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Public and Private Partner Selection in Battle of Sexes

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ABSTRACT

In this paper the authors investigate what factors can promote population diversity. They compare different partner selection models and strategy mobility on the Battle of Sexes game. This is a game with a coordination dilemma where players must decide which event to attend given that each one has its preferred event but they prefer going together. They investigate two types of partner selection: one based in private information and another based on public information, which is based on an opinion model. The authors analyze two variants of the opinion model. Experimental analysis shows that partner selection plays a minor role of favoring population diversity. One of the most important factors is strategy mobility either implicitly through mutation or explicitly when an offspring is placed in a different location.

Keywords Battle of Sexes, Coordination, Partner Selection, Stability

INTRODUCTION

In this paper we compare two methods of partner selection, namely one based on private information and another based on public information. The ability to select with whom one interacts has advantageous because an agent can select the most favorable partners (Santos, Pacheco, & Lenaerts, 2006; Aktipis, 2004). If an agent only uses private information, then it must rely on past interactions and the ability to distinguish partners. On the other hand, if agents use public information this can rely on agent communication and signaling. Agents only interact if they send the same message (Hamblin & Hurd, 2009; Santos, Pacheco, & Skyrms, 2011; Helbing & Johansson, 2010).

Partner selection based on private information requires the ability to remember past interactions namely partner identity and interaction payoff. An agent may try different partners before settling to the most promising ones (Aktipis, 2004; Izquierdo, Izquierdo, & Vega-Redondo,

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2010; Mariano & Correia, 2013). With a stable set of candidate partners, an agent does not need to share information on partner quality.

Partner selection based on public information can be based on signaling (Pawlowitsch, 2008), on reputation (Sabater & Sierra, 2005), or on norms (Helbing & Johansson, 2010). Signaling requires that sender and receiver agree on a common signal. In games with cooperative dilemmas, exploiters try to find the signal used by cooperators. In games with coordination dilemmas, each Nash Equilibrium should have its own signal, otherwise agents from different Nash Equilibria will interact thus failing coordination. Reputation serves to avoid exploiters or partners that do not belong to the Nash Equilibria of an agent. A norm tells how one should play a game, therefore agents must reach a consensus on which norm to adopt.

Opinion dynamics can be used model the evolution of how to play a game. They have been used in the study of consensus evolution. An agent's opinion reflects the way the game should be played. This agent should select other agents with the same opinion provided they also have the right strategy.

In this paper we compare two methods of partner selection in the context of the Battle of Sexes. This game has a coordination dilemma. Agents must reach a consensus on how to play the game. We compare the population dynamics with agents that randomly select partners.

RELATED WORK

There is research on partner selection (Izquierdo, Izquierdo, & Vega-Redondo, 2010; Pacheco, Traulsen, & Nowak, 2006; Santos, Pacheco, & Lenaerts, 2006; Zimmermann & Eguíluz, 2005; Aktipis, 2004; Semmann, Krambeck, & Milinski, 2003; Hauert, 2002; Stanley, Ashlock, & Smucker, 1995; Orbell & Dawes, 1993; Vanberg, 1992). However, these models are often tailored for a specific game such as PGP or IPD (Izquierdo, Izquierdo, & Vega-Redondo, 2010; Aktipis, 2004).

Research similar to ours is (Santos, Pacheco, & Lenaerts, 2006; Pacheco, Traulsen, & Nowak, 2006) where population structure is able to evolve. Players are embedded in a network. If a player can change his links, selection favors cooperators that prefer to maintain links with their kin and to drop links with defectors. However, their findings were done in 2-player games and they only considered two types of strategies.

Research on opinion dynamics (Deffuant, Amblard, & Faure, 2002; Hegselmann & Krause, 2002; Groeber, Schweitzer, & Press, 2009) has largely focused on how a group of agents can reach a consensus in the presence of extremists. There is some research were interactions are mediated by some game (Helbing & Johansson, 2010), although they focus on cooperative games.

When agents select based on public information usually they use some kind of reputation (Cong, 2012; Janssen, 2006). An agent reputation depends on its past actions which means that the reputation update rule is tied to a particular game. Reputation is also used in online shops where it is built not only from an agent's action in a shop but also from messages or signals that he conveys in order to convince prospective buyers.

MODEL DESCRIPTION

In this section we describe the evolutionary algorithm that we use in our experiments, the two partner selection models that we use, and the Battle of Sexes (BoS) game.

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Evolutionary Algorithm

For our model we need an evolutionary algorithm that does not influence any partner selection model. To this end, we use the framework Energy Based Evolutionary Algorithm (EBEA) which we have used in previous works on partner selection (Mariano, Nunes, & Correia, 2014; Mariano & Correia, 2015). In this framework there is no explicit fitness function. Instead, agents accumulate energy by playing games, and reproduce when achieve a certain threshold.

In EBEA there is a population of agents. In each iteration of the algorithm, agents are born, they interact with each other, they reproduce and they may die. Agent interaction is mediated by some game. Although in this paper we only focus on the BoS game, one of EBEA parameters is the game. The game is used as an energy transfer process. The game payoff dictates how much energy an agent gains or losses. Energy is used for reproduction. Whenever an agent reaches the reproduction threshold, e_R, it produces one offspring, and its energy is decreased by the birth energy, e_B. The offspring chromosome is equal to the parent's chromosome but is subject to a one-point mutation. The offspring's starting energy is e_B. In the last step in each iteration all players go through two death events. One depends on population size while the other depends on an agent's age.

The first event is a death by carrying capacity. The probability of an agent dying is given by

$$\frac{1}{1+e^{6\frac{K+|\mathcal{P}|}{K}}},$$

where $|\mathcal{P}|$ is the population size and K is the carrying capacity. This probability is a sigmoid function. The number 6 was placed in the exponent to avoid certain extinction in the event of all agents in the current iteration generating an offspring. The population would double size and could go from a zero probability of dying due to excess capacity to certain death.

