Supporting Information

Here we derive the analytical results that we have given in the main text. In Section 1 we investigate the coexistence of responsive and unresponsive strategies. To this end we analyze the one-stage game depicted in Figure 1 in the main text. We show that whenever the payoffs of the two options *L* and *R* are negatively frequency dependent, then also the benefits of responsiveness are negatively frequency dependent (Result 1). As argued in the main text, this favors the coexistence of responsive and unresponsive strategies. In Section 2 we address the question why individuals are consistent in their responsiveness. To this end we analyze the two-stage game described in the main text. We assume that positive feedbacks act on responsiveness; that is, responsiveness is less costly (or more beneficial) for individuals that have been responsive before. We show that under this assumption, at any ESS, individuals that are responsive in the first stage have a higher tendency to be responsive in the second stage than individuals that are unresponsive in the first stage (Result 2). As a result individuals differ consistently in their responsiveness.

1. Coexistence of responsive and unresponsive individuals

Consider the one-stage game depicted in Figure 1 in the main text. A strategy in this game is a quadruple $p = (p_r, \bar{l}, l_0, l_1)$, where

p_r	is the probability that an individual is responsive,
$\bar{l}$	is the probability that an unresponsive individual chooses option *L* and
l_i	is the probability that a responsive individual chooses option *L* in state $i = 0,1$.

We consider a monomorphic population where each individual is responsive with probability p_r. We assume that for any given level p_r of responsiveness, individuals show the corresponding ESS behavior $(\bar{l}^*, l_0^*, l_1^*)$. Selection increases the level of responsiveness p_r whenever the benefits of responsiveness exceed the costs of responsiveness *C*. The benefits of responsiveness are given by the expected excess payoff

E of a responsive over an unresponsive individual. In state *i*, a responsive individual plays strategy l_i^* and obtains the payoff $l_i^* \cdot a_i + \left(1 - l_i^*\right) \cdot b_i$, an unresponsive individual plays $\bar{l}^*$ and obtains the payoff $\bar{l}^* \cdot a_i + \left(1 - \bar{l}^*\right) \cdot b_i$. The payoff difference in state *i* is therefore $\left(l_i^* - \bar{l}^*\right) \cdot \left(a_i - b_i\right)$ and the benefits of responsiveness are thus given by

$$E\left(p_r\right) = \sum_i s_i \cdot \left(l_i^* - \bar{l}^*\right) \cdot \Delta_i \tag{1}$$

where

$$\Delta_i = a_i - b_i \tag{2}$$

gives the excess payoff of option *L* over *R* in state *i*. Note that $E\left(p_r\right) \geq 0$ since a responsive individual can always achieve a payoff at least as high as unresponsive individual.

Result 1: If the excess payoff Δ_i of choosing *L* over *R* in state *i* is negatively frequency dependent, that is, if Δ_i decreases with the frequency of individuals f_i that choose option *L* in state *i*, then the benefits of responsiveness are also negatively frequency dependent. Technically,

$$\frac{d\Delta_i}{df_i} < 0 \quad \Rightarrow \quad \frac{dE}{dp_r} < 0 \tag{3}$$

as long as $E > 0$.

Proof. Note that

$$\frac{dE}{dp_r} = \sum_i s_i \cdot \left(l_i^* - \bar{l}^*\right) \cdot \frac{d\Delta_i}{dp_r} + \sum_i s_i \cdot \Delta_i \cdot \frac{dl_i^*}{dp_r} - \frac{d\bar{l}^*}{dp_r} \cdot \sum_i s_i \cdot \Delta_i \tag{4}$$

which simplifies to

$$\frac{dE}{dp_r} = \sum_i s_i \cdot \left(l_i^* - \bar{l}^*\right) \cdot \frac{d\Delta_i}{dp_r} \tag{5}$$

since the last two terms in (4) equal to zero. This can be seen at follows. The expected payoffs of a responsive and an unresponsive individual are given by $\sum_i s_i \cdot l_i \cdot \Delta_i$ and $\bar{l} \cdot \sum_i s_i \cdot \Delta_i$, respectively. From this follows that at any ESS $(\bar{l}^*, l_0^*, l_1^*)$,

$$l_i^* = \begin{cases} 1 & \text{for} \quad \Delta_i > 0 \\ 0 & \text{for} \quad \Delta_i < 0 \end{cases} \qquad \text{and} \qquad \bar{l}^* = \begin{cases} 1 & \text{for} \quad \sum_i s_i \cdot \Delta_i > 0 \\ 0 & \text{for} \quad \sum_i s_i \cdot \Delta_i < 0 \end{cases} \tag{6}$$

which implies that the last two terms in (4) equal to zero since either $\Delta_i = 0$ or

$$\Delta_i \neq 0 \Rightarrow \frac{dl_i^*}{dp_r} = \frac{dl_i^*}{d\Delta_i} \cdot \frac{d\Delta_i}{dp_r} = 0, \tag{7}$$

and either $\sum_i s_i \cdot \Delta_i = 0$ or

$$\sum_i s_i \cdot \Delta_i \neq 0 \Rightarrow \frac{d\bar{l}^*}{dp_r} = \frac{d\bar{l}^*}{d(\sum_i s_i \cdot \Delta_i)} \cdot \frac{d(\sum_i s_i \cdot \Delta_i)}{dp_r} = 0. \tag{8}$$

