Predating Predators
– An Experimental Study –

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Abstract

Predating predators requires at least three specimen to which we refer as players 1, 2, and 3. Player 1 has simply to guess nature when trying to find food. Player 2 is hunting player 1 in the hope that 1 is well-fed but must also avoid being hunted by player 3. One major motivation is to test three benchmark solutions (uniformly perfect, impulse balance and payoff balance equilibrium) in such a complex strategic setting. In the experiment three participants play repeatedly the game (partner design) which allows to test whether certain types of behavior are just initial inclinations or stable patterns which survive learning and experience.

1 Introduction

Evolutionary stability usually implies that behavior is well adapted to one's environment but not necessarily to specific circumstances which are either rare or non-existent.[1] As a consequence certain types of behavior may appear as rather unreasonable in special situations. Probability matching, for instance, could be a quite reasonable attitude in our usual environment although it is clearly suboptimal in the experiments confirming it as a stylized fact.

Consider a situation where one can bet on two locations H and T whose probabilities of providing food are either known or more or less certainly learned over time. It is assumed that food is available only at one location and that nature's repeated choice of providing food at H or T satisfies the iid-property (the successive chance moves are independent and governed by an identic (probability) distribution). Probability matching then refers to choosing locations proportionally to their probabilities of providing food although optimality dictates the constant choice of the more likely location.

One could try to justify probability matching by questioning the iid-assumption. For a habitat to be sustainable locations with a rich food supply today will have to recover and therefore

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[1] Animals, kept in zoological gardens, display often behavior which is not very well suited in such an environment (see, for instance, Kummer, 1995).

offer little or no food next time. Probability matching then may imply that the various locations offer the same chances of finding food and that the habitat with its multiplicity of feeding locations is sustainable. In our view, a study of probability matching in such a dynamic decision environment is very much needed and should receive a lot of attention.

Here we, however, focus on a different aspect which is also neglected by usual probability matching experiments. If optimality dictates always the same choice, optimal behavior becomes highly predictable. In a strategic settings where one does not only want to guess nature but also to avoid being outguessed by one's predator or competitors such predictable behavior can be disastrous. To capture such possibilities we consider a 3person-game with

- player 1 who tries to guess nature as in usual probability matching experiments but also has to avoid being hunted by

- player 2 who is 1's potential predator but also the potential prey of

- player 3 who has to outguess player 2 as his only prey.

Thus the phenomenon of "Predating Predators" can be studied by theoretically and experimentally analyzing player 2's decision behavior. It will be shown that (commonly known) rational behavior predicts probability matching by player 2 which is, however, only poorly confirmed by the overall experimental results. We will therefore also test other equilibrium concepts.

Section 2 introduces the basic game whose benchmark solutions are derived in section 3 and 4. The experimental procedure is described in section 5 and the results are analyzed in section 6 before concluding and summarizing the findings in section 7.

2 The game model

Imagine a habitat populated by three specimen,

- player 1 who has to guess whether nature provides food at location *H* (with probability w) or *T* (with probability $1-w$),

- player 2 whose potential prey is a well fed player 1 but who also may fall prey to

- player 3 who is only interested in hunting a well fed player 2.

Situations like these are paradigmatic food ladders since 1 feeds on the habitat, 2 on 1 and 3 on 2 and since thus all three specimen are more or less indirectly relying on the supply of their common habitat.

Since *H* and *T* are the locations where player 1 can search for food, they are also the possible hunting grounds for players 2 and 3. Thus the notation of choice alternatives in the extensive form (Figure II.1) or $2\times2\times2$-trimatrix (Table II.2) representation of the game is essential as usual in evolutionary game theory. Payoffs (at the endpoints, i.e. the last nodes in Figure II.1, the cells in Table II.2) are given in the natural order. What these payoffs capture is that for i = 1, 2, 3 hunting success of player i presupposes hunting success of player $i-1$ (where we rely on the usual convention of denoting nature as chance player 0 who starts the game at the origin o of Figure II.1). Furthermore, hunting success leads only to a win (of 1) if one is not hunted in turn.