The second event is a death by old age. The probability of dying is given by a sigmoid expression:

$$\frac{1}{1+e^{\frac{L+a}{V}}},$$

where a is an agent's age, L is agents life expectancy, and V is the variance in the age at which agents die of old age.

Private Partner Selection

We choose the model presented in (Mariano & Correia, 2011). An agent in this partner selection model has two vectors of size l. Vector $\mathfrak{p}$ contains probabilities while vector c contains sets of candidate partners. When an agent needs to play a game, he selects a set of candidate partners from c. Sets with higher probability have more chance of being picked. After the agent played the game he compares the payoff he obtained with threshold π_T. If the payoff is higher the vectors are not changed. Otherwise, the selected set of candidate partners is replaced by a ran-

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domly set and its associated probability is multiplied by factor $\delta < 1$, the probability decrease factor. Since the probability decreases, in order to maintain unit sum, the decreased amount is distributed evenly among the other positions in vector $\mathfrak{p}$.

As long as the population remains stable, the net effect of this partner selection is for good sets of candidate partners absorb the probabilities of discarded sets of candidate partners. Whenever an agent that is in a set of candidate partners dies, a randomly set with live candidate partners is inserted in the corresponding vector position.

We augmented this model with the possibility of a parent passing some of his combinations to his offspring. The rationale is to give some information on who are the best partners instead of every newborn having to start from scratch. The combinations that are passed are randomly chosen, without consideration for $\mathfrak{p}$. The remaining positions of $\boldsymbol{c}$ are randomly filled.

Partner Selection based on Public Opinion

We adapted a model of opinion formation (Deffuant, Amblard, & Faure, 2002) to perform partner selection. A player's opinion is a public fact that represents how a game should be played. Players with the same opinion prefer playing among themselves compared to players with opposite opinions. Besides an opinion, a player also has an uncertainty which is used to filter out players with different opinions. Thus a player is characterized by (o, u), where o is the opinion and u is the uncertainty.

Opinion dynamics occurs during partner selection and is influenced by available partners and game payoff. Player α_1 starts by computing the weight of candidate partners. The weight depends on the overlap, h_{12}, between player α_1's opinion and partner α_2's opinion. This overlap represents their overall agreement on how to play the game. Following (Deffuant, Amblard, & Faure, 2002), the overlap is defined by

$$h_{12} = \min\left(o_1 + u_1, o_2 + u_2\right) - \max\left(o_1 - u_1, o_2 - u_2\right)$$

The weight of partner α_2 is given by

$$\begin{cases} 2 - \left|o_1 - o_2\right| & h_{12} \leq u_1 \\ 0 & \text{otherwise} \end{cases}$$

This means that whenever there is a disagreement, a partner is not chosen because its weight is zero. After computing candidate partners' weight a player performs a weighted random selection of partners.

If all candidate partners get zero weight, the player cannot play a game. In this case, the player's uncertainty is increased by factor u_{IF}. The purpose is for a player to become less extreme and accept partners with different opinions.

When $n-1$ partners have been selected, player α_1 plays a game. Afterwards it updates his opinion and uncertainty based on the payoff it obtained. We follow the same procedure described in (Deffuant, Amblard, & Faure, 2002) but we additionally consider the hypothesis of opinions diverging. The rationale is if the payoff is above some threshold, meaning it is consid-

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ered good, then players' opinions should converge. Otherwise opinions diverge. The opinion update rule is

$$o_1 \leftarrow o_1 \pm \mu \left(\frac{h_{12}}{u_2} - 1 \right) \left(o_2 - o_1 \right)$$

The uncertainty update rule is

$$u_1 \leftarrow u_1 \pm \mu \left(\frac{h_{12}}{u_2} - 1 \right) \left(u_2 - u_1 \right)$$

Convergence and divergence speed depend on parameter μ with higher values causing higher speeds. We add, respectively subtract, if the payoff obtained by player α_1 is higher than π_T.

When a parent produces an offspring, he gets the parent's opinion and uncertainty. To reflect the fact that juvenile tend to seek other opinions, offspring's uncertainty is increased by parameter u_{IF}.

Agent Characterization

Agents in population $\mathcal{P}$ have a chromosome and a set of phenotypic traits. The chromosome contains the strategy used to play the game, and parameters that control partner selection. The phenotypic traits contain its energy, e, its age, a, and others related to the partner selection. In this paper we investigate three classes of partner selection: random, private and public. The first set of experiments consisted of the following five scenarios, which were reported in (Mariano, Nunes, & Correia, 2014):

- **Private Selection Simple (PCVS):** Agents use the private selection model. All initial agents had the same genes. The parameters of the private selection model are: $l = 4$, $\delta = 0.5$, and $\pi_T = 0.5$. An offspring did not receive any combination from his parent.
- **Private Selection Transmission (PCVT):** This scenario is equal to PCVS, but an offspring received half the parent's combinations.
- **Opinion Slow (OPNS):** Agents use the opinion based selection model. The agent chromosome does not contain any gene that control partner selection. The initial opinion and uncertainty were drawn from a normal distribution with standard deviation one. For one site the average was -0.25 while for the other was 0.25. The selection model parameters were $u_{IF} = 1.001$ and $\mu = 0.25$.
- **Opinion Fast (OPNF):** This scenario is equal to OPNS but an offspring's uncertainty increased more, $u_{IF} = 1.01$.
- **Random (RND):** Agents randomly selected partners.

In these scenarios the main goal was to compare which partner selection promoted diversity. The results that we obtained led us to consider one additional scenario. The main motivation of the last scenarios was to put under evolutionary control the parameters of the public partner selection in contrast with scenarios OPNS and OPNF.

