1)

feet\_marker\_sim(

ngroups=2,

tmax=200,

d=0.5, #coordination benefit

g=0, #extra coordination benefit among mutualists

h=0, #mis-coordination cost for mutualists

a=1, #probability of assorting on marker

m0=0.01, #base proportion of each group that migrates

mu=0, #mean-payoff bias in migration decisions

s=c(0.5, 0.5), #proportion of total population in each group

init\_p=c(0.9,0.1), #intial proportion of behavior 0 in each group

init\_q=c(0.9,0.1), #intial proportion of marker 0 in each group

draw=TRUE )

circles=behav 0, solid line=marker 0, dashed line=population proportion, dotted line=covariance



Perfect coordination. Results in x00 = x11 = 0.5 in both groups. Initial frequency dependence while covariance is low causes first dip/spike in behavior frequencies. Migration causes covariance to rise. Once covariance is high, alternative phenotype from the other group can migrate in and achieve equal payoffs.

2)

feet\_marker\_sim(

ngroups=2,

tmax=200,

d=0.5, #coordination benefit

g=0, #extra coordination benefit among mutualists

h=0, #mis-coordination cost for mutualists

a=0, #probability of assorting on marker

m0=0.01, #base proportion of each group that migrates

mu=0, #mean-payoff bias in migration decisions

s=c(0.5, 0.5), #proportion of total population in each group

init\_p=c(0.9,0.1), #intial proportion of behavior 0 in each group

init\_q=c(0.9,0.1), #intial proportion of marker 0 in each group

draw=TRUE )



Random assortment. Frequency-dependence drives most common norm close to fixation. Migration keeps the rare norm at low frequency in each population. Markers are irrelevant.

3)

feet\_marker\_sim(

ngroups=2,

tmax=200,

d=0.5, #coordination benefit

g=0.5, #extra coordination benefit among mutualists

h=0, #mis-coordination cost for mutualists

a=1, #probability of assorting on marker

m0=0.01, #base proportion of each group that migrates

mu=0, #mean-payoff bias in migration decisions

s=c(0.5, 0.5), #proportion of total population in each group

init\_p=c(0.9,0.1), #intial proportion of behavior 0 in each group

init\_q=c(0.9,0.1), #intial proportion of marker 0 in each group

draw=TRUE )



Perfect assortment, behave 0 has an extra coordination payoff advantage. Results in x00=1 in both groups. Initial dip in behave 0 in group 2 due to initial freq dependence before covariance gets big, like in 1) above. Covariance in group 2 jumps due to migration of almost exclusively x00 individuals from group 1. Assorting on marker 0 in group 2 then results in big payoff and x00 grows due to payoff-biased copying.

4)

feet\_marker\_sim(

ngroups=2,

tmax=200,

d=0.5, #coordination benefit

g=0.5, #extra coordination benefit among mutualists

h=0, #mis-coordination cost for mutualists

a=0, #probability of assorting on marker

m0=0.01, #base proportion of each group that migrates

mu=0, #mean-payoff bias in migration decisions

s=c(0.5, 0.5), #proportion of total population in each group

init\_p=c(0.9,0.1), #intial proportion of behavior 0 in each group

init\_q=c(0.9,0.1), #intial proportion of marker 0 in each group

draw=TRUE )



Random assortment. Same dynamic as 2) above. Payoff advantage to behave 0 keeps it at slightly higher freq in group 2 than in 2) above.

5)

feet\_marker\_sim(

ngroups=2,

tmax=500,

d=0.5, #coordination benefit

g=0.5, #extra coordination benefit among mutualists

h=0, #mis-coordination cost for mutualists

a=0, #probability of assorting on marker

m0=0.01, #base proportion of each group that migrates

mu=0.1, #mean-payoff bias in migration decisions

s=c(0.5, 0.5), #proportion of total population in each group

init\_p=c(0.9,0.1), #intial proportion of behavior 0 in each group

init\_q=c(0.9,0.1), #intial proportion of marker 0 in each group

draw=TRUE )



Random assortment with behav 0 advantage and payoff-biased migration. Same dynamic as 4) above, but now group 1 stabilizes with 52% of the population. Migrants from group 2 to group 1 bring down the mean fitness of group 1 because those migrants (mostly behav 1) do poorly in a group of almost entirely behav 0. Thus, as it accepts more immigrants, group 1 becomes less attractive to potential immigrants from group 2.

6)

feet\_marker\_sim(

ngroups=2,

tmax=1000,

d=0.5, #coordination benefit

g=2, #extra coordination benefit among mutualists

h=0, #mis-coordination cost for mutualists

a=0, #probability of assorting on marker

m0=0.01, #base proportion of each group that migrates

mu=0.1, #mean-payoff bias in migration decisions

s=c(0.5, 0.5), #proportion of total population in each group

init\_p=c(0.9,0.1), #intial proportion of behavior 0 in each group

init\_q=c(0.9,0.1), #intial proportion of marker 0 in each group

draw=TRUE )



Same as 5) above, but with a larger advantage to behav 0. Group 1 is initially very attractive, but the attractiveness decreases as more immigrants arrive from group 2 who do poorly.

