0 timearray who ;; assigns turtles identity
set timearray replace-item 1 timearray 1 ;; assigns individuals age, 1 represents 1 month.

set timearray replace-item 2 timearray 0
set timearray replace-item 3 timearray 0
set timearray replace-item 4 timearray 0
set timearray replace-item 5 timearray 0
set timearray replace-item 6 timearray 0
set timearray replace-item 7 timearray 0
set timearray replace-item 8 timearray 0
set timearray replace-item 9 timearray 1 ;; describes your overall activity. Changes with age.

set timearray replace-item 10 timearray 0
set timearray replace-item 11 timearray 0
set timearray replace-item 12 timearray 0
set timearray replace-item 13 timearray 0
set timearray replace-item 14 timearray 0
set timearray replace-item 15 timearray 0
set timearray replace-item 16 timearray 1 ;; describes infectivity, changes with stages.

set timearray replace-item 17 timearray 0
; ; To determine if they will receive HAART treatment, 0 is no treatment 1 is treatment.
set timearray replace-item 18 timearray 0
; counter turns to 1 once infected individual reach end of latent age, so that they are only deciding for treatment once.

set timearray replace-item 19 timearray 0 ; 0, or 1 counter to determine if individual has received vaccination. 1 means vaccinated.
set timearray replace-item 20 timearray 0 ;;; counter for protection with vaccine, is assigned and then counts down!
set timearray replace-item 21 timearray 0 ;;; Individual BELIEVES they are Vaccinated, 0 means they think they aren’t, 1 means they think they are.
set timearray replace-item 22 timearray 0 ;;; Counter for when an individual will check to see that they are still covered, begins as soon as they are vaccinated
set timearray replace-item 23 timearray 0 ;;; Vaccination category, 0 - pre-vacc, vacccatchupgroup 15-29 after initialization, vacccoveragetheta - in new age class
set timearray replace-item 24 timearray 0 ;;; Place holder for new individuals that are gonna be 16-30 when vaccine is released
set timearray replace-item 25 timearray 0 ;;; Place holder for if they have been infected and need to reset their cumsexactarray. 0 not infected, 1 if have been infected and need to go through process, 2 if info has been reset.

if (ticks > startvacc) ; Initialize a % of incoming people to be vaccinated
[ ;print word "Time for initial vaccination program " ticks
set tempinitvacc random-float 1
set tempvacceff random-float 1
set timearray replace-item 23 timearray vacccoveragetheta
;; If the individual enters after vaccination starts, they are in this vacc category
;print word "individuals chance for vacc " tempinitvacc
if ( tempinitvacc < vacccoverage) and ( tempvacceff < vaccineefficacy)
;; meaning individual must be selected for coverage, and the vaccine must be effective, since 90%, they are also tested immediately afterwards so
this removes those chosen where the vaccine doesn’t take.
May have to change this if there is lag between testing!

[ set timearray replace-item 19 timearray 1
set timearray replace-item 21 timearray 1
set timearray replace-item 22 timearray 1
let k 0
while [k < 1]

[let provacc-level random-normal 120 36
 ;; This is mean of 10 years, 12x10 = 120 and standard deviation of 3 years, 3x12 = 36
if (provacc-level > 0) ;and (p-level < 1)
[ set provacc-level round provacc-level ;;Round level to closest integer
set timearray replace-item 20 timearray provacc-level
;print word "individuals pro-vacc level:;;;;;;;;;;;;;;;;" provacc-level
;print timearray
set k k + 1
]
]
]
];print timearray
]

if ( ticks < startvacc ) and ( ticks > (startvacc - 300))
;;;;;if the time is 25 years before the initialization of the vaccine

[ set timearray replace-item 24 timearray 1
;;;If the individual is gonna be 15-40 when the vaccine comes out, this is their vacc category.
]

]
]
set totalturtles count turtles
;print totalturtles
set totalturtlesEVER totalturtlesEVER + totalturtlesaddedpermonth
]
if (ticks >= startvacc)

[ 
ask turtles
[ if ( item 24 timearray = 1)
[ 
set timearray replace-item 23 timearray vacccatchupgroup
]
]
]

ask turtles
[ 
if (remainder ticks 12 = 0)

[ 
if (actual-status != 1) and (item 19 timearray != 1)

;;If they are not already infected and already vaccinated

[ 
if (ticks > startvacc) and (ticks < (startvacc + lengthofcatchupprogram))

;;This is the catch-up program, for 10 yrs, a % of older people have a chance to get vaccinated
[ ;print word "Time for catch-up vaccination program " ticks
 ;print timearray
set tempcatchupage item 1 timearray
 ;print word "Individuals age is " tempcatchupage
if ( tempcatchupage >= 61) and (tempcatchupage < 180)

[ ;print word "is in their 20's " who

set tempcatchup20 random-float 1
set tempvacceff random-float 1

;print word "individuals chance for catch up vacc in 20s " tempcatchup20
if ( tempcatchup20 < catchupvacc20) and ( tempvacceff < vaccineefficacy)

[ set timearray replace-item 19 timearray 1 
set timearray replace-item 21 timearray 1

334
set timearray replace-item 22 timearray 1
;print timearray
let k 0
while [k < 1]
[let provacc-level random-normal 120 36
 ;; This is mean mean of 10 years, 12x10 = 120 and standard deviation of 3 years, 3x12 = 36
if (provacc-level > 0) ;and (p-level < 1)
[ set provacc-level round provacc-level ;;Round level to closest integer
set timearray replace-item 20 timearray provacc-level
;print word "individuals pro-vacc level
for 20’s;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;" provacc-level
;print timearray
set k k + 1
]
]
]
]
]
]

if ( tempcatchupage >= 180) and (tempcatchupage < 300)
[ ;print word "is in their 30’s " who
set tempcatchup30 random-float 1
set tempvacceff random-float 1
;print word "individuals chance for catch up vacc in 30s " tempcatchup30
if ( tempcatchup30 < catchupvacc30) and ( tempvacceff < vaccineefficacy)
[ set timearray replace-item 19 timearray 1
set timearray replace-item 21 timearray 1
set timearray replace-item 22 timearray 1
;print timearray
let k 0
while [k < 1]
[let provacc-level random-normal 120 36
 ;; This is mean mean of 10 years, 12x10 = 120 and standard deviation of 3 years, 3x12 = 36
if (provacc-level > 0) ;and (p-level < 1)
[ set provacc-level round provacc-level ;;Round level to closest integer
set timearray replace-item 20 timearray provacc-level
;print word "individuals pro-vacc level
for 30's;...............................................................;" provacc-level
;print timearray
set k k + 1
]
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]
; if all? turtles [color = red]
; [ print "All turtles are infected"
; stop
; ]
;
; if (remainder ticks 12 = 0) ;; every 12 months or 1 year do this..
; [
; set i 0
; while[ i < 1]
; [ ask one-of turtles
; [ ; print who
; if (own-status = 0)
; [ ; print own-status
; set own-status 1
; set offer replace-item 4 offer own-status
; set color red
; set i i + 1
; ]
; ]
; ]
; ]

if (ticks = startART)
[ set ARTcoverage 0.75 ; 0.75
; print word "ARTcoverage" ARTcoverage
]
set age50 0
set age60 0
set age70 0
set HIVnegpop (count turtles with [actual-status = 0])
ask turtles
[ if actual-status = 0
[set HIVnegage (item 1 timearray)
if (HIVnegage <= 60)
[ set age15 (age15 + 1)
if (HIVnegage <= 180) and (HIVnegage > 60)
[ set age20 (age20 + 1)
if (HIVnegage <= 300) and (HIVnegage > 180)
[ set age30 (age30 + 1)
if (HIVnegage <= 420) and (HIVnegage > 300)
[ set age40 (age40 + 1)
if (HIVnegage <= 540) and (HIVnegage > 420)
[ set age50 (age50 + 1)
if (HIVnegage <= 660) and (HIVnegage > 540)
[ set age60 (age60 + 1)
if (HIVnegage <= 780) and (HIVnegage > 660)
[ set age70 (age70 + 1)
]
]
];print age15 / HIVnegpop
;print age20 / HIVnegpop
;print age30 / HIVnegpop
;print age40 / HIVnegpop
;print age50 / HIVnegpop
;print age60 / HIVnegpop
;print age70 / HIVnegpop
]

if (ticks = 700)
[ set age15 0
set age20 0
set age30 0
set age40 0
set age50 0
set age60 0
set age70 0
set HIVpospop (count turtles with [actual-status = 1])
ask turtles
[ if actual-status = 1
 [ set HIVposage (item 1 timearray)
  if (HIVposage <= 60)
   [ set age15 (age15 + 1)]
  if (HIVposage <= 180) and (HIVposage > 60)
   [ set age20 (age20 + 1)]
  if (HIVposage <= 300) and (HIVposage > 180)
   [ set age30 (age30 + 1)]
  if (HIVposage <= 420) and (HIVposage > 300)
   [ set age40 (age40 + 1)]
  if (HIVposage <= 540) and (HIVposage > 420)
   [ set age50 (age50 + 1)]
  if (HIVposage <= 660) and (HIVposage > 540)
   [ set age60 (age60 + 1)]
  if (HIVposage <= 780) and (HIVposage > 660)
   [ set age70 (age70 + 1)]
]
]

];Note, this will crash if there are no HIV pos people!!!!!!

;print age15 / HIVpospop
;print age20 / HIVpospop
;print age30 / HIVpospop
;print age40 / HIVpospop
;print age50 / HIVpospop
;print age60 / HIVpospop

339
;print age70 / HIVpospop
]

;findincidence

;if (ticks = 800)
    ;[
    ; set j 0
    ; set i 0
    ; while [j < 39]
    ; [set i random 1580
    ; ;print i
    ; if ( i > 800)
    ; [;
    ; ask turtle i
    ; ;[;
    ; ifelse (own-status = 0) ;;This prevents double infecting the same turtle!!
    ; ;[
    ; set own-status 1
    ; set offer replace-item 4 offer own-status
    ; set color red
    ; set initialinfected initialinfected + 1
    ; set actual-status 1
    ; set offer replace-item 21 offer actual-status
    ; print word "This turtle is now Infected " who
    ; ]]
    ; ;
    ; [ set j j - 1
    ; ;]
    ;]
    ; set j j + 1
; set j 0
; set i 0
; while [j < initialnuminfected]
; [set i random num
; ;print i
; ask turtle i
; [ ; ifelse (own-status = 0)
; [ set own-status 1
; ; set offer replace-item 4 offer own-status
; ; set color red
; ; set initialinfected initialinfected + 1
; ; set actual-status 1
; ; set offer replace-item 21 offer actual-status
; ]
; ]
; [ set j j - 1
; ]
; ]
; set j j + 1
; ]
;
;if (ticks < 780)
;[
; ask turtle 0
; [
if (remainder ticks 12 = 0) and (ticks < 779)
  [ ;print RSencounters
  ; ;print PSencounters
  ; ]
  ]
  ]

if (ticks = 700)
[ getavgp1520
 ; getavgp2030
 ; getavgp3040
 ; getavgp4050
 ; getavgp5060
 ; getavgp6070
 ; getavgp7080
 ; getavgp
 ; print word "hivnegavgp " hivnegavgp
 ; print word "hivposavgp " hivposavgp
 ; print word "hivposdontknow " hivposdontknow
 ; print word "avgtotalp " avgtotalp
 ; print word "totalhivpos " totalhivpos
 ; print word "totalhivposdontknow " totalhivposdontknow
 ; print word "hivprevpercent " hivprevpercent
 ; print word "hivprevpercentdontknow " hivprevpercentdontknow ]
 ;
;if (ticks = 800)
[ getavgp1520
 ; getavgp2030
 ; getavgp3040
 ; getavgp4050
 ; getavgp5060
 ; getavgp6070
 ; getavgp7080
 ; getavgp
; print word "hivnegavgp  " hivnegavgp
; print word "hivposavgp  " hivposavgp
; print word "hivposdontknow " hivposdontknow
; print word "avgtotalp   " avgtotalp
; print word "totalhivpos  " totalhivpos
; print word "totalhivposdontknow " totalhivposdontknow
; print word "hivprevpercent " hivprevpercent
; print word "hivprevpercentdontknow " hivprevpercentdontknow

;if (ticks = 900)
;[ getavgp1520
 ; getavgp2030
 ; getavgp3040
 ; getavgp4050
 ; getavgp5060
 ; getavgp6070
 ; getavgp7080
 ; getavgp
 ; print word "hivnegavgp  " hivnegavgp
 ; print word "hivposavgp  " hivposavgp
 ; print word "hivposdontknow " hivposdontknow
 ; print word "avgtotalp   " avgtotalp
 ; print word "totalhivpos  " totalhivpos
 ; print word "totalhivposdontknow " totalhivposdontknow
 ; print word "hivprevpercent " hivprevpercent
 ; print word "hivprevpercentdontknow " hivprevpercentdontknow ]

;if (ticks = 1000)
;[ getavgp1520
 ; getavgp2030
 ; getavgp3040
 ; getavgp4050
 ; getavgp5060
 ; getavgp6070
 ; getavgp7080

343
ask turtles ;;if turtle is older than 25 years of age and was not part of the catchup age class, then the theta reverts back to 0 after 10 years
[
  if (ticks > startvacc)
  [
    if ((( item 1 timearray > 120) and ( item 24 timearray = 0) )
      [ set timearray replace-item 23 timearray 0
        ]
    )
  ]

;;if time is 25 years after the initialization group, all those that received catchup after vacc initialized go back to zero as theta
;;[ set timearray replace-item 23 timearray 0
  ;]

if ((( item 1 timearray > 300) )
  ;;if you are greater than or equal to 40 your theta is 0 regardless
  [ set timearray replace-item 23 timearray 0
    ;print timearray
  ]
)

if ((( item 1 timearray > 300) and (item 23 timearray != 0))
  ;;if you are greater than or equal to 40 your theta is 0 regardless
}
print timearray

;write-data
;write-data2
;write-data3
;write-data4
;write-data5
;write-data6
;write-data7
;write-data8
;write-data9
;write-data10
;write-data11
;write-data12
;write-data13
;print prevalence
findprevalence
getavgp
getavgp1520
getavgp2030
getavgp3040
getavgp4050
getavgp5060
getavgp6070
getavgp7080
getavgp50+
getavgtheta

writecumsexactbytype
update-plot
update-plot2
;update-plot3
;update-plotincidence
update-plot-HIV+byage
update-plot-HIV-byage
update-plot-Average-b-value-HIV+-by-age
update-plot-Average-b-value-HIV--by-age
update-plot-HIV+prevpercent
;update-plot-Average-theta-value-by-age

update-plot-sex-act-percentHIV-3040
update-plot-sex-act-percentHIV+3040
update-plot-sex-act-percentHIV-1520
update-plot-sex-act-percentHIV-2030
update-plot-sex-act-percentHIV-4050
update-plot-sex-act-percentHIV-50+
update-plot-sex-act-percentHIV+1520
update-plot-sex-act-percentHIV+2030
update-plot-sex-act-percentHIV+4050
update-plot-sex-act-percentHIV+50+

;update-plot-sexactstotalbyageRSHIVnegpos
;update-plot-sexactstotalbyageRSHIVnegneg
update-plot-CumUSnegposperyear

ask turtles
[
  if (ticks = 12)
  [
    if ( (item 1 timearray > 180) and (item 1 timearray <= 300) and item 21 offer = 1) and ( item 4 offer = 1) )
  [346]
ask turtles  ;;Resets their sextotalbytype everytime they reach a new age bracket
[ if ( item 1 timearray = 60) or ( item 1 timearray = 180) or
  ( item 1 timearray = 300) or ( item 1 timearray = 420)
  [ ;set sextotalbytype n-values 9 [0] ;;reset their sextotalbytype array.
   set sextotalbytype replace-item 0 sextotalbytype 0
   set sextotalbytype replace-item 1 sextotalbytype 0
   set sextotalbytype replace-item 2 sextotalbytype 0
   set sextotalbytype replace-item 3 sextotalbytype 0
   set sextotalbytype replace-item 4 sextotalbytype 0
   set sextotalbytype replace-item 5 sextotalbytype 0
   set sextotalbytype replace-item 6 sextotalbytype 0
   set sextotalbytype replace-item 7 sextotalbytype 0
   set sextotalbytype replace-item 8 sextotalbytype 0
  ]
 ]

if (ticks = 1999)
[
  set HIV+turtles1520 count turtles with [actual-status = 1 and
own-status = 1 and item 1 timearray <= 60]
/ ( count turtles with [ item 1 timearray <= 60 ] )
set HIV+turtles2030 count turtles with [actual-status = 1 and
own-status = 1 and item 1 timearray >= 61 and item 1 timearray <= 180]
/ (count turtles with [item 1 timearray >= 61 and item 1 timearray <= 180])
set HIV+turtles3040 count turtles with [actual-status = 1 and
own-status = 1 and item 1 timearray >= 181 and item 1 timearray <= 300]
/ (count turtles with [item 1 timearray >= 181 and item 1 timearray <= 300])
set HIV+turtles4050 count turtles with [actual-status = 1 and
own-status = 1 and item 1 timearray >= 301 and item 1 timearray <= 420]
/ (count turtles with [item 1 timearray >= 301 and item 1 timearray <= 420])
set HIV+turtles50+ count turtles with [actual-status = 1 and
own-status = 1 and item 1 timearray >= 421] /
/ (count turtles with [item 1 timearray >= 421])
set HIV-turtles1520 count turtles with [actual-status = 0 and
item 1 timearray <= 60]
set HIV-turtles2030 count turtles with [actual-status = 0 and
item 1 timearray >= 61 and item 1 timearray <= 180]
set HIV-turtles3040 count turtles with [actual-status = 0 and
item 1 timearray >= 181 and item 1 timearray <= 300]
set HIV-turtles4050 count turtles with [actual-status = 0 and
item 1 timearray >= 301 and item 1 timearray <= 420]
set HIV-turtles50+ count turtles with [actual-status = 0 and item 1 timearray >= 421]
]

end
; to color-collaborations
; ask links with [[in-team?] of end1 and [in-team?] of end2]
; [
; ifelse new-collaboration?
; [
; ifelse ([incumbent?] of end1) and ([incumbent?] of end2)
; [
; set color yellow ;; both members are incumbents
; ]
; [
; ifelse ([incumbent?] of end1) or ([incumbent?] of end2)
; [ set color green ] ;; one member is an incumbent
; [ set color blue ] ;; both members are newcomers
; ]
; ]
; ]
; [
; set color red ;; members are previous collaborators
; ]
; ]
;end

;----------------

to many-encounters ;; Set nodes to blue if they have a pre-determined number of links.
This could be useful later.
ask turtles
[if (count out-link-neighbors >= 4)
[ set color blue ]
]
end
to couple ;; turtle procedure - they couple along the incoming links

;;This is a directed graph. If no arrow point to an actor, it is regarded as alone despite having outward links.
set coupled? false ;;Initialize as with nobody
set partner1 nobody
let potential-partner one-of (in-link-neighbors)
;with [not coupled? ]
ifelse potential-partner != nobody
[ set partner1 potential-partner
set coupled? true
ask partner1 [ set coupled? true ]
ask partner1 [ set partner1 myself ]
;;;;;print word "Origin node = actor 1" partner1
;;;;;print word " Destination node = actor 2" self
]
[;;;;;print "No mate (alone or no incoming links):"
]
end

;;;;each person makes an offer of sex in this procedure

;;;;each person makes an offer of sex in this procedure
to interact ;; turtle procedure

set updateP2a 0
set updateP2b 0
set updateP1a 0
set updateP1b 0

couple
if coupled?
[ ask partner1
[ ;print self
;print (item 20 offer) ;; is who (id)
;get id from offer
]
ask self
[ ;print self
;print (item 20 offer)
set tempencounterarraynumber (item 20 offer)
;print tempencounterarraynumber
;get id from offer, set as a temp var. use this temp var below as a reference for the RSencounters array to get that info
]
ask partner1
[ ;print self
;print word "now the array number " tempencounterarraynumber
;print "P1’s RS encounter number "
;print RSencounters
;print (item tempencounterarraynumber RSencounters)
;set tempencounterarraynumber2 (item tempencounterarraynumber RSencounters)
;print word "tempencounterarraynumber2 " tempencounterarraynumber2
;set tempencounterarraynumber3 (item tempencounterarraynumber RSencounters)
;print word "tempencounterarraynumber3 " tempencounterarraynumber3
;set c (tempencounterarraynumber2 + tempencounterarraynumber3)
set delta (item 9 timearray)
;print word "delta is" delta
;print word "c " c
let randomrho random-float 1 ;; less than 1 greater than or equal to zero
;print word "randomrho " randomrho
set rho delta ;(delta * ((omega + c)/ (1 + c)) )
;print word "rho " rho
ifelse (rho < randomrho)
[ ;print "P1 is gonna say NS, interaction never occurs"
set nointeractionrho 0
ifelse ( (coupled?) and (nointerac) = 1 )
[
    ask partner1
    [:print self
     ;print word " HIV status of actor1 = " (item 4 offer)
    ifelse ( (item 4 offer) != 0) ;;item 4 offer 0 is HIV-, 1 is HIV+
        [set EU11RS (item 3 offer)*(item 5 offer) + (1 + (-1)*(item 3 offer))* (item 8 offer)
        set EU11PS (item 3 offer)*(item 6 offer) + (1 + (-1)*(item 3 offer))* (item 9 offer)
        set EU11NS (item 3 offer)*(item 7 offer) + (1 + (-1)*(item 3 offer))* (item 10 offer)
        let deltaEU (EU11RS - EU11PS)
        let fermi ( 1 / (1 + e ^ (-1 * fermi * (deltaEU - fermi)))
        let tempfermi random-float 1
        ifelse ( fermi > tempfermi)
        [set partner-action (item 0 offer)]
        [set partner-action (item 1 offer)]
    ]
    ; if ( (EU11RS >= EU11PS) and (EU11RS >= EU11NS))
    ; [set partner-action (item 0 offer)] ;;0 is RS
if ( (EU11PS > EU11RS) and (EU11PS >= EU11NS))

[set partner-action (item 1 offer)] ;;1 is PS

if ( (EU11NS > EU11RS) and (EU11NS > EU11PS))

[set partner-action (item 2 offer)] ;;2 is NS

set print-partner1 n-values 6 [0]
set print-partner1 replace-item 0 print-partner1 self
set print-partner1 replace-item 1 print-partner1 partner-action
set print-partner1 replace-item 2 print-partner1 (item 4 offer)
set print-partner1 replace-item 3 print-partner1 EU11RS
set print-partner1 replace-item 4 print-partner1 EU11PS
set print-partner1 replace-item 5 print-partner1 EU11NS

[ ifelse (item 21 timearray = 1) ;;If they believe they are provaccinatd protected
[ set RSutilitypos 100
]

[set RSutilitypos ( (ARTcoverage ^ (kdecision)) * ( (item 11 offer) + ARTcoverd ) +
(1 - (ARTcoverage ^ (kdecision)) ) * (item 11 offer) )
]

;set word "ARTcoverage " ARTcoverage
;set word "ARTcoverd " ARTcoverd
;set word "item 11 RS " item 11 offer
;set word "item 12 PS " item 12 offer
;set word "item 14 RS " item 14 offer
;set word "item 15 PS " item 15 offer
;set word RSutilityneg

set EU10RS (item 3 offer)* RSutilitypos + (1 + (-1)*(item 3 offer))* (item 14 offer)
set EU10PS (item 3 offer)*(item 12 offer) + (1 + (-1)*(item 3 offer))* (item 15 offer)
set EU10NS (item 3 offer)*(item 13 offer) + (1 + (-1)*(item 3 offer))* (item 16 offer)
let deltaEU (EU10RS - EU10PS)

let fermidirac ( 1 / (1 + e ^ ( -1 * fermidiraca * (deltaEU - fermidiracp))))

let tempfermi random-float 1

ifelse ( fermidirac > tempfermi)
[set partner-action (item 0 offer)]
[set partner-action (item 1 offer)]

; if ( (EU10RS >= EU10PS) and (EU10RS >= EU10NS))
; [set partner-action (item 0 offer)] ;;0 is RS
; if ( (EU10PS > EU10RS) and (EU10PS >= EU10NS))
; [set partner-action (item 1 offer)] ;;1 is PS
; if ( (EU10NS > EU10RS) and (EU10NS > EU10PS))
; [set partner-action (item 2 offer)] ;;2 is NS

set print-partner1 n-values 6 [0]
set print-partner1 replace-item 0 print-partner1 self
set print-partner1 replace-item 1 print-partner1 partner-action
set print-partner1 replace-item 2 print-partner1 (item 4 offer)
set print-partner1 replace-item 3 print-partner1 EU10RS
set print-partner1 replace-item 4 print-partner1 EU10PS
set print-partner1 replace-item 5 print-partner1 EU10NS

];;;print word " Actor1=" print-partner1
;print print-partner1

set choiceP1a partner-action
set tempnum1 (item 0 print-partner1)
set tempturnnum1 (item 20 offer)
set origpvaluep1 (item 3 offer)
;print word "this is tempnum1" tempnum1
set hivstatusP1 (item 21 offer)
set transSpreadP1 (item 16 timearray)
set P1theta (item 23 timearray)
set P1ageclass (item 1 timearray)
;if ( (ticks = 920) and (item 1 timearray < 13) )
;print word "P1theta for Partner1 " P1theta

;print word "trans by stage P1" transSpreadP1

;if ( (ticks = 920) and (item 1 timearray < 13) ) ;;print test partner 1 before
;[ print word "self " self
 ; print word "partner-action " partner-action
 ; print word "RS utility " item 3 print-partner1
 ; print word "PS utility " item 4 print-partner1
 ; print word "Ns Utility " item 5 print-partner1
 ; print word "offer " offer
 ; print word "timearray " timearray
 ;]

;]

ask self
[ ;print self
 ;print word " HIV status of actor2 = " (item 4 offer)
set transSpreadP2 (item 16 timearray)
;print word "trans by stage P2" transSpreadP2

;if ( (ticks = 920) and (item 1 timearray < 13) ) ;print test self before
;[ ;print word "self " self
 ;print word "partner-action " self-action
 ;print word "RS utility " item 3 print-self
 ;print word "PS utility " item 4 print-self
 ;print word "Ns Utility " item 5 print-self
 ; print word "offer " offer
 ; print word "timearray " timearray
ifelse (choiceP1a = (item 0 offer)); If P1 offers RS
[
set origpvaluep2 (item 3 offer)
;set updatepP2a ((item 3 offer)* (1 - (item 3 offer))*(sigma))
;set updatepP2b ( ((lambda)*(item 3 offer)) + ((1 - lambda)*(updatepP2a)) )
;print word " actor2 updated perceived p " updatepP2b

set thetadecision P1theta
set fnctheta ( thetadecision ^ kdecision)

set updatepP2a ( beta *((alpha * (1 - fnctheta)) + (( 1 - (alpha))*(item 3 offer))) +
(1 - beta) * prevalence )

set offer replace-item 3 offer updatepP2a
ifelse ( (item 4 offer) != 0 );; item 4 offer 0 is HIV-, 1 is HIV+
;;player is HIV+
[ set EU21RS (item 3 offer)*(item 5 offer) + (1 + (-1)*(item 3 offer))*(item 8 offer)
set EU21PS (item 3 offer)*(item 6 offer) + (1 + (-1)*(item 3 offer))*(item 9 offer)
set EU21NS (item 3 offer)*(item 7 offer) + (1 + (-1)*(item 3 offer))*(item 10 offer)