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- **Diverse Public Selection (DPS):** This partner selection is also based on the opinion model, but the agent's chromosome has genes that control the partner selection dynamics. The genes are the payoff threshold, π_T, the convergence and divergence speed, μ, the uncertainty increase factor u_{IF}, (used when all partners have zero weight), and the opinion and uncertainty change of offspring. Contrary to the previous variant, offspring's opinion can decrease and offspring uncertainty also changes.

Battle of Sexes

We have selected the Battle of Sexes game because it is a coordination dilemma. Two players must decide on which event to go, either a tennis match or an opera concert. If they go to separate events they get zero payoff. Both players are better off if they go together. Each one has his favorite event: the man prefers the tennis match and the woman the opera concert. The player that goes to his favorite event gets a payoff of one. This game as a single parameter, π_U, that is the payoff obtained by the player that does not go to his favorite event when he joins the other partner. The game payoff is thus:

$$\begin{bmatrix} 1, \pi_U & 0, 0 \\ 0, 0 & \pi_U, 1 \end{bmatrix}$$

with the restriction $0 < \pi_U < 1$. The top row and left column correspond to the opera concert, while the bottom row and right column correspond to the tennis match. The man has to select columns while the woman selects rows. In this paper a game strategy s is characterized by the agent's role in the game, either F if he plays the woman or M if he plays the man, and by the agent's action, either 0 if he does not go his favorite event or 1 otherwise. We thus have the following set of possible strategies:

$$s \in \left\{ \left(F, 0\right), \left(F, 1\right), \left(M, 0\right), \left(M, 1\right) \right\}$$

EXPERIMENTAL ANALYSIS

In this paper we report the experiments done with scenarios and compare them with scenarios PCVS, PCVT, OPNS, OPNF and DPS. We have also performed a control experiment were agents randomly selected their partners.

Simulation Parameters

We have performed several experiments with variant DPS in order to investigate the conditions that favored diverse populations. In the case of BoS game this means that all 4 strategy profiles were present in the population. In (Mariano, Nunes, & Correia, 2014) we have observed that only the public partner selection model favored diverse populations. However, given enough time, the population would tend to one of the two pure strategy profiles that are Nash Equilibrium.

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Game payoff π_U was set to 0.5 meaning that whenever both agents selected the same event, the agent that went to his favorite event got twice as much energy as the other agent. Each offspring was subject to a one gene mutation with probability 10%. The offspring was placed in the parent's site.

Energy needed to reproduce was set to 50 and agent longevity was set to 150. This means that an agent that only selects partners can generate six offspring.

In the first set of scenarios (PCVS, PCVT, OPNS, OPNF and RND) each simulation was run for 10000 iterations. In scenario DPS each simulation was run for 100000 iterations. The purpose was to check if any partner selection could maintain population diversity. For each parameter combination, we performed 30 simulation runs.

Simulation Results from Base Scenarios

In this section we will present the results[1] from scenarios PCVS, PCVT, OPNS, OPNF and RND. The parameters of private partner selection model are part of the agent's chromosome. However, the parameters of public partner selection model are not.

The first set of results that we present is the average number of different partners selected by agents. This number gives a rough picture of how selective are the partner selection models and if there are groups of agents that only select among themselves. For each simulation iteration we have considered a window that includes all the selections occurred in past iterations. For every agent in this window we computed how many different partners were selected. We then divide by the number of agents and window size plus one. A value near one means an agent is not selective, while a value near zero means an agent always selects the same partner. Figure 1 shows the evolution in typical simulation runs. The plots were obtained with a window of size ten. In scenarios PCVS and PCVT agents focus on fewer partners than in the other scenarios.

In order to compare the effect of each partner selection scenario on diversity, for each simulation we computed the average diversity and grouped by scenario, yielding five sets of numbers. We then applied the Kolmogorov-Smirnov test to all pairs of sets to see if they were drawn from the same distribution or not. Table 1 shows the result of this test and the last column the average diversity. For space considerations we show the base ten logarithm of the p-value. Considering a confidence level of 1% the only scenarios that are similar are the ones using the private partner selection model, PCVS and PCVT. Control scenario RND shows the highest diversity since agents randomly select partners, so the chance of picking the same partner decreases as population reaches the carrying capacity. Agents in scenarios OPNS and OPNF also have a higher diversity mainly because they select partners by their opinion. As the number of available partners with the same opinion increases, so thus partner diversity. Although OPNS, OPNF and RND have high diversity, the p-value is very small. Scenarios PCVS and PCVT have the lowest diversity because of agents' combination vector. Moreover, diversity changes throughout evolution due to the mutations in the pool size gene. In the simulation shown a mutation with lower l appeared around the 500^{th} iteration.

The next set of results that we present is the occurrence of specific strategy profiles, presented in Figure 2. Each colored point in this figure represents the data collected during a single run. The black circumferences are the result of applying a Self-Organized Map (SOM) to the points presented in the plot. The size of each circumference represents the number of points mapped to it.