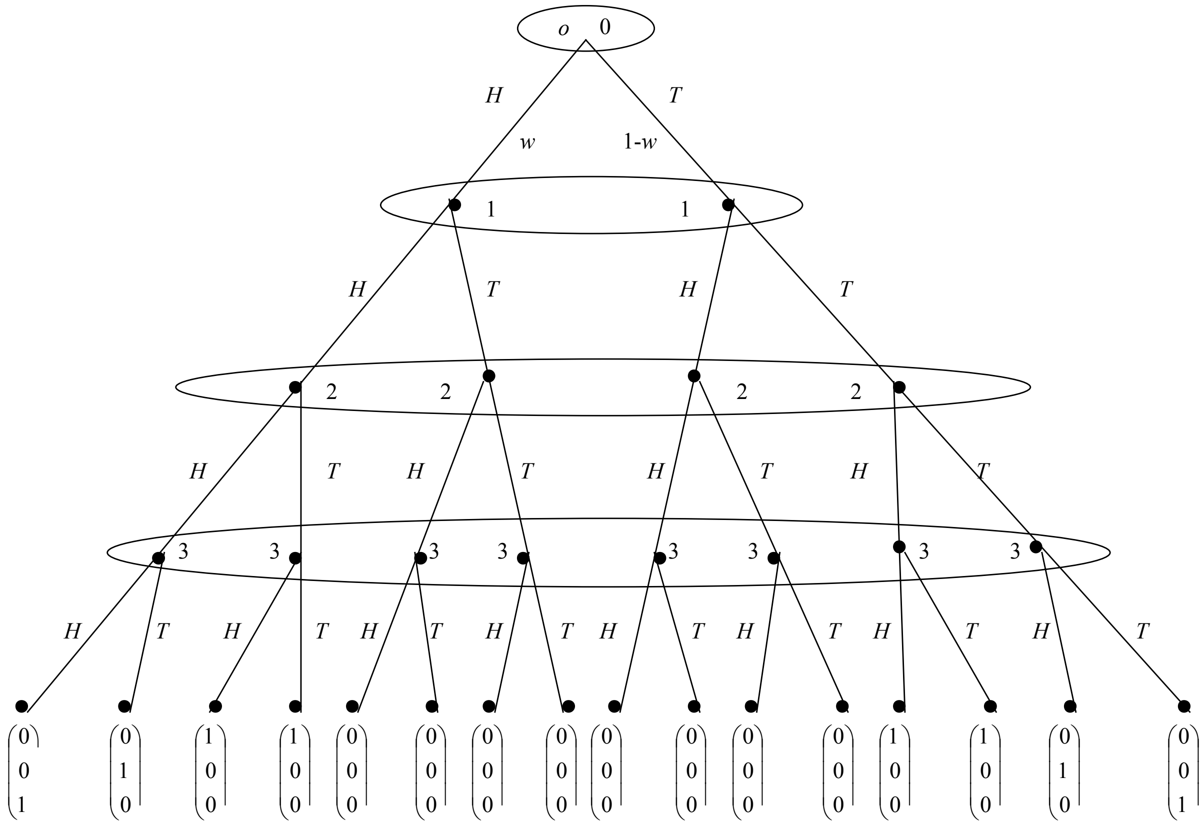

Figure II.1: The extensive form game (play starts at the origin with nature/player 0's choice and proceeds to a final/lowest node where payoffs for players 1, 2, 3 are given in the natural order)

$s_3 = H$		s_2	
		H	T
s_1	H	0, 0, w	w, 0, 0
	T	$1-w$, 0, 0	0, $1-w$, 0

$s_3 = T$		s_2	
		H	T
s_1	H	0, w, 0	w, 0, 0
	T	$1-w$, 0, 0	0, 0, $1-w$

Table II.2: The $2\times2\times2$-trimatrix game (a strategy vector $s=(s_1,s_2,s_3)$ with $s_i \in \{H,T\}$ for $i=1,2,3$ corresponds to a cell, payoffs expectations of player 1, 2, 3 are given in the natural order for each cell)

Thus at most one player can gain which, furthermore, requires that player 1 has chosen the right location by guessing nature. If player 1 misses nature, no player can gain. This illustrates that the game is partly very competitive (if a player wins at all, he will be the only one) and partly strictly non zero-sum (all players want player 1 to guess nature as often as possible, i.e. they all want 1 to choose the more likely location, e.g. location H if $w \geq 1/2$). Furthermore, there are three candidates who could probability match by letting their choice behavior depend more or less specifically on the probability parameter w which is restricted without loss of generality to $1/2 \leq w < 1$.