;; USING FERMI DIRAC, Player 2 is deciding amongst what Player 1 wanted and NS
let deltaEU (EU21RS - EU21NS)
let fermidirac ( 1 / (1 + e ^ (-1 * fermidiraca * (deltaEU - fermidiracp))))
let tempfermi random-float 1
ifelse ( fermidirac > tempfermi)
[set self-action (item 0 offer)]
[set self-action (item 2 offer)]
if ( (EU21RS >= EU21PS) and (EU21RS >= EU21NS))
[set self-action (item 0 offer)]; 0 is RS
if ( (EU21PS > EU21RS) and (EU21PS >= EU21NS))
[set self-action (item 1 offer)]; 1 is PS
if ( (EU21NS > EU21RS) and (EU21NS > EU21PS))
[set self-action (item 2 offer)]; 2 is NS

set print-self n-values 6 [0]
set print-self replace-item 0 print-self self
set print-self replace-item 1 print-self self-action
set print-self replace-item 2 print-self (item 4 offer)
set print-self replace-item 3 print-self EU21RS
set print-self replace-item 4 print-self EU21PS
set print-self replace-item 5 print-self EU21NS

;; player is HIV-
[ ifelse (item 21 timearray = 1) ;; If they believe they are provaccinatd protected
[ set RSutilitypos 100
]
[ set RSutilitypos ( (ARTcoverage ^ (kdecision)) * ( (item 11 offer) + ARTcoverd ) + (1 - (ARTcoverage ^ (kdecision))) * (item 11 offer) ) ]

set EU20RS (item 3 offer)* RSutilitypos + (1 + (-1)*(item 3 offer))* (item 14 offer)
set EU20PS (item 3 offer)*(item 12 offer) + (1 + (-1)*(item 3 offer))* (item 15 offer)
set EU20NS (item 3 offer)*(item 13 offer) + (1 + (-1)*(item 3 offer))* (item 16 offer)

let deltaEU (EU20RS - EU20NS)
let fermidirac ( 1 / (1 + e ^ ( -1 * fermidiraca * (deltaEU - fermidiracp))))
let tempfermi random-float 1
ifelse ( fermidirac > tempfermi)
[set self-action (item 0 offer)]
[set self-action (item 2 offer)]
if ((EU20RS >= EU20PS) and (EU20RS >= EU20NS))
set self-action (item 0 offer) ;;0 is RS
if ((EU20PS > EU20RS) and (EU20PS >= EU20NS))
set self-action (item 1 offer) ;;1 is PS
if ((EU20NS > EU20RS) and (EU20NS > EU20PS))
set self-action (item 2 offer) ;;2 is NS

set print-self n-values 6 [0]
set print-self replace-item 0 print-self self
set print-self replace-item 1 print-self self-action
set print-self replace-item 2 print-self (item 4 offer)
set print-self replace-item 3 print-self EU20RS
set print-self replace-item 4 print-self EU20PS
set print-self replace-item 5 print-self EU20NS

;print word " Actor2=" print-self
;print print-self
;set choiceP2a self-action
;set tempnum2 (item 0 print-self)
;set tempturnum2 (item 20 offer)
;set hivstatusP2 (item 21 offer)
;print word "this is tempnum2" tempnum2
]

;;;;;;;;;;;;;;If choiceP1a is PS [ ;
;set updatepP2a ((item 3 offer)- (((item 3 offer) - 0)•(sigma)))
;set updatepP2b (((lambda)•(item 3 offer)) + (((1 - lambda)•(updatepP2a) )
;print word " actor2 updated perceived p " updatepP2b
set updatepP2a ( beta * (((1 - alpha)•(item 3 offer)) + (((1 - beta) • prevalence) )
set offer replace-item 3 offer updatepP2a
ifelse ((item 4 offer) != 0 );;item 4 offer 0 is HIV-, 1 is HIV+
;; player is HIV+
[ set EU21RS (item 3 offer) * (item 5 offer) + (1 + (-1) * (item 3 offer)) * (item 8 offer) 
set EU21PS (item 3 offer) * (item 6 offer) + (1 + (-1) * (item 3 offer)) * (item 9 offer) 
set EU21NS (item 3 offer) * (item 7 offer) + (1 + (-1) * (item 3 offer)) * (item 10 offer) ]

let deltaEU (EU21PS - EU21NS) 
let fermidirac ( 1 / (1 + e ^ ( -1 * fermidiraca * (deltaEU - fermidiracp)))) 
let tempfermi random-float 1 
ifelse ( fermidirac > tempfermi) 
[ set self-action (item 1 offer) ] 
[ set self-action (item 2 offer) ]

; if ( (EU21RS >= EU21PS) and (EU21RS >= EU21NS) ) ;;0 is RS
; [ set self-action (item 0 offer) ] ;;0 is RS
; if ( (EU21PS > EU21RS) and (EU21PS >= EU21NS) )
; [ set self-action (item 1 offer) ] ;;1 is PS
; if ( (EU21NS > EU21RS) and (EU21NS > EU21PS) )
; [ set self-action (item 2 offer) ] ;;2 is NS

set print-self n-values 6 [ 0 ]
set print-self replace-item 0 print-self self 
set print-self replace-item 1 print-self self-action 
set print-self replace-item 2 print-self (item 4 offer) 
set print-self replace-item 3 print-self EU21RS 
set print-self replace-item 4 print-self EU21PS 
set print-self replace-item 5 print-self EU21NS ] 

;; player is HIV-
[ ifelse (item 21 timearray = 1) ;;If they believe they are provaccinatd protected 
[ set RSUtilitypos 100 ]
[ set RSUtilitypos ( (ARTcoverage ^ (kdecision)) * (item 11 offer) + ARTcoverd ) + 
(1 - (ARTcoverage ^ (kdecision)) ) * (item 11 offer) ) ]
set EU20RS (item 3 offer) * RSutilitypos + (1 + (-1) * (item 3 offer)) * (item 14 offer)
set EU20PS (item 3 offer) * (item 12 offer) + (1 + (-1) * (item 3 offer)) * (item 15 offer)
set EU20NS (item 3 offer) * (item 13 offer) + (1 + (-1) * (item 3 offer)) * (item 16 offer)

let deltaEU (EU20PS - EU20NS)
let fermidirac (1 / (1 + e ^ (-1 * fermidiraca * (deltaEU - fermidiracp))))
let tempfermi random-float 1
ifelse (fermidirac > tempfermi)
  [set self-action (item 1 offer)]
  [set self-action (item 2 offer)]

; if (EU20RS >= EU20PS) and (EU20RS >= EU20NS)
  [set self-action (item 0 offer)]; 0 is RS
; if (EU20PS > EU20RS) and (EU20PS >= EU20NS)
  [set self-action (item 1 offer)]; 1 is PS
; if (EU20NS > EU20RS) and (EU20NS > EU20PS)
  [set self-action (item 2 offer)]; 2 is NS

set print-self n-values 6 [0]
set print-self replace-item 0 print-self self
set print-self replace-item 1 print-self self-action
set print-self replace-item 2 print-self (item 4 offer)
set print-self replace-item 3 print-self EU20RS
set print-self replace-item 4 print-self EU20PS
set print-self replace-item 5 print-self EU20NS]

;print word " Actor2=" print-self
;print print-self
set choiceP2a self-action
set tempnum2 (item 0 print-self)
set temturnum2 (item 20 offer)
set hivstatusP2 (item 21 offer)
set P2theta (item 23 timearray)
set P2ageclass (item 1 timearray)

; if ( (ticks = 920) and (item 1 timearray < 13) )
; [ print word "P2theta for self " P2theta ]

; if ( (ticks = 920) and (item 1 timearray < 13) ) ;;print test self after
; [ print word "self " self
; [ print word "partner-action " self-action
; [ print word "RS utility " item 3 print-self
; [ print word "PS utility " item 4 print-self
; [ print word "Ns Utility " item 5 print-self
; [ print word "offer " offer
; [ print word "timearray " timearray
; ]
]

];;Now Player 1 reevaluates what it wants...

;;The game progresses. If same choices, that type of sex will occur,
if not, another round of questions.
;print word = " choiceP1a
if else choiceP1a = choiceP2a
[
if else choiceP1a = "RS"
[
;print word " Players will have, after 1st round " choiceP1a
;print word " status of partner1 " hivstatusP1
;print word " status of self " hivstatusP2

if (hivstatusP1 = 1 and hivstatusP2 = 1) ;;1 is HIV pos
[ set cumsexactstemp ((item 0 sextotalbytype)+ 1)
set sextotalbytype replace-item 0 sextotalbytype cumsexactstemp
]
if (hivstatusP1 = 1 and hivstatusP2 = 0) or (hivstatusP1 = 0 and hivstatusP2 = 1) ;;1 is HIV pos
[ set cumsexactstemp ((item 1 sextotalbytype)+ 1)
set sextotalbytype replace-item 1 sextotalbytype cumsexactstemp
]
if (hivstatusP1 = 0 and hivstatusP2 = 0) ;;1 is HIV pos
[ set cumsexactstemp ((item 2 sextotalbytype)+ 1)
set sextotalbytype replace-item 2 sextotalbytype cumsexactstemp
]

if (hivstatusP1 = 1 and hivstatusP2 = 0) or (hivstatusP1 = 0 and hivstatusP2 = 1) ;;1 is HIV pos
[
if ((P1ageclass < 60) and (hivstatusP1 = 0))
[set totalsexactstemp ((item 0 totalsexactsbyage)+ 1)
set totalsexactsbyage replace-item 0 totalsexactsbyage totalsexactstemp
]
if ((P1ageclass > 60) and (P1ageclass < 180) and (hivstatusP1 = 0))
[set totalsexactstemp ((item 1 totalsexactsbyage)+ 1)
set totalsexactsbyage replace-item 1 totalsexactsbyage totalsexactstemp
]
if ((P1ageclass > 180) and (P1ageclass < 300) and (hivstatusP1 = 0))
[set totalsexactstemp ((item 2 totalsexactsbyage)+ 1)
set totalsexactsbyage replace-item 2 totalsexactsbyage totalsexactstemp
[
if ((P1ageclass > 300) and (P1ageclass < 420) and (hivstatusP1 = 0))
(set totalsexactstemp ((item 3 totalsexactsbyage)+ 1))
set totalsexactsbyage replace-item 3 totalsexactsbyage totalsexactstemp
]
if ((P1ageclass > 420) and (hivstatusP1 = 0))
(set totalsexactstemp ((item 4 totalsexactsbyage)+ 1))
set totalsexactsbyage replace-item 4 totalsexactsbyage totalsexactstemp
]
if ((P2ageclass < 60) and (hivstatusP2 = 0))
(set totalsexactstemp ((item 0 totalsexactsbyage)+ 1))
set totalsexactsbyage replace-item 0 totalsexactsbyage totalsexactstemp
]
if ((P2ageclass > 60) and (P2ageclass < 180) and (hivstatusP2 = 0))
(set totalsexactstemp ((item 1 totalsexactsbyage)+ 1))
set totalsexactsbyage replace-item 1 totalsexactsbyage totalsexactstemp
]
if ((P2ageclass > 180) and (P2ageclass < 300) and (hivstatusP2 = 0))
(set totalsexactstemp ((item 2 totalsexactsbyage)+ 1))
set totalsexactsbyage replace-item 2 totalsexactsbyage totalsexactstemp
]
if ((P2ageclass > 300) and (P2ageclass < 420) and (hivstatusP2 = 0))
(set totalsexactstemp ((item 3 totalsexactsbyage)+ 1))
set totalsexactsbyage replace-item 3 totalsexactsbyage totalsexactstemp
]
if ((P2ageclass > 420) and (hivstatusP2 = 0))
(set totalsexactstemp ((item 4 totalsexactsbyage)+ 1))
set totalsexactsbyage replace-item 4 totalsexactsbyage totalsexactstemp
]
;set tempnum2 item 0 print-partner1
;ask link (item 0 print-self) (item 0 print-partner1)
;ask link tempnum1 tempnum2
;ask links with [[self] of end1 and [partner1] of end2]
;[set color red]
;ask self [create-blue-link-to partner1]
;print word " tempnum1=" tempnum1
;create-blue-link-with tempnum1
;[set color blue]
;;Here probability of spread for RS
set exnum1 1
;print word "P1 trans spread " transSpreadP1
;print word "P2 trans spread " transSpreadP2
;set spreadRS 0.85
set exnum1 random-float 1 ;;random number between 0 and exnum1
ifelse (exnum1 < (spreadRS * transSpreadP1 * transSpreadP2) )
[

ifelse (hivstatusP1 != hivstatusP2)
[ask partner1
[ ifelse ( item 19 timearray = 0) ;;0 meaning they have no protection
[

set thetadecision P2theta
set fnctheta ( thetadecision - kdecision)
;print word "fnctheta for partner1 " fnctheta
set updatepP1a ( beta *((alpha * (1 - fnctheta)) +
(( 1 - (alpha))*((item 3 offer))) + (1 - beta) * prevalence )

;if ( (ticks = 920) and (item 1 timearray < 13) )
;[ print word " partner1 update their b-value as 1 " updatepP1a ]

set offer replace-item 3 offer updatepP1a

364
if (actual-status = 0) ;they were HIV - before this and will now be infected
[ if ( item 1 timearray < 61 ) ;;they are 15-20
[ set incidenceHIV1520 ( incidenceHIV1520 + 1 )
]
if ( (item 1 timearray >= 61 ) and (item 1 timearray < 181) ) ;;they are 20-30
[ set incidenceHIV2030 ( incidenceHIV2030 + 1 )
]
if ( (item 1 timearray >= 181 ) and (item 1 timearray < 301) ) ;;they are 30-40
[ set incidenceHIV3040 ( incidenceHIV3040 + 1 )
]
if ( (item 1 timearray >= 301 ) and (item 1 timearray < 421) ) ;;they are 40-50
[ set incidenceHIV4050 ( incidenceHIV4050 + 1 )
]
if ( item 1 timearray >= 421 ) ;;they are 50+
[ set incidenceHIV50+ ( incidenceHIV50+ + 1 )
]
set timearray replace-item 25 timearray 1
]

set actual-status 1
set offer replace-item 21 offer actual-status
set RScounter ((item 17 offer)+ 1)
;set offer replace-item 4 offer own-status
set offer replace-item 17 offer RScounter
set color red

;set tempencount ((item tempturnum2 encounters)+ 1)
;set encounters replace-item tempturnum2 encounters tempencount
;set tempencount ((item tempturnum2 RSencounters)+ 1)
;set RSencounters replace-item tempturnum2 RSencounters tempencount
set incidenceHIV (incidenceHIV + 1)
set theadecision P2theta
set fnctheta ( theadecision - kdecision)

set updatepP1a ( beta *((alpha * (1 - fnctheta)) +
    (( 1 - (alpha))*(item 3 offer))) + (1 - beta) * prevalence )

;if ( (ticks = 920) and (item 1 timearray < 13) )
    ;[ print word " partner1 update their b-value as 2 " updatepP1a ]

set offer replace-item 3 offer updatepP1a
set RScounter ((item 17 offer)+ 1)
set offer replace-item 17 offer RScounter
;set tempencount ((item tempturnum2 encounters)+ 1)
;set encounters replace-item tempturnum2 encounters tempencount
;set tempencount ((item tempturnum2 RSencounters)+ 1)
;set RSencounters replace-item tempturnum2 RSencounters tempencount
]

ask self
[ ifelse ( item 19 timearray = 0) ;;0 meaning they have no protection
    [ [ if (actual-status = 0) ;they were HIV - before this and will now be infected
        [ if ( item 1 timearray < 61 ) ;;they are 15-20
            [ set incidenceHIV1520 ( incidenceHIV1520 + 1 )
            ]
        ]
        if ( (item 1 timearray >= 61 ) and (item 1 timearray < 181) ) ;;they are 20-30
            [ set incidenceHIV2030 ( incidenceHIV2030 + 1 )
            ]
    ]
]
if ( (item 1 timearray >= 181 ) and (item 1 timearray < 301) ) ;;they are 30-40
[ set incidenceHIV3040 ( incidenceHIV3040 + 1 ) ]

if ( (item 1 timearray >= 301 ) and (item 1 timearray < 421) ) ;;they are 40-50
[ set incidenceHIV4050 ( incidenceHIV4050 + 1 ) ]

if ( item 1 timearray >= 421 ) ;;they are 50+
[ set incidenceHIV50+ ( incidenceHIV50+ + 1 ) ]

set timearray replace-item 25 timearray 1
]

set actual-status 1
set offer replace-item 21 offer actual-status
set RScounter ( (item 17 offer) + 1 )
set offer replace-item 17 offer RScounter
set color red
;set tempencount ( (item tempturnum2 encounters) + 1 )
;set encounters replace-item tempturnum2 encounters tempencount
;set tempencount ( (item tempturnum2 RSencounters) + 1 )
;set RSencounters replace-item tempturnum2 RSencounters tempencount
]
[ set RScounter ( (item 17 offer) + 1 )
set offer replace-item 17 offer RScounter
;set tempencount ( (item tempturnum2 encounters) + 1 )
;set encounters replace-item tempturnum2 encounters tempencount
;set tempencount ( (item tempturnum2 RSencounters) + 1 )
;set RSencounters replace-item tempturnum2 RSencounters tempencount
]
;; If players have same HIV status, meaning no spread
[ask partner1

set theadecision P2theta
set fnctheta ( theadecision ^ kdecision)
;print word "fnctheta for partner1" fnctheta

set updateP1a ( beta *((alpha * (1 - fnctheta)) +
        (( 1 - (alpha))*(item 3 offer))) + (1 - beta) * prevalence )
if ( (ticks = 920) and (item 1 timearray < 13) )
[ print word " partner1 update their b-value as 3 " updateP1a ]
set offer replace-item 3 offer updateP1a
set RScounter ((item 17 offer)+ 1)
set offer replace-item 17 offer RScounter
;set tempencount ((item tempturnum2 encounters)+ 1)
;set encounters replace-item tempturnum2 encounters tempencount
;set tempencount ((item tempturnum2 RSencounters)+ 1)
;set RSencounters replace-item tempturnum2 RSencounters tempencount
]

ask self
[ set RScounter ((item 17 offer)+ 1)
set offer replace-item 17 offer RScounter
;set tempencount ((item tempturnum1 encounters)+ 1)
;set encounters replace-item tempturnum1 encounters tempencount
;set tempencount ((item tempturnum1 RSencounters)+ 1)
;set RSencounters replace-item tempturnum1 RSencounters tempencount
]

;;otherwise same thing but not going to spread from ifelse
[ ifelse (hivstatusP1 != hivstatusP2)
one player is HIV + and one is not and HIV WILL NOT spread

[ask partner1

set thetadecision P2theta

set fnctheta ( thetadecision - kdecision)

;print word " fnctheta for Partner1 " fnctheta

set updateP1a ( beta *((alpha * (1 - fnctheta)) + (1 - (alpha))*(item 3 offer))) +
    (1 - beta) * prevalence )

;if ( (ticks = 920) and (item 1 timearray < 13) )
    ;[ print word " partner1 update their b-value as 4 " updateP1a ]

set offer replace-item 3 offer updateP1a
set RScounter ((item 17 offer)+ 1)
set offer replace-item 17 offer RScounter

;set tempencount ((item tempturnum2 encounters)+ 1)
;set encounters replace-item tempturnum2 encounters tempencount
;set tempencount ((item tempturnum2 RSencounters)+ 1)
;set RSencounters replace-item tempturnum2 RSencounters tempencount

]

ask self

[ set RScounter ((item 17 offer)+ 1)
set offer replace-item 17 offer RScounter

;set tempencount ((item tempturnum1 encounters)+ 1)
;set encounters replace-item tempturnum1 encounters tempencount
;set tempencount ((item tempturnum1 RSencounters)+ 1)
;set RSencounters replace-item tempturnum1 RSencounters tempencount

]

];;If players have same HIV status, meaning no spread
[ask partner1

[
set thetadecision P2theta
set fnctheta ( thetadecision - kdecision)

; if ( (ticks = 920) and (item 1 timearray < 13) )
    ;[ print word " previous b-value " (item 3 offer)
    ; print word " what partner1 thinks self's theta is " thetadecision
    ; print word " kdecision is " kdecision
    ; print word " fnctheta for Partner1 " fnctheta ]

set updatepP1a ( beta *((alpha * (1 - fnctheta)) + (( 1 - (alpha))*(item 3 offer)))
+ (1 - beta) * prevalence )

; if ( (ticks = 920) and (item 1 timearray < 13) )
    ;[ print word " partner1 update their b-value as 5 " updatepP1a ]

set offer replace-item 3 offer updatepP1a
set RScounter ((item 17 offer)+ 1)
set offer replace-item 17 offer RScounter
; set tempencount ((item tempturnum2 encounters)+ 1)
; set encounters replace-item tempturnum2 encounters tempencount
; set tempencount ((item tempturnum2 RSencounters)+ 1)
; set RSencounters replace-item tempturnum2 RSencounters tempencount

]

ask self
[ set RScounter ((item 17 offer)+ 1)
set offer replace-item 17 offer RScounter
; set tempencount ((item tempturnum1 encounters)+ 1)
; set encounters replace-item tempturnum1 encounters tempencount
; set tempencount ((item tempturnum1 RSencounters)+ 1)
; set RSencounters replace-item tempturnum1 RSencounters tempencount

]
;; If Both players engage in PS
[   ;print word " Players will have, after 1st round " choiceP1a    
;print word " hivstatusP1    
;print word " hivstatusP2    
;ask links [set color blue]    
;print word " tempnum1=" tempnum1

if (hivstatusP1 = 1 and hivstatusP2 = 1) ;;1 is HIV pos
[ set cumsexactstemp ((item 3 sextotalbytype)+ 1)
set sextotalbytype replace-item 3 sextotalbytype cumsexactstemp
]

if (hivstatusP1 = 1 and hivstatusP2 = 0) or (hivstatusP1 = 0 and hivstatusP2 = 1) ;;1 is HIV pos
[ set cumsexactstemp ((item 4 sextotalbytype)+ 1)
set sextotalbytype replace-item 4 sextotalbytype cumsexactstemp
]

if (hivstatusP1 = 0 and hivstatusP2 = 0) ;;1 is HIV pos
[ set cumsexactstemp ((item 5 sextotalbytype)+ 1)
set sextotalbytype replace-item 5 sextotalbytype cumsexactstemp
]

;create-blue-link-with tempnum1
; [set color yellow]

371
set exnum2 1
set spreadPS 0.25
set exnum2 random-float 1 ;; random number between 0 and exnum2
ifelse exnum2 < spreadPS
   [ifelse (hivstatusP1 != hivstatusP2)
      ;; one player is HIV + and one is not and HIV WILL spread
      [ask partner1
      [ifelse (item 19 timearray = 0) ;; 0 meaning they have no protection
      [set updatepP1a (beta * ((1 - alpha)*(item 3 offer)) + ((1 - beta) * prevalence))]
      ; if (ticks = 920) and (item 1 timearray < 13)
      ;[print word " partner1 update their b-value as 6 " updatepP1a ]
      set offer replace-item 3 offer updatepP1a
   if (actual-status = 0) ; they were HIV - before this and will now be infected
      [if (item 1 timearray < 61) ;; they are 15-20
      [set incidenceHIV1520 (incidenceHIV1520 + 1)]
      if (item 1 timearray >= 61) and (item 1 timearray < 181) ;; they are 20-30
      [set incidenceHIV2030 (incidenceHIV2030 + 1)]
      if (item 1 timearray >= 181) and (item 1 timearray < 301) ;; they are 30-40
      [set incidenceHIV3040 (incidenceHIV3040 + 1)]
      if (item 1 timearray >= 301) and (item 1 timearray < 421) ;; they are 40-50
      [set incidenceHIV4050 (incidenceHIV4050 + 1)]
      if (item 1 timearray >= 421) ;; they are 50+
      [set incidenceHIV50+ (incidenceHIV50+ + 1)]
      set timearray replace-item 25 timearray 1]
set actual-status 1
set offer replace-item 21 offer actual-status
set PScounter ((item 18 offer)+ 1)
set offer replace-item 18 offer PScounter
set color red
;set tempencount ((item tempturnum2 encounters)+ 1)
;set encounters replace-item tempturnum2 encounters tempencount
;set tempencount ((item tempturnum2 PSencounters)+ 1)
;set PSencounters replace-item tempturnum2 PSencounters tempencount
set incidenceHIV (incidenceHIV + 1)
]
[ set updateP1a ( beta * ( (1 - alpha)*(item 3 offer)) + ((1 - beta) * prevalence) )

;[ if ( (ticks = 920) and (item 1 timearray < 13) ) ]
;[ print word " partner1 update their b-value as 7 " updateP1a ]

set offer replace-item 3 offer updateP1a
set PScounter ((item 18 offer)+ 1)
set offer replace-item 18 offer PScounter
;set tempencount ((item tempturnum2 encounters)+ 1)
;set encounters replace-item tempturnum2 encounters tempencount
;set tempencount ((item tempturnum2 PSencounters)+ 1)
;set PSencounters replace-item tempturnum2 PSencounters tempencount
]
]

ask self
[ ifelse ( item 19 timearray = 0 ) ;;0 meaning they have no protection
[ if (actual-status = 0) ;they were HIV - before this and will now be infected
[ if ( item 1 timearray < 61 ) ;;they are 15-20
[ set incidenceHIV1520 ( incidenceHIV1520 + 1 )

373
if ( (item 1 timearray >= 61 ) and (item 1 timearray < 181) ) ;;they are 20-30
[ set incidenceHIV2030 ( incidenceHIV2030 + 1 ) ]

if ( (item 1 timearray >= 181 ) and (item 1 timearray < 301) ) ;;they are 30-40
[ set incidenceHIV3040 ( incidenceHIV3040 + 1 ) ]

if ( (item 1 timearray >= 301 ) and (item 1 timearray < 421) ) ;;they are 40-50
[ set incidenceHIV4050 ( incidenceHIV4050 + 1 ) ]

if ( item 1 timearray >= 421 ) ;;they are 50+
[ set incidenceHIV50+ ( incidenceHIV50+ + 1 ) ]

set timearray replace-item 25 timearray 1 ]

set actual-status 1
set offer replace-item 21 offer actual-status
set PScounter ((item 18 offer)+ 1)
set offer replace-item 18 offer PScounter
set color red
;set tempencount ((item tempturnum2 encounters)+ 1)
;set encounters replace-item tempturnum2 encounters tempencount
;set tempencount ((item tempturnum2 PSencounters)+ 1)
;set PSencounters replace-item tempturnum2 PSencounters tempencount
]
[ set PScounter ((item 18 offer)+ 1)
set offer replace-item 18 offer PScounter
;set tempencount ((item tempturnum2 encounters)+ 1)
;set encounters replace-item tempturnum2 encounters tempencount
;set tempencount ((item tempturnum2 PSencounters)+ 1)
;set PSencounters replace-item tempturnum2 PSencounters tempencount
]
[ask partner1
[ set updateP1a ( beta * ( (1 - alpha) * (item 3 offer) ) + (1 - beta) * prevalence ) ]