To show Result 1 we thus have to show that whenever the excess payoff Δ_i of choosing *L* over *R* is negatively frequency dependent, then also

$$\frac{dE}{dp_r} = \sum_i s_i \cdot \left(l_i^* - \bar{l}^*\right) \cdot \frac{d\Delta_i}{dp_r} \quad < \quad 0 \tag{9}$$

or, equivalently

$$\frac{dE}{dp_r} = \sum_i s_i \cdot \left(l_i^* - \bar{l}^*\right) \cdot \frac{d\Delta_i}{df_i} \cdot \frac{df_i}{dp_r} \quad < \quad 0. \tag{10}$$

The frequency of individuals f_i that chooses option *L* in state *i* is given by $f_i = p_r \cdot l_i^* + (1 - p_r) \cdot \bar{l}^*$ and thus $\frac{df_i}{dp_r} = l_i^* - \bar{l}^* + p_r \cdot \frac{dl_i^*}{dp_r} + \left(1 - p_r\right) \cdot \frac{d\bar{l}^*}{dp_r}$. Note that from equations (1) and (6) follows that whenever $E(p_r) > 0$ then $\Delta_i \neq 0$ in both states and therefore $\frac{dl_i^*}{dp_r} = 0$. Consequently,

$$\frac{df_i}{dp_r} = l_i^* - \bar{l}^* + \left(1 - p_r\right) \cdot \frac{d\bar{l}^*}{dp_r}. \tag{11}$$

We now distinguish two cases.

Case 1: Unresponsive individuals play a pure strategy, i.e. $\bar{l}^* = 1$ or $\bar{l}^* = 0$. In this case, $\sum_i s_i \Delta_i \neq 0$ and thus $\frac{d\bar{l}^*}{dp_r} = 0$. But this implies with equation (10) and (11) that

$$\frac{dE}{dp_r} = \sum_i s_i \cdot \left(l_i^* - \bar{l}^*\right)^2 \cdot \frac{d\Delta_i}{df_i} \quad < \quad 0 \tag{12}$$

since $\frac{d\Delta_i}{df_i} < 0$.

Case 2: Unresponsive individuals play a mixed strategy, i.e. $0<\overline{l}^*<1$. In this case, $\sum_i s_i\Delta_i=0$ and $\sum_i s_i \frac{d\Delta_i}{dp_r}=0$. This, in combination with the facts that $\frac{d\Delta_i}{dp_r}=\frac{d\Delta_i}{df_i}\cdot\frac{df_i}{dp_r}$ and $\left.\frac{df_i}{dp_r}\right|_{l_i^*=1} > \left.\frac{df_i}{dp_r}\right|_{l_i^*=0}$ implies that $\frac{d\Delta_i}{dp_r}>0$ in one state and $\frac{d\Delta_j}{dp_r}<0$ in the other state. From this follows that

$$\text{sign}(l_i^*-\overline{l}^*)=-\text{sign}\frac{d\Delta_i}{dp_r} \tag{13}$$

and thus $\frac{dE}{dp_r}=\sum_i s_i\cdot\left(l_i^*-\overline{l}^*\right)\cdot\frac{d\Delta_i}{dp_r}<0$. This establishes Result 1.

Calculating the benefits of responsiveness for specific applications. As argued in the main text, both the responsive and the unresponsive strategy can spread when rare whenever

$$E(0) \quad > \quad C \quad > \quad E(1) \tag{14}$$

leading to the coexistence of both strategies. For any particular application at hand we might thus want to know $E(0)$ and $E(1)$.

Consider first the benefits of responsiveness $E(1)$ in a population of responsive individuals. We distinguish three cases. First, if responsive individuals play a mixed ESS in both states (i.e., $0<l_i^*<1$), as in the patch choice and hawk dove game in the main text, the frequency dependent payoffs between the two choice *L* and *R* will be equalized in both states (i.e.,$\Delta_i=0$) and thus

$$E(1)=0. \tag{15}$$

Second, when responsive individuals mix in one of the states but not in the other, $\Delta_i\neq 0\Rightarrow l_i^*-\overline{l}^*=0$ and thus, as above, $E(1)=0$. Third, when responsive individuals do not mix in any of the two states (i.e., play a pure strategy in both states) we get $E(1)=\min(s_0\cdot|\Delta_0|, s_1\cdot|\Delta_1|)$.