The top plot of Figure 2 shows the occurrence of the NE strategy profiles. This is a measure of how successful are agents in selecting the right partners. The horizontal axis represents the number of occurrences of strategy profile $\left(F,0\right),\left(M,1\right)$, while the vertical axis stands for strat-

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Figure 1. Agent partners diversity throughout typical simulations in all treatments. In scenarios PCVS, PCVT, OPNS, OPNS and RND diversity converges to 0.3, 0.307, 0.862, 0.838, and 0.846, respectively. A rolling average with size 201 was applied to all data series

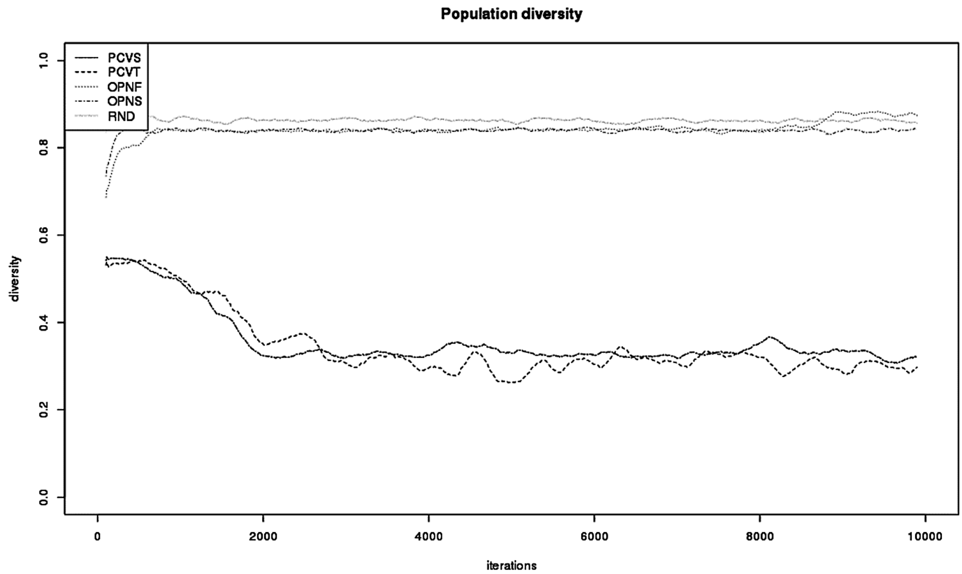

Table 1. Kolmogorov-Smirnov statistical test on agent partners diversity. Only in scenarios PCVS and PCVT the diversity belongs to the same distribution, meaning in these scenarios the diversity is similar

	$\log_{10}$ ***p*-value**				**average diversity**
	PCVT	**OPNS**	**OPNF**	**RND**	
PCVS	−0.0211	−12.7	−12.7	−12.7	.402
PCVT		−12.7	−12.7	−12.7	.403
OPNS			−3.88	−10.3	.844
OPNF				−9.49	.84
RND					.862

egy profile $(F,1),(M,0)$. Scenarios PCVS and PCVT show the highest counts due to having the highest number of agents. The SOM circumferences show that in these scenarios either the strategies in both sites are able to prosper or that a single mutant strategy in a site is able to take over. In scenarios OPNS, OPNF and RND there are fewer counts, but population composition

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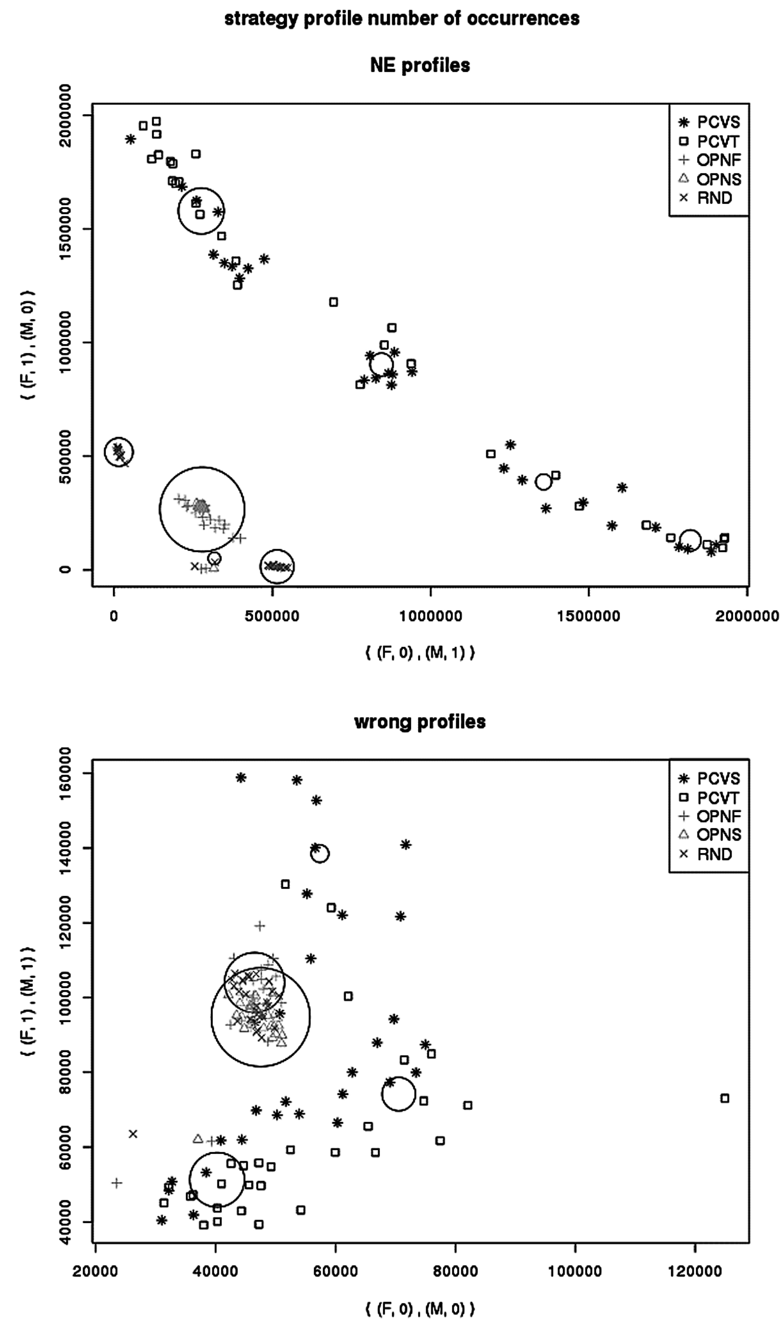
Figure 2. Number of times a strategy profile has occurred in the scenarios. PCVS, PCVT, OPNS, OPNS and RND. Each point corresponds to a simulation run. The circumferences represent the result of a Self-Organizing Map. Circumferences radius represent the number of simulation runs that belong to its corresponding cluster



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is different. While in RND strategies converge on a single strategy profile, in OPNS and OPNF the strategies in both sites are able to thrive.