; if ( (ticks = 920) and (item 1 timearray < 13) )
;[ print word " partner1 update their b-value as 8 " updateP1a ]

set offer replace-item 3 offer updateP1a
set PScounter ((item 18 offer) + 1)
set offer replace-item 18 offer PScounter
; set tempencount ((item tempturnum2 encounters) + 1)
; set encounters replace-item tempturnum2 encounters tempencount
; set tempencount ((item tempturnum2 PSencounters) + 1)
; set PSencounters replace-item tempturnum2 PSencounters tempencount

]

ask self
[ set PScounter ((item 18 offer) + 1)
set offer replace-item 18 offer PScounter
; set tempencount ((item tempturnum1 encounters) + 1)
; set encounters replace-item tempturnum1 encounters tempencount
; set tempencount ((item tempturnum1 PSencounters) + 1)
; set PSencounters replace-item tempturnum1 PSencounters tempencount

]

[ ]

]

]

]

ifelse (hivstatusP1 != hivstatusP2)
[ask partner1
\[
\text{set updateP1a} \ ( \beta \cdot (1 - \alpha) \cdot \text{(item 3 offer)}) + ((1 - \beta) \cdot \text{prevalence}) \]

;\text{if} \ (\text{ticks} = 920 \text{ and item 1 timearray} < 13) 
\;\text{[ print word " partner1 update their b-value as 9 " updateP1a ]}

\text{set offer replace-item 3 offer updateP1a}
\text{set PScounter ((item 18 offer)+ 1)}
\text{set offer replace-item 18 offer PScounter}
\;\text{set tempencount ((item tempturnum2 encounters)+ 1)}
\;\text{set encounters replace-item tempturnum2 encounters tempencount}
\;\text{set tempencount ((item tempturnum2 PSencounters)+ 1)}
\;\text{set PSencounters replace-item tempturnum2 PSencounters tempencount}

\]

\text{ask self}
\[\text{set PScounter ((item 18 offer)+ 1)}
\text{set offer replace-item 18 offer PScounter}
\;\text{set tempencount ((item tempturnum1 encounters)+ 1)}
\;\text{set encounters replace-item tempturnum1 encounters tempencount}
\;\text{set tempencount ((item tempturnum1 PSencounters)+ 1)}
\;\text{set PSencounters replace-item tempturnum1 PSencounters tempencount}
\]

\]

\[\text{ask partner1}
\[\text{set updateP1a} \ ( \beta \cdot (1 - \alpha) \cdot \text{(item 3 offer)}) + ((1 - \beta) \cdot \text{prevalence}) \]

;\text{if} \ (\text{ticks} = 920 \text{ and item 1 timearray} < 13) 
\;\text{[ print word " partner1 update their b-value as 10 " updateP1a ]}

\text{set offer replace-item 3 offer updateP1a}
\text{set PScounter ((item 18 offer)+ 1)}

376
set offer replace-item 18 offer PScounter
;set tempencount ((item tempturnum2 encounters)+ 1)
;set encounters replace-item tempturnum2 encounters tempencount
;set tempencount ((item tempturnum2 PSencounters)+ 1)
;set PSencounters replace-item tempturnum2 PSencounters tempencount

]

ask self
[ set PScounter ((item 18 offer)+ 1)
set offer replace-item 18 offer PScounter
;set tempencount ((item tempturnum1 encounters)+ 1)
;set encounters replace-item tempturnum1 encounters tempencount
;set tempencount ((item tempturnum1 PSencounters)+ 1)
;set PSencounters replace-item tempturnum1 PSencounters tempencount

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ask self
[
;if ( (ticks = 920) and (item 1 timearray < 13) )
    ;;print test self after again, is same?
    ;[ print word "self " self
    ;print word "partner-action " partner-action
    ;print word "RS utility " item 3 print-partner1
    ;print word "PS utility " item 4 print-partner1
    ;print word "Ns Utility " item 5 print-partner1
    ;print word "offer " offer
    ;print word "timearray " timearray
    ;]
]

]

[;
;;Heads up! These shouldn’t occur under these settings!
ask partner1
[
;ifelse (choiceP2a = (item 0 offer)) ;;If P2 counteroffers RS
    [
    set thetadecision P2theta
    set fnctheta ( thetadecision ^ kdecision)
    set updateP1a ( beta *((alpha * (1 - fnctheta)) + (( 1 - (alpha))*(item 3 offer))) +
    (1 - beta) * prevalence )

    ;if ( (ticks = 920) and (item 1 timearray < 13) )
    ;[ print word " partner1 update their b-value as 11 " updateP1a ]

]
set offer replace-item 3 offer updatepP1a

;;If Player 2 counteroffers PS or NS
[
set updatepP1a ( beta * ( (1 - alpha)*(item 3 offer)) + ((1 - beta) * prevalence) )
]

;if ( (ticks = 920) and (item 1 timearray < 13) )
;[ print word " partner1 update their b-value as 12 " updatepP1a ]

set offer replace-item 3 offer updatepP1a
]

if (hivstatusP1 = 1 and hivstatusP2 = 1) ;;1 is HIV pos
[ set cumsexactstemp ((item 6 sextotalbytype)+ 1)
set sextotalbytype replace-item 6 sextotalbytype cumsexactstemp
]

if (hivstatusP1 = 1 and hivstatusP2 = 0) or (hivstatusP1 = 0 and hivstatusP2 = 1)
;;1 is HIV pos
[ set cumsexactstemp ((item 7 sextotalbytype)+ 1)
set sextotalbytype replace-item 7 sextotalbytype cumsexactstemp
]

if (hivstatusP1 = 0 and hivstatusP2 = 0) ;;1 is HIV pos
[ set cumsexactstemp ((item 8 sextotalbytype)+ 1)
set sextotalbytype replace-item 8 sextotalbytype cumsexactstemp
]

set NScounter ((item 19 offer)+ 1)
set offer replace-item 19 offer NScounter
;set tempencount ((item tempturnum2 NSencounters)+ 1)
;set NSencounters replace-item tempturnum2 NSencounters tempencount
;if (item 1 timearray < 13)
;[ print word "self " self
;print word "partner-action " partner-action
;print word "RS utility " item 3 print-partner1
;print word "PS utility " item 4 print-partner1
;print word "Ns Utility " item 5 print-partner1
; print word "offer " offer
; print word "timearray " timearray
; ]

ask self
[ set NScounter ((item 19 offer)+ 1)
set offer replace-item 19 offer NScounter
;set tempencount ((item tempturnum1 NSencounters)+ 1)
;set NSencounters replace-item tempturnum1 NSencounters tempencount

;if (item 1 timearray < 13)
;[ print word "self " self
;print word "partner-action " partner-action
;print word "RS utility " item 3 print-partner1
;print word "PS utility " item 4 print-partner1
;print word "Ns Utility " item 5 print-partner1
; print word "offer " offer
; print word "timearray " timearray
;]
;;if they are not coupled
[ set self-action (item 2 offer) 
set print-self n-values 2 [0] 
set print-self replace-item 0 print-self self 
set print-self replace-item 1 print-self self-action 
;;;;print word " actor1 alone = " print-self 
] 

;update-plot 

;;;Afterwards you can remove print statements 
;;Need to implement next stage of interaction now that their preferences have been established. 
;;;Need to keep track of HIV pos players in game (infection) 
;;;How do we update p? 
;;;How do we accept or reject? 
;set exnum1 1 
;set spreadRS 0.85
The Players HIV status will effect their utility function, with a different numerical value representing different sexual outcomes, with each player trying to optimize this outcome.

end

to findprevalence
  set i 0 ; Set i to 0
  set infected 0
  while [i < num]
    ;[ ask turtle i
    ; [ if (color = red)
    ;[ set infected infected + 1 ]
    ;]
    ; set i i + 1
    ;]
    ; set prevalence infected / num ;* 100
  end
  to findprevalence
  set infected 0
  ask turtles
  [ if (color = red)
  if (actual-status = 1)
[;print who
set infected infected + 1]
]

;print infected
;print totalturtles
set prevalence infected / totalturtles ;* 100
end

;;;
;;; PLOTTING PROCEDURES
;;;
to setup-plot
set-current-plot "Population"
set-plot-y-range 0 (num + 10)
end
;
to update-plot
if (remainder ticks 12 = 0)
[
set-current-plot "Population"
; set-current-plot-pen "Uncoupled"
; plot count turtles with [not infected?]
; set-current-plot-pen "Coupled"
; plot count turtles with [infected?] -
; count turtles with [known?]
set-current-plot-pen "HIV+"
plot count turtles with [actual-status = 1 and own-status = 1];[ item 21 offer = 1]
;own-status = 1 or
set-current-plot-pen "HIV-"
plot count turtles with [actual-status = 0]
set-current-plot-pen "HIV+dontknow"
plot count turtles with [actual-status = 1 and own-status = 0]
]
end

; to getjustp
; set i 0
; while [i < num]
; [
;   ask turtle i
;   [ let theps (item 3 offer)
;     print theps
;     set i i + 1
;   ];
; ]
;]
;end

to write-data-initial
file-delete "data-test.txt"
set i 0
set listturtle n-values num [0]
while [i < num]
[
set listturtle replace-item i listturtle i
set i i + 1
]

;print listturtle
file-open "data-test.txt"
file-print listturtle
file-close
file-open "data-test.txt"
set j 0
set listinitialp n-values num [0]
let temporaryp 100
while [j < num]
[
ask turtle j
[
set temporaryp (item 3 offer)
]
set listinitialp replace-item j listinitialp temporaryp
set j j + 1
]
;print listinitialp
file-print listinitialp
file-close
end

to write-data
file-open "data-test.txt"
set j 0
set listgen n-values num [0]
let temporaryp 100
while [j < num]
[
ask turtle j
[
set temporaryp (item 3 offer)
]
]
set listgen replace-item j listgen temporaryp
set j j + 1
]
;print listgen
file-print listgen
file-close
end

to write-data-initial2
file-delete "data-test2.txt"
set i 0
set listturtlenum n-values num [0]
while [i < num]
[
set listturtlenum replace-item i listturtlenum i
set i i + 1
]
;print listturtlenum
file-open "data-test2.txt"
file-print listturtlenum
file-close
;file-open "data-test2.txt"
;set j 0
; set listinitialp n-values num [0]
;let temporaryp 100
; while [j < num]
;
;
;   ask turtle j
;
;   [   
;;
;       set temporaryp (item 3 offer)
;   ]
;
;   set listinitialp replace-item j listinitialp temporaryp
;
;   set j j + 1
;
;
386
;;;print listinitialp
;file-print listinitialp
;file-close
end

;;;to write-data2
;file-open "data-test2.txt"
;set j 0
;set listgen n-values num [0]
;let temporaryp 100
;while [j < num]
[;
ask turtle j
;
[;
set temporaryp (item 3 offer)
;
]
;set listgen replace-item j listgen temporaryp
;set j j + 1
;]
;;print listgen
;file-print listgen
;file-close
;
; turtle 1 [ count my-blue-links ] to turtle 0
;; ask turtle 1
;;[]
;; show my-blue-links ;; shows an agentset containing the link 0 1
;;[]
;end

;;;to write-data2
;file-open "data-test2.txt"
; set i 0
; set j 0
; set listgen n-values num [0]
; let temporaryp 100
; while [i < num]
; [  
;   ask turtle j
;     [  
;       set temporaryp (item 3 offer)
;     ]
;   set listgen replace-item j listgen temporaryp
;   set j j + 1
; ]
; print listgen
; file-print listgen
; file-close
;
; print [ count my-blue-links ] of turtle 0
;
;end

; to write-data2
; file-open "data-test2.txt"
; set i 0
; set j 0
; set listgenlinks n-values num [0]
; let temporarylinks 100
; while [j < num]
; [  
;   while [i < num]
;     [  
;       ask turtle j
;         [  
;           set temporarylinks [ count my-blue-links ] of turtle j
;         ]
;     ]  
;   ]
; set listgenlinks replace-item i listgenlinks temporarylinks
; set i i + 1
; ]
; set j j + 1
; file-print listgenlinks
; set i 0
;
; file-close
;end

to write-data3
; file-delete "data-test3.txt"
; set i 0
; set listturencount n-values num [0]
; while [i < num]
; [ set listturencount replace-item i listturencount i
; set i i + 1
; ]
; ;print listturtle
; file-open "data-test3.txt"
; file-print listturtle
; file-close
; file-open "data-test3.txt"
; set j 0
; set i 0
; set listencount n-values num [0]
; let temporarycount 100
; while [j < num]

389
; [  
;   while [i < num]  
;   [  
;     ask turtle j  
;     [  
;       set temporaryencount (item i encounters)  
;     ]  
;     set listencount replace-item j listencount temporaryencount  
;     set i i + 1  
;   ]  
;   file-print listencount  
;   print listencount  
;   set j j + 1  
;   set i 0  
; ]  
;];;print listencount  
;;  
;file-close  
;end

;to write-data3  
;file-delete "data-test3.txt"  
;file-open "data-test3.txt"  
;set j 0  
; while [j < num]  
; [  
;   ask turtle j  
;   [  
;     file-print encounters  
;   ]  
;   set j j + 1  

390
to write-data4
; file-delete "data-test4.txt"
; file-open "data-test4.txt"
; set j 0
; while [j < num]
; [  
;   ask turtle j
;   [  
;     file-print RSencounters
;   ]
;   set j j + 1
; ]
; file-close
; end
; to write-data5
; file-delete "data-test5.txt"
; file-open "data-test5.txt"
; set j 0
; while [j < num]
; [  
; ask turtle j
; [  
; file-print PSencounters
; ]
; set j j + 1
; ]
; file-close
; end

; to write-data6
; file-delete "data-test6.txt"
; file-open "data-test6.txt"
; set j 0
; while [j < num]
; [  
; ask turtle j
; [  
; file-print NSencounters
; ]
; set j j + 1
; ]
to write-data7initial
file-delete "data-test7.txt"
file-open "data-test7.txt"
file-print hivnegavgp
file-close
end

to write-data7
file-open "data-test7.txt"
file-print hivnegavgp
file-close
end

to write-data8initial
file-delete "data-test8.txt"
file-open "data-test8.txt"
file-print hivposavgp
file-close
end

to write-data8
file-open "data-test8.txt"
file-print hivposavgp

393
to write-data9initial
file-delete "data-test9.txt"
file-open "data-test9.txt"
file-print totalhivpos
file-close
end

to write-data9
file-open "data-test9.txt"
file-print totalhivpos
file-close
end

;to write-data10initial
;file-delete "data-test10.txt"
;file-open "data-test10.txt"
;set j 0
; while [j < 1]
; [ 
;   ask turtle j 
;   [ 
;     file-print RSencounters
;     ] 
;   set j j + 1
; ]
;file-close
;end
;to write-data10
;file-open "data-test10.txt"
;set j 0
;if (remainder ticks 24 = 0) and (ticks < 779)
;[ while [j < 1]
 ; [
 ;   ask turtle j
 ;   [  
 ;     file-print RSencounters
 ;   ]
 ;   set j j + 1
 ; ]
;]
;file-close
;end

;to write-data11initial
;file-delete "data-test11.txt"
;file-open "data-test11.txt"
;set j 0
; while [j < 1]
; [  
 ;   ask turtle j
 ;   [  
 ;     file-print PSencounters
 ;   ]
 ;   set j j + 1
 ; ]
;file-close
;end

;to write-data11
;file-open "data-test11.txt"
;set j 0
;if (remainder ticks 24 = 0) and (ticks < 779)
[ while [j < 1]
;[ ask turtle j
;[ file-print PSencounters
; ]
; set j j + 1
; ]
;
];file-close
;end

;to write-data12initial
;file-delete "data-test12.txt"
;file-open "data-test12.txt"
;set j 0
; while [j < 1]
;[ ask turtle j
;[ file-print NSencounters
; ]
; set j j + 1
; ]
;file-close
;end

;to write-data12
;file-open "data-test12.txt"
;set j 0
;if (remainder ticks 24 = 0) and (ticks < 779)
[ while [j < 1]

396
; [  
;   ask turtle j  
;   [  
;     file-print NSencounters  
;   ]  
;   set j j + 1  
; ]  
;]  
;file-close  
;end

;to write-data13initial  
;file-delete "data-test13.txt"  
;file-open "data-test13.txt"  
;set j 0  
; while [j < 1]  
; [  
;   ask turtle j  
;   [  
;     file-print encounters  
;   ]  
;   set j j + 1  
; ]  
;file-close  
;end

;to write-data13  
;file-open "data-test13.txt"  
;set j 0  
;if (remainder ticks 24 = 0) and (ticks < 779)  
;charset [ while [j < 1]  
; [  
;   ask turtle j  
;   [  
;     file-print encounters  
;   ]  
;   set j j + 1  
; ]  
;file-close  
;end
to getavgp

set hivposavgp 0
set hivnegavgp 0
set hivposdon'tknow 0
set thenegp 0
set theposp 0
set thepospdon'tknow 0

ask turtles
[
  if (actual-status = 0)
  [ set thenegp (item 3 offer)
    set hivnegavgp (hivnegavgp + thenegp / (count turtles with [actual-status = 0]))
    ;print thenegp
  ]

  if (actual-status = 1) and (own-status = 1) ;;meaning they are hiv+ and know they are
  [ set theposp (item 3 offer)
    set hivposavgp (hivposavgp + theposp / (count turtles with [own-status = 1 and actual-status = 1]))
    ;print theposp
  ]

  if (actual-status = 1) and (own-status = 0)
    ;;meaning they are hiv+ and don't know they are
[ set theposdopntknow (item 3 offer)
set hivposdopntknow (hivposdopntknow + theposdopntknow / (count turtles with
[own-status = 0 and actual-status = 1] ))
;print theposp
]

set avgtotalp 0

ask turtles

[ set theturtlep (item 3 offer)
set avgtotalp (avgtotalp + theturtlep / (count turtles))
]

;print avgtotalp

set hivpreverpercent 0
set hivpreverpercentdopntknow 0
set totalhivpos 0
set totalhivposdopntknow 0

ask turtles

[ if (actual-status = 1) and (own-status = 1)
[ set totalhivpos totalhivpos + 1
] ]
if (actual-status = 1) and (own-status = 0)
[ set totalhivposdontknow totalhivposdontknow + 1 ]
]
]

set hivprevpercent (totalhivpos / (count turtles))
set hivprevpercentdontknow (totalhivposdontknow / (count turtles))

;print hivprevpercent
;print hivprevpercentdontknow
end

to setup-plot2
set-current-plot "Average P"
;set-plot-y-range 0 (num + 1)
end

to update-plot2
if (remainder ticks 12 = 0)
[ set-current-plot "Average P"
set-current-plot-pen "hivnegavgp"
plot hivnegavgp
set-current-plot-pen "hivposavgp"
plot hivposavgp
set-current-plot-pen "hivposdontknow"
plot hivposdontknow
]
end

to setup-plot3
set-current-plot "Average P"

400
to update-plot3
    ; set-current-plot "Individual P Values"
    ; set-current-plot-pen "Player 0"
    ; ask turtle 0
    ; [ set player0p (item 3 offer) ]
    ; plot player0p
    ;
    ; set-current-plot-pen "Player 1"
    ; ask turtle 1
    ; [ set player1p (item 3 offer) ]
    ; plot player1p
    ;
    ; set-current-plot-pen "Player 2"
    ; ask turtle 2
    ; [ set player2p (item 3 offer) ]
    ; plot player2p
    ;
    ; set-current-plot-pen "Player 3"
    ; ask turtle 3
    ; [ set player3p (item 3 offer) ]
    ; plot player3p
    ;
    ; set-current-plot-pen "Player 4"
    ; ask turtle 4
    ; [ set player4p (item 3 offer) ]
    ; plot player4p
    ;
    ; set-current-plot-pen "Player 5"
    ; ask turtle 5
    ; [ set player5p (item 3 offer) ]
    ; plot player5p
    ;
; set-current-plot-pen "Player 6"
; ask turtle 6
; [ set player6p (item 3 offer) ]
; plot player6p
;
; set-current-plot-pen "Player 7"
; ask turtle 7
; [ set player7p (item 3 offer) ]
; plot player7p
;
; set-current-plot-pen "Player 8"
; ask turtle 8
; [ set player8p (item 3 offer) ]
; plot player8p
;
; set-current-plot-pen "Player 9"
; ask turtle 9
; [ set player9p (item 3 offer) ]
; plot player9p
;
; set-current-plot-pen "Player 10"
; ask turtle 10
; [ set player10p (item 3 offer) ]
; plot player10p
;
; set-current-plot-pen "Player 11"
; ask turtle 11
; [ set player11p (item 3 offer) ]
; plot player11p
;
; set-current-plot-pen "Player 12"
; ask turtle 12
; [ set player12p (item 3 offer) ]
; plot player12p
;
; set-current-plot-pen "Player 13"
; ask turtle 13
; [ set player13p (item 3 offer) ]
; plot player13p
;
; set-current-plot-pen "Player 14"
; ask turtle 14
; [ set player14p (item 3 offer) ]
; plot player14p
;
; set-current-plot-pen "Player 15"
; ask turtle 15
; [ set player15p (item 3 offer) ]
; plot player15p
;
; set-current-plot-pen "Player 16"
; ask turtle 16
; [ set player16p (item 3 offer) ]
; plot player16p
;
; set-current-plot-pen "Player 17"
; ask turtle 17
; [ set player17p (item 3 offer) ]
; plot player17p
;
; set-current-plot-pen "Player 18"
; ask turtle 18
; [ set player18p (item 3 offer) ]
; plot player18p
;
; set-current-plot-pen "Player 19"
; ask turtle 19
; [ set player19p (item 3 offer) ]
; plot player19p
;
; set-current-plot-pen "Player 20"
; ask turtle 20
; [ set player20p (item 3 offer) ]
; plot player20p
;
; set-current-plot-pen "Player 21"
; ask turtle 21
; [ set player21p (item 3 offer) ]
; plot player21p
;
; set-current-plot-pen "Player 22"
; ask turtle 22
; [ set player22p (item 3 offer) ]
; plot player22p
;
; set-current-plot-pen "Player 23"
; ask turtle 23
; [ set player23p (item 3 offer) ]
; plot player23p
;
; set-current-plot-pen "Player 24"
; ask turtle 24
; [ set player24p (item 3 offer) ]
; plot player24p
;
; set-current-plot-pen "Player 25"
; ask turtle 25
; [ set player25p (item 3 offer) ]
; plot player25p
;
; set-current-plot-pen "Player 26"
; ask turtle 26
; [ set player26p (item 3 offer) ]
; plot player26p
;

; set-current-plot-pen "Player 27"
; ask turtle 27
; [ set player27p (item 3 offer) ]
; plot player27p
;
; set-current-plot-pen "Player 28"
; ask turtle 28
; [ set player28p (item 3 offer) ]
; plot player28p
;
; set-current-plot-pen "Player 29"
; ask turtle 29
; [ set player29p (item 3 offer) ]
; plot player29p
;
; set-current-plot-pen "Player 30"
; ask turtle 30
; [ set player30p (item 3 offer) ]
; plot player30p
;
; set-current-plot-pen "Player 31"
; ask turtle 31
; [ set player31p (item 3 offer) ]
; plot player31p
;
; set-current-plot-pen "Player 32"
; ask turtle 32
; [ set player32p (item 3 offer) ]
; plot player32p
;
; set-current-plot-pen "Player 33"
; ask turtle 33
; [ set player33p (item 3 offer) ]
; plot player33p
;

to writecumsexactbytype
;set j 0
set tempnum3 0
set totalRSpospos 0
set totalRSposneg 0
set totalRSnegneg 0
set totalPSpospos 0
set totalPSposneg 0
set totalPSnegneg 0
set totalNSpospos 0
set totalNSposneg 0
set totalNSnegneg 0

;while [j < num]
[
ask turtles
[ set tempnum3 (item 0 sextotalbytype)
set totalRSpospos (totalRSpospos + tempnum3)
set tempnum4 (item 1 sextotalbytype)
set totalRSposneg (totalRSposneg + tempnum4)
set tempnum5 (item 2 sextotalbytype)
set totalRSnegneg (totalRSnegneg + tempnum5)
set tempnum6 (item 3 sextotalbytype)
set totalPSpospos (totalPSpospos + tempnum6)
set tempnum7 (item 4 sextotalbytype)
set totalPSposneg (totalPSposneg + tempnum7)
set tempnum8 (item 5 sextotalbytype)
set totalPSnegneg (totalPSnegneg + tempnum8)
set tempnum9 (item 6 sextotalbytype)
set totalNSpospos (totalNSpospos + tempnum9)
set tempnum10 (item 7 sextotalbytype)
set totalNSposneg (totalNSposneg + tempnum10)
set tempnum11 (item 8 sextotalbytype)
set totalNSnegneg (totalNSnegneg + tempnum11)
]
;set j j + 1
;]
to writecumsexactbytypeHIV-3040
set tempnum0HIV-3040 0
set tempnum1HIV-3040 0
set tempnum2HIV-3040 0
set tempnum3HIV-3040 0
set tempnum4HIV-3040 0
set tempnum5HIV-3040 0
set tempnum6HIV-3040 0
set tempnum7HIV-3040 0
set tempnum8HIV-3040 0
set tempnum9HIV-3040 0
set totalcumalltypesHIV-3040 0
set totalRSposHIV-3040 0
set totalRSnegHIV-3040 0
set totalRsnegHIV-3040 0
set totalPSposHIV-3040 0
set totalPSnegHIV-3040 0
set totalPSnegHIV-3040 0
set totalNSposHIV-3040 0
set totalNSnegHIV-3040 0

408
set totalNSposnegHIV-3040 0
set totalNSnegnegHIV-3040 0

set totalRSposposHIV-3040percent 0
set totalRSposnegHIV-3040percent 0
set totalRSnegnegHIV-3040percent 0
set totalPSposposHIV-3040percent 0
set totalPSposnegHIV-3040percent 0
set totalPSnegnegHIV-3040percent 0
set totalNSposposHIV-3040percent 0
set totalNSposnegHIV-3040percent 0
set totalNSnegnegHIV-3040percent 0

ask turtles
[
  if ( (item 1 timearray > 180) and (item 1 timearray <= 300) and (item 21 offer = 0) )
  [
    set tempnum0HIV-3040 ((item 0 sextotalbytype) + (item 1 sextotalbytype) +
      (item 2 sextotalbytype) + (item 3 sextotalbytype) + (item 4 sextotalbytype) +
      (item 5 sextotalbytype) + (item 6 sextotalbytype) + (item 7 sextotalbytype) +
      (item 8 sextotalbytype) )
    set totalcumalltypesHIV-3040 (totalcumalltypesHIV-3040 + tempnum0HIV-3040)