3 Equilibrium solution

The usual solution concept to solve games like the one described in the previous section, is that of an equilibrium point (Cournot, 1838; Nash, 1951), i.e. a strategy vector from which no single player can profitably deviate. Let us denote by

$$x = \text{Probability } \{s_1 = H\} \text{ with } 0 \le x \le 1,$$
$$y = \text{Probability } \{s_2 = H\} \text{ with } 0 \le y \le 1,$$
$$z = \text{Probability } \{s_3 = H\} \text{ with } 0 \le z \le 1.$$

Proposition 1: The game has three types of equilibria, namely

$$\hat{s} = (H, y, H) \text{ or } (\hat{x}, y, \hat{z}) = (1, y, 1) \text{ with } y \in [0, w],$$
$$\tilde{s} = (T, y, T) \text{ or } (\tilde{x}, y, \tilde{z}) = (0, y, 0) \text{ with } y \in [w, 1]$$
$$\text{and } q^* = (x^*, y^*, z^*) = \left(\frac{(1-w)^2}{(1-w)^2 + w^2}, w, 1-w \right).$$

Proof: $x \in (0,1)$ requires that player 1 is indifferent between choosing $s_1 = H$ or $s_1 = T$, i.e. $w(1-y)z + w(1-y)(1-z) = (1-w)yz + (1-w)y(1-z)$ or $y = w$. Due to $1/2 \le w < 1$ this requires player 2's indifference between $s_2 = H$ and $s_2 = T$ or $wx(1-z) = (1-w)(1-x)z$. Since $z = 0$ would imply $x = 0$ and $z = 1$ also $x = 1$ contrary to our initial assumption $x \in (0,1)$, one must have

$$z = \frac{wx}{(1-w)(1-x) + wx}$$

which is well defined in the sense of $z \in (0,1)$ due to $1/2 \le w < 1$ and $x \in (0,1)$. Indifference of player 3 between $s_3 = H$ and $s_3 = T$ requires $w^2 x = (1-w)^2 (1-x)$ due to $y = w$ and thus $x = \frac{(1-w)^2}{(1-w)^2 + w^2} \in (0,1)$. Inserting this into the equation for *z* yields $z = 1 - w$. Thus q^* is the only equilibrium satisfying $x \in (0,1)$.

If $x = 0$ would go along with $z > 0$, this would imply $y = 0$ which, in turn, induces $z = 0$. Both, $x = 0$ and $z = 0$, however, allow for any $y \in [0,1]$. Any $y < w$ would, however, induce player 1 to deviate from $x = 0$. Thus $\tilde{s}$ requires $y \in [w,1]$. Similarly, $x = 1$ and $z < 1$ would imply $y = 1$ which, in turn, induces $z = 1$. Together $x = 1$ and $z = 1$ allow for any $y \in [0,1]$. Since, however, any $y > w$ induces player 1 to deviate from $x = 1$, any $\hat{s}$ requires $y \in [0, w]$. The intuitive interpretation of these two classes $\hat{s}$ and $\tilde{s}$ of equilibria is obvious: Since players 1 and 3 go to the same location, it does not matter for player 2 whether or not he catches player 1 since, if he does, he is caught by player 3. Player 2 should only not seduce player 1 to deviate.

q.e.d.

The infinite number of equilibria may be viewed as troublesome although the equilibrium predictions are quite specific: Either player 1 and 3 go with certainty to the same location (so that for player 2 his choice of *y* does not matter) or all three players mix in the unambiguous way of q^*. The latter, furthermore requires (counter) probability matching on behalf of player 2(3). We nevertheless want to explore whether the usual refinement of the equilibrium concept (Selten, 1975) will reduce the multiplicity of equilibria.

Proposition 2: All equilibria $\hat{s}$ with $0 < \hat{y} \leq w$ and $\tilde{s}$ with $1 > \tilde{y} \geq w$ as well as q^* are perfect.[2]

Proof: Since q^* is completely mixed $(0 < x^*, y^*, z^* < 1)$, it exist as an equilibrium also in perturbed games (with small but positive minimum choice probabilities for $s_i = H$ and $s_i = T$ and for $i = 1, 2, 3$). The equilibrium q^* can thus be approximated by itself as an equilibrium of perturbed games whose minimum choice probabilities vanish. Thus q^* is perfect.