The bottom plot in Figure 2 shows strategies profiles that we call wrong, in the sense that players go separately thus earn zero payoff. The SOM shows a single circumference where all simulations from OPNS, OPNF and RND are located. In this sense opinion based selection is not very different from random partner selection. The PCVS and PCVT scenarios show more dispersion. Overall, wrong strategy profiles occur less often than the NE strategy profiles, with the private based selection model having more success in avoiding wrong strategy profiles. There is a bias towards strategy profile $\left(F,1\right),\left(M,1\right)$ because when both NE strategy profiles prevail in the population, strategies $\left(F,1\right)$) and $\left(M,1\right)$ are the majority in the population, so all things being equal, this strategy profile occurs more often than the other wrong strategy profile.

The selection model influences the population dynamics namely if one of the NE strategy profile dominates or both can coexist. Figure 3 shows typical population dynamics for each selection model. In scenarios PCVS and PCVT there is a higher number of agents per iteration. This is a consequence of agents being capable of selecting the right partner, i.e. a male prefers females and vice-versa. In contrast, in scenarios OPNS, OPNF and RND population size is lower. Since in OPNS and OPNF an agent selects based on a common opinion, males (females) sometimes select other males (females). When this happen, an agent does not earn energy in that iteration. However, in OPNS and OPNF both NE are able to coexist more often than compared to other scenarios.

The last result we discuss is opinion formation. Figure 4 and Figure 5 show two samples of opinion dynamics and games strategies in the first 1000 iterations. We observe that when two opinions fixate in the population (Figure 5), then both strategy profiles are able to coexist in the population. The plots only show the first 1000 iterations. From then on population levels and opinion remain the same. In contrast, agent's uncertainty, keeps increasing due to parameter u_{IF}. At some point, there is an overlap between the two niches' opinions and both opinions collapse into a single one. After that one of the two strategy profiles takes over the entire population. This means that as long as two sub-populations have different opinions that do not overlap (low uncertainty), each sub-population can use its unique strategy.

Simulation Results from Extended Scenarios

The results from the previous section showed that only the opinion based partner selection model favored diversity. However, this diversity given enough time would be lost, because uncertainty would keep rising until both player profiles would select each other. Afterward only one player profile would be present.

The first result that we represent the occurrence of specific strategy profiles, presented in Figure 6. This figure is similar to Figure 2, again each point represents data from a single simulation run. As can be seen, in almost all simulations either one of the two NE prevails. We have also applied a SOM to identify major classes of occurrences, and they all lie next to the axis. There is still the problem of a player selecting a partner with the same role in the opinion based simulations.

If we examine particular simulation runs, we see that whenever players uncertainty increase, one of the NE will prevail. Figure 7 shows an example of such simulation run. In the first iterations, agent's uncertainty is low. However as soon as offspring uncertainty change and uncertainty increase factor genes increase agent's uncertainty start increasing. This leads to one of the NE dominating the other one.

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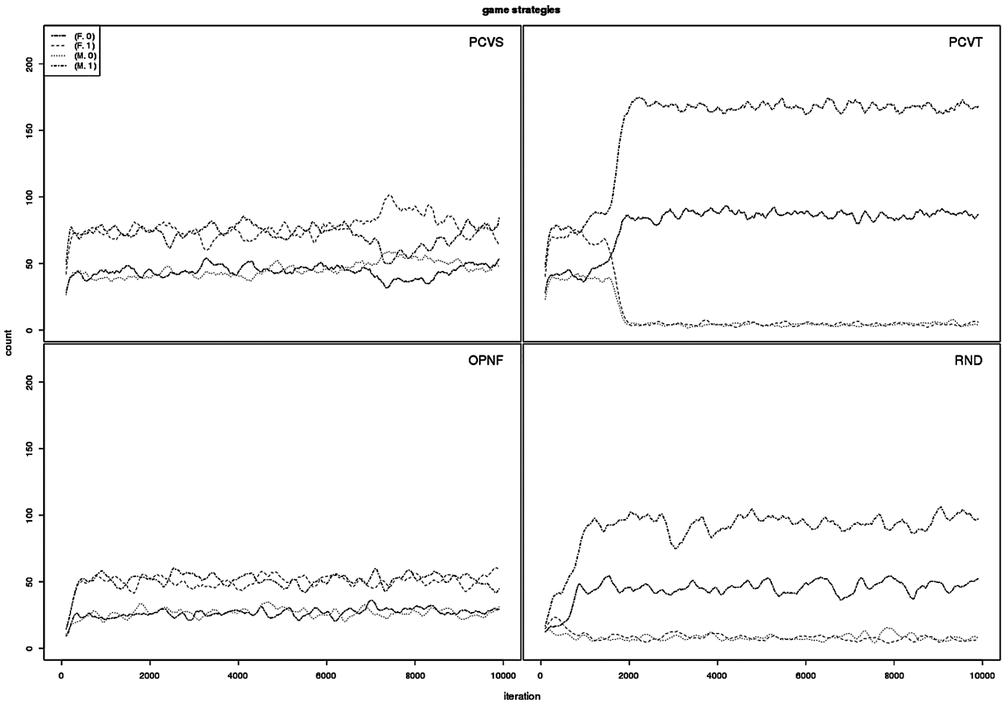
Figure 3. Population dynamics of typical simulations in the scenarios PCVS, PCVT, OPNS, and RND. A rolling average with size 201 was applied to all data series



Another result that we observed in simulation runs was extinctions. If we increase the number of iterations to 100000, no simulation is able to run that last. One of the reasons lie on the fact that with the opinion based partner selection, an agent can select a partner with the same role. Whenever this happens the selecting agent does not obtain energy in that iteration. The reason may lie on the fact that in the opinion based partner selection model NE strategy profile occurs less compared to the private partner selection as can be seen in Figure 2.