  ]
]

;print word "totalcumalltypesHIV-3040 " totalcumalltypesHIV-3040

ask turtles
[
  if ( (item 1 timearray > 180) and (item 1 timearray <= 300) and (item 21 offer = 0) )
  [
    set tempnum1HIV-3040 (item 0 sextotalbytype)
    set totalRSposposHIV-3040 (totalRSposposHIV-3040 + tempnum1HIV-3040)
    set tempnum2HIV-3040 (item 1 sextotalbytype)
    set totalRSposnegHIV-3040 (totalRSposnegHIV-3040 + tempnum2HIV-3040)
  ]
]

409
set tempnum3HIV-3040 (item 2 sextotalbytype)
set totalRSnegnegHIV-3040 (totalRSnegnegHIV-3040 + tempnum3HIV-3040)
set tempnum4HIV-3040 (item 3 sextotalbytype)
set totalPSposposHIV-3040 (totalPSposposHIV-3040 + tempnum4HIV-3040)
set tempnum5HIV-3040 (item 4 sextotalbytype)
set totalPSposnegHIV-3040 (totalPSposnegHIV-3040 + tempnum5HIV-3040)
set tempnum6HIV-3040 (item 5 sextotalbytype)
set totalPSnegnegHIV-3040 (totalPSnegnegHIV-3040 + tempnum6HIV-3040)
set tempnum7HIV-3040 (item 6 sextotalbytype)
set totalNSposposHIV-3040 (totalNSposposHIV-3040 + tempnum7HIV-3040)
set tempnum8HIV-3040 (item 7 sextotalbytype)
set totalNSposnegHIV-3040 (totalNSposnegHIV-3040 + tempnum8HIV-3040)
set tempnum9HIV-3040 (item 8 sextotalbytype)
set totalNSnegnegHIV-3040 (totalNSnegnegHIV-3040 + tempnum9HIV-3040)

set totalRSposposHIV-3040percent (totalRSposposHIV-3040 / totalcumalltypesHIV-3040)
set totalRSposnegHIV-3040percent (totalRSposnegHIV-3040 / totalcumalltypesHIV-3040)
set totalRSnegnegHIV-3040percent (totalRSnegnegHIV-3040 / totalcumalltypesHIV-3040)
set totalPSposposHIV-3040percent (totalPSposposHIV-3040 / totalcumalltypesHIV-3040)
set totalPSposnegHIV-3040percent (totalPSposnegHIV-3040 / totalcumalltypesHIV-3040)
set totalPSnegnegHIV-3040percent (totalPSnegnegHIV-3040 / totalcumalltypesHIV-3040)
set totalNSposposHIV-3040percent (totalNSposposHIV-3040 / totalcumalltypesHIV-3040)
set totalNSposnegHIV-3040percent (totalNSposnegHIV-3040 / totalcumalltypesHIV-3040)
set totalNSnegnegHIV-3040percent (totalNSnegnegHIV-3040 / totalcumalltypesHIV-3040)

;print word "totalRSnegnegHIV-3040 " totalRSnegnegHIV-3040
;print word "totalRSnegnegHIV-3040percent " totalRSnegnegHIV-3040percent
end

towritecumsexactbytypeHIV-1520
set tempnumOHHIV-1520 0
set tempnum1HIV-1520 0
set tempnum2HIV-1520 0
set tempnum3HIV-1520 0
set tempnum4HIV-1520 0
set tempnum5HIV-1520 0
set tempnum6HIV-1520 0
set tempnum7HIV-1520 0
set tempnum8HIV-1520 0
set tempnum9HIV-1520 0
set totalcumalltypesHIV-1520 0
set totalRSposposHIV-1520 0
set totalRSposnegHIV-1520 0
set totalRSnegnegHIV-1520 0
set totalPSposposHIV-1520 0
set totalPSposnegHIV-1520 0
set totalPSnegnegHIV-1520 0
set totalNSposposHIV-1520 0
set totalNSposnegHIV-1520 0
set totalNSnegnegHIV-1520 0
set totalRSposposHIV-1520percent 0
set totalRSposnegHIV-1520percent 0
set totalRSnegnegHIV-1520percent 0
set totalPSposposHIV-1520percent 0
set totalPSposnegHIV-1520percent 0
set totalPSnegnegHIV-1520percent 0
set totalNSposposHIV-1520percent 0
set totalNSposnegHIV-1520percent 0
set totalNSnegnegHIV-1520percent 0
ask turtles
[ if ( (item 1 timearray <= 60) and (item 21 offer = 0) )}
set tempnum0HIV-1520 ((item 0 sextotalbytype) + (item 1 sextotalbytype) + 
(item 2 sextotalbytype) + (item 3 sextotalbytype) + (item 4 sextotalbytype) + 
(item 5 sextotalbytype) + (item 6 sextotalbytype) + (item 7 sextotalbytype) + 
(item 8 sextotalbytype))
set totalcumalltypesHIV-1520 (totalcumalltypesHIV-1520 + tempnum0HIV-1520)

; print word "totalcumalltypesHIV-1520 " totalcumalltypesHIV-1520

ask turtles
[
    if ( (item 1 timearray <= 60) and (item 21 offer = 0) )
    [
        set tempnum1HIV-1520 (item 0 sextotalbytype)
        set totalRSposposHIV-1520 (totalRSposposHIV-1520 + tempnum1HIV-1520)
        set tempnum2HIV-1520 (item 1 sextotalbytype)
        set totalRSposnegHIV-1520 (totalRSposnegHIV-1520 + tempnum2HIV-1520)
        set tempnum3HIV-1520 (item 2 sextotalbytype)
        set totalRSnegnegHIV-1520 (totalRSnegnegHIV-1520 + tempnum3HIV-1520)
        set tempnum4HIV-1520 (item 3 sextotalbytype)
        set totalPSposposHIV-1520 (totalPSposposHIV-1520 + tempnum4HIV-1520)
        set tempnum5HIV-1520 (item 4 sextotalbytype)
        set totalPSposnegHIV-1520 (totalPSposnegHIV-1520 + tempnum5HIV-1520)
        set tempnum6HIV-1520 (item 5 sextotalbytype)
        set totalPSnegnegHIV-1520 (totalPSnegnegHIV-1520 + tempnum6HIV-1520)
        set tempnum7HIV-1520 (item 6 sextotalbytype)
        set totalNSposposHIV-1520 (totalNSposposHIV-1520 + tempnum7HIV-1520)
        set tempnum8HIV-1520 (item 7 sextotalbytype)
        set totalNSposnegHIV-1520 (totalNSposnegHIV-1520 + tempnum8HIV-1520)
        set tempnum9HIV-1520 (item 8 sextotalbytype)
        set totalNSnegnegHIV-1520 (totalNSnegnegHIV-1520 + tempnum9HIV-1520)
        set totalRSposposHIV-1520percent (totalRSposposHIV-1520 / totalcumalltypesHIV-1520)
        set totalRSposnegHIV-1520percent (totalRSposnegHIV-1520 / totalcumalltypesHIV-1520)
    ]
]
set totalRSnegnegHIV-1520percent (totalRSnegnegHIV-1520 / totalcumalltypesHIV-1520)
set totalPSposposHIV-1520percent (totalPSposposHIV-1520 / totalcumalltypesHIV-1520)
set totalPSposnegHIV-1520percent (totalPSposnegHIV-1520 / totalcumalltypesHIV-1520)
set totalPSnegnegHIV-1520percent (totalPSnegnegHIV-1520 / totalcumalltypesHIV-1520)
set totalNSposposHIV-1520percent (totalNSposposHIV-1520 / totalcumalltypesHIV-1520)
set totalNSposnegHIV-1520percent (totalNSposnegHIV-1520 / totalcumalltypesHIV-1520)
set totalNSnegnegHIV-1520percent (totalNSnegnegHIV-1520 / totalcumalltypesHIV-1520)

];print word "totalRSnegnegHIV-1520 " totalRSnegnegHIV-1520
];print word "totalRSnegnegHIV-1520percent " totalRSnegnegHIV-1520percent
end

to writecumsexactbytypeHIV-2030
set tempnum0HIV-2030 0
set tempnum1HIV-2030 0
set tempnum2HIV-2030 0
set tempnum3HIV-2030 0
set tempnum4HIV-2030 0
set tempnum5HIV-2030 0
set tempnum6HIV-2030 0
set tempnum7HIV-2030 0
set tempnum8HIV-2030 0
set tempnum9HIV-2030 0
set totalcumalltypesHIV-2030 0

set totalRSposposHIV-2030 0
set totalRSposnegHIV-2030 0
set totalRSnegnegHIV-2030 0
set totalPSposposHIV-2030 0
set totalPSposnegHIV-2030 0
set totalPSnegnegHIV-2030 0
set totalNSposposHIV-2030 0
set totalNSposnegHIV-2030 0
set totalNSnegnegHIV-2030 0

set totalPSposnegHIV-2030 0
set totalPSnegnegHIV-2030 0
set totalNSposposHIV-2030 0
set totalNSposnegHIV-2030 0
set totalNSnegnegHIV-2030 0
set totalRSposposHIV-2030percent 0
set totalRSposnegHIV-2030percent 0
set totalRSnegnegHIV-2030percent 0
set totalPSposposHIV-2030percent 0
set totalPSposnegHIV-2030percent 0
set totalPSnegnegHIV-2030percent 0
set totalNSposposHIV-2030percent 0
set totalNSposnegHIV-2030percent 0
set totalNSnegnegHIV-2030percent 0

ask turtles
[ if ( (item 1 timearray > 60) and (item 1 timearray <= 180) and ( item 21 offer = 0) )
  [ set tempnum0HIV-2030 ((item 0 sextotalbytype) + (item 1 sextotalbytype) +
    (item 2 sextotalbytype) + (item 3 sextotalbytype) + (item 4 sextotalbytype) +
    (item 5 sextotalbytype) + (item 6 sextotalbytype) + (item 7 sextotalbytype) +
    (item 8 sextotalbytype) )
  set totalcumalltypesHIV-2030 (totalcumalltypesHIV-2030 + tempnum0HIV-2030) ]
]

;print word "totalcumalltypesHIV-2030 " totalcumalltypesHIV-2030

ask turtles
[ if ( (item 1 timearray > 60) and (item 1 timearray <= 180) and ( item 21 offer = 0) )
  [ set tempnum1HIV-2030 (item 0 sextotalbytype)
    set totalRSposposHIV-2030 (totalRSposposHIV-2030 + tempnum1HIV-2030) ]
]
set tempnum2HIV-2030 (item 1 sextotalbytype)
set totalRSposnegHIV-2030 (totalRSposnegHIV-2030 + tempnum2HIV-2030)
set tempnum3HIV-2030 (item 2 sextotalbytype)
set totalRSnegnegHIV-2030 (totalRSnegnegHIV-2030 + tempnum3HIV-2030)
set tempnum4HIV-2030 (item 3 sextotalbytype)
set totalPSposposHIV-2030 (totalPSposposHIV-2030 + tempnum4HIV-2030)
set tempnum5HIV-2030 (item 4 sextotalbytype)
set totalPSposnegHIV-2030 (totalPSposnegHIV-2030 + tempnum5HIV-2030)
set tempnum6HIV-2030 (item 5 sextotalbytype)
set totalPSnegnegHIV-2030 (totalPSnegnegHIV-2030 + tempnum6HIV-2030)
set tempnum7HIV-2030 (item 6 sextotalbytype)
set totalNSposposHIV-2030 (totalNSposposHIV-2030 + tempnum7HIV-2030)
set tempnum8HIV-2030 (item 7 sextotalbytype)
set totalNSposnegHIV-2030 (totalNSposnegHIV-2030 + tempnum8HIV-2030)
set tempnum9HIV-2030 (item 8 sextotalbytype)
set totalNSnegnegHIV-2030 (totalNSnegnegHIV-2030 + tempnum9HIV-2030)

set totalRSposposHIV-2030percent (totalRSposposHIV-2030 / totalcumalltypesHIV-2030)
set totalRSposnegHIV-2030percent (totalRSposnegHIV-2030 / totalcumalltypesHIV-2030)
set totalRSnegnegHIV-2030percent (totalRSnegnegHIV-2030 / totalcumalltypesHIV-2030)
set totalPSposposHIV-2030percent (totalPSposposHIV-2030 / totalcumalltypesHIV-2030)
set totalPSposnegHIV-2030percent (totalPSposnegHIV-2030 / totalcumalltypesHIV-2030)
set totalPSnegnegHIV-2030percent (totalPSnegnegHIV-2030 / totalcumalltypesHIV-2030)
set totalNSposposHIV-2030percent (totalNSposposHIV-2030 / totalcumalltypesHIV-2030)
set totalNSposnegHIV-2030percent (totalNSposnegHIV-2030 / totalcumalltypesHIV-2030)
set totalNSnegnegHIV-2030percent (totalNSnegnegHIV-2030 / totalcumalltypesHIV-2030)

;print word "totalRSnegnegHIV-2030 " totalRSnegnegHIV-2030
;print word "totalRSnegnegHIV-2030percent " totalRSnegnegHIV-2030percent
end
set tempnum0HIV-4050 0
set tempnum1HIV-4050 0
set tempnum2HIV-4050 0
set tempnum3HIV-4050 0
set tempnum4HIV-4050 0
set tempnum5HIV-4050 0
set tempnum6HIV-4050 0
set tempnum7HIV-4050 0
set tempnum8HIV-4050 0
set tempnum9HIV-4050 0

set totalcumalltypesHIV-4050 0
set totalRSposposHIV-4050 0
set totalRSposnegHIV-4050 0
set totalRSnegnegHIV-4050 0
set totalPSposposHIV-4050 0
set totalPSposnegHIV-4050 0
set totalPSnegnegHIV-4050 0
set totalNSposposHIV-4050 0
set totalNSposnegHIV-4050 0
set totalNSnegnegHIV-4050 0

set totalRSposposHIV-4050percent 0
set totalRSposnegHIV-4050percent 0
set totalRSnegnegHIV-4050percent 0
set totalPSposposHIV-4050percent 0
set totalPSposnegHIV-4050percent 0
set totalPSnegnegHIV-4050percent 0
set totalNSposposHIV-4050percent 0
set totalNSposnegHIV-4050percent 0
set totalNSnegnegHIV-4050percent 0

ask turtles
if ( (item 1 timearray > 300) and (item 1 timearray <= 420) and (item 21 offer = 0) ) [
  set tempnum0HIV-4050 ((item 0 sextotalbytype) + (item 1 sextotalbytype) +
  (item 2 sextotalbytype) + (item 3 sextotalbytype) + (item 4 sextotalbytype) +
  (item 5 sextotalbytype) + (item 6 sextotalbytype) + (item 7 sextotalbytype) +
  (item 8 sextotalbytype))
  set totalcumalltypesHIV-4050 (totalcumalltypesHIV-4050 + tempnum0HIV-4050)
]
]
;print word "totalcumalltypesHIV-4050 " totalcumalltypesHIV-4050

ask turtles
[
  if ( (item 1 timearray > 300) and (item 1 timearray <= 420) and (item 21 offer = 0) ) [
    set tempnum1HIV-4050 (item 0 sextotalbytype)
    set totalRSposposHIV-4050 (totalRSposposHIV-4050 + tempnum1HIV-4050)
    set tempnum2HIV-4050 (item 1 sextotalbytype)
    set totalRSposnegHIV-4050 (totalRSposnegHIV-4050 + tempnum2HIV-4050)
    set tempnum3HIV-4050 (item 2 sextotalbytype)
    set totalRSnegnegHIV-4050 (totalRSnegnegHIV-4050 + tempnum3HIV-4050)
    set tempnum4HIV-4050 (item 3 sextotalbytype)
    set totalPSposposHIV-4050 (totalPSposposHIV-4050 + tempnum4HIV-4050)
    set tempnum5HIV-4050 (item 4 sextotalbytype)
    set totalPSposnegHIV-4050 (totalPSposnegHIV-4050 + tempnum5HIV-4050)
    set tempnum6HIV-4050 (item 5 sextotalbytype)
    set totalPSnegnegHIV-4050 (totalPSnegnegHIV-4050 + tempnum6HIV-4050)
    set tempnum7HIV-4050 (item 6 sextotalbytype)
    set totalNSposposHIV-4050 (totalNSposposHIV-4050 + tempnum7HIV-4050)
    set tempnum8HIV-4050 (item 7 sextotalbytype)
    set totalNSposnegHIV-4050 (totalNSposnegHIV-4050 + tempnum8HIV-4050)
    set tempnum9HIV-4050 (item 8 sextotalbytype)
    set totalNSnegnegHIV-4050 (totalNSnegnegHIV-4050 + tempnum9HIV-4050)
  ]
]
set totalRSposposHIV-4050percent (totalRSposposHIV-4050 / totalcumalltypesHIV-4050)
set totalRSposnegHIV-4050percent (totalRSposnegHIV-4050 / totalcumalltypesHIV-4050)
set totalRSnegnegHIV-4050percent (totalRSnegnegHIV-4050 / totalcumalltypesHIV-4050)
set totalPSposposHIV-4050percent (totalPSposposHIV-4050 / totalcumalltypesHIV-4050)
set totalPSposnegHIV-4050percent (totalPSposnegHIV-4050 / totalcumalltypesHIV-4050)
set totalPSnegnegHIV-4050percent (totalPSnegnegHIV-4050 / totalcumalltypesHIV-4050)
set totalNSposposHIV-4050percent (totalNSposposHIV-4050 / totalcumalltypesHIV-4050)
set totalNSposnegHIV-4050percent (totalNSposnegHIV-4050 / totalcumalltypesHIV-4050)
set totalNSnegnegHIV-4050percent (totalNSnegnegHIV-4050 / totalcumalltypesHIV-4050)

end

to writecumsexactbytypeHIV-50+
set tempnum0HIV-50+ 0
set tempnum1HIV-50+ 0
set tempnum2HIV-50+ 0
set tempnum3HIV-50+ 0
set tempnum4HIV-50+ 0
set tempnum5HIV-50+ 0
set tempnum6HIV-50+ 0
set tempnum7HIV-50+ 0
set tempnum8HIV-50+ 0
set tempnum9HIV-50+ 0
set totalcumalltypesHIV-50+ 0
set totalRSposposHIV-50+ 0
set totalRSposnegHIV-50+ 0
set totalRSnegnegHIV-50+ 0
set totalPSposposHIV-50+ 0
set totalPSposnegHIV-50+ 0
set totalPSnegnegHIV-50+ 0
set totalNSposposHIV-50+ 0
set totalNSposnegHIV-50+ 0
set totalNSnegnegHIV-50+ 0
set totalRSposposHIV-50+percent 0
set totalRSposnegHIV-50+percent 0
set totalRSnegnegHIV-50+percent 0
set totalPSposposHIV-50+percent 0
set totalPSposnegHIV-50+percent 0
set totalPSnegnegHIV-50+percent 0
set totalNSposposHIV-50+percent 0
set totalNSposnegHIV-50+percent 0
set totalNSnegnegHIV-50+percent 0

ask turtles
[
  if ( (item 1 timearray > 420) and ( item 21 offer = 0) )
  [  
    set tempnum0HIV-50+ ((item 0 sextotalbytype) + (item 1 sextotalbytype) +
    (item 2 sextotalbytype) + (item 3 sextotalbytype) + (item 4 sextotalbytype) +
    (item 5 sextotalbytype) + (item 6 sextotalbytype) + (item 7 sextotalbytype) +
    (item 8 sextotalbytype) )
    set totalcumalltypesHIV-50+ (totalcumalldtypesHIV-50+ + tempnum0HIV-50+)
  ]
  ]
;print word "totalcumalltypesHIV-50+ " totalcumalltypesHIV-50+

ask turtles
if ( (item 1 timearray > 420) and (item 21 offer = 0) )

set tempnum1HIV-50+ (item 0 sextotalbytype)
set totalRSposHIV-50+ (totalRSposHIV-50+ + tempnum1HIV-50+)
set tempnum2HIV-50+ (item 1 sextotalbytype)
set totalRSnegHIV-50+ (totalRSnegHIV-50+ + tempnum2HIV-50+)
set tempnum3HIV-50+ (item 2 sextotalbytype)
set totalRSnegHIV-50+ (totalRSnegHIV-50+ + tempnum3HIV-50+)
set tempnum4HIV-50+ (item 3 sextotalbytype)
set totalPSposHIV-50+ (totalPSposHIV-50+ + tempnum4HIV-50+)
set tempnum5HIV-50+ (item 4 sextotalbytype)
set totalPSposHIV-50+ (totalPSposHIV-50+ + tempnum5HIV-50+)
set tempnum6HIV-50+ (item 5 sextotalbytype)
set totalPSnegHIV-50+ (totalPSnegHIV-50+ + tempnum6HIV-50+)
set tempnum7HIV-50+ (item 6 sextotalbytype)
set totalPSnegHIV-50+ (totalPSnegHIV-50+ + tempnum7HIV-50+)
set tempnum8HIV-50+ (item 7 sextotalbytype)
set totalNSposHIV-50+ (totalNSposHIV-50+ + tempnum8HIV-50+)
set tempnum9HIV-50+ (item 8 sextotalbytype)
set totalNSposHIV-50+ (totalNSposHIV-50+ + tempnum9HIV-50+)

set totalRSposHIV-50+percent (totalRSposHIV-50+ / totalcumalltypesHIV-50+)
set totalRSnegHIV-50+percent (totalRSnegHIV-50+ / totalcumalltypesHIV-50+)
set totalPSposHIV-50+percent (totalPSposHIV-50+ / totalcumalltypesHIV-50+)
set totalPSnegHIV-50+percent (totalPSnegHIV-50+ / totalcumalltypesHIV-50+)
set totalNSposHIV-50+percent (totalNSposHIV-50+ / totalcumalltypesHIV-50+)
set totalNSnegHIV-50+percent (totalNSnegHIV-50+ / totalcumalltypesHIV-50+)

;print word "totalRSnegHIV-50+ " totalRSnegHIV-50+
to writecumsexactbytypeHIV+3040
set tempnum0HIV+3040 0
set tempnum1HIV+3040 0
set tempnum2HIV+3040 0
set tempnum3HIV+3040 0
set tempnum4HIV+3040 0
set tempnum5HIV+3040 0
set tempnum6HIV+3040 0
set tempnum7HIV+3040 0
set tempnum8HIV+3040 0
set tempnum9HIV+3040 0
set totalcumalltypesHIV+3040 0
set totalRSposposHIV+3040 0
set totalRSnegnegHIV+3040 0
set totalPSposposHIV+3040 0
set totalPSnegnegHIV+3040 0
set totalNSposposHIV+3040 0
set totalNSnegnegHIV+3040 0
set totalRSposposHIV+3040percent 0
set totalRSnegnegHIV+3040percent 0
set totalRSnegnegHIV+3040percent 0
set totalPSposposHIV+3040percent 0
set totalPSposnegHIV+3040percent 0
set totalPSnegnegHIV+3040percent 0
set totalNSposposHIV+3040percent 0
set totalNSposnegHIV+3040percent 0
set totalNSnegnegHIV+3040percent 0

set numofHIV+temp count turtles with [actual-status = 1 and own-status = 1 and
item 1 timearray > 180 and item 1 timearray <= 300]
if (numofHIV+temp != 0)
[

ask turtles with [ (item 0 sextotalbytype) + (item 1 sextotalbytype) +
(item 2 sextotalbytype) + (item 3 sextotalbytype) + (item 4 sextotalbytype) +
(item 5 sextotalbytype) + (item 6 sextotalbytype) + (item 7 sextotalbytype) +
(item 8 sextotalbytype) != 0)]
[
if ( (item 1 timearray > 180) and (item 1 timearray <= 300) and (item 21 offer = 1) and
(item 4 offer = 1) ) ;item 21 offer actual status, 0 not infected, 1 if infected.
item 4 offer = 1 means they know they are infected.
[
set tempnum0HIV+3040 ( (item 0 sextotalbytype) + (item 1 sextotalbytype)
+ (item 2 sextotalbytype) + (item 3 sextotalbytype) + (item 4 sextotalbytype)
+ (item 5 sextotalbytype) + (item 6 sextotalbytype) + (item 7 sextotalbytype)
+ (item 8 sextotalbytype) )
set totalcumalltypesHIV+3040 (totalcumalltypesHIV+3040 + tempnum0HIV+3040)
]
]
;print word "totalcumalltypesHIV+3040 " totalcumalltypesHIV+3040

ask turtles with [ (item 0 sextotalbytype) + (item 1 sextotalbytype) +
(item 2 sextotalbytype) + (item 3 sextotalbytype) + (item 4 sextotalbytype)
+ (item 5 sextotalbytype) + (item 6 sextotalbytype) + (item 7 sextotalbytype)
+ (item 8 sextotalbytype) != 0])
[
if ( (item 1 timearray > 180) and (item 1 timearray <= 300) and (item 21 offer = 1) and
( item 4 offer = 1 )
]
[
set tempnum1HIV+3040 (item 0 sextotalbytype)
set totalRSposposHIV+3040 (totalRSposposHIV+3040 + tempnum1HIV+3040)
set tempnum2HIV+3040 (item 1 sextotalbytype)
set totalRSposnegHIV+3040 (totalRSposnegHIV+3040 + tempnum2HIV+3040)
set tempnum3HIV+3040 (item 2 sextotalbytype)
set totalRSnegnegHIV+3040 (totalRSnegnegHIV+3040 + tempnum3HIV+3040)
set tempnum4HIV+3040 (item 3 sextotalbytype)
set totalPSposposHIV+3040 (totalPSposposHIV+3040 + tempnum4HIV+3040)
set tempnum5HIV+3040 (item 4 sextotalbytype)
set totalPSposnegHIV+3040 (totalPSposnegHIV+3040 + tempnum5HIV+3040)
set tempnum6HIV-3040 (item 5 sextotalbytype)
set totalPSnegnegHIV+3040 (totalPSnegnegHIV+3040 + tempnum6HIV+3040)
set tempnum7HIV-3040 (item 6 sextotalbytype)
set totalNSposposHIV+3040 (totalNSposposHIV+3040 + tempnum7HIV+3040)
set tempnum8HIV-3040 (item 7 sextotalbytype)
set totalNSposnegHIV+3040 (totalNSposnegHIV+3040 + tempnum8HIV+3040)
set tempnum9HIV-3040 (item 8 sextotalbytype)
set totalNSnegnegHIV+3040 (totalNSnegnegHIV+3040 + tempnum9HIV+3040)
set totalRSposposHIV+3040percent (totalRSposposHIV+3040 / totalcumalltypesHIV+3040)
set totalRSposnegHIV+3040percent (totalRSposnegHIV+3040 / totalcumalltypesHIV+3040)
set totalRSnegnegHIV+3040percent (totalRSnegnegHIV+3040 / totalcumalltypesHIV+3040)
set totalPSposposHIV+3040percent (totalPSposposHIV+3040 / totalcumalltypesHIV+3040)
set totalPSposnegHIV+3040percent (totalPSposnegHIV+3040 / totalcumalltypesHIV+3040)
set totalPSnegnegHIV+3040percent (totalPSnegnegHIV+3040 / totalcumalltypesHIV+3040)
set totalNSposposHIV+3040percent (totalNSposposHIV+3040 / totalcumalltypesHIV+3040)
set totalNSposnegHIV+3040percent (totalNSposnegHIV+3040 / totalcumalltypesHIV+3040)
set totalNSnegnegHIV+3040percent (totalNSnegnegHIV+3040 / totalcumalltypesHIV+3040)
to writecumsexactbytypeHIV+1520
set tempnum0HIV+1520 0
set tempnum1HIV+1520 0
set tempnum2HIV+1520 0
set tempnum3HIV+1520 0
set tempnum4HIV+1520 0
set tempnum5HIV+1520 0
set tempnum6HIV+1520 0
set tempnum7HIV+1520 0
set tempnum8HIV+1520 0
set tempnum9HIV+1520 0
set totalcumalltypesHIV+1520 0
set totalRSposposHIV+1520 0
set totalRSposnegHIV+1520 0
set totalRSnegnegHIV+1520 0
set totalPSposposHIV+1520 0
set totalPSposnegHIV+1520 0
set totalPSnegnegHIV+1520 0
set totalNSposposHIV+1520 0
set totalNSposnegHIV+1520 0
set totalNSnegnegHIV+1520 0
set totalRSposposHIV+1520percent 0
set totalRSposnegHIV+1520percent 0
set totalRSnegnegHIV+1520percent 0
set totalPSposposHIV+1520 percent 0
set totalPSposnegHIV+1520 percent 0
set totalPSnegnegHIV+1520 percent 0
set totalNSposposHIV+1520 percent 0
set totalNSposnegHIV+1520 percent 0
set totalNSnegnegHIV+1520 percent 0