Consider next the benefits of responsiveness $E(0)$ in a population of unresponsive individuals. In such a population, unresponsive individuals will typically play a mixed strategy. Using the facts that in this case $\sum_i s_i\cdot\Delta_i=0$ and Δ_i is positive in some state (i.e., $l_i^*=1$) and negative in the other (i.e., $l_i^*=0$) we get

$$E(0) = s_0 \cdot s_1 \cdot \Delta \tag{16}$$

where $\Delta = \sum_i |\Delta_i|$ is a measure for the environmental asymmetry in such a population that can be readily calculated. For example, in case of the hawk-dove game considered in the main text $\Delta = \frac{1}{2} \cdot |V_0 - V_1|$. In case of the patch choice game considered in the main text, $\Delta_i = A_i / \tilde{A} - B_i / \tilde{B}$ where $\tilde{X} = \bar{X} / \left(\bar{A} + \bar{B}\right)$ and $\bar{X} = s_0 \cdot X_0 + s_1 \cdot X_1$ for $X = A, B$.

2. Consistent individual differences in responsiveness

Consider the two-stage game described in the main text. Both, in the first and in the second stage, individuals face a situation as depicted in Figure 1 in the main text. Both stages might either represent the same context at different points in time (e.g., patch choice early and late in the season) or different contexts (e.g., patch choice and aggressive encounters, as in the main text). For simplicity we assume that the environmental states in both stages are uncorrelated. The total payoff of an individual is given by the sum of payoffs this individual obtains in both stages.

To investigate consistency in responsiveness we allow that individuals can make their responsiveness in the second stage dependent on their responsiveness in the first stage. A strategy in the two-stage game is a tuple $p = (p_r, p_r|_r, p_r|_{ur}, l)$, where

p_r is the probability that an individual is responsive in the first stage,

$p_r|_r$ ($p_r|_{ur}$) is the probability that an individual that is responsive (unresponsive) in the first stage is responsive in the second stage,

l is a vector that specifies the behavior in the *L* vs. *R* choice situations, both in the first and in the second stage.

The expected net payoff of a rare mutant with strategy *p* in a resident population with strategy $\hat{p}$ is given by

$$w(p, \hat{p}) = p_r \cdot \left(p_r|_r \cdot w_{r,r} + (1 - p_r|_r) \cdot w_{r,ur} \right) + (1 - p_r) \cdot \left(p_r|_{ur} \cdot w_{ur,r} + (1 - p_r|_{ur}) \cdot w_{ur,ur} \right) \tag{17}$$

where $w_{j,i} = w_{j,i}(p, \hat{p})$ is the expected net payoff of an individual with responsiveness *j* = *r*,*ur* in the first stage and *i* = *r*,*ur* in the second stage (*r* = responsive, *ur* = unresponsive). These payoffs are given by

$$w_{j,i}(p, \hat{p}) = w_j(p, \hat{p}) + w_i\big|_j (p, \hat{p}) \tag{18}$$

where w_j is the expected first-stage net payoff of an individual with first-stage responsiveness *j* = *r*,*ur* and $w_i\big|_j$ is the expected second-stage net payoff of an individual with first-stage responsiveness *j* = *r*,*ur* and second-stage responsiveness *i* = *r*,*ur*.

Positive feedbacks on responsiveness. We say that positive feedbacks act on responsiveness whenever

$$w_r\big|_r (p, \hat{p}) \geq w_r\big|_{ur} (p, \hat{p}) \quad \text{and} \quad w_{ur}\big|_{ur} (p, \hat{p}) \geq w_{ur}\big|_r (p, \hat{p}) \tag{19}$$

with at least one inequality being strict. In words, either the expected second-stage net payoff of being responsive is higher for individuals that were responsive in the first-stage or the expected second-stage net payoff of being unresponsive is higher for individuals that were unresponsive also in the first stage. Such feedbacks might be the result of increased benefits of responsiveness or decreased costs of responsiveness for individuals that are consistently responsive.

Positive feedbacks via a reduction of costs. In the main text we assumed that the cost of responsiveness in the second-stage is lower for individuals that are responsive in the first stage (C_r) than for individuals that are unresponsive in the first stage (C_{ur}):

$$C_r < C_{ur}. \tag{20}$$

Note that this is a special case of positive feedbacks on responsiveness (19) since (20) implies that for an