For equilibria of the type $\hat{s}$ in Proposition 1, one has $y \in [0, w]$ in a perturbed game. Denote by ε_i for $i = 1, 3$ player *i*'s positive but small minimum choice probability for $s_i = T$. We want to explore when using $s_i = T$ with probability ε_i for $i = 1, 3$ constitutes an equilibrium of the perturbed game. For players $j = 1, 2, 3$ the condition that $s_j = H$ is at least as good as $s_j = T$ is as follows:

- $j = 1$: $w(1-y) \geq (1-w)y$ or $w \geq y$
- $j = 2$: $w(1-\varepsilon_1)\varepsilon_3 \geq (1-w)\varepsilon_1(1-\varepsilon_3)$
- $j = 3$: $wy(1-\varepsilon_1) \geq (1-w)(1-y)\varepsilon_1$

Clearly one needs $y > 0$ to satisfy the condition for $j = 3$. If trembles vanish, for $i = 1, 3$ the probabilities ε_i or their relations $e_i = \varepsilon_i / (1-\varepsilon_i)$ have to converge to 0. By $w/(1-w) = e_1 / e_3$ all equilibria $\hat{s}$ with $0 < \hat{y} \leq w$ can be approximated by equilibria of such perturbed games[3] when ε_1 and ε_3 converge to 0.

For equilibria of type $\tilde{s}$ let now for $i = 1, 3$ the actual and minimum choice probability be denoted by ε_i for $s_i = H$ and assume $y \in [0,1]$. For $j = 1, 2, 3$ the best reply requirement for $s_j = T$ is then:

- $j = 1$: $w(1-y) \leq (1-w)y$ or $w \leq y$
- $j = 2$: $w\varepsilon_1(1-\varepsilon_3) \leq (1-w)(1-\varepsilon_1)\varepsilon_3$
- $j = 3$: $w\varepsilon_1 y \leq (1-w)(1-\varepsilon_1)(1-y)$

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[2] Perfectness considerations are based on strategy trembles (Selten, 1975): A player *i*, wanting to use strategy s_i^*, cannot avoid using other strategies $s_i \neq s_i^*$ with small but positive (mistake) probabilities. An equilibrium s^* is perfect if it can be approximated by equilibria of (by trembles) perturbed games whose (mistake) probabilities vanish. Thus perfectness alludes to a world where irrationality (in the form of strategy trembles) is present and studies the limiting behavior when irrationality becomes very unlikely.

[3] Since y with $0 < y \leq w < 1$ has to be approximated for player 2 both choices, $s_2 = H$ and $s_2 = T$ must yield the same payoff expectation which is guaranteed by $w/(1-w) = e_1 / e_3$.

For $e_1 = \varepsilon_1/(1-\varepsilon_1) \to 0$ the condition for $j=3$ holds sooner or later for $y<1$. To justify $w \le y < 1$ one must have $we_1 = (1-w)e_3$. For trembles $w/(1-w) = e_3/e_1$ all equilibria $\tilde{s}$ with $w \le \tilde{y} < 1$ can be approximated and are therefore perfect.

q.e.d.

According to Proposition 2 perfectness hardly restricts the multiplicity of equilibria by narrowing down the scope of mixing by player 2 ($\hat{y}$, respectively $\tilde{y}$). It cannot avoid the large multiplicity of potential solution candidates. We therefore apply an even more refined equilibrium concept which rules out arbitrariness when specifying trembles. For a uniformly perfect equilibrium[4] all minimum choice probabilities are the same, namely ε where ε is a small but positive number. According to this more refined equilibrium concept we can usually, namely for $w \neq 1/2$, derive a unique solution.

Proposition 3: Except for the special case $w = 1/2$ only the equilibrium q^* is uniformly perfect.

Proof: We rely on the notation and the conditions in the proof of Proposition 2. Uniform trembles imply $\varepsilon_i = \varepsilon_j$ for all $i, j = 1, 2, 3$ and thus $e_1 = e_3$. Remember, furthermore, that w is assumed to satisfy $1/2 \le w < 1$. For $w > 1/2$ the condition for $j=2$ in view of $\hat{s}$ (see the proof of Proposition 2) is thus satisfied as a strict inequality implying that only $y=1$ can be approximated which, however, is excluded by the condition for $j=1$. Thus for $1/2 < w < 1$ no equilibrium of the type $\hat{s}$ can be uniformly perfect.

For $\tilde{s}$ the assumption $1/2 < w < 1$ implies again $y=1$ due to $e_1 = e_3$. For $y=1$ the condition for $j=3$ can, however, not be true in the range $e_1 > 0$. Thus also no equilibrium of type $\tilde{s}$ can be uniformly perfect for $1/2 < w < 1$.

For $w = 1/2$ the condition for $j=2$ is always satisfied in form of an equality. But then uniform perfectness of $\hat{s}$ requires only $0 < \hat{y} \le w$, i.e. all equilibria of type $\hat{s}$ with $0 < \hat{y} \le w$ and, similarly, of type $\tilde{s}$ with $w \le \tilde{y} < 1$ are uniformly perfect for $w = 1/2$.