set numofHIV+temp count turtles with 
[actual-status = 1 and own-status = 1 and item 1 timearray <= 60]
if (numofHIV+temp != 0)
[
ask turtles with [ 
((item 0 sextotalbytype) + (item 1 sextotalbytype) + 
(item 2 sextotalbytype) + (item 3 sextotalbytype) + (item 4 sextotalbytype) + 
(item 5 sextotalbytype) + (item 6 sextotalbytype) + (item 7 sextotalbytype) + 
(item 8 sextotalbytype) != 0)]

if ( (item 1 timearray <= 60) and ( item 21 offer = 1) and ( item 4 offer = 1) )
;item 21 offer actual status, 0 not infected, 1 if infected.
item 4 offer = 1 means they know they are infected.
[
set tempnum0HIV+1520 ((item 0 sextotalbytype) + (item 1 sextotalbytype) + 
(item 2 sextotalbytype) + (item 3 sextotalbytype) + (item 4 sextotalbytype) + 
(item 5 sextotalbytype) + (item 6 sextotalbytype) + (item 7 sextotalbytype) + 
(item 8 sextotalbytype) )
set totalcumalltypesHIV+1520 (totalcumalltypesHIV+1520 + tempnum0HIV+1520) 
]
]
;print word "totalcumalltypesHIV+1520 " totalcumalltypesHIV+1520

ask turtles with [ 
((item 0 sextotalbytype) + (item 1 sextotalbytype) + 
(item 2 sextotalbytype) + (item 3 sextotalbytype) + (item 4 sextotalbytype) + 
(item 5 sextotalbytype) + (item 6 sextotalbytype) + (item 7 sextotalbytype) + 
(item 8 sextotalbytype) != 0)]

if ( (item 1 timearray <= 60) and ( item 21 offer = 1) and ( item 4 offer = 1) )
set tempnum1HIV+1520 (item 0 sextotalbytype)
set tempnum2HIV+1520 (item 1 sextotalbytype)
set tempnum3HIV+1520 (item 2 sextotalbytype)
set tempnum4HIV+1520 (item 3 sextotalbytype)
set tempnum5HIV+1520 (item 4 sextotalbytype)
set tempnum6HIV+1520 (item 5 sextotalbytype)
set tempnum7HIV+1520 (item 6 sextotalbytype)
set tempnum8HIV+1520 (item 7 sextotalbytype)
set tempnum9HIV+1520 (item 8 sextotalbytype)
set totalRSposposHIV+1520 (totalRSposposHIV+1520 + tempnum1HIV+1520)
set totalRSposnegHIV+1520 (totalRSposnegHIV+1520 + tempnum2HIV+1520)
set totalRSnegnegHIV+1520 (totalRSnegnegHIV+1520 + tempnum3HIV+1520)
set totalPSposposHIV+1520 (totalPSposposHIV+1520 + tempnum4HIV+1520)
set totalPSposnegHIV+1520 (totalPSposnegHIV+1520 + tempnum5HIV+1520)
set totalPSnegnegHIV+1520 (totalPSnegnegHIV+1520 + tempnum6HIV+1520)
set totalNSposposHIV+1520 (totalNSposposHIV+1520 + tempnum7HIV+1520)
set totalNSposnegHIV+1520 (totalNSposnegHIV+1520 + tempnum8HIV+1520)
set totalNSnegnegHIV+1520 (totalNSnegnegHIV+1520 + tempnum9HIV+1520)
set totalRSposposHIV+1520percent (totalRSposposHIV+1520 / totalcumalltypesHIV+1520)
set totalRSposnegHIV+1520percent (totalRSposnegHIV+1520 / totalcumalltypesHIV+1520)
set totalRSnegnegHIV+1520percent (totalRSnegnegHIV+1520 / totalcumalltypesHIV+1520)
set totalPSposposHIV+1520percent (totalPSposposHIV+1520 / totalcumalltypesHIV+1520)
set totalPSposnegHIV+1520percent (totalPSposnegHIV+1520 / totalcumalltypesHIV+1520)
set totalPSnegnegHIV+1520percent (totalPSnegnegHIV+1520 / totalcumalltypesHIV+1520)
set totalNSposposHIV+1520percent (totalNSposposHIV+1520 / totalcumalltypesHIV+1520)
set totalNSposnegHIV+1520percent (totalNSposnegHIV+1520 / totalcumalltypesHIV+1520)
set totalNSnegnegHIV+1520percent (totalNSnegnegHIV+1520 / totalcumalltypesHIV+1520)
end
to writecumexactbytypeHIV+2030
set tempnum0HIV+2030 0
set tempnum1HIV+2030 0
set tempnum2HIV+2030 0
set tempnum3HIV+2030 0
set tempnum4HIV+2030 0
set tempnum5HIV+2030 0
set tempnum6HIV+2030 0
set tempnum7HIV+2030 0
set tempnum8HIV+2030 0
set tempnum9HIV+2030 0
set totalcumalltypesHIV+2030 0
set totalRSposposHIV+2030 0
set totalRSposnegHIV+2030 0
set totalRSnegnegHIV+2030 0
set totalPSposposHIV+2030 0
set totalPSposnegHIV+2030 0
set totalPSnegnegHIV+2030 0
set totalNSposposHIV+2030 0
set totalNSposnegHIV+2030 0
set totalNSnegnegHIV+2030 0
set totalRSposposHIV+2030percent 0
set totalRSposnegHIV+2030percent 0
set totalRSnegnegHIV+2030percent 0
set totalPSposposHIV+2030percent 0
set totalPSposnegHIV+2030percent 0
set totalPSnegnegHIV+2030percent 0
set totalNSposposHIV+2030percent 0
set totalNSposnegHIV+2030percent 0
set totalNSnegnegHIV+2030percent 0

set numofHIV+temp count turtles with [actual-status = 1 and own-status = 1 and
item 1 timarray >= 61 and item 1 timarray <= 180]
if (numofHIV+temp != 0)
[

ask turtles with [ (((item 0 sextotalbytype) + (item 1 sextotalbytype) +
(item 2 sextotalbytype) + (item 3 sextotalbytype) + (item 4 sextotalbytype) +
(item 5 sextotalbytype) + (item 6 sextotalbytype) + (item 7 sextotalbytype) +
(item 8 sextotalbytype) != 0)]
[
if ( (item 1 timarray > 60) and (item 1 timarray <= 180) and
( item 21 offer = 1) and ( item 4 offer = 1) )
;item 21 offer actual status, 0 not infected, 1 if infected.
item 4 offer = 1 means they know they are infected.
[
set tempnum0HIV+2030 ((item 0 sextotalbytype) + (item 1 sextotalbytype) +
(item 2 sextotalbytype) + (item 3 sextotalbytype) + (item 4 sextotalbytype) +
(item 5 sextotalbytype) + (item 6 sextotalbytype) + (item 7 sextotalbytype) +
(item 8 sextotalbytype) )
set totalcumalltypesHIV+2030 (totalcumalltypesHIV+2030 + tempnum0HIV+2030)
]
]
;print word "totalcumalltypesHIV+2030 " totalcumalltypesHIV+2030

ask turtles with [ (((item 0 sextotalbytype) + (item 1 sextotalbytype) +
(item 2 sextotalbytype) +
(item 3 sextotalbytype) + (item 4 sextotalbytype) + (item 5 sextotalbytype) +
(item 6 sextotalbytype) + (item 7 sextotalbytype) + (item 8 sextotalbytype) != 0)]
[
if ( (item 1 timarray > 60) and (item 1 timarray <= 180) and ( item 21 offer = 1) and
( item 4 offer = 1 )
[
  set tempnumHIV+2030 (item 0 sextotalbytype)
  set totalRSposposHIV+2030 (totalRSposposHIV+2030 + tempnumHIV+2030)
  set tempnum2HIV+2030 (item 1 sextotalbytype)
  set totalRSposnegHIV+2030 (totalRSposnegHIV+2030 + tempnum2HIV+2030)
  set tempnum3HIV+2030 (item 2 sextotalbytype)
  set totalRSnegnegHIV+2030 (totalRSnegnegHIV+2030 + tempnum3HIV+2030)
  set tempnum4HIV+2030 (item 3 sextotalbytype)
  set totalPSposposHIV+2030 (totalPSposposHIV+2030 + tempnum4HIV+2030)
  set tempnum5HIV+2030 (item 4 sextotalbytype)
  set totalPSposnegHIV+2030 (totalPSposnegHIV+2030 + tempnum5HIV+2030)
  set tempnum6HIV+2030 (item 5 sextotalbytype)
  set totalPSnegnegHIV+2030 (totalPSnegnegHIV+2030 + tempnum6HIV+2030)
  set tempnum7HIV+2030 (item 6 sextotalbytype)
  set totalNSposposHIV+2030 (totalNSposposHIV+2030 + tempnum7HIV+2030)
  set tempnum8HIV+2030 (item 7 sextotalbytype)
  set totalNSposnegHIV+2030 (totalNSposnegHIV+2030 + tempnum8HIV+2030)
  set tempnum9HIV+2030 (item 8 sextotalbytype)
  set totalNSnegnegHIV+2030 (totalNSnegnegHIV+2030 + tempnum9HIV+2030)
  set totalRSposposHIV+2030percent (totalRSposposHIV+2030 / totalcumalltypesHIV+2030)
  set totalRSposnegHIV+2030percent (totalRSposnegHIV+2030 / totalcumalltypesHIV+2030)
  set totalRSnegnegHIV+2030percent (totalRSnegnegHIV+2030 / totalcumalltypesHIV+2030)
  set totalPSposposHIV+2030percent (totalPSposposHIV+2030 / totalcumalltypesHIV+2030)
  set totalPSposnegHIV+2030percent (totalPSposnegHIV+2030 / totalcumalltypesHIV+2030)
  set totalPSnegnegHIV+2030percent (totalPSnegnegHIV+2030 / totalcumalltypesHIV+2030)
  set totalNSposposHIV+2030percent (totalNSposposHIV+2030 / totalcumalltypesHIV+2030)
  set totalNSposnegHIV+2030percent (totalNSposnegHIV+2030 / totalcumalltypesHIV+2030)
  set totalNSnegnegHIV+2030percent (totalNSnegnegHIV+2030 / totalcumalltypesHIV+2030)
]
]
;print word "totalRSposposHIV+2030 " totalRSposposHIV+2030
;print word "totalRSposposHIV+2030percent " totalRSposposHIV+2030percent

429
] end

towritecumsexactbytypeHIV+4050
set tempnum0HIV+4050 0
set tempnum1HIV+4050 0
set tempnum2HIV+4050 0
set tempnum3HIV+4050 0
set tempnum4HIV+4050 0
set tempnum5HIV+4050 0
set tempnum6HIV+4050 0
set tempnum7HIV+4050 0
set tempnum8HIV+4050 0
set tempnum9HIV+4050 0
set totalcumalltypesHIV+4050 0
set totalRSposposHIV+4050 0
set totalRSposnegHIV+4050 0
set totalRSnegnegHIV+4050 0
set totalPSposposHIV+4050 0
set totalPSposnegHIV+4050 0
set totalPSnegnegHIV+4050 0
set totalNSposposHIV+4050 0
set totalNSposnegHIV+4050 0
set totalNSnegnegHIV+4050 0
set totalRSposposHIV+4050percent 0
set totalRSposnegHIV+4050percent 0
set totalRSnegnegHIV+4050percent 0
set totalPSposposHIV+4050percent 0
set totalPSposnegHIV+4050percent 0
set totalPSnegnegHIV+4050percent 0
set totalNSposposHIV+4050percent 0
set totalNSposnegHIV+4050percent 0
set totalNSnegnegHIV+4050percent 0

430
set totalNSposnegHIV+4050percent 0
set totalNSnegnegHIV+4050percent 0

set numofHIV+temp count turtles with [actual-status = 1 and own-status = 1 and
item 1 timearray > 300 and item 1 timearray <= 420]
if (numofHIV+temp != 0)
[

ask turtles with [ ((item 0 sextotalbytype) + (item 1 sextotalbytype) +
(item 2 sextotalbytype) + (item 3 sextotalbytype) + (item 4 sextotalbytype) +
(item 5 sextotalbytype) + (item 6 sextotalbytype) + (item 7 sextotalbytype) +
(item 8 sextotalbytype) != 0)]
[
if ( (item 1 timearray > 300) and (item 1 timearray <= 420) and (item 21 offer = 1) and
( item 4 offer = 1) )

;item 21 offer actual status, 0 not infected, 1 if infected.
item 4 offer = 1 means they know they are infected.
[
set tempnum0HIV+4050 ((item 0 sextotalbytype) + (item 1 sextotalbytype) +
(item 2 sextotalbytype) + (item 3 sextotalbytype) + (item 4 sextotalbytype) +
(item 5 sextotalbytype) + (item 6 sextotalbytype) + (item 7 sextotalbytype) +
(item 8 sextotalbytype) )
set totalcumalltypesHIV+4050 (totalcumalltypesHIV+4050 + tempnum0HIV+4050)
]
]

/print word "totalcumalltypesHIV+4050 " totalcumalltypesHIV+4050

ask turtles with [ ((item 0 sextotalbytype) + (item 1 sextotalbytype) +
(item 2 sextotalbytype) + (item 3 sextotalbytype) + (item 4 sextotalbytype) +
(item 5 sextotalbytype) + (item 6 sextotalbytype) + (item 7 sextotalbytype) +
(item 8 sextotalbytype) != 0)]
[
if ( (item 1 timearray > 300) and (item 1 timearray <= 420) and (item 21 offer = 1) and
( item 4 offer = 1) )
[
set tempnum1HIV+4050 (item 0 sextotalbytype)
set totalRSposposHIV+4050 (totalRSposposHIV+4050 + tempnum1HIV+4050)
set tempnum2HIV+4050 (item 1 sextotalbytype)
set totalRSposnegHIV+4050 (totalRSposnegHIV+4050 + tempnum2HIV+4050)
set tempnum3HIV+4050 (item 2 sextotalbytype)
set totalRSnegnegHIV+4050 (totalRSnegnegHIV+4050 + tempnum3HIV+4050)
set tempnum4HIV+4050 (item 3 sextotalbytype)
set totalPSposposHIV+4050 (totalPSposposHIV+4050 + tempnum4HIV+4050)
set tempnum5HIV+4050 (item 4 sextotalbytype)
set totalPSposnegHIV+4050 (totalPSposnegHIV+4050 + tempnum5HIV+4050)
set tempnum6HIV+4050 (item 5 sextotalbytype)
set totalPSnegnegHIV+4050 (totalPSnegnegHIV+4050 + tempnum6HIV+4050)
set tempnum7HIV+4050 (item 6 sextotalbytype)
set totalNSposposHIV+4050 (totalNSposposHIV+4050 + tempnum7HIV+4050)
set tempnum8HIV+4050 (item 7 sextotalbytype)
set totalNSposnegHIV+4050 (totalNSposnegHIV+4050 + tempnum8HIV+4050)
set tempnum9HIV+4050 (item 8 sextotalbytype)
set totalNSnegnegHIV+4050 (totalNSnegnegHIV+4050 + tempnum9HIV+4050)
set totalRSposposHIV+4050percent (totalRSposposHIV+4050 / totalcumalltypesHIV+4050)
set totalRSposnegHIV+4050percent (totalRSposnegHIV+4050 / totalcumalltypesHIV+4050)
set totalRSnegnegHIV+4050percent (totalRSnegnegHIV+4050 / totalcumalltypesHIV+4050)
set totalPSposposHIV+4050percent (totalPSposposHIV+4050 / totalcumalltypesHIV+4050)
set totalPSposnegHIV+4050percent (totalPSposnegHIV+4050 / totalcumalltypesHIV+4050)
set totalPSnegnegHIV+4050percent (totalPSnegnegHIV+4050 / totalcumalltypesHIV+4050)
set totalNSposposHIV+4050percent (totalNSposposHIV+4050 / totalcumalltypesHIV+4050)
set totalNSposnegHIV+4050percent (totalNSposnegHIV+4050 / totalcumalltypesHIV+4050)
set totalNSnegnegHIV+4050percent (totalNSnegnegHIV+4050 / totalcumalltypesHIV+4050)

;print word "totalRSposposHIV+4050 " totalRSposposHIV+4050
;print word "totalRSposposHIV+4050percent " totalRSposposHIV+4050percent

] end
to writecumsexactbytypeHIV+50+
set tempnumOHIV+50+ 0

set tempnum1HIV+50+ 0
set tempnum2HIV+50+ 0
set tempnum3HIV+50+ 0
set tempnum4HIV+50+ 0
set tempnum5HIV+50+ 0
set tempnum6HIV+50+ 0
set tempnum7HIV+50+ 0
set tempnum8HIV+50+ 0
set tempnum9HIV+50+ 0

set totalcumalltypesHIV+50+ 0

set totalRSposposHIV+50+ 0
set totalRSposnegHIV+50+ 0
set totalRSnegnegHIV+50+ 0
set totalPSposposHIV+50+ 0
set totalPSposnegHIV+50+ 0
set totalPSnegnegHIV+50+ 0
set totalNSposposHIV+50+ 0
set totalNSposnegHIV+50+ 0
set totalNSnegnegHIV+50+ 0

set totalRSposposHIV+50+percent 0
set totalRSposnegHIV+50+percent 0
set totalRSnegnegHIV+50+percent 0
set totalPSposposHIV+50+percent 0
set totalPSposnegHIV+50+percent 0
set totalPSnegnegHIV+50+percent 0
set totalNSposposHIV+50+percent 0
set totalNSposnegHIV+50+percent 0
set totalNSnegnegHIV+50+percent 0

433
set totalNSposposHIV+50+percent 0
set totalNSposnegHIV+50+percent 0
set totalNSnegnegHIV+50+percent 0

set numofHIV+temp count turtles with [actual-status = 1 and own-status = 1
and item 1 timearray > 420 ]
if (numofHIV+temp != 0)
[

ask turtles with [((item 0 sextotalbytype) + (item 1 sextotalbytype) +
(item 2 sextotalbytype) + (item 3 sextotalbytype) + (item 4 sextotalbytype) +
(item 5 sextotalbytype) + (item 6 sextotalbytype) + (item 7 sextotalbytype) +
(item 8 sextotalbytype) != 0)]
[
if ( (item 1 timearray > 420) and ( item 21 offer = 1) and ( item 4 offer = 1) )
;item 21 offer actual status, 0 not infected, 1 if infected.
item 4 offer = 1 means they know they are infected.
[

set tempnum0HIV+50+ ((item 0 sextotalbytype) + (item 1 sextotalbytype) +
(item 2 sextotalbytype) + (item 3 sextotalbytype) + (item 4 sextotalbytype) +
(item 5 sextotalbytype) + (item 6 sextotalbytype) + (item 7 sextotalbytype) +
(item 8 sextotalbytype) )
set totalcumalltypesHIV+50+ (totalcumalltypesHIV+50+ + tempnum0HIV+50+)
]
]
;print word "totalcumalltypesHIV+50+ " totalcumalltypesHIV+50+

ask turtles with [((item 0 sextotalbytype) + (item 1 sextotalbytype) +
(item 2 sextotalbytype) + (item 3 sextotalbytype) + (item 4 sextotalbytype) +
(item 5 sextotalbytype) + (item 6 sextotalbytype) + (item 7 sextotalbytype) +
(item 8 sextotalbytype) != 0)]
[
if ( (item 1 timearray > 420) and ( item 21 offer = 1) and ( item 4 offer = 1) )
[ 
  set tempnum1HIV+50+ (item 0 sextotalbytype)
  set totalRSposposHIV+50+ (totalRSposposHIV+50+ + tempnum1HIV+50+)
  set tempnum2HIV+50+ (item 1 sextotalbytype)
  set totalRSposnegHIV+50+ (totalRSposnegHIV+50+ + tempnum2HIV+50+)
  set tempnum3HIV+50+ (item 2 sextotalbytype)
  set totalRSnegnegHIV+50+ (totalRSnegnegHIV+50+ + tempnum3HIV+50+)
  set tempnum4HIV+50+ (item 3 sextotalbytype)
  set totalPSposposHIV+50+ (totalPSposposHIV+50+ + tempnum4HIV+50+)
  set tempnum5HIV+50+ (item 4 sextotalbytype)
  set totalPSposnegHIV+50+ (totalPSposnegHIV+50+ + tempnum5HIV+50+)
  set tempnum6HIV+50+ (item 5 sextotalbytype)
  set totalPSnegnegHIV+50+ (totalPSnegnegHIV+50+ + tempnum6HIV+50+)
  set tempnum7HIV+50+ (item 6 sextotalbytype)
  set totalNSposposHIV+50+ (totalNSposposHIV+50+ + tempnum7HIV+50+)
  set tempnum8HIV+50+ (item 7 sextotalbytype)
  set totalNSposnegHIV+50+ (totalNSposnegHIV+50+ + tempnum8HIV+50+)
  set tempnum9HIV+50+ (item 8 sextotalbytype)
  set totalNSnegnegHIV+50+ (totalNSnegnegHIV+50+ + tempnum9HIV+50+)

  set totalRSposposHIV+50+percent (totalRSposposHIV+50+ / totalcumalltypesHIV+50+)
  set totalRSposnegHIV+50+percent (totalRSposnegHIV+50+ / totalcumalltypesHIV+50+)
  set totalRSnegnegHIV+50+percent (totalRSnegnegHIV+50+ / totalcumalltypesHIV+50+)
  set totalPSposposHIV+50+percent (totalPSposposHIV+50+ / totalcumalltypesHIV+50+)
  set totalPSposnegHIV+50+percent (totalPSposnegHIV+50+ / totalcumalltypesHIV+50+)
  set totalPSnegnegHIV+50+percent (totalPSnegnegHIV+50+ / totalcumalltypesHIV+50+)
  set totalNSposposHIV+50+percent (totalNSposposHIV+50+ / totalcumalltypesHIV+50+)
  set totalNSposnegHIV+50+percent (totalNSposnegHIV+50+ / totalcumalltypesHIV+50+)
  set totalNSnegnegHIV+50+percent (totalNSnegnegHIV+50+ / totalcumalltypesHIV+50+)

] ]

;print word "totalRSposposHIV+50+ " totalRSposposHIV+50+
;print word "totalRSposposHIV+50+percent " totalRSposposHIV+50+percent

]