DISCUSSION

We have performed simulations with agents distributed in two niches. Each niche had its own strategy profile. The only interaction between niches was limited to partner selection. Even so, whenever a mutation introduced a new strategy in a niche, this mutant was capable of producing enough offspring to take over both niches. The population performs a random walk with mutation, death by carrying capacity and partner selection dictating which strategy profile prevails. If a parent is capable of putting an offspring in another niche, then such take overs are more frequent and occur sooner. This is not surprising as the fixed points of the underlying system dynamics only contain one of the strategy profiles. A population composed of both strategy profiles is unstable and in the end only one strategy profile will prevail. Even so it is quite remarkable that both private and public based selection models can maintain strategy diversity in the Battle of Sexes game. The opinion based selection with lower uncertainty increase factor is able to sustain a longer diversity when compared with other methods. However, this diversity

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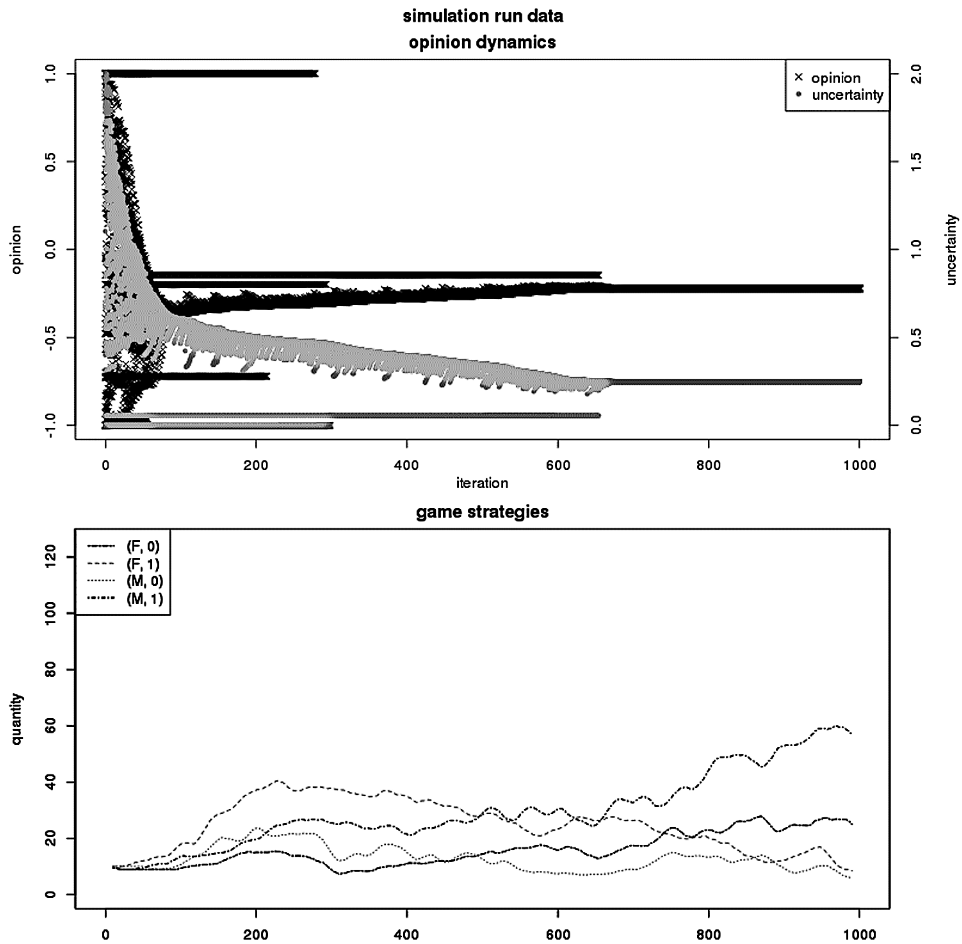
Figure 4. Dynamics of a sample simulation run using the opinion selection model where only one strategy profile prevails. Data shown only up to the 〖1000〗^"th" iteration as afterwards simulation data does not change much. A rolling average with size 21 was applied to the game strategies plot



is short lived because the occurrence of NE is lower compared to the private partner selection model. This means agents take longer to acquire enough energy to reproduce, thus they run the risk of extinction.

CONCLUSION AND FUTURE WORK

In this paper we analyzed the effect of two models of partner selection in a coordination game, the Battle of Sexes (BoS). This game has two Nash Equilibria (NE) and we have analyzed in which conditions a population initially composed of both NE is able to maintain them. We have restricted the analysis in a two site population with a NE per site. Communication between sites is limited to partner selection. Even in this condition a mutant strategy in a site is able to