Finally, q^* is uniformly perfect since one can always find small enough uniform trembles such that q^* describes a possible strategy vector of the uniformly perturbed game.

q.e.d.

Note that efficiency in the sense of a larger payoff sum of all three players implies $x=1$ due to $w > 1/2$. Thus the inefficiency of the unique benchmark equilibrium q^* increases with w. The maximal payoff sum of w, implied by $x=1$, could be distributed continuously between 1 and 2 or 3 by choosing y accordingly (the larger y the less 1 would earn) and the share y of 2 and 3 between 2 and 3 by an appropriate choice of z (the larger z the less 2 would earn).

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[4] According to uniform perfectness all mistake probabilities on which perfectness relies are the same, namely ε which is a small but positive number. The idea is that mistakes just occur and do not depend on the specific choice problem. Thus uniform perfectness denies rationality in making mistakes as it is, for instance, assumed by proper equilibria (Myerson, 1978).

4 Balance equilibria

Equilibrium points rely on common and commonly known rationality. If they fail to account for actual, e.g. experimentally observed decision behavior, one can either question the adequacy of the game theoretic representation[5] or the rationality assumption. The first attempt would render the rational choice approach as tautologic.[6] Here we want to confront it, however, with more behavioral ideas which have been inspired by stylized facts of actual decision making.

Whereas the usual rationality assumption requires (often local) optimization the two more behavioral concepts suggest that behavior is guided by comparing the overall effects of the competing decision alternatives. For the case at hand this means that for players $i = 1, 2, 3$ the total impact of the choice $s_i = H$ should be balanced by what $s_i = T$ yields. For an impulse balance equilibrium (Selten, Abbink and Cox, 2001) what has to be balanced, i.e. be equal, is the regret implied by $s_i = H$, respectively *T*, for a payoff balance equilibrium it is the expected payoff for $s_i = H$ and $s_i = T$.

Proposition 4: There is only one payoff balance equilibrium $q^+ = (x^+, y^+, z^+)$ given by $x^+ = 1 - w$, $y^+ = 1/2$, $z^+ = 1/2$ and only one impulse balance equilibrium $q^- = (x^-, y^-, z^-)$ with $x^- = w$, $y^- = 1/2$, $z^- = w^2 / (w^2 + (1-w)^2)$.

Proof: For player 1 the choice of $s_i = T$ with probability $1 - x$ means that he gains $(1-w)(1-x)y$ in expected payoff whereas for $s_i = H$ his (expected) payoff is given by $wx(1-y)$. Balancing yields

$$(1-w)(1-x)y = wx(1-y).$$

The corresponding equations for players 2 and 3 are

$$(1-w)(1-x)(1-y)z = wxy(1-z)$$

and

$$(1-w)(1-x)(1-y)(1-z) = wxyz.$$

The only solution of the system of three equations in the three unknowns *x*, *y*, and *z* is given by (x^+, y^+, z^+). For an impulse balance equilibrium the regret of $s_1 = H$ is $xy(1-w)$ and for $s_1 = T$ it is $(1-x)(1-y)w$. Balancing means that these have to be equal. For players 2 and 3 the corresponding equations are $z(1-x)y(1-w) = (1-z)x(1-y)w$ and $z(1-x)(1-y)(1-w) = (1-z)xyw$, respectively. The unique solution of these three equations is (x^-, y^-, z^-).

q.e.d.

[5] Players may not only care for their own payoff as captured by Figure II.1 and Table II.2 but also for the well-being of others (for an analysis of such repairs, which do not allow to question the rationality assumption, see Avrahami, Güth and Kareev, 2001).

[6] All that one learns from repairing the game theoretic representation is which structural aspects can better account for actual behavior if all players would be perfectly aware of them and take them rationally into consideration.

5 Experimental procedure

Unlike in our companion study (Avrahami et al., 2001) we do not rely on a rich experimental design. We rather concentrate on one of the six treatments of the other study for which we can compare the behavior of players 1 and 2 in the 2 person-(Parasite)game with that one in the 3 person-game analyzed above. This allows to explore how the existence of player 3, which captures the phenomenon of "Predating Predators", influences the behavior of players 1 and 2 and how player 3 behaves whose role is similar to the one of player 2 in the "Parasite" game except that his potential prey is also a hunter.

More specifically, we focus on $w = 3/4$ and on the case where this probability is initially not known but must be learned by experience (see Appendix for the instructions). Three participants just learn that nature will locate food for player 1 either at *H* or *T* and how player 2 (3) can gain by successively hunting a well-fed player 1 (2). Since the same team of three participants plays together about 100 successive rounds, they sooner or later learn how likely the locations *H* and *T* are.