435
to writeCumUSnegposperyyear

set cumUS1520peryear (item 0 totalsexactsbyage)
set cumUS2030peryear (item 1 totalsexactsbyage)
set cumUS3040peryear (item 2 totalsexactsbyage)
set cumUS4050peryear (item 3 totalsexactsbyage)
set cumUS50+peryear (item 4 totalsexactsbyage)

end

;to findincidence
;if (ticks = 699)
;[ set incidenceHIV 0
 ;]
;if (ticks = 710)
;[ print word "Total new infections" incidenceHIV
 ; set incidenceHIV 0
 ;]
;if (ticks = 720)
;[ print word "Total new infections" incidenceHIV
 ; set incidenceHIV 0
 ;]
;if (ticks = 730)
;[ print word "Total new infections" incidenceHIV
 ; set incidenceHIV 0
 ;]
if (ticks = 740)
{/print word "Total new infections" incidenceHIV
 ; set incidenceHIV 0
 ;}
if (ticks = 750)
{/print word "Total new infections" incidenceHIV
 ; set incidenceHIV 0
 ;}
if (ticks = 760)
{/print word "Total new infections" incidenceHIV
 ; set incidenceHIV 0
 ;}
if (ticks = 770)
{/print word "Total new infections" incidenceHIV
 ; set incidenceHIV 0
 ;}
if (ticks = 780)
{/print word "Total new infections" incidenceHIV
 ; set incidenceHIV 0
 ;}
if (ticks = 790)
{/print word "Total new infections" incidenceHIV
 ; set incidenceHIV 0
 ;}
if (ticks = 800)
{/print word "Total new infections" incidenceHIV
 ; set incidenceHIV 0
 ;}
if (ticks = 810)
{/print word "Total new infections" incidenceHIV
 ; set incidenceHIV 0
 ;}
if (ticks = 820)
{/print word "Total new infections" incidenceHIV
 ;}
; set incidenceHIV 0
;
;if (ticks = 830)
;if (ticks = 840)
;if (ticks = 850)
;if (ticks = 860)
;if (ticks = 870)
;if (ticks = 880)
;if (ticks = 890)
;if (ticks = 900)
;if (ticks = 910)
;[ print word "Total new infections" incidenceHIV
; set incidenceHIV 0
;]
;if (ticks = 920)
;[ print word "Total new infections" incidenceHIV
; set incidenceHIV 0
;]
;if (ticks = 930)
;[ print word "Total new infections" incidenceHIV
; set incidenceHIV 0
;]
;if (ticks = 940)
;[ print word "Total new infections" incidenceHIV
; set incidenceHIV 0
;]
;if (ticks = 950)
;[ print word "Total new infections" incidenceHIV
; set incidenceHIV 0
;]
;if (ticks = 960)
;[ print word "Total new infections" incidenceHIV
; set incidenceHIV 0
;]
;if (ticks = 970)
;[ print word "Total new infections" incidenceHIV
; set incidenceHIV 0
;]
;if (ticks = 980)
;[ print word "Total new infections" incidenceHIV
; set incidenceHIV 0
;]
;if (ticks = 990)
;[ print word "Total new infections" incidenceHIV
; set incidenceHIV 0
;]
;if (ticks = 1000)
 ;[ print word "Total new infections" incidenceHIV
 ; set incidenceHIV 0
 ;]
 ;if (ticks = 1010)
 ;[ print word "Total new infections" incidenceHIV
 ; set incidenceHIV 0
 ;]
 ;if (ticks = 1020)
 ;[ print word "Total new infections" incidenceHIV
 ; set incidenceHIV 0
 ;]
 ;if (ticks = 1030)
 ;[ print word "Total new infections" incidenceHIV
 ; set incidenceHIV 0
 ;]
 ;if (ticks = 1040)
 ;[ print word "Total new infections" incidenceHIV
 ; set incidenceHIV 0
 ;]
 ;if (ticks = 1050)
 ;[ print word "Total new infections" incidenceHIV
 ; set incidenceHIV 0
 ;]
 ;if (ticks = 1060)
 ;[ print word "Total new infections" incidenceHIV
 ; set incidenceHIV 0
 ;]
 ;if (ticks = 1070)
 ;[ print word "Total new infections" incidenceHIV
 ; set incidenceHIV 0
 ;]
 ;if (ticks = 1080)
 ;[ print word "Total new infections" incidenceHIV
 ; set incidenceHIV 0
 ;]
if (ticks = 1090)
{ print word "Total new infections" incidenceHIV
 ; set incidenceHIV 0
 ;}
;if (ticks = 1100)
{ print word "Total new infections" incidenceHIV
 ; set incidenceHIV 0
 ;}
;if (ticks = 1110)
{ print word "Total new infections" incidenceHIV
 ; set incidenceHIV 0
 ;}
;if (ticks = 1120)
{ print word "Total new infections" incidenceHIV
 ; set incidenceHIV 0
 ;}
;if (ticks = 1130)
{ print word "Total new infections" incidenceHIV
 ; set incidenceHIV 0
 ;}
;if (ticks = 1140)
{ print word "Total new infections" incidenceHIV
 ; set incidenceHIV 0
 ;}
;if (ticks = 1150)
{ print word "Total new infections" incidenceHIV
 ; set incidenceHIV 0
 ;}
;if (ticks = 1160)
{ print word "Total new infections" incidenceHIV
 ; set incidenceHIV 0
 ;}
;if (ticks = 1170)
{ print word "Total new infections" incidenceHIV
 ;}
; set incidenceHIV 0
;
;if (ticks = 1180)
;[ print word "Total new infections" incidenceHIV
 ; set incidenceHIV 0
 ;]
;if (ticks = 1190)
;[ print word "Total new infections" incidenceHIV
 ; set incidenceHIV 0
 ;]
;if (ticks = 1200)
;[ print word "Total new infections" incidenceHIV
 ; set incidenceHIV 0
 ;]
;if (ticks = 1210)
;[ print word "Total new infections" incidenceHIV
 ; set incidenceHIV 0
 ;]
;if (ticks = 1220)
;[ print word "Total new infections" incidenceHIV
 ; set incidenceHIV 0
 ;]
;if (ticks = 1230)
;[ print word "Total new infections" incidenceHIV
 ; set incidenceHIV 0
 ;]
;if (ticks = 1240)
;[ print word "Total new infections" incidenceHIV
 ; set incidenceHIV 0
 ;]
;if (ticks = 1250)
;[ print word "Total new infections" incidenceHIV
 ; set incidenceHIV 0
 ;]
;if (ticks = 1260)
to getavgp1520

set hivposavgp1520 0
set hivnegavgp1520 0
set hivposdontknow1520 0
set thenegp1520 0
set theposp1520 0
set thepospdo1520 0
set hivprevpercent1520 0
set hivprevpercentdo1520 0
set totalhivpos1520 0
set totalhivposdontknow1520 0
set avgtotalp1520 0

if (count turtles with [(item 1 timearray) <= 60] != 0)
[
    ask turtles
    [
        if (actual-status = 0) and ((item 1 timearray) <= 60)
        [ set thenegp1520 (item 3 offer)
            set hivnegavgp1520 (hivnegavgp1520 + thenegp1520 / (count turtles with [actual-status = 0 and ((item 1 timearray) <= 60)])
        ;print word "thenegp1520" thenegp1520
        ]

        if (actual-status = 1) and (own-status = 1) and ((item 1 timearray) <= 60) ;;meaning they are hiv+ and know they are
        [ set theposp1520 (item 3 offer)
            set hivposavgp1520 (hivposavgp1520 + theposp1520 / (count turtles with [own-status = 1 and actual-status = 1 and ((item 1 timearray) <= 60)])
        ;print word "theposp1520" theposp1520
        ]

        if (actual-status = 1) and (own-status = 0) and ((item 1 timearray) <= 60) ;;meaning they are hiv+ and dont know they are
        [ set thepospdontknow1520 (item 3 offer)
            set hivposdontknow1520 (hivposdontknow1520 + thepospdontknow1520 / (count turtles with [own-status = 0 and actual-status = 1 and ((item 1 timearray) <= 60)])
        ;print word "thepospdontknow1520" thepospdontknow1520
        ]
    ]
]
;print word "total 1520 turtles " (count turtles with
[(item 1 timearray) <= 60 ])
;print word "total 1520 turtles HIV - " (count turtles with
[((item 1 timearray) <= 60) and (actual-status = 0) ])
;print word "total 1520 turtles HIV + know it " (count turtles with
[((item 1 timearray) <= 60) and (actual-status = 1) and (own-status = 1) ])
;print word "total 1520 turtles HIV + dont know it " (count turtles with
[((item 1 timearray) <= 60) and (actual-status = 1) and (own-status = 0) ])
;print word "thenegp1520 " thenegp1520
;print word "theposp1520 " theposp1520
;print word "thepospdontknow1520 " thepospdontknow1520
;print word "hivnegavgp1520 " hivnegavgp1520

ask turtles
[
  if ((item 1 timearray) <= 60)
    [ set theturtlep1520 (item 3 offer) ]
  set avgtotalp1520 (avgtotalp1520 + theturtlep1520 / (count turtles with
    [(item 1 timearray) <= 60 ]))
]
]
;print word "avgtotalp1520 " avgtotalp1520

ask turtles
[
  if (actual-status = 1) and (own-status = 1) and ((item 1 timearray) <= 60 )
    [ set totalhivpos1520 totalhivpos1520 + 1 }
if (actual-status = 1) and (own-status = 0) and ((item 1 timearray) <= 60 )
[ set totalhivposdontknow1520 totalhivposdontknow1520 + 1
]
]

set hivprevpercent1520 (totalhivpos1520 / (count turtles with
[(item 1 timearray) <= 60 ]))
set hivprevpercentdontknow1520 (totalhivposdontknow1520 / (count turtles with
[(item 1 timearray) <= 60 ]))

;print word "hivprevpercent1520 " hivprevpercent1520
;print word "hivprevpercentdontknow1520 " hivprevpercentdontknow1520
]
end
to getavgp2030

set hivposavgp2030 0
set hvnegavgp2030 0
set hivposdontknow2030 0
set thenegp2030 0
set theposp2030 0
set thepospdontknow2030 0
set hivprevpercent2030 0
set hivprevpercentdontknow2030 0
set totalhivpos2030 0
set totalhivposdontknow2030 0
set avgtotalp2030 0

if ((count turtles with [((item 1 timearray) > 60) and ((item 1 timearray) <= 180) ]) != 0)
[
ask turtles

[ if (actual-status = 0) and ((item 1 timearray) > 60) and ((item 1 timearray) <= 180)
  [ set thenegp2030 (item 3 offer)
    set hivnegavgp2030 (hivnegavgp2030 + thenegp2030 / (count turtles with 
      [actual-status = 0 and ((item 1 timearray) > 60) and ((item 1 timearray) <= 180) ] ))
    ;print word "thenegp1520" thenegp1520
  ]
]

if (actual-status = 1) and (own-status = 1) and ((item 1 timearray) > 60)
  and ((item 1 timearray) <= 180) ;;meaning they are hiv+ and know they are
  [ set theposp2030 (item 3 offer)
    set hivposavgp2030 (hivposavgp2030 + theposp2030 / (count turtles with
      [own-status = 1 and actual-status = 1 and ((item 1 timearray) > 60) and
      ((item 1 timearray) <= 180) ] )
    )
    ;print word "theposp1520" theposp1520
  ]

if (actual-status = 1) and (own-status = 0) and ((item 1 timearray) > 60)
  and ((item 1 timearray) <= 180) ;;meaning they are hiv+ and dont know they are
  [ set theposdontknow2030 (item 3 offer)
    set hivposdontknow2030 (hivposdontknow2030 + theposdontknow2030 / (count turtles with
      [own-status = 0 and actual-status = 1 and ((item 1 timearray) > 60) and
      ((item 1 timearray) <= 180) ] )
    )
    ;print word "theposdontknow1520" theposdontknow1520
  ]

;print word "total 2030 turtles " (count turtles with
  [((item 1 timearray) > 60) and ((item 1 timearray) <= 180) ]
)
;print word "total 2030 turtles HIV + know it " (count turtles with

[([item 1 timearray] > 60) and ([item 1 timearray] <= 180) and
(actual-status = 1) and (own-status = 1)]

;print word "total 2030 turtles HIV + dont know it " (count turtles with

[([item 1 timearray] > 60) and ([item 1 timearray] <= 180) and
(actual-status = 1) and (own-status = 0)]

;print word "thenegp2030 " thenegp2030

;print word "theposp2030 " theposp2030

;print word "thepospdontknow2030 " thepospdontknow2030

ask turtles
[
if ([item 1 timearray] > 60) and ([item 1 timearray] <= 180)
[ set theturtlep2030 (item 3 offer)
set avgtotalp2030 (avgtotalp2030 + theturtlep2030 / (count turtles with

[([item 1 timearray] > 60) and ([item 1 timearray] <= 180)])
]
]

;print word "avgtotalp2030 " avgtotalp2030

ask turtles
[
if (actual-status = 1) and (own-status = 1) and ([item 1 timearray] > 60 )
and ([item 1 timearray] <= 180)
[ set totalhivpos2030 totalhivpos2030 + 1
]
if (actual-status = 1) and (own-status = 0) and ([item 1 timearray] > 60 )
and ([item 1 timearray] <= 180)
[ set totalhivposdontknow2030 totalhivposdontknow2030 + 1
]
set hivprevpercent2030 (totalhivpos2030 / (count turtles with
[((item 1 timearray) > 60) and ((item 1 timearray) <= 180) )))
set hivprevpercentdontknow2030 (totalhivposdontknow2030 /
(count turtles with [((item 1 timearray) > 60) and ((item 1 timearray) <= 180) ]))

;print word "hivprevpercent2030 " hivprevpercent2030
;print word "hivprevpercentdontknow2030 " hivprevpercentdontknow2030
]
end
to getavgp3040

set hivposavgp3040 0
set hivnegavgp3040 0
set hivposdontknow3040 0
set thenegp3040 0
set theposp3040 0
set theposp3040 0
set theposp3040 0
set hivprevpercent3040 0
set hivprevpercentdontknow3040 0
set totalhivpos3040 0
set totalhivposdontknow3040 0
set avgtotalp3040 0

if ((count turtles with [((item 1 timearray) > 180) and
((item 1 timearray) <= 300) ]) != 0)
[}
ask turtles
[
if (actual-status = 0) and ((item 1 timearray) > 180) and ((item 1 timearray) <= 300)
[ set thenegp3040 (item 3 offer)
set hivnegavgp3040 (hivnegavgp3040 + thenegp3040 / (count turtles with
[actual-status = 0 and ((item 1 timearray) > 180) and ((item 1 timearray) <= 300) ] ))
;print word "thenegp1520" thenegp1520
]

if (actual-status = 1) and (own-status = 1) and ((item 1 timearray) > 180)
and ((item 1 timearray) <= 300) ;;meaning they are hiv+ and know they are
[ set theosp3040 (item 3 offer)
set hivposavgp3040 (hivposavgp3040 + theosp3040 / (count turtles with
[own-status = 1 and actual-status = 1 and ((item 1 timearray) > 180) and
((item 1 timearray) <= 300) ] ) )
;print word "theposp1520" theosp1520
]

if (actual-status = 1) and (own-status = 0) and ((item 1 timearray) > 180) and
((item 1 timearray) <= 300) ;;meaning they are hiv+ and dont know they are
[ set theospdontknow3040 (item 3 offer)
set hivposdontknow3040 (hivposdontknow3040 + theospdontknow3040 /
(count turtles with [own-status = 0 and actual-status = 1 and ((item 1 timearray) > 180)
and ((item 1 timearray) <= 300) ] ))
;print word "thepospdontknow1520" theospdontknow1520
]

;print word "total 3040 turtles " (count turtles with
[[(item 1 timearray) > 180) and ((item 1 timearray) <= 300) ]
;print word "total 3040 turtles HIV - " (count turtles with
[[(item 1 timearray) > 180) and ((item 1 timearray) <= 300) and (actual-status = 0) ]
]
;print word "total 3040 turtles HIV+ know it" (count turtles with
[(item 1 timearray) > 180) and ((item 1 timearray) <= 300) and
(actual-status = 1) and (own-status = 1)]
;print word "total 3040 turtles HIV+ dont know it" (count turtles with
[(item 1 timearray) > 180) and ((item 1 timearray) <= 300) and
(actual-status = 1) and (own-status = 0)]
;print word "thenegp3040" thenegp3040
;print word "theposp3040" theposp3040
;print word "thepospdontknow3040" thepospdontknow3040

ask turtles
[
if ((item 1 timearray) > 180) and ((item 1 timearray) <= 300)
[ set theturtlep3040 (item 3 offer)
set avgtotalp3040 (avgtotalp3040 + theturtlep3040 / (count turtles with
[(item 1 timearray) > 180) and ((item 1 timearray) <= 300)])
]
]
;print word "avgtotalp3040" avgtotalp3040

ask turtles
[
if (actual-status = 1) and (own-status = 1) and ((item 1 timearray) > 180)
and ((item 1 timearray) <= 300)
[ set totalhivpos3040 totalhivpos3040 + 1
]
if (actual-status = 1) and (own-status = 0) and ((item 1 timearray) > 180)
and ((item 1 timearray) <= 300)
[ set totalhivposdontknow3040 totalhivposdontknow3040 + 1
]
set hivprevpercent3040 (totalhivpos3040 / (count turtles with
    [((item 1 timearray) > 180) and ((item 1 timearray) <= 300)]))
set hivprevpercentdontknow3040 (totalhivposdontknow3040 / (count turtles with
    [((item 1 timearray) > 180) and ((item 1 timearray) <= 300)]))

;print word "hivprevpercent3040 " hivprevpercent3040
;print word "hivprevpercentdontknow3040 " hivprevpercentdontknow3040
]
end

to getavgp4050

set hivposavgp4050 0
set hivnegavgp4050 0
set hivposdontknow4050 0
set thenegp4050 0
set theposp4050 0
set thepospdontknow4050 0
set hivprevpercent4050 0
set hivprevpercentdontknow4050 0
set totalhivpos4050 0
set totalhivposdontknow4050 0
set avgtotalp4050 0

if ((count turtles with [((item 1 timearray) > 300) and ((item 1 timearray) <= 420)] !≠ 0)
[

;ask turtles
if (count turtles with [actual-status = 1] != 0)

ask turtles

[ if (actual-status = 0) and ((item 1 timearray) > 300) and ((item 1 timearray) <= 420)
    set thenegp4050 (item 3 offer)
    set hivnegavgp4050 (hivnegavgp4050 + thenegp4050 / (count turtles with [actual-status = 0 and ((item 1 timearray) > 300) and ((item 1 timearray) <= 420) ] ))
    ;print word "thenegp1520" thenegp1520
]

if (actual-status = 1) and (own-status = 1) and ((item 1 timearray) > 300) and ((item 1 timearray) <= 420) ;;meaning they are hiv+ and know they are

set theposp4050 (item 3 offer)
set hivposavgp4050 (hivposavgp4050 + theposp4050 / (count turtles with [own-status = 1 and actual-status = 1 and ((item 1 timearray) > 300) and ((item 1 timearray) <= 420) ] ))
;print word "theposp1520" theposp1520
]

if (actual-status = 1) and (own-status = 0) and ((item 1 timearray) > 300) and ((item 1 timearray) <= 420) ;;meaning they are hiv+ and dont know they are

set thepospdontknow4050 (item 3 offer)
set hivposdontknow4050 (hivposdontknow4050 + thepospdontknow4050 / (count turtles with [own-status = 0 and actual-status = 1 and ((item 1 timearray) > 300) and ((item 1 timearray) <= 420) ] ))

;print word "theposp1520" theposp1520

]
;print word "thepospdontknow1520" thepospdontknow1520
]

;print word "total 4050 turtles " (count turtles with

[[(item 1 timearray) > 300) and ((item 1 timearray) <= 420) ])
;print word "total 4050 turtles HIV - " (count turtles with

[[(item 1 timearray) > 300) and ((item 1 timearray) <= 420) and (actual-status = 0) ])
;print word "total 4050 turtles HIV + know it " (count turtles with

[[(item 1 timearray) > 300) and ((item 1 timearray) <= 420) and (actual-status = 1) and (own-status = 1) ])
;print word "total 4050 turtles HIV + dont know it " (count turtles with

[[(item 1 timearray) > 300) and ((item 1 timearray) <= 420) and (actual-status = 1) and (own-status = 0) ])
;print word "thenegp4050 " thenegp4050
;print word "theposp4050 " theposp4050
;print word "thepospdontknow4050 " thepospdontknow4050

ask turtles
[
if ((item 1 timearray) > 300) and ((item 1 timearray) <= 420)
[ set theturtlep4050 (item 3 offer)
set avgtotalp4050 (avgtotalp4050 + theturtlep4050 / (count turtles with

[[(item 1 timearray) > 300) and ((item 1 timearray) <= 420) ]])
]
]
;print word "avgtotalp4050 " avgtotalp4050

ask turtles
[
if (actual-status = 1) and (own-status = 1) and ((item 1 timearray) > 300 ) and
((item 1 timearray) <= 420)
[ set totalhivpos4050 totalhivpos4050 + 1
]
if (actual-status = 1) and (own-status = 0) and ((item 1 timearray) > 300 ) and
((item 1 timearray) <= 420)
[ set totalhivposdontknow4050 totalhivposdontknow4050 + 1
]
]

set hivprevpercent4050 (totalhivpos4050 / (count turtles with
[[((item 1 timearray) > 300) and ((item 1 timearray) <= 420) ]])
set hivprevpercentdontknow4050 (totalhivposdontknow4050 / (count turtles with
[[((item 1 timearray) > 300) and ((item 1 timearray) <= 420) ]])

;print word "hivprevpercent4050   " hivprevpercent4050
;print word "hivprevpercentdontknow4050   " hivprevpercentdontknow4050
] end
to getavgp5060
set hivposavgp5060 0
set hivnegavgp5060 0
set hivposdowntp5060 0
set thenegp5060 0
set theposp5060 0
set theposdowntp5060 0
set avgtotalp5060 0
set hivprevpercent5060 0
set hivprevpercentdowntp5060 0
set totalhivpos5060 0
set totalhivposdowntp5060 0
if ((count turtles with [[((item 1 timearray) > 420) and ((item 1 timearray) <= 540) ]]) != 0)
if (actual-status = 0) and ((item 1 timearray) > 420) and ((item 1 timearray) <= 540)
[ set thenegp5060 (item 3 offer)
set hivnegavgp5060 (hivnegavgp5060 + thenegp5060 / (count turtles with [actual-status = 0 and ((item 1 timearray) > 420) and ((item 1 timearray) <= 540) ] ))
;print word "thenegp1520" thenegp1520
]

if (actual-status = 1) and (own-status = 1) and ((item 1 timearray) > 420) and ((item 1 timearray) <= 540) ;;meaning they are hiv+ and know they are
[ set theposp5060 (item 3 offer)
set hivposavgp5060 (hivposavgp5060 + theposp5060 / (count turtles with [own-status = 1 and actual-status = 1 and ((item 1 timearray) > 420) and ((item 1 timearray) <= 540) ] ))
;print word "theposp1520" theposp1520
]

if (actual-status = 1) and (own-status = 0) and ((item 1 timearray) > 420) and ((item 1 timearray) <= 540) ;;meaning they are hiv+ and dont know they are
[ set thepospdontknow5060 (item 3 offer)
set hivposdontknow5060 (hivposdontknow5060 + thepospdontknow5060 / (count turtles with [own-status = 0 and actual-status = 1 and ((item 1 timearray) > 420) and ((item 1 timearray) <= 540) ] ))
;print word "thepospdontknow1520" thepospdontknow1520
]

if ((item 1 timearray) > 420) and ((item 1 timearray) <= 540)
[ set theturtlep5060 (item 3 offer)
set avgtotalp5060 (avgtotalp5060 + theturtlep5060 / (count turtles with [((item 1 timearray) > 420) and ((item 1 timearray) <= 540) ]))
]
if (actual-status = 1) and (own-status = 1) and ((item 1 timearray) > 420 ) and
((item 1 timearray) <= 540)
[ set totalhivpos5060 totalhivpos5060 + 1
]
if (actual-status = 1) and (own-status = 0) and ((item 1 timearray) > 420 ) and
((item 1 timearray) <= 540)
[ set totalhivposdontknow5060 totalhivposdontknow5060 + 1
]
]

set hivprevpercent5060 (totalhivpos5060 / (count turtles with
[(((item 1 timearray) > 420) and ((item 1 timearray) <= 540 )]))
set hivprevpercentdontknow5060 (totalhivposdontknow5060 / (count turtles with
[(((item 1 timearray) > 420) and ((item 1 timearray) <= 540 )]))

;print word "total 5060 turtles " (count turtles with
[(((item 1 timearray) > 420) and ((item 1 timearray) <= 540 )])
;print word "total 5060 turtles HIV - " (count turtles with
[(((item 1 timearray) > 420) and ((item 1 timearray) <= 540 ) and (actual-status = 0 )])
;print word "total 5060 turtles HIV + know it " (count turtles with
[(((item 1 timearray) > 420) and ((item 1 timearray) <= 540 ) and (actual-status = 1)
and (own-status = 1 )])
;print word "total 5060 turtles HIV + dont know it " (count turtles with
[(((item 1 timearray) > 420) and ((item 1 timearray) <= 540 ) and (actual-status = 1)
and (own-status = 0 )])
;print word "thenegp5060 " thenegp5060
;print word "theposp5060 " theposp5060
;print word "thepospdontknow5060 " thepospdontknow5060
;print word "avgtotalp5060 " avgtotalp5060
;print word "hivprevpercent5060 " hivprevpercent5060
;print word "hivprevpercentdontknow5060 " hivprevpercentdontknow5060
]
to getavgp6070

set hivposavgp6070 0
set hivnegavgp6070 0
set hivposdontknow6070 0
set thenegp6070 0
set theposp6070 0
set theposdontknow6070 0
set avgtotalp6070 0
set hivprevpercent6070 0
set hivprevpercentdontknow6070 0
set totalhivpos6070 0
set totalhivposdontknow6070 0
if ((count turtles with [[(item 1 timearray) > 540) and
((item 1 timearray) <= 660) ]] != 0)
[ ask turtles
[ if (actual-status = 0) and ((item 1 timearray) > 540) and ((item 1 timearray) <= 660)
[ set thenegp6070 (item 3 offer)
set hivnegavgp6070 (hivnegavgp6070 + thenegp6070 / (count turtles with
[actual-status = 0 and ((item 1 timearray) > 540) and ((item 1 timearray) <= 660) ] ) )
;print word "thenegp1520" thenegp1520
]

if (actual-status = 1) and (own-status = 1) and ((item 1 timearray) > 540) and
((item 1 timearray) <= 660) ;;meaning they are hiv+ and know they are
[ set theposp6070 (item 3 offer)
set hivposavgp6070 (hivposavgp6070 + theposp6070 / (count turtles with
[own-status = 1 and actual-status = 1 and ((item 1 timearray) > 540) and
((item 1 timearray) <= 660) ] ) )
;print word "theposp1520" theposp1520
]
if (actual-status = 1) and (own-status = 0) and ((item 1 timearray) > 540) and ((item 1 timearray) <= 660) ;;meaning they are hiv+ and dont know they are
[ set thepospdontknow6070 (item 3 offer) 
set hivposdontknow6070 (hivposdontknow6070 + thepospdontknow6070 / (count turtles with [own-status = 0 and actual-status = 1 and ((item 1 timearray) > 540) and ((item 1 timearray) <= 660) ]))
;print word "thepospdontknow1520" thepospdontknow1520 ]
if ((item 1 timearray) > 540) and ((item 1 timearray) <= 660) 
[ set theturtlep6070 (item 3 offer) 
set avgtotalp6070 (avgtotalp6070 + theturtlep6070 / (count turtles with 
[[(item 1 timearray) > 540] and ((item 1 timearray) <= 660)]))
] 
if (actual-status = 1) and (own-status = 1) and ((item 1 timearray) > 540 ) and 
((item 1 timearray) <= 660)
[ set totalhivpos6070 totalhivpos6070 + 1 
]
if (actual-status = 1) and (own-status = 0) and ((item 1 timearray) > 540 ) and 
((item 1 timearray) <= 660)
[ set totalhivposdontknow6070 totalhivposdontknow6070 + 1 
]

set hivprevpercent6070 (totalhivpos6070 / (count turtles with 
[[(item 1 timearray) > 540] and ((item 1 timearray) <= 660)]))
set hivprevpercentdontknow6070 (totalhivposdontknow6070 / 
(count turtles with [[(item 1 timearray) > 540] and ((item 1 timearray) <= 660)]))
;print word "total 6070 turtles " (count turtles with 
[[(item 1 timearray) > 540] and ((item 1 timearray) <= 660)]))
;print word "total 6070 turtles HIV - " (count turtles with 
[[(item 1 timearray) > 540] and ((item 1 timearray) <= 660)]))
(actual-status = 0))]
;print word "total 6070 turtles HIV + know it " (count turtles with
[((item 1 timearray) > 540) and ((item 1 timearray) <= 660) and
(actual-status = 1) and (own-status = 1))]
;print word "total 6070 turtles HIV + dont know it " (count turtles with
[((item 1 timearray) > 540) and ((item 1 timearray) <= 660) and
(actual-status = 1) and (own-status = 0))]
;print word "thenegp6070" thenegp6070
;print word "theposp6070" theposp6070
;print word "thepospdontknow6070" thepospdontknow6070
;print word "avgtotalp6070" avgtotalp6070
;print word "hivprevpercent6070" hivprevpercent6070
;print word "hivprevpercentdontknow6070" hivprevpercentdontknow6070
]
end

to getavgp7080

set hivposavgp7080 0
set hivnegavgp7080 0
set hivposdontknow7080 0
set thenegp7080 0
set theosp7080 0
set thepospdontknow7080 0
set avgtotalp7080 0
set hivprevpercent7080 0
set hivprevpercentdontknow7080 0
set totalhivpos7080 0
set totalhivposdontknow7080 0
if ((count turtles with (((item 1 timearray) > 660) and
((item 1 timearray) <= 780)) != 0)
[
ask turtles
[getavgp7080