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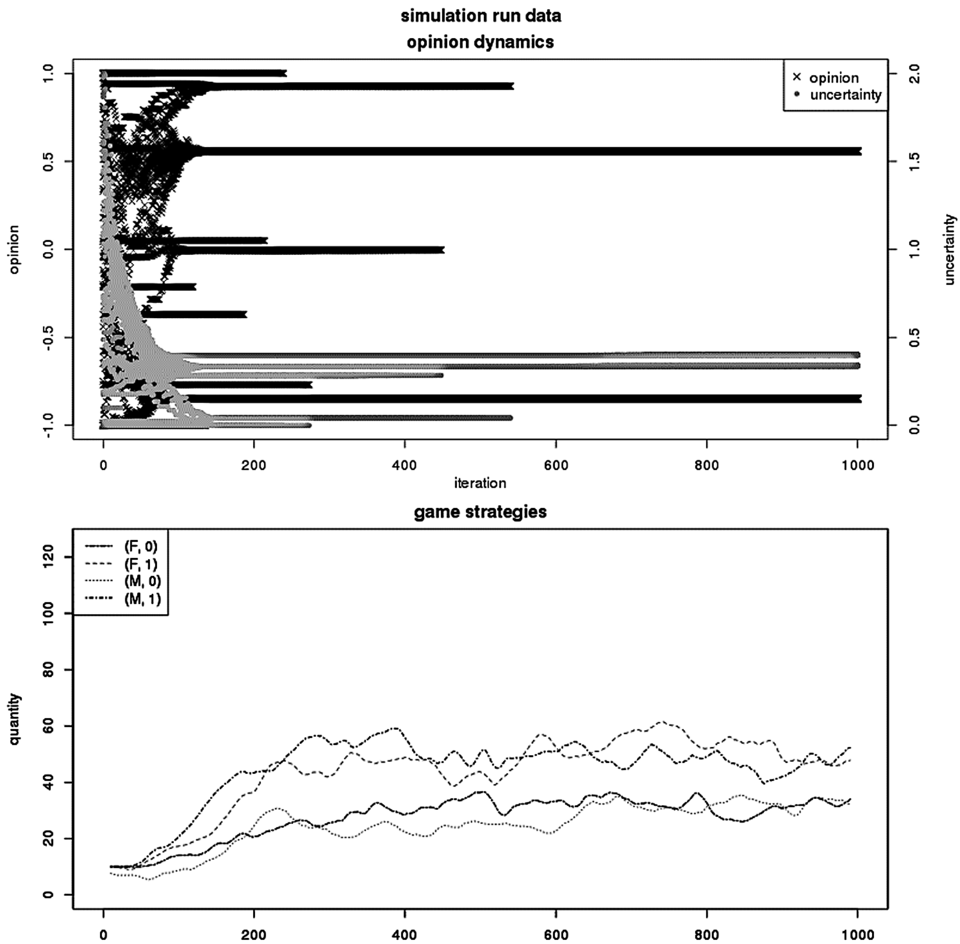
Figure 5. Dynamics of a sample simulation run using the opinion selection model where both strategy profiles are able to coexist for some time Data shown only up to the 〖1000〗^"th" iteration as afterwards simulation data does not change much. A rolling average with size 21 was applied to the game strategies plot



overcome the local strategies and drive the entire population to a single NE. Partner selection models influence such result with a public based selection model showing better resistance to such population homogenization, however this model is prone to extinctions due to a lower reproduction rate. A diverse population is more resilience because it contains more than one NE. If one disappears, other can take the space left by it.

We have performed simulations where the partner selection parameters were under evolutionary control. The public partner selection model has parameters that negatively affect diversity. When such genes have a certain value, only one NE prevails. The private partner selection does not have genes that directly influence diversity.

Regarding future work we plan to investigate other conditions that favor diversity. We intend to increase the number of sites. We also plan applying the public partner selection model to games with cooperative dilemma such as Prisoner's Dilemma, Public Good Provision, or

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Figure 6. Number of times a strategy profile has occurred in scenario DPS. Each point corresponds to a simulation run. The circumferences represent the result of a Self-Organizing Map. Circumferences radius represent the number of simulation runs that belong to its corresponding cluster