Since we view the experiment as an explorative attempt to compare behavior in a simpler habitat (the "Parasite" game) with a richer and more adequate one, we do not introduce specific hypotheses in addition to the "benchmark solutions", derived above. Our main motivation is to compare actual behavior with the three benchmark solutions, derived above. For an easy comparison Table V.2 lists the strategies, the payoffs, the efficiency in the sense of the total payoff $(u_1 + u_2 + u_3)$ and also the relations of the solution payoffs $(u_1 / u_2 / u_3)$ for general probability w as well as for the experimentally used parameter $w = 3/4$ for all three benchmarks, the equilibrium solution q^*, the impulse balance equilibrium q^- and the payoff balance equilibrium q^+.

		Benchmarks					
		q^*		q^-		q^+	
		general w	$w = 3/4$	general w	$w = 3/4$	general w	$w = 3/4$
Strategies	s_1	$\frac{(1-w)^2}{(1-w)^2 + w^2}$	1/10	w	3/4	$1-w$	1/4
	s_2	w	3/4	1/2	1/2	1/2	1/2
	s_3	$1-w$	1/4	$\frac{w^2}{w^2 + (1-w)^2}$	9/10	1/2	1/2
Payoffs	u_1	$(1-w)w$	3/16	$\frac{w^2 + (1-w)^2}{2}$	5/16	$w(1-w)$	3/16
	u_2	$(1-w)^2 w^2 / \left[(1-w)^2 + w^2\right]$	9/160	$\frac{w^2 + (1-w)^2}{w^2 + (1-w)^2}$	9/160	$(1-w)w/2$	3/32
	u_3	$(1-w)^2 w^2 / \left[(1-w)^2 + w^2\right]$	9/160	$\left[w^4 + (1-w)^4\right] / \left[2w^2 + 2(1-w)^2\right]$	41/160	$(1-w)w/2$	3/32
Total Payoff $u_1 + u_2 + u_3$		$(1-w)w / \left[(1-w)^2 + w^2\right]$	3/10	$(1-w)^2 + w^2$	5/8	$2w(1-w)$	3/8
Payoff Relations $u_1 / u_2 / u_3$		Footnote[7]	10/3/3	Footnote[8]	50/9/41	2/1/1	2/1/1

Table V.1: Strategies, payoffs, payoff sum and relations of the three benchmark solutions for general *w* and *w* = ¾

6 Results

To ignore beginning and end effects the first and last few rounds are excluded from analysis and only rounds 6 to 95 are reported. Since the probability $w = 3/4$ has not been known initially and could only be learned from experience, these are divided into three periods: Period 1 (rounds 6-35), Period 2 (rounds 36-65), and Period 3 (rounds 66-95). Distinguishing Periods 1, 2 and 3 should allow to check whether learning takes place and if so, how it changes the decision making of players 1, 2, and 3 vis-à-vis the different benchmarks. Table VI.1 presents the average strategies for the three players in each of the three periods. Although we are more interested in the predictive power of the three benchmark equilibria, derived above, it seems interesting to note that efficiency as measured by the sum $u_1 + u_2 + u_3$ of individual payoffs is monotonically declining (the same applies to $u_1 + 2u_2 + 2u_3$ which takes into account that for players 2 and 3 the gains are twice the number of their tokens won). So, whatever players learn, it does not enhance overall efficiency.

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7 $\left[(1-w)^2 + w^2\right] / (1-w)w / (1-w)w$

8 $\left[w^4 + 2w^2(1-w)^2 + (1-w)^4\right] / 2w^2(1-w)^2 / \left[w^4 + (1-w)^4\right]$

		Period 1	Period 2	Period 3	Mean
Strategies	s_1	.58	.59	.62	.60
	s_2	.53	.54	.46	.51
	s_3	.58	.72	.72	.68
Payoffs	u_1	.30	.25	.26	.27
	u_2	.11 ($\times 2$)	.11 ($\times 2$)	.11 ($\times 2$)	.11 ($\times 2$)
	u_3	.19 ($\times 2$)	.21 ($\times 2$)	.17 ($\times 2$)	.19 ($\times 2$)
Total Payoffs $u_1 + u_2 + u_3$		.60	.57	.54	.57
Payoff Relations $u_1 / u_2 / u_3$		30 / 11 / 19	25 / 11 / 21	26 / 11 / 17	27 / 11 / 19

Table VI.1: Average behavior, payoffs, payoff sum, and relations, separately for each period. The payoffs are given as proportions of the number of tokens each player won; the actual gains for Players 2 and 3 were twice the number of their tokens.