7)

feet\_marker\_sim(

ngroups=2,

tmax=200,

d=0.5, #coordination benefit

g=0.5, #extra coordination benefit among mutualists

h=0, #mis-coordination cost for mutualists

a=1, #probability of assorting on marker

m0=0.01, #base proportion of each group that migrates

mu=0.1, #mean-payoff bias in migration decisions

s=c(0.5, 0.5), #proportion of total population in each group

init\_p=c(0.9,0.1), #intial proportion of behavior 0 in each group

init\_q=c(0.9,0.1), #intial proportion of marker 0 in each group

draw=TRUE )



Perfect assortment. Same dynamic as 3) above. Payoff-biased migration quickly goes away as both groups converge on x00=1, meaning they have same mean fitness. Thus, if one group adopts the other’s phenotype very quickly, then there is no payoff-biased migration.

An interesting situation would be if a minority group with a higher payoff equilibrium will become ethnically-marked, which will allow it to maintain its norm distribution in the face of migrant exchange with the majority group.

8)

feet\_marker\_sim(

ngroups=2,

tmax=200,

d=0.5, #coordination benefit

g=0.5, #extra coordination benefit among mutualists

h=0, #mis-coordination cost for mutualists

a=1, #probability of assorting on marker

m0=0.01, #base proportion of each group that migrates

mu=0.1, #mean-payoff bias in migration decisions

s=c(0.2, 0.8), #proportion of total population in each group

init\_p=c(0.9,0.1), #intial proportion of behavior 0 in each group

init\_q=c(0.9,0.1), #intial proportion of marker 0 in each group

draw=TRUE )



Now group 1 is a minority with a high payoff equilibrium. Same dynamic as 7) above. It just takes a little longer for group 2 to adopt the behavs and markers of the minority group 1, because there are relatively fewer group 1 migrants coming in to drive the covariance up. At equilibrium, group 1 is no longer a minority. Both groups have the same size.

9)

feet\_marker\_sim(

ngroups=2,

tmax=200,

d=0.5, #coordination benefit

g=0.5, #extra coordination benefit among mutualists

h=0.5, #mis-coordination cost for mutualists

a=1, #probability of assorting on marker

m0=0.01, #base proportion of each group that migrates

mu=0.1, #mean-payoff bias in migration decisions

s=c(0.2, 0.8), #proportion of total population in each group

init\_p=c(0.9,0.1), #intial proportion of behavior 0 in each group

init\_q=c(0.9,0.1), #intial proportion of marker 0 in each group

draw=TRUE )



Adding a mis-coordination cost for behav 0 doesn’t change the dynamic much from that of 8) above. It keeps the freq of behav 0 low in group 2 for a longer time before enough migration happens to get the covariance started.

10)

feet\_marker\_sim(

ngroups=2,

tmax=500,

d=0.5, #coordination benefit

g=0.5, #extra coordination benefit among mutualists

h=0.5, #mis-coordination cost for mutualists

a=0.5, #probability of assorting on marker

m0=0.01, #base proportion of each group that migrates

mu=0.1, #mean-payoff bias in migration decisions

s=c(0.2, 0.8), #proportion of total population in each group

init\_p=c(0.9,0.1), #intial proportion of behavior 0 in each group

init\_q=c(0.9,0.1), #intial proportion of marker 0 in each group

draw=TRUE )



Same as 9), but now assortment is weaker. Freq dependence drives the initially most common behav and marker close fixation in group 1, and also keeps them high in group 2. The initial minority becomes the majority at equilibrium. This comes from a dynamic similar to 6) above.

11)

feet\_marker\_sim(

ngroups=2,

tmax=200,

d=0.5, #coordination benefit

g=0.5, #extra coordination benefit among mutualists

h=0.5, #mis-coordination cost for mutualists

a=0.5, #probability of assorting on marker

m0=0.02, #base proportion of each group that migrates

mu=0.1, #mean-payoff bias in migration decisions

s=c(0.2, 0.8), #proportion of total population in each group

init\_p=c(0.9,0.1), #intial proportion of behavior 0 in each group

init\_q=c(0.9,0.1), #intial proportion of marker 0 in each group

draw=TRUE )



Same as 10) above, but with a tiny increase in migration rate. This makes a dynamic similar to 9) above.

12)

feet\_marker\_sim(

ngroups=2,

tmax=200,

d=0.5, #coordination benefit

g=0.5, #extra coordination benefit among mutualists

h=0.5, #mis-coordination cost for mutualists

a=0.5, #probability of assorting on marker

m0=0.07, #base proportion of each group that migrates

mu=0.1, #mean-payoff bias in migration decisions

s=c(0.2, 0.8), #proportion of total population in each group

init\_p=c(0.9,0.1), #intial proportion of behavior 0 in each group

init\_q=c(0.9,0.1), #intial proportion of marker 0 in each group

draw=TRUE )



Same as 11) above, but with a slightly higher migration rate. Now the x11 migrants from the majority group 2 become common enough in group 1 (and there is enough assortment that they do well enough) that freq dependence drives x11 to fixation. The payoff advantage of the few x00 migrants to the majority group 2 is counteracted by freq dependence.