460
if (actual-status = 0) and ((item 1 timearray) > 660) and ((item 1 timearray) <= 780)
[ set thenegp7080 (item 3 offer)
set hivnegavgp7080 (hivnegavgp7080 + thenegp7080 / (count turtles with
[actual-status = 0 and ((item 1 timearray) > 660) and ((item 1 timearray) <= 780) ] ) )
;print word "thenegp1520" thenegp1520
]

if (actual-status = 1) and (own-status = 1) and ((item 1 timearray) > 660) and
((item 1 timearray) <= 780) ;;meaning they are hiv+ and know they are
[ set theposp7080 (item 3 offer)
set hivposavgp7080 (hivposavgp7080 + theposp7080 / (count turtles with
[own-status = 1 and actual-status = 1 and ((item 1 timearray) > 660) and
((item 1 timearray) <= 780) ] ) )
;print word "theposp1520" theposp1520
]

if (actual-status = 1) and (own-status = 0) and ((item 1 timearray) > 660) and
((item 1 timearray) <= 780) ;;meaning they are hiv+ and dont know they are
[ set thepospdontknow7080 (item 3 offer)
set hivposdontknow7080 (hivposdontknow7080 + thepospdontknow7080 / (count turtles with
[own-status = 0 and actual-status = 1 and ((item 1 timearray) > 660) and
((item 1 timearray) <= 780) ] ))
;print word "thepospdontknow1520" thepospdontknow1520
]

if (((item 1 timearray) > 660) and (((item 1 timearray) <= 780)
[ set theturtlep7080 (item 3 offer)
set avgtotalp7080 (avgtotalp7080 + theturtlep7080 / (count turtles with
[[((item 1 timearray) > 660) and ((item 1 timearray) <= 780) ]])
]

if (actual-status = 1) and (own-status = 1) and ((item 1 timearray) > 660 ) and
((item 1 timearray) <= 780)
[ set totalhivpos7080 totalhivpos7080 + 1
if (actual-status = 1) and (own-status = 0) and ((item 1 timearray) > 660 ) and 
((item 1 timearray) <= 780)
[ set totalhivposdontknow7080 totalhivposdontknow7080 + 1
]

set hivprevpercent7080 (totalhivpos7080 / (count turtles with 
[[(item 1 timearray) > 660] and ((item 1 timearray) <= 780 )]]))
set hivprevpercentdontknow7080 (totalhivposdontknow7080 / (count turtles with 
[[(item 1 timearray) > 660] and ((item 1 timearray) <= 780 )]]))
;print word "total 7080 turtles " (count turtles with 
[[(item 1 timearray) > 660] and ((item 1 timearray) <= 780 )])
;print word "total 7080 turtles HIV - " (count turtles with 
[[(item 1 timearray) > 660] and ((item 1 timearray) <= 780) and (actual-status = 0 )])
;print word "total 7080 turtles HIV + know it " (count turtles with 
[[(item 1 timearray) > 660] and ((item 1 timearray) <= 780) and 
(actual-status = 1) and (own-status = 1) ])
;print word "total 7080 turtles HIV + dont know it " (count turtles with 
[[(item 1 timearray) > 660] and ((item 1 timearray) <= 780) and 
(actual-status = 1) and (own-status = 0) ])
;print word "thenegp7080 " thenegp7080
;print word "theposp7080 " theposp7080
;print word "thepospdontknow7080 " thepospdontknow7080
;print word "avgtotalp7080 " avgtotalp7080
;print word "hivprevpercent7080 " hivprevpercent7080
;print word "hivprevpercentdontknow7080 " hivprevpercentdontknow7080
]
end

to getavgp50+

set hivposavgp50+ 0
set hivnegavgp50+ 0
set hivposdontknow50+ 0
set thenegp50+ 0
set theosp50+ 0
set theospdontknow50+ 0
set avgtotalp50+ 0
set hivprevpercent50+ 0
set hivprevpercentdontknow50+ 0
set totalhivpos50+ 0
set totalhivposdontknow50+ 0
if ((count turtles with [item 1 timearray) > 420]) != 0)
[
  ask turtles
  [
    if (actual-status = 0) and ((item 1 timearray) > 420)
    [ set thenegp50+ (item 3 offer)
      set hivnegavgp50+ (hivnegavgp50+ + thenegp50+ / (count turtles with
      [actual-status = 0 and ((item 1 timearray) > 420)) ]
    ]
  ]
  if (actual-status = 1) and (own-status = 1) and ((item 1 timearray) > 420)
    ;;meaning they are hiv+ and know they are
    [ set theosp50+ (item 3 offer)
      set hivposavgp50+ (hivposavgp50+ + theosp50+ / (count turtles with
      [own-status = 1 and actual-status = 1 and ((item 1 timearray) > 420)])]
    ]
  if (actual-status = 1) and (own-status = 0) and ((item 1 timearray) > 420)
    ;;meaning they are hiv+ and dont know they are
    [ set theospdontknow50+ (item 3 offer)
      set hivposdontknow50+ (hivposdontknow50+ + theospdontknow50+ / (count turtles with
      [own-status = 0 and actual-status = 1 and ((item 1 timearray) > 420)])]
    ]
]
if ((item 1 timearray) > 420)
[ set theturtlep50+ (item 3 offer)
set avgtotalp50+ (avgtotalp50+ + theturtlep50+ / (count turtles with
[[(item 1 timearray) > 420] ]))
]

if (actual-status = 1) and (own-status = 1) and ((item 1 timearray) > 420 )
[ set totalhivpos50+ totalhivpos50+ + 1
]
if (actual-status = 1) and (own-status = 0) and ((item 1 timearray) > 420 )
[ set totalhivposdontknow50+ totalhivposdontknow50+ + 1
]

set hivprevpercent50+ (totalhivpos50+ / (count turtles with [[(item 1 timearray) > 420] ]))
set hivprevpercentdontknow50+ (totalhivposdontknow50+ / (count turtles with
[[(item 1 timearray) > 420] ]))

;print word "total 5060 turtles " (count turtles with [[(item 1 timearray) > 420] and
((item 1 timearray) <= 540) ])
;print word "total 5060 turtles HIV - " (count turtles with
[[(item 1 timearray) > 420] and ((item 1 timearray) <= 540) and (actual-status = 0) ])
;print word "total 5060 turtles HIV + know it " (count turtles with
[[(item 1 timearray) > 420] and ((item 1 timearray) <= 540) and (actual-status = 1)
and (own-status = 1) ])
;print word "total 5060 turtles HIV + dont know it " (count turtles with
[[(item 1 timearray) > 420] and ((item 1 timearray) <= 540) and
(actual-status = 1) and (own-status = 0) ])
;print word "thenegp5060 " thenegp5060
;print word "theposp5060 " theposp5060
;print word "thepospdontknow5060 " thepospdontknow5060
;print word "avgtotalp5060 " avgtotalp5060

464
to getavgtheta

set avgtheta1520 0
set avgtheta2030 0
set avgtheta3040 0
set avgtheta4050 0
set avgtheta50+ 0
set theta1520 0
set theta2030 0
set theta3040 0
set theta4050 0
set theta50+ 0

if ( ((count turtles with [(item 1 timearray) <= 60]) != 0) and ((count turtles with [(item 1 timearray) > 60) and ((item 1 timearray) <= 180)] != 0) and ((count turtles with [(item 1 timearray) > 180) and ((item 1 timearray) <= 300)] != 0) and ((count turtles with [(item 1 timearray) > 300) and ((item 1 timearray) <= 420)] != 0) and ((count turtles with [(item 1 timearray) > 420]) != 0) and ((count turtles with [(item 1 timearray) > 420]) != 0) )
[ask turtles
[if (item 1 timearray) <= 60)
[set theta1520 (item 23 timearray)
]
set avgtheta1520 (avgtheta1520 + theta1520 / (count turtles with [ ((item 1 timearray) <= 60) ] ))

if ((item 1 timearray) > 60) and ((item 1 timearray) <= 180)
[ set theta2030 (item 23 timearray)
set avgtheta2030 (avgtheta2030 + theta2030 / (count turtles with [ ((item 1 timearray) > 60) and ((item 1 timearray) <= 180) ] ))
]

if ((item 1 timearray) > 180) and ((item 1 timearray) <= 300)
[ set theta3040 (item 23 timearray)
set avgtheta3040 (avgtheta3040 + theta3040 / (count turtles with [ ((item 1 timearray) > 180) and ((item 1 timearray) <= 300) ] ))
]

if ((item 1 timearray) > 300) and ((item 1 timearray) <= 420)
[ set theta4050 (item 23 timearray)
set avgtheta4050 (avgtheta4050 + theta4050 / (count turtles with [ ((item 1 timearray) > 300) and ((item 1 timearray) <= 420) ] ))
]

if ((item 1 timearray) > 420)
[ set theta50+ (item 23 timearray)
set avgtheta50+ (avgtheta50+ + theta50+ / (count turtles with [ ((item 1 timearray) > 420) ] ))
]

end
to setup-plotincidence
set-current-plot "Incidence"
;set-plot-y-range 0 (num + 10)
end

; to update-plotincidence

if (remainder ticks 12 = 0)
[ set-current-plot "Incidence"
set-current-plot-pen "numinfectedperyear"
plot incidenceHIV
;print word "incidenceHIV " incidenceHIV
set incidenceHIV 0

set-current-plot-pen "numinfectedperyear1520"
plot incidenceHIV1520
;print word "incidenceHIV1520 " incidenceHIV1520
set incidenceHIV1520 0

set-current-plot-pen "numinfectedperyear2030"
plot incidenceHIV2030
;print word "incidenceHIV2030 " incidenceHIV2030
set incidenceHIV2030 0

set-current-plot-pen "numinfectedperyear3040"
plot incidenceHIV3040
;print word "incidenceHIV3040 " incidenceHIV3040
set incidenceHIV3040 0

set-current-plot-pen "numinfectedperyear4050"
plot incidenceHIV4050
;print word "incidenceHIV4050 " incidenceHIV4050
set incidenceHIV4050 0

467
set-current-plot-pen "numinfectedperyear50+
plot incidenceHIV50+
;print word "incidenceHIV50+" incidenceHIV50+
set incidenceHIV50+ 0
]
end

to setup-plot-HIV+byage
set-current-plot "HIV+ by age"
;set-plot-y-range 0 (num + 10)
end

to update-plot-HIV+byage
if (remainder ticks 12 = 0)
[
set-current-plot "HIV+ by age"
set-current-plot-pen "HIV+1519"
plot count turtles with [actual-status = 1 and own-status = 1 and
item 1 timearray <= 60];[ item 21 offer = 1] ;own-status = 1 or
set-current-plot-pen "HIV+2029"
plot count turtles with [actual-status = 1 and own-status = 1 and
item 1 timearray >= 61 and item 1 timearray <= 180
set-current-plot-pen "HIV+3039"
plot count turtles with [actual-status = 1 and own-status = 1 and
item 1 timearray >= 181 and item 1 timearray <= 300
set-current-plot-pen "HIV+4049"
plot count turtles with [actual-status = 1 and own-status = 1 and
item 1 timearray >= 301 and item 1 timearray <= 420]
set-current-plot-pen "HIV+50+
plot count turtles with [actual-status = 1 and own-status = 1 and
item 1 timearray >= 421]

;set-current-plot-pen "HIV-"
;plot count turtles with [actual-status = 0]
;set-current-plot-pen "HIV+dontknow"
;plot count turtles with [actual-status = 1 and own-status = 0]
]
end

to setup-plot-HIV-byage
set-current-plot "HIV- by age"
end

to update-plot-HIV-byage
if (remainder ticks 12 = 0)
[ set-current-plot "HIV- by age"
set-current-plot-pen "HIV-1519"
plot count turtles with [actual-status = 0 and item 1 timearray <= 60]
set-current-plot-pen "HIV-2029"
plot count turtles with [actual-status = 0 and item 1 timearray >= 61 and
item 1 timearray <= 180]
set-current-plot-pen "HIV-3039"
plot count turtles with [actual-status = 0 and item 1 timearray >= 181 and
item 1 timearray <= 300]
set-current-plot-pen "HIV-4049"
plot count turtles with [actual-status = 0 and item 1 timearray >= 301 and
item 1 timearray <= 420]
set-current-plot-pen "HIV-50+
plot count turtles with [actual-status = 0 and item 1 timearray >= 421]
]
end
to setup-plot-Average-b-value-HIV+-by-age
set-current-plot "Average b-value HIV+ by age"
end

to update-plot-Average-b-value-HIV+-by-age
if (remainder ticks 12 = 0)
[
set-current-plot "Average b-value HIV+ by age"
set-current-plot-pen "HIV+1519b"
plot hivposavgp1520
set-current-plot-pen "HIV+2029b"
plot hivposavgp2030
set-current-plot-pen "HIV+3039b"
plot hivposavgp3040
set-current-plot-pen "HIV+4049b"
plot hivposavgp4050
set-current-plot-pen "HIV+50+b"
plot hivposavgp50+
]
end

to setup-plot-Average-b-value-HIV--by-age
set-current-plot "Average b-value HIV- by age"
end

to update-plot-Average-b-value-HIV--by-age
if (remainder ticks 12 = 0)
[
set-current-plot "Average b-value HIV- by age"
set-current-plot-pen "HIV-1519b"
plot hivnegavgp1520
plot hivnegavgp1520

set-current-plot-pen "HIV-2029b"
plot hivnegavgp2030
set-current-plot-pen "HIV-3039b"
plot hivnegavgp3040
set-current-plot-pen "HIV-4049b"
plot hivnegavgp4050
set-current-plot-pen "HIV-50+b"
plot hivnegavgp50+
]
end

to setup-plot-Average-theta-value-by-age
set-current-plot "Average theta by age"
end
to update-plot-Average-theta-value-by-age
if (remainder ticks 12 = 0)
[
set-current-plot "Average theta by age"
set-current-plot-pen "theta1520"
plot avgtheta1520
set-current-plot-pen "theta2030"
plot avgtheta2030
set-current-plot-pen "theta3040"
plot avgtheta3040
set-current-plot-pen "theta4050"
plot avgtheta4050
set-current-plot-pen "theta50+
plot avgtheta50+
]
end
to setup-plot-sex-act-percentHIV-3040
set-current-plot "sexactpercentHIV-3040"
end

to update-plot-sex-act-percentHIV-3040
if (remainder ticks 12 = 0) and (ticks != 0)
[
  writecumsexactbytypeHIV-3040

  set-current-plot "sexactpercentHIV-3040"
  set-current-plot-pen "RSposposHIV-3040"
  plot totalRSposposHIV-3040percent
  set-current-plot-pen "RSposnegHIV-3040"
  plot totalRSposnegHIV-3040percent
  set-current-plot-pen "RSnegnegHIV-3040"
  plot totalRSnegnegHIV-3040percent

  set-current-plot-pen "PSposposHIV-3040"
  plot totalPSposposHIV-3040percent
  set-current-plot-pen "PSposnegHIV-3040"
  plot totalPSposnegHIV-3040percent
  set-current-plot-pen "PSnegnegHIV-3040"
  plot totalPSnegnegHIV-3040percent

  set-current-plot-pen "NSposposHIV-3040"
  plot totalNSposposHIV-3040percent
  set-current-plot-pen "NSposnegHIV-3040"
  plot totalNSposnegHIV-3040percent
  set-current-plot-pen "NSnegnegHIV-3040"
  plot totalNSnegnegHIV-3040percent
]
end
to setup-plot-sex-act-percentHIV+3040
set-current-plot "sexactpercentHIV+3040"
end

to update-plot-sex-act-percentHIV+3040
if ((remainder ticks 12 = 0) and (ticks != 0))
[
writecumsexactbytypeHIV+3040

set-current-plot "sexactpercentHIV+3040"
set-current-plot-pen "RSposposHIV+3040"
plot totalRSposposHIV+3040percent
set-current-plot-pen "RSposnegHIV+3040"
plot totalRSposnegHIV+3040percent
set-current-plot-pen "RSnegnegHIV+3040"
plot totalRSnegnegHIV+3040percent
set-current-plot-pen "PSposposHIV+3040"
plot totalPSposposHIV+3040percent
set-current-plot-pen "PSposnegHIV+3040"
plot totalPSposnegHIV+3040percent
set-current-plot-pen "PSnegnegHIV+3040"
plot totalPSnegnegHIV+3040percent
set-current-plot-pen "NSposposHIV+3040"
plot totalNSposposHIV+3040percent
set-current-plot-pen "NSposnegHIV+3040"
plot totalNSposnegHIV+3040percent
set-current-plot-pen "NSnegnegHIV+3040"
plot totalNSnegnegHIV+3040percent
]

473
end

to setup-plot-sex-act-percentHIV+1520
set-current-plot "sexactpercentHIV+1520"
end

to update-plot-sex-act-percentHIV+1520
if ((remainder ticks 12 = 0) and (ticks != 0))
[
writecumsexactbytypeHIV+1520

set-current-plot "sexactpercentHIV+1520"
set-current-plot-pen "RSposposHIV+1520"
plot totalRSposposHIV+1520percent
set-current-plot-pen "RSposnegHIV+1520"
plot totalRSposnegHIV+1520percent
set-current-plot-pen "RSnegnegHIV+1520"
plot totalRSnegnegHIV+1520percent
set-current-plot-pen "PSposposHIV+1520"
plot totalPSposposHIV+1520percent
set-current-plot-pen "PSposnegHIV+1520"
plot totalPSposnegHIV+1520percent
set-current-plot-pen "PSnegnegHIV+1520"
plot totalPSnegnegHIV+1520percent
set-current-plot-pen "NSposposHIV+1520"
plot totalNSposposHIV+1520percent
set-current-plot-pen "NSposnegHIV+1520"
plot totalNSposnegHIV+1520percent
set-current-plot-pen "NSnegnegHIV+1520"
plot totalNSnegnegHIV+1520percent
]
end
to setup-plot-sex-act-percentHIV+2030
set-current-plot "sexactpercentHIV+2030"
end

to update-plot-sex-act-percentHIV+2030
if ((remainder ticks 12 = 0) and (ticks != 0))
[
writecumsexactbytypeHIV+2030

set-current-plot "sexactpercentHIV+2030"
set-current-plot-pen "RSposposHIV+2030"
plot totalRSposposHIV+2030percent
set-current-plot-pen "RSposnegHIV+2030"
plot totalRSposnegHIV+2030percent
set-current-plot-pen "RSnegnegHIV+2030"
plot totalRSnegnegHIV+2030percent
set-current-plot-pen "PSposposHIV+2030"
plot totalPSposposHIV+2030percent
set-current-plot-pen "PSposnegHIV+2030"
plot totalPSposnegHIV+2030percent
set-current-plot-pen "PSnegnegHIV+2030"
plot totalPSnegnegHIV+2030percent
set-current-plot-pen "NSposposHIV+2030"
plot totalNSposposHIV+2030percent
set-current-plot-pen "NSposnegHIV+2030"
plot totalNSposnegHIV+2030percent
set-current-plot-pen "NSnegnegHIV+2030"
plot totalNSnegnegHIV+2030percent
]
end
to setup-plot-sex-act-percentHIV+4050
set-current-plot "sexactpercentHIV+4050"
end

to update-plot-sex-act-percentHIV+4050
if ((remainder ticks 12 = 0) and (ticks != 0))
[
writecumsexactbytypeHIV+4050

set-current-plot "sexactpercentHIV+4050"
set-current-plot-pen "RSposposHIV+4050"
plot totalRSposposHIV+4050percent
set-current-plot-pen "RSposnegHIV+4050"
plot totalRSposnegHIV+4050percent
set-current-plot-pen "RSnegnegHIV+4050"
plot totalRSnegnegHIV+4050percent
set-current-plot-pen "PSposposHIV+4050"
plot totalPSposposHIV+4050percent
set-current-plot-pen "PSposnegHIV+4050"
plot totalPSposnegHIV+4050percent
set-current-plot-pen "PSnegnegHIV+4050"
plot totalPSnegnegHIV+4050percent
set-current-plot-pen "NSposposHIV+4050"
plot totalNSposposHIV+4050percent
set-current-plot-pen "NSposnegHIV+4050"
plot totalNSposnegHIV+4050percent
set-current-plot-pen "NSnegnegHIV+4050"
plot totalNSnegnegHIV+4050percent
]
end

to setup-plot-sex-act-percentHIV+50+
set-current-plot "sexactpercentHIV+50+"
end

to update-plot-sex-act-percentHIV+50+
if ((remainder ticks 12 = 0) and (ticks != 0))
[ writecumsexactbytypeHIV+50+

set-current-plot "sexactpercentHIV+50+"
set-current-plot-pen "RSposposHIV+50+"
plot totalRSposposHIV+50+percent
set-current-plot-pen "RSposnegHIV+50+"
plot totalRSposnegHIV+50+percent
set-current-plot-pen "RSnegnegHIV+50+"
plot totalRSnegnegHIV+50+percent
set-current-plot-pen "PSposposHIV+50+"
plot totalPSposposHIV+50+percent
set-current-plot-pen "PSposnegHIV+50+"
plot totalPSposnegHIV+50+percent
set-current-plot-pen "PSnegnegHIV+50+"
plot totalPSnegnegHIV+50+percent
set-current-plot-pen "NSposposHIV+50+"
plot totalNSposposHIV+50+percent
set-current-plot-pen "NSposnegHIV+50+"
plot totalNSposnegHIV+50+percent
set-current-plot-pen "NSnegnegHIV+50+"
plot totalNSnegnegHIV+50+percent
]
end

to setup-plot-sex-act-percentHIV-1520
set-current-plot "sexactpercentHIV-1520"
end
to update-plot-sex-act-percentHIV-1520
if ((remainder ticks 12 = 0) and (ticks != 0))
[
writecumsexactbytypeHIV-1520

set-current-plot "sexactpercentHIV-1520"
set-current-plot-pen "RSposposHIV-1520"
plot totalRSposposHIV-1520percent
set-current-plot-pen "RSposnegHIV-1520"
plot totalRSposnegHIV-1520percent
set-current-plot-pen "RNegnegHIV-1520"
plot totalRNegnegHIV-1520percent
set-current-plot-pen "PSposposHIV-1520"
plot totalPSposposHIV-1520percent
set-current-plot-pen "PSposnegHIV-1520"
plot totalPSposnegHIV-1520percent
set-current-plot-pen "PSnegnegHIV-1520"
plot totalPSnegnegHIV-1520percent
set-current-plot-pen "NSposposHIV-1520"
plot totalNSposposHIV-1520percent
set-current-plot-pen "NSposnegHIV-1520"
plot totalNSposnegHIV-1520percent
set-current-plot-pen "NSnegnegHIV-1520"
plot totalNSnegnegHIV-1520percent
]
end

to setup-plot-sex-act-percentHIV-2030
set-current-plot "sexactpercentHIV-2030"
end
to update-plot-sex-act-percentHIV-2030
if ((remainder ticks 12 = 0) and (ticks != 0))
[
writecumsexactbytypeHIV-2030

set-current-plot "sexactpercentHIV-2030"
set-current-plot-pen "RSposposHIV-2030"
plot totalRSposposHIV-2030percent
set-current-plot-pen "RSposnegHIV-2030"
plot totalRSposnegHIV-2030percent
set-current-plot-pen "RSnegnegHIV-2030"
plot totalRSnegnegHIV-2030percent
set-current-plot-pen "PSposposHIV-2030"
plot totalPSposposHIV-2030percent
set-current-plot-pen "PSposnegHIV-2030"
plot totalPSposnegHIV-2030percent
set-current-plot-pen "PSnegnegHIV-2030"
plot totalPSnegnegHIV-2030percent
set-current-plot-pen "NSposposHIV-2030"
plot totalNSposposHIV-2030percent
set-current-plot-pen "NSposnegHIV-2030"
plot totalNSposnegHIV-2030percent
set-current-plot-pen "NSnegnegHIV-2030"
plot totalNSnegnegHIV-2030percent
]
end

to setup-plot-sex-act-percentHIV-4050
set-current-plot "sexactpercentHIV-4050"
end

to update-plot-sex-act-percentHIV-4050
if ((remainder ticks 12 = 0) and (ticks != 0))
[writecumsexactbytypeHIV-4050]

set-current-plot "sexactpercentHIV-4050"
plot totalRSposposHIV-4050percent
set-current-plot-pen "RSposnegHIV-4050"
plot totalRSposnegHIV-4050percent
set-current-plot-pen "RSnegnegHIV-4050"
plot totalRSnegnegHIV-4050percent
set-current-plot-pen "PSposposHIV-4050"
plot totalPSposposHIV-4050percent
set-current-plot-pen "PSposnegHIV-4050"
plot totalPSposnegHIV-4050percent
set-current-plot-pen "PSnegnegHIV-4050"
plot totalPSnegnegHIV-4050percent
set-current-plot-pen "NSposposHIV-4050"
plot totalNSposposHIV-4050percent
set-current-plot-pen "NSposnegHIV-4050"
plot totalNSposnegHIV-4050percent
set-current-plot-pen "NSnegnegHIV-4050"
plot totalNSnegnegHIV-4050percent

] end

to setup-plot-sex-act-percentHIV-50+
set-current-plot "sexactpercentHIV-50+"
end

to update-plot-sex-act-percentHIV-50+
if ((remainder ticks 12 = 0) and (ticks != 0))
[
writecumsexactbytypeHIV-50+
]
set-current-plot "sexactpercentHIV-50+
set-current-plot-pen "RSposposHIV-50+
plot totalRSposposHIV-50+percent
set-current-plot-pen "RSposnegHIV-50+
plot totalRSposnegHIV-50+percent
set-current-plot-pen "RSnegnegHIV-50+
plot totalRSnegnegHIV-50+percent
set-current-plot-pen "PSposposHIV-50+
plot totalPSposposHIV-50+percent
set-current-plot-pen "PSposnegHIV-50+
plot totalPSposnegHIV-50+percent
set-current-plot-pen "PSnegnegHIV-50+
plot totalPSnegnegHIV-50+percent
set-current-plot-pen "NSposposHIV-50+
plot totalNSposposHIV-50+percent
set-current-plot-pen "NSposnegHIV-50+
plot totalNSposnegHIV-50+percent
set-current-plot-pen "NSnegnegHIV-50+
plot totalNSnegnegHIV-50+percent
]
end

to setup-plot-HIV+prevpercent
set-current-plot "HIV+prevpercent"
end
;
to update-plot-HIV+prevpercent
if (remainder ticks 12 = 0)
[
set-current-plot "HIV+prevpercent"
set-current-plot-pen "HIV+prevpercent"
plot prevalence

] end

to setup-plot-sexactstotalbyageRSHIVnegpos
set-current-plot "sexactstotalbyageRSHIVnegpos"
end

to update-plot-sexactstotalbyageRSHIVnegpos
if ((remainder ticks 12 = 0) and (ticks != 0))
[ set-current-plot "sexactstotalbyageRSHIVnegpos"
set-current-plot-pen "US-+1520total"
plot totalRSposnegHIV-1520
set-current-plot-pen "US-+2030total"
plot totalRSposnegHIV-2030
set-current-plot-pen "US-+3040total"
plot totalRSposnegHIV-3040
set-current-plot-pen "US-+4050total"
plot totalRSposnegHIV-4050
set-current-plot-pen "US-+50+total"
plot totalRSposnegHIV-50+
]
end

to setup-plot-sexactstotalbyageRSHIVnegneg

set-current-plot "sexacttotalbyagerSHIVnegneg"
end

to update-plot-sexacttotalbyagerSHIVnegneg
if ((remainder ticks 12 = 0) and (ticks != 0))
[
set-current-plot "sexacttotalbyagerSHIVnegneg"
set-current-plot-pen "US--1520total"
plot totalRSnegnegHIV-1520
set-current-plot-pen "US--2030total"
plot totalRSnegnegHIV-2030
set-current-plot-pen "US--3040total"
plot totalRSnegnegHIV-3040
set-current-plot-pen "US--4050total"
plot totalRSnegnegHIV-4050
set-current-plot-pen "US--50+total"
plot totalRSnegnegHIV-50+
]
end

to setup-plot-CumUSnegposperyear
set-current-plot "CumUSnegposperyear"
end

to update-plot-CumUSnegposperyear
if ((remainder ticks 12 = 0) and (ticks != 0))
[
writeCumUSnegposperyear
set-current-plot "CumUSnegposperyear"
set-current-plot-pen "USnegpos1520"
plot cumUS1520peryear
]
6.3 Simulation Code: Chapter 4

%Chapter 4 was coded using Matlab. The simulation can be computed using the following scripts:
%Comput.m, to formulate the derivatives to formulate the vector field.
%Input depends on which age group is being studied as well as population,
%and whether or not vaccine is included.
%vfield.m establishes the vector field as well as setting the parameters
%cost.m, are the restrictions placed upon decisions available to the players.
%script.m computes the output based on the aforementioned files.
%Inside script.m you can determine which parameter(s) to vary over the
%course of the simulation.
%The code described below represents a 3 player game for the youngest age group
%with no vaccination using U.S. demographic age distribution varying U(USE,-,-)
%and U(USE,-,+).