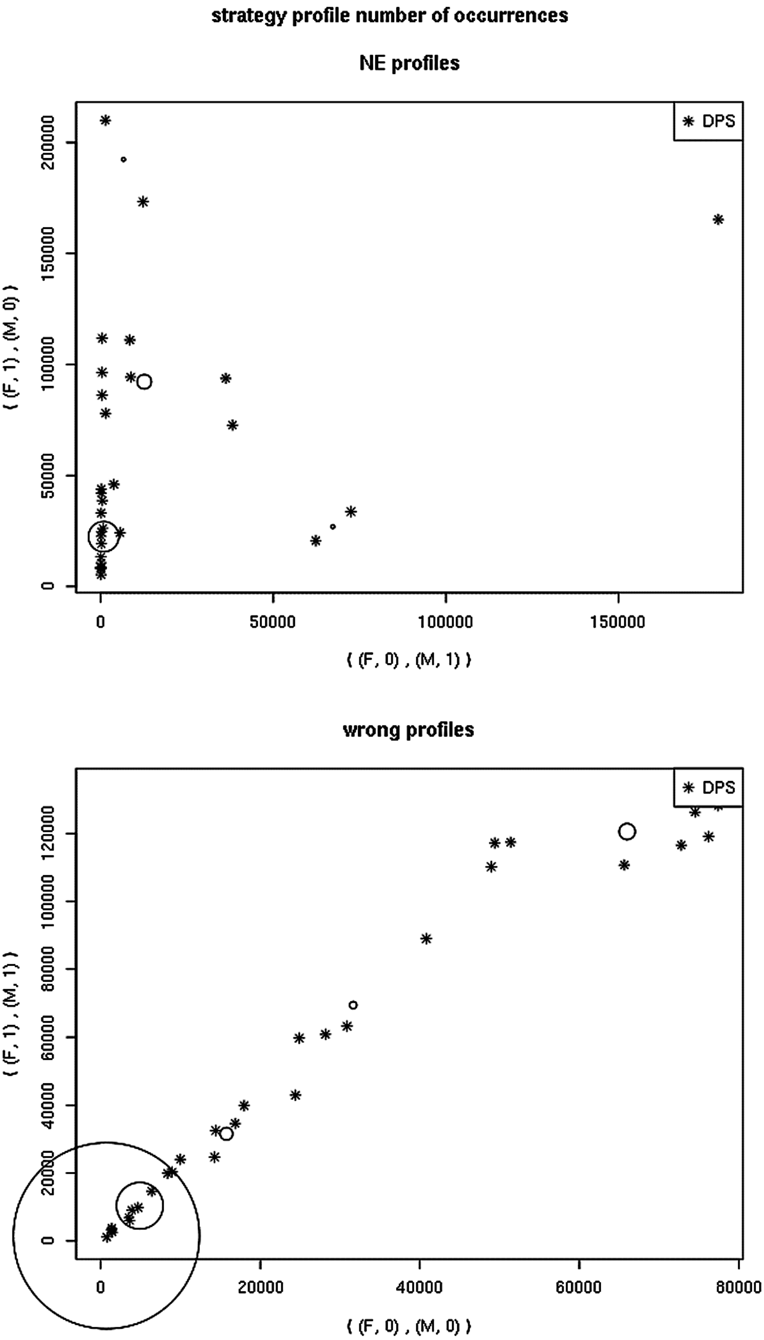

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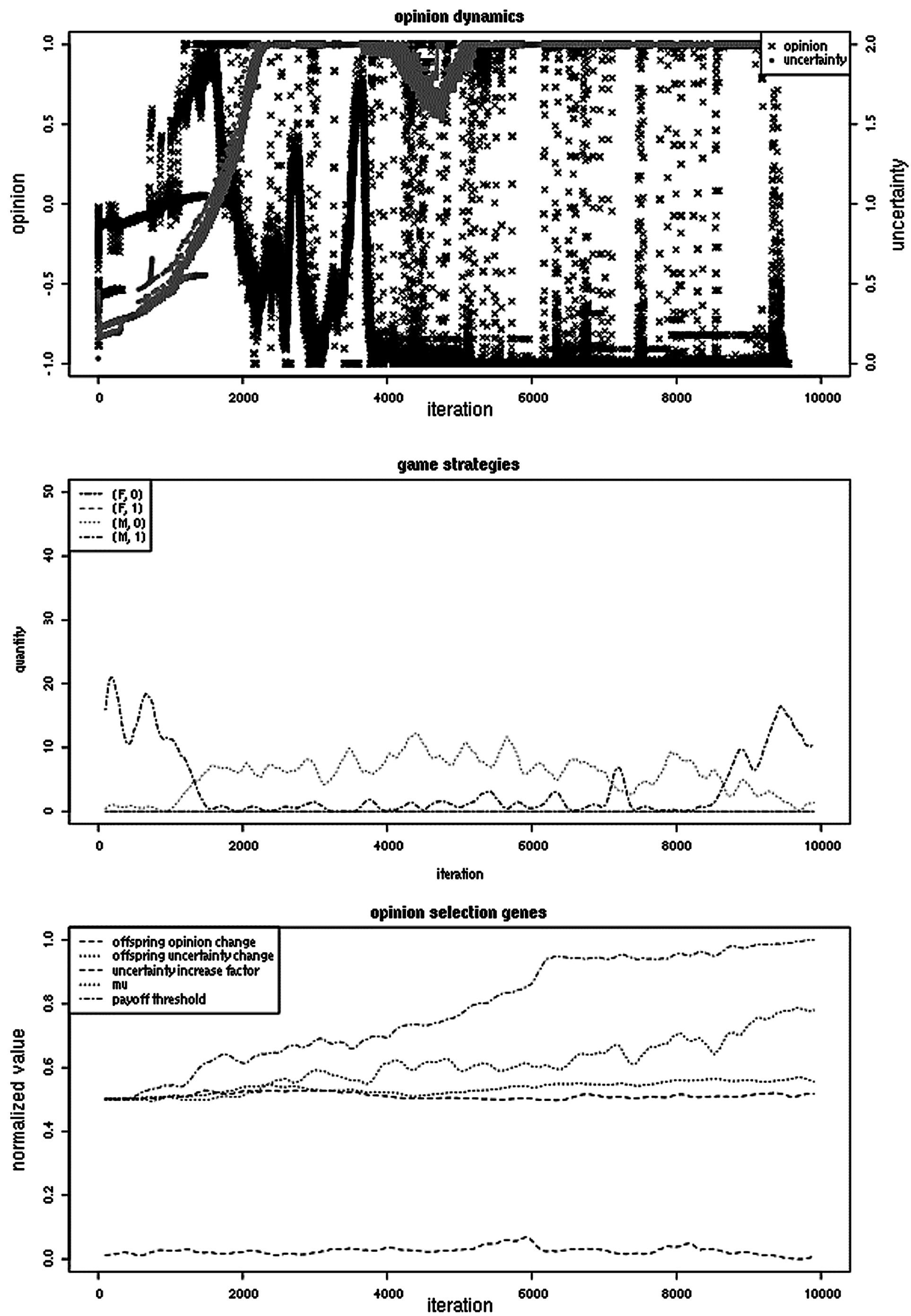
Figure 7. Dynamics of a sample simulation from scenario DPS



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Centipede. In these games an exploiter or a key role can take over the population. This in turn will lead to extinction in the framework of EBEA. Both private (Han, Pereira, & Santos, 2011) (Mariano & Correia, 2013) (Santos, Pacheco, & Lenaerts, 2006) and public models (Santos, Pacheco, & Skyrms, 2011) of partner selection have been shown to promote cooperation albeit in fixed-size populations.

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ENDNOTES

1 Simulations where performed in the EBEA framework, http://github.com/plsm/EBEA.

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