13)

feet\_marker\_sim(

ngroups=2,

tmax=200,

d=0.5, #coordination benefit

g=0.5, #extra coordination benefit among mutualists

h=0.5, #mis-coordination cost for mutualists

a=0.6, #probability of assorting on marker

m0=0.07, #base proportion of each group that migrates

mu=0.1, #mean-payoff bias in migration decisions

s=c(0.2, 0.8), #proportion of total population in each group

init\_p=c(0.9,0.1), #intial proportion of behavior 0 in each group

init\_q=c(0.9,0.1), #intial proportion of marker 0 in each group

draw=TRUE )



Same as 12) above, but now assortment is slightly stronger. As in 12), initially, majority group 2 x11 migrants flood into minority group 1. But because assortment is strong enough, the few x00 migrants to group 2 can hold their own against freq dependence, given their higher coordination payoff. They start to grow in freq within the majority group 2, ad eventually take over.

14)

feet\_marker\_sim(

ngroups=2,

tmax=200,

d=0.5, #coordination benefit

g=0.4, #extra coordination benefit among mutualists

h=0.5, #mis-coordination cost for mutualists

a=0.6, #probability of assorting on marker

m0=0.07, #base proportion of each group that migrates

mu=0.1, #mean-payoff bias in migration decisions

s=c(0.2, 0.8), #proportion of total population in each group

init\_p=c(0.9,0.1), #intial proportion of behavior 0 in each group

init\_q=c(0.9,0.1), #intial proportion of marker 0 in each group

draw=TRUE )



Same as 14) above, but now minority group 1 has less of an advantage in payoff equilibrium. Results in same dynamic as 12) above.

15)

feet\_marker\_sim(

ngroups=2,

tmax=200,

d=0.5, #coordination benefit

g=0.5, #extra coordination benefit among mutualists

h=0.5, #mis-coordination cost for mutualists

a=0.2, #probability of assorting on marker

m0=0.03, #base proportion of each group that migrates

mu=0.1, #mean-payoff bias in migration decisions

s=c(0.2, 0.8), #proportion of total population in each group

init\_p=c(0.9,0.1), #intial proportion of behavior 0 in each group

init\_q=c(0.9,0.1), #intial proportion of marker 0 in each group

draw=TRUE )



Same as 10) above, but assortment is lower and migration is higher. An ethnic boundary forms. Both groups are almost entirely x00 and x11, but in different proportions. There is reasonable covariance in both groups.

16)

feet\_marker\_sim(

ngroups=2,

tmax=200,

d=0.5, #coordination benefit

g=0.2, #extra coordination benefit among mutualists

h=0.5, #mis-coordination cost for mutualists

a=0.2, #probability of assorting on marker

m0=0.03, #base proportion of each group that migrates

mu=0.1, #mean-payoff bias in migration decisions

s=c(0.2, 0.8), #proportion of total population in each group

init\_p=c(0.9,0.1), #intial proportion of behavior 0 in each group

init\_q=c(0.9,0.1), #intial proportion of marker 0 in each group

draw=TRUE )



Same as 15) above, but with a lower payoff equilibrium for the minority group. No ethnic boundary forms and the minority norms and markers are lost from the population.

17)

feet\_marker\_sim(

ngroups=2,

tmax=200,

d=0.5, #coordination benefit

g=0.5, #extra coordination benefit among mutualists

h=0.5, #mis-coordination cost for mutualists

a=0.2, #probability of assorting on marker

m0=0.03, #base proportion of each group that migrates

mu=0, #mean-payoff bias in migration decisions

s=c(0.2, 0.8), #proportion of total population in each group

init\_p=c(0.9,0.1), #intial proportion of behavior 0 in each group

init\_q=c(0.9,0.1), #intial proportion of marker 0 in each group

draw=TRUE )



Same as 15) but with no payoff-biased migration. You don’t need payoff biased migration to form an ethnic boundary.

18)

feet\_marker\_sim(

ngroups=2,

tmax=200,

d=0.5, #coordination benefit

g=0.2, #extra coordination benefit among mutualists

h=0.5, #mis-coordination cost for mutualists

a=0.2, #probability of assorting on marker

m0=0.03, #base proportion of each group that migrates

mu=0, #mean-payoff bias in migration decisions

s=c(0.2, 0.8), #proportion of total population in each group

init\_p=c(0.9,0.1), #intial proportion of behavior 0 in each group

init\_q=c(0.9,0.1), #intial proportion of marker 0 in each group

draw=TRUE )



Same as 16) above, but with no payoff-biased migration. You don’t need payoff-biased migration to kill an ethnic boundary.

Conclusion:

Boyd and Richerson claim that large society with low payoff equilibrium can overwhelm a small society with a higher payoff equilibrium is true when assortment is weak, migration is high, and the payoff equilibrium advantage is low.

Second claim that minority societies with high payoff equilibria are more likely to evolve ethnic boundaries (become marked) than those with low payoff equilibria is also true. Ethnic boundaries can form depending on the levels of assortment and migration. Higher payoff equilibria for the minority group make this more likely.

However, payoff-biased migration has nothing to do with either effect.