The typical behavior in Period 1 is close to 1/2 for all three players. This was to be expected in view of the fact that *w* had not been announced in advance and could only be learned over time. Actually, by an unbiased guess one should have a priorily expected $w = 1/2$ instead of $w = 3/4$. Furthermore, for $w = 1/2$ all three benchmark solutions suggest unbiased mixing ($x = y = z = 1/2$) for all players. The average strategy of Player 3 rises markedly in Period 2 and remains high in Period 3, that of Player 1 rises moderately in each period while that of Player 2 remains close to 1/2 and even goes somewhat down in Period 3. The payoffs of the three players (less so for player 1) remain more or less constant over the three periods in spite of the changes in strategies.

One could argue, of course, that the averages, and in particular that close to 1/2 do not necessarily reflect a strategy of $s = 1/2$ but a combination of, e.g., two groups employing two opposed extreme strategies or any other combination. We therefore divided the range of 0-1 into five categories such that:

s = min, if *s* is closer to 0 than to $1 - w$;
s = $1 - w$, if *s* is closer to $1 - w$ than to either 0 or 1/2;
s = 1/2, if *s* is closer to 1/2 than to either $1 - w$ or *w*;
s = *w*, if *s* is closer to *w* than to either 1/2 or 1;
s = max, if *s* is closer to 1 than to *w*.

We could thus count the number of players in each role whose strategy falls into each of these categories. In other words, we can assess the frequency of the following (in the sense of *H*-shares):

$$x, y, z \in [0, \varepsilon], x, y, z \in [1/4 \pm \varepsilon], x, y, z \in [1/2 \pm \varepsilon], x, y, z \in [3/4 \pm \varepsilon], x, y, z \in [1 - \varepsilon, 1],$$

with ε = 1/8. Note that, since the range of the min and max categories is half that of the other categories (1/8 versus 1/4) and, since two of the benchmarks predict that one player would use one of these extreme categories (s_1^* is min and s_1^- is max) one should multiply the number of cases found in these extreme categories by two for a better comparison. Table VI.2 presents the number of cases found in each category for players in each role, separately for each of the three periods.

	Period 1					Period 2					Period 3				
Player	min	1-*w*	1/2	*w*	max	min	1-*w*	1/2	*w*	max	min	1-*w*	1/2	*w*	max
1		2	8	6			2	8	6			1	6	9	
2		3	10	2	1×2		3	9	3	1×2		4	10	2	
3		2	8	4	2×2			5	7	4×2			4	9	3×2

Table VI.2: The number of cases in every strategy-category for each player in each period. Note that since the range of the min and max categories is half that of the other categories, the number of cases should be doubled for a better comparison.

As can be seen in Table VI.2, the prominent strategy in Period 1 is close to 1/2 for all three players, although for Player 1 and 3 there are more cases above than there are below 1/2. In Period 2 the strategy of Player 3 becomes more extreme (in the sense of *H*-plays) with 11 (or 15 after correction for range) choosing a strategy higher than 1/2. In Period 3 the number of Players 3 who play higher than 1/2 is 12 (or 15 after correction for range) but here also Player 1's strategy changes such that the prominent strategy of Player 1 is now *w* rather than 1/2. It is easy to see that of the three benchmarks, the Impulse Balance best describes the players' behavior in Period 3 and the Unique Equilibrium – worst.

To better evaluate the degree by which the different benchmarks predict participants' behavior in the game we calculated, for every player in a triad, the absolute difference between the strategy the player adopted in a period and the strategy predicted by the benchmarks. Table VI.3 presents the mean absolute distance between the actual strategy adopted by participants and that predicted by each of the benchmarks – separately for every player in each period.

Benchmark	Player	Period 1	Period 2	Period 3	All
UE	1	.477	.490	.522	.496
	2	.241	.237	.288	.255
	3	.341	.473	.468	.427
	all	.353	.400	.426	.393
IB	1	.204	.198	.151	.184
	2	.108	.131	.100	.113
	3	.330	.206	.203	.246
	all	.214	.178	.151	.181
PB	1	.327	.340	.372	.346
	2	.108	.131	.100	.113
	3	.175	.235	.231	.214
	all	.203	.235	.234	.224