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
function comput()

function comput()

p_vect=[0.08603;0.17331;0.15960;0.17082;0.41024];

tau=0.02;

notUSnm = 0.25;
notUSnp = 0.25;
notUSpn = 0.25;
notUSpp = 0.25;

syms x11n x12n x13n x11p x12p x13p x21n x22n x21p x22p x31n x32n x31p x32p x33p
x42n x43n x42p x43p USnn USnp USpn USpp rho1 rho2 rho3 rho4 rho5 bp bn betap beta
n epsilong1p0 epsilong2p0 epsilong3p0 epsilong4p0 epsilong5p0 epsilong1n epsilong2n
epsilong3n epsilong4n epsilong5n

epsilontotal = ((epsilong1p0 + (x11n*epsilong1p0 +x21p*epsilong1n)*tau) +
(epsilong2p0 + (x12n*epsilong1p0 +x31p*epsilong2n)*tau) + epsilong3p0
+ epsilong4p0 + epsilong5p0);  
bptotal = (betap*bp + (1 - betap)*epsilontotal);
\[
\text{bntotal} = (\text{betan} \times \text{bn} + (1 - \text{betan}) \times \text{epsilontotal});
\]
\[
f = ((1 - \text{bptotal}) \times (\text{rho1} \times ((x11n + x12n) \times \text{USpn} + (1 - (x11n + x12n) \times \text{notUSpn}))) +
(\text{bptotal} \times (\text{rho1} \times ((x11p) \times \text{USpp} + (1 - (x11p) \times \text{notUSpp})))));
\]
\[
g = ((1 - \text{bntotal}) \times (\text{rho1} \times ((x21n + x22n) \times \text{USnn} + (1 - (x21n + x22n) \times \text{notUSnn}))) +
(\text{bntotal} \times (\text{rho1} \times ((x21p) \times \text{USnp} + (1 - (x21p) \times \text{notUSnp})))));
\]
\[
h = ((1 - \text{bntotal}) \times (\text{rho2} \times ((x31n + x32n) \times \text{USnn} + (1 - (x31n + x32n) \times \text{notUSnn}))) +
(\text{bntotal} \times (\text{rho2} \times ((x31p) \times \text{USnp} + (1 - (x31p) \times \text{notUSnp})))));
\]
\[
\text{DE1x11n} = \text{diff}(f, x11n)
\]
\[
\text{DE1x12n} = \text{diff}(f, x12n)
\]
\[
\text{DE1x11p} = \text{diff}(f, x11p)
\]
\[
\text{DE2x21n} = \text{diff}(g, x21n)
\]
\[
\text{DE2x22n} = \text{diff}(g, x22n)
\]
\[
\text{DE2x21p} = \text{diff}(g, x21p)
\]
\[
\text{DE3x31n} = \text{diff}(h, x31n)
\]
\[
\text{DE3x32n} = \text{diff}(h, x32n)
\]
\[
\text{DE3x31p} = \text{diff}(h, x31p)
\]
\[
y(1) = (\text{USpn} - 0.250000000000000000) \times \text{rho1} \times (1 - \text{bp} \times \text{betap} - (\text{epsilon1p0}
+ 0.0200000000000000004 \times \text{epsilon1p0} \times x(1)) + 0.0200000000000000004 \times \text{epsilon1n} \times x(6) + \text{epsilon1p0} \times x(2)
+ 0.0200000000000000004 \times \text{epsilon2p0} \times x(9) + \text{epsilon3p0} + \text{epsilon4p0} + \text{epsilon5p0}) \times (1 - \text{betap}) - 0.0200000000000000004
\times (\text{USpn} \times (x(1) + x(2)) + 1 - 0.250000000000000000 \times x(1)
- 0.250000000000000000 \times x(2)) \times \text{rho1} \times \text{epsilon1p0} \times (1 - \text{betap}) +
0.0200000000000000004 \times (\text{USpp} \times x(3) + 1 - 0.250000000000000000 \times x(3)) \times \text{rho1} \times
\text{epsilon1p0} \times (1 - \text{betap});
\]
\[
y(2) = (\text{USpn} - 0.250000000000000000) \times \text{rho1} \times (1 - \text{bp} \times \text{betap} - (\text{epsilon1p0}
+ 0.0200000000000000004 \times \text{epsilon1p0} \times x(1)) + 0.0200000000000000004 \times \text{epsilon1n} \times x(6) + \text{epsilon1p0} \times x(2)
+ 0.0200000000000000004 \times \text{epsilon2p0} \times x(9) + \text{epsilon3p0} + \text{epsilon4p0} + \text{epsilon5p0}) \times (1 - \text{betap}) +
0.0200000000000000004 \times (\text{USpp} \times x(3) + 1 - 0.250000000000000000 \times x(3)) \times \text{rho1} \times
\text{epsilon1p0} \times (1 - \text{betap});
\]
\[
y(3) = (USpp - 0.250000000000000000) * \rho_1 \ (bp + betap) + (epsilon1p0 + 0.0200000000000000004 * epsilon1n * x(6) + epsilon2p0 + 0.0200000000000000004 * epsilon1p0 * x(2) + 0.0200000000000000004 * epsilon2n * x(9) + epsilon3p0 + epsilon4p0 + epsilon5p0) \ (1 - betap);
\]

\[
y(4) = (USnn - 0.250000000000000000) * \rho_1 \ (1 - bn + betan) - (epsilon1p0 + 0.0200000000000000004 * epsilon1n * x(6) + epsilon2p0 + 0.0200000000000000004 * epsilon1p0 * x(2) + 0.0200000000000000004 * epsilon2n * x(9) + epsilon3p0 + epsilon4p0 + epsilon5p0) \ (1 - betan) + 0.0200000000000000004 \ (USnp - 0.250000000000000000) * \rho_1 \ (bn + betan) + (epsilon1p0 + 0.0200000000000000004 * epsilon1n * x(6) + epsilon2p0 + 0.0200000000000000004 * epsilon1p0 * x(2) + 0.0200000000000000004 * epsilon2n * x(9) + epsilon3p0 + epsilon4p0 + epsilon5p0) \ (1 - betan));
\]

\[
y(5) = (USnn - 0.250000000000000000) * \rho_1 \ (1 - bn + betan) - (epsilon1p0 + 0.0200000000000000004 * epsilon1n * x(6) + epsilon2p0 + 0.0200000000000000004 * epsilon1p0 * x(2) + 0.0200000000000000004 * epsilon2n * x(9) + epsilon3p0 + epsilon4p0 + epsilon5p0) \ (1 - betan));
\]

\[
y(6) = -0.0200000000000000004 \ (USnn + x(4) + x(5)) + 1 - 0.250000000000000000 \ x(4) - 0.250000000000000000 \ x(5)) * \rho_1 \ * (1 - betan) + (USnp - 0.250000000000000000) * \rho_1 \ * (bn + betan) + (epsilon1p0 + 0.0200000000000000004 * epsilon1n * x(6) + epsilon2p0 + 0.0200000000000000004 * epsilon1p0 * x(2) + 0.0200000000000000004 * epsilon2n * x(9) + epsilon3p0 + epsilon4p0 + epsilon5p0) \ (1 - betan)) + 0.0200000000000000004 \ (USnp * x(6) + 1 - 0.250000000000000000 * x(6)) * \rho_1 \ * (1 - betan);
\]

487
function \[ y \] = vfield( x, par1, par2 )

global USnp USnn \%beta1 beta2

betap = 0.5;
betan = 0.5;
bp = 0.6;
bn = 0.3;
USpp = 0.01*100;
USpn = 0.01*75;

rho1 = 0.5;
rho2 = 1;
rho3 = 0.8;
rho4 = 0.6;
rho5 = 0.3;

p_vect = [0.08603; 0.17331; 0.15960; 0.17082; 0.41024];

epsilong1p0 = p_vect(1)*0.05;
epsilong2p0 = p_vect(2)*0.05;
epsilong3p0 = p_vect(3)*0.05;
epsilong4p0 = p_vect(4)*0.05;
epsilong5p0 = p_vect(5)*0.05;

epsilong1n = p_vect(1)*0.95; % epsilong1p = 0.2*0.05;
epsilong2n = p_vect(2)*0.95; % epsilong2p = 0.2*0.05;
epsilong3n = p_vect(3)*0.95; % epsilong3p = 0.2*0.05;
epsilong4n = p_vect(4)*0.95; % epsilong4p = 0.2*0.05;
epsilong5n = p_vect(5)*0.95; % epsilong5p = 0.2*0.05;

tau = 0.02;

y(1) = (USpn - 0.250000000000000000) * rho1 * (1 - bp * betap - (epsilong1p0
+ 0.0200000000000000004 * epsilong1p0 * x(1) + 0.0200000000000000004
* epsilong1n * x(6) + epsilong2p0 + 0.0200000000000000004 * epsilong1p0 * x(2)
+ 0.0200000000000000004 * epsilong2n * x(9) + epsilong3p0 + epsilong4p0
+ 0.0200000000000000004 * epsilong5p0 + epsilong5n)
y(2) = (USpn - 0.250000000000000000) *rho1* (1 - bp *betap - (epsilong1p0
+ 0.0200000000000000004 *epsilong1p0 *x(1)) + 0.0200000000000000004
epsilong1p0 *x(2)) + 0.0200000000000000004 epsilong1p0 *x(2)
+ 0.0200000000000000004 epsilong2n *x(9) + epsilong3p0 + epsilong4p0
+ epsilong5p0) *(1 - betap)) - 0.0200000000000000004 *( USpn *(x(1) + x(2)) + 1 - 0.250000000000000000 *x(1) - 0.250000000000000000 *x(2))
+ 0.0200000000000000004 epsilong1p0 *(1 - betap) + 0.0200000000000000004 epsilong1p0 *(1 - betap);

y(3) = (USpp - 0.250000000000000000) *rho1* (bp *betap + (epsilong1p0
+ 0.0200000000000000004 *epsilong1p0 *x(1) + 0.0200000000000000004 *epsilong1n *x(6) + epsilong2p0 + 0.0200000000000000004 *epsilong1p0 *x(2) + 0.0200000000000000004 *epsilong2n *x(9) + epsilong3p0 + epsilong4p0
+ epsilong5p0) *(1 - betap));

y(4) = (par2 - 0.250000000000000000) *rho1* (1 - bn *betan - (epsilong1p0
+ 0.0200000000000000004 *epsilong1p0 *x(1)) + 0.0200000000000000004 *epsilong1n
*epsilong2p0) + 0.0200000000000000004 *epsilong1p0 *x(2)
+ 0.0200000000000000004 epsilong2n *x(9) + epsilong3p0 + epsilong4p0
+ epsilong5p0) *(1 - betap));

y(5) = (par2 - 0.250000000000000000) *rho1* (1 - bn *betan - (epsilong1p0
+ 0.0200000000000000004 *epsilong1p0 *x(1)) + 0.0200000000000000004 *epsilong1n
*epsilong2p0) + 0.0200000000000000004 *epsilong1p0 *x(2)
+ 0.0200000000000000004 epsilong2n *x(9) + epsilong3p0 + epsilong4p0
+ epsilong5p0) *(1 - betan));

y(6) = -0.0200000000000000004 *(par2 *(x(4) + x(5)) + 1 - 0.250000000000000000 *x(4) + 0.0200000000000000004 *epsilong5p0) *(1 - betan));
\[-0.250000000000000000 \times 5) \times \rho_1 \times \varepsilon_1 \times (1 - \beta) + \\
(par1 - 0.250000000000000000) \times \rho_1 \times (bn \times \beta + (\varepsilon_1p0 \\
+ 0.0200000000000000004) \times \varepsilon_1p0 \times x(1) \\
+ 0.0200000000000000004 \times \varepsilon_1n \times x(6) \\
+ \varepsilon_2p0 + 0.0200000000000000004 \times \varepsilon_2p0 \times x(2) \\
+ 0.0200000000000000004 \times \varepsilon_2n \times x(9) + \varepsilon_3p0 + \varepsilon_4p0 \\
+ \varepsilon_5p0) \times (1 - \beta) + 0.0200000000000000004 \times \par1 \times x(6) \\
+ 1 - 0.250000000000000000 \times x(6) \times \rho_1 \times \varepsilon_1n \times (1 - \beta);
\]

\[y(7) = (par2 - 0.250000000000000000) \times \rho_2 \times (1 - bn \times \beta - (\varepsilon_1p0 \\
+ 0.0200000000000000004) \times \varepsilon_1p0 \times x(1) + 0.0200000000000000004 \times \varepsilon_1n \times x(6) + \varepsilon_2p0 + 0.0200000000000000004 \times \varepsilon_1p0 \times x(2) \\
+ 0.0200000000000000004 \times \varepsilon_2n \times x(9) + \varepsilon_3p0 + \varepsilon_4p0 + \varepsilon_5p0) \times (1 - \betahyph);\]

\[y(8) = (par2 - 0.250000000000000000) \times \rho_2 \times (1 - bn \times \beta - (\varepsilon_1p0 \\
+ 0.0200000000000000004) \times \varepsilon_1p0 \times x(1) + 0.0200000000000000004 \times \varepsilon_1n \times x(6) + \varepsilon_2p0 + 0.0200000000000000004 \times \varepsilon_1p0 \times x(2) \\
+ 0.0200000000000000004 \times \varepsilon_2n \times x(9) + \varepsilon_3p0 + \varepsilon_4p0 + \varepsilon_5p0) \times (1 - \beta);\]

\[y(9) = -0.0200000000000000004 \times (par2 \times x(7) + x(8)) + 1 - 0.250000000000000000 \times x(7) \\
- 0.250000000000000000 \times x(8) \times \rho_2 \times \varepsilon_3p0 \times (1 - \beta) + \\
(par1 - 0.250000000000000000) \times \rho_1 \times (bn \times \beta + (\varepsilon_1p0 \\
+ 0.0200000000000000004) \times \varepsilon_1p0 \times x(1) \\
+ 0.0200000000000000004 \times \varepsilon_1n \times x(6) + \varepsilon_2p0 + \varepsilon_4p0 \\
+ \varepsilon_5p0) \times (1 - \beta);\]

\[y=y';\]

return;
function [f]=cost(x,~)
global s
f(1) = (norm(s-x,2))^2;
f(2) = x(1)+x(2)+x(3)-1;
f(3) = x(4)+x(5)+x(6)-1;
f(4) = x(7)+x(8)+x(9)-1;
f=f';
end

function script(tt)
global s USnegpos USnegneg %USnegpos %beta1 beta2
global var_eps2g1G1 var_eps2g2G1

p_vect=[0.08603;0.17331;0.15960;0.17082;0.41024];

epsilon1p0 = p_vect(1)*0.05;
epsilon2p0 = p_vect(2)*0.05;
epsilon3p0 = p_vect(3)*0.05;
epsilon4p0 = p_vect(4)*0.05;
epsilon5p0 = p_vect(5)*0.05;

tau=0.02;

epsilon1n = p_vect(1)*0.95; %epsilon1p = 0.2*0.05;
\begin{verbatim}
epsilon2n = p_vect(2)*0.95; %epsilon2p = 0.2*0.05;
epsilon3n = p_vect(3)*0.95; %epsilon3p = 0.2*0.05;
epsilon4n = p_vect(4)*0.95; %epsilon4p = 0.2*0.05;
epsilon5n = p_vect(5)*0.95; %epsilon5p = 0.2*0.05;

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
for d3 = 1:61
  d3
  for d2 = 1:61
    d2;
    xvar(d2) = 0.05* d2 - 31*0.05;
    yvar(d3) = 0.05* d3 - 31*0.05;
    assignin('base', 'USnegpos', 'xvar(d2)');
    assignin('base', 'USnegneg', 'yvar(d3)');
    c(:,1,d2,d3) = [0.334;0.333;0.333; 0.334;0.333;0.333; 0.334;0.333;0.333];
    for i = 1:tt;
      multip = 0.025;
      [z] = vfield(c(:,1,i,d2,d3), xvar(d2), yvar(d3));
      s = c(:,1,i,d2,d3) + (multip*z);
      u = zeros(9,1);
      v = ones(9,1);
      % xb are the lower, resp. upper bounds of the vector x
      xb = [u, v];
      [x] = solnp(xb);
      c(:,i+1,d2,d3) = [x];
      if norm(c(:,i+1,d2,d3)-c(:,i,d2,d3),2) <= 10^-3
        i
        cc(:,1,d2,d3) = c(:,i+1,d2,d3);
        break
    end
  end
end
\end{verbatim}
Soltt(:,d2, d3) = squeeze(cc(:,1,d2, d3));
%Soltt(:,d2, d3) = squeeze(c(:,end,d2, d3));
end
end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
for k=1:61
x11neg(k,:)=Soltt(1,:,k);
x12neg(k,:)=Soltt(2,:,k);
x11pos(k,:)=Soltt(3,:,k);
x21neg(k,:)=Soltt(4,:,k);
x22neg(k,:)=Soltt(5,:,k);
x21pos(k,:)=Soltt(6,:,k);
x31neg(k,:)=Soltt(7,:,k);
x32neg(k,:)=Soltt(8,:,k);
x31pos(k,:)=Soltt(9,:,k);
end

for k=1:61
vard3(:,k) = Soltt(:,21,k);
end % --- variation of d3=USnegneg for a fixed value of d2, holding d2 at 21 is equivalent to USnp =-0.5
vard3

for k=1:61
vard2(:,k) = Soltt(:,k,51);
end % --- variation of d2=USnpV for a fixed value of d3, holding d3 at 51 is equivalent to USnn = 1
vard2
\begin{verbatim}
var_eps2g1(:, :) = epsilong1p0 + x11neg * tau * epsilong1p0 + x21pos * tau * epsilong2n;
var_eps2g2(:, :) = epsilong2p0 + x12neg * tau * epsilong1p0 + x31pos * tau * epsilong2n;
var_eps2g3(:, :) = epsilong3p0;
var_eps2g4(:, :) = epsilong4p0;
var_eps2g5(:, :) = epsilong5p0;

var_eps2g1G1 = var_eps2g1;
var_eps2g2G1 = var_eps2g2;

var_eps2(:, :) = var_eps2g1(:, :) + var_eps2g2(:, :) + var_eps2g3(:, :) + var_eps2g4(:, :)
+ var_eps2g5(:, :) ;
\end{verbatim}

% thus value is then compared to 0.05

\begin{verbatim}
figure
surf(xvar, yvar, x11neg(:, :))
xlabel('US(-,+)' (-1.5 - 1.5)');
ylabel('US(-,-) (-1.5 - 1.5)');
zlabel('x11-')
title('US negative results')
axis([-2, 2, -2, 2, 0, 1])

figure
surf(xvar, yvar, x12neg(:, :))
xlabel('US(-,+)' (-1.5 - 1.5)');
ylabel('US(-,-) (-1.5 - 1.5)');
zlabel('x12-')
title('US negative results')
axis([-2, 2, -2, 2, 0, 1])

figure
surf(xvar, yvar, x11pos(:, :))
\end{verbatim}
xlabel('US(-,+) (-1.5 - 1.5)');
ylabel('US(-,-) (-1.5 - 1.5)');
zlabel('x11+');
title('US negative results');
axis([-2, 2, -2, 2, 0, 1])

figure
surf(xvar, yvar, x21neg(:,:))
xlabel('US(-,+) (-1.5 - 1.5)');
ylabel('US(-,-) (-1.5 - 1.5)');
zlabel('x21-');
title('US negative results');
axis([-2, 2, -2, 2, 0, 1])

figure
surf(xvar, yvar, x22neg(:,:))
xlabel('US(-,+) (-1.5 - 1.5)');
ylabel('US(-,-) (-1.5 - 1.5)');
zlabel('x22-');
title('US negative results');
axis([-2, 2, -2, 2, 0, 1])

figure
surf(xvar, yvar, x21pos(:,:))
xlabel('US(-,+) (-1.5 - 1.5)');
ylabel('US(-,-) (-1.5 - 1.5)');
zlabel('x21+');
title('US negative results');
axis([-2, 2, -2, 2, 0, 1])

figure
surf(xvar, yvar, x31neg(:,:))
xlabel('US(-,+) (-1.5 - 1.5)');
ylabel('US(-,-) (-1.5 - 1.5)');
zlabel('x31-');
title('US negative results')
axis([-2, 2, -2, 2, 0, 1])

figure
surf(xvar, yvar, x32neg(:,:))
xlabel('US(-,+), (-1.5 - 1.5)')
ylabel('US(-,-), (-1.5 - 1.5)')
zlabel('x32-')
title('US negative results')
axis([-2, 2, -2, 2, 0, 1])

figure
surf(xvar, yvar, x31pos(:,:))
xlabel('US(-,+), (-1.5 - 1.5)')
ylabel('US(-,-), (-1.5 - 1.5)')
zlabel('x31+')
title('US negative results')
axis([-2, 2, -2, 2, 0, 1])

figure
surf(xvar, yvar, var_eps2g1(:,:))
xlabel('US(-,+), (-1.5 - 1.5)')
ylabel('US(-,-), (-1.5 - 1.5)')
zlabel('epsilon+G1')
title('US negative results')
axis([-2, 2, -2, 2, 0, 1])

figure
surf(xvar, yvar, var_eps2g2(:,:))
xlabel('US(-,+), (-1.5 - 1.5)')
ylabel('US(-,-), (-1.5 - 1.5)')
zlabel('epsilon+G2')
title('US negative results')
figure
surf(xvar, yvar, var_322)
xlabel('US(-,+) (-1.5 - 1.5)');
ylabel('US(-,-) (-1.5 - 1.5)');
zlabel('epsilon+');
title('US negative results');
axis([-2, 2, -2, 2, 0, 1])

%holding USnp at -0.5 which is its baseline (row 21)
figure
plot([-1.5:0.05:1.5], vard3(1,:), 'go')
hold on;
plot([-1.5:0.05:1.5], vard3(2,:), 'bs')
hold on;
plot([-1.5:0.05:1.5], vard3(3,:), 'r*')
hold off;
xlabel('US(-,-) (-1.5-1.5), US(-,+) = -0.5');
ylabel('x11-, x12-, x11+');
title('Choices for Player 1 varying US(-,-)');
leg1 = legend('x11-', 'x12-', 'x11+');

figure
plot([-1.5:0.05:1.5], vard3(4,:), 'go')
hold on;
plot([-1.5:0.05:1.5], vard3(5,:), 'bs')
hold on;
plot([-1.5:0.05:1.5], vard3(6,:), 'r*')
hold off;
xlabel('US(-,-) (-1.5-1.5), US(-,+) = -0.5');
ylabel('x21-, x22-, x21+');

498
title('Choices for Player 2 varying US(-,-)')
hleg1 = legend('x21-', 'x22-', 'x21+');

figure
plot([-1.5:0.05:1.5], vard3(7,:), 'go')
hold on;
plot([-1.5:0.05:1.5], vard3(8,:), 'bs')
hold on;
plot([-1.5:0.05:1.5], vard3(9,:), 'r*')
hold off;
xlabel('US(-,-) (-1.5-1.5), US(-,+)= -0.5');
ylabel('x31-, x32-, x31+');
title('Choices for Player 3 varying US(-,-)')
hleg1 = legend('x31-', 'x32-', 'x31+');

% variation of d2=USnp for a fixed value of d3, holding d3 at 51 is equivalent to USnn = 1

figure
plot([-1.5:0.05:1.5], vard2(1,:), 'go')
hold on;
plot([-1.5:0.05:1.5], vard2(2,:), 'bs')
hold on;
plot([-1.5:0.05:1.5], vard2(3,:), 'r*')
hold off;
xlabel('US(-,+)(-1.5-1.5), US(-,-)= 1');
ylabel('x11-, x12-, x11+');
title('Choices for Player 1 varying US(-,+)')
hleg1 = legend('x11-', 'x12-', 'x11+');

figure
plot([-1.5:0.05:1.5], vard2(4,:), 'go')
hold on;
plot([-1.5:0.05:1.5], vard2(5,:), ':bs')
hold on;
plot([-1.5:0.05:1.5], vard2(6,:), '-.r*')
hold off;
xlabel('US(-,+), US(-,-) = 1');
ylabel('x21-, x22-, x21+');
title('Choices for Player 2 varying US(-,+)

hleg1 = legend('x21-', 'x22-', 'x21+');

figure
plot([-1.5:0.05:1.5], vard2(7,:), '--go')
hold on;
plot([-1.5:0.05:1.5], vard2(8,:), ':bs')
hold on;
plot([-1.5:0.05:1.5], vard2(9,:), '-.r*')
hold off;
xlabel('US(-,+), US(-,-) = 1');
ylabel('x31-, x32-, x31+');
title('Choices for Player 3 varying US(-,+)

hleg1 = legend('x31-', 'x32-', 'x31+');

end