Table VI.3

As is clear from the table, the Impulse Balance best predicts participants' behavior. What is more, participants' strategies (although less clearly for player 2) move closer to the strategy predicted by Impulse Balance as the game proceeds and as participants' knowledge of *w* improves. Indeed, an analysis of variance of the absolute distances, with Benchmark and Period as within-participants variables and Player's role as a between-participants variable reveals a significant effect of Benchmark, with means of .393, .181, and .224 for the Unique

Equilibrium, Impulse Balance, and Payoff Balance, respectively (F (2,30) = 27.42, $p < .001$). The interaction between Benchmark and Player is also statistically significant as Impulse Balance better predicts Player 1 than Player 3 while the opposite is true for the Unique Equilibrium and Payoff Balance (F (4,60) = 3.94, $p = .007$). More important is the interaction between Benchmark and Period (F (4,60) = 5.73, $p = .001$). Not only does Impulse Balance best predict participants' behavior overall, it improves over time while both Unique Equilibrium and Payoff Balance deteriorate. The triple interaction of Benchmark, Player and Period is also statistically significant with Impulse Balance's predictions improving over time for each Player while the other two deteriorate for each Player (F (8,120) = 3.04, $p = .004$).

7 Conclusions

Already our companion study (Avrahami et al., 2001) of the Parasite Game with just one predator player did support the impulse balance equilibrium. Compared to this the confirmation found here is even stronger. Of the three benchmark solutions the impulse balance equilibrium is the only one improving with experience (as measured by Period) whereas the two others deteriorate. Of the two others the payoff balance equilibrium fairs significantly and consistently much better than the unique uniformly perfect equilibrium. Bad news for game theory indeed[9]: In our view, it is remarkable that a static equilibrium concept is so successful in explaining strategic behavior in an experimental environment where learning about nature and about others is crucial.

From an ecological point of view the pure prey species (player 1) and the pure predator species (player 3) appear as moving somewhat parallel to better exploitation of their habitat although for player 1 the increase of *H*-choices is rather weak. The hybrid prey as well as predator-species (player 2) cannot take advantage of player 1's shift towards *H* since player 3 would very likely catch him when choosing *H*. This illustrates how predation of predators may help to understand decision behavior better in a stable but highly stochastic habitat.

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[9] For the non-(uniformly) perfect equilibria the results would be even worse since they predict $s_1 = s_3 \in \{0,1\}$ what is not at all in line with the results, listed in Table VI.1.

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Appendix: Instructions♦

We shall play a game of three participants, Player *A*, Player *B*, and Player *C*, who will be determined by a lottery that we shall conduct now. (Out of three pieces of paper in a box each participant drew one with either "Player *A*", "Player *B*" or "Player *C*").

I will explain the procedure of the game and ask you not to talk to one another from now on. Any talk or communication between you will cause an interruption of the game.

The procedure of the game:

In this bag there are tokens of two colors: red and green, and each of you has an apparatus by which you can signal red or green, like that. On every round, each of you will choose red or green and signal it in the apparatus, so that the color that you chose will be revealed. You have to do that while hiding the apparatus under the table and show it only when I say so. At the same time, I will draw one token out of the bag, without looking, and show it to you. After I show you the token I will return it to the bag.

If the color chosen by Player *A* will be the color of the token I drew and the color that Player *B* chose is different – irrespective of the color chosen by Player *C* – Player *A* will get a token worth 1 NIS.

If the color that Player *A* chose is the color of the token I drew and the color that Player *B* chose is also the same and the color that Player *C* chose is different – Player *B* will get a token worth 2 NIS.

If the color that Player *A* chose is the color of the token I drew and the color that Player *B* chose is the same but the color that Player *C* chose is also the same – Player *C* will get a token worth 2 NIS.

If the color that Player *A* chose is different from the color of the token I drew out of the box – none of the players gains anything.

We shall perform this a large number of times – more than a hundred – and it is, of course, worth your while to earn as many tokens as you can. In the end of the game we shall count the tokens and each of you will get paid accordingly.

I will repeat the scheme of payoffs.

Imagine that I drew green and that Player *A* chose red – no one gets anything.

Imagine that I drew green, Player *A* chose green and Player *B* chose red – *A* gets a token.

♦ The game was advertised as "The Color Game" to prevent any preliminary expectations on the parts of participants concerning predating behavior.

Imagine that I drew green, Player *A* chose green, Player *B* chose green and Player *C* chose red – *B* gets a token.

Imagine that I drew green, Player *A* chose green, Player *B* chose green and also Player *C* chose green – *C* gets a token.

Obviously, the same payoffs hold for a match in red.

In the end of the game we shall trade every token of Player *A* for 1 NIS and every token of Players *B* and *C* for 2 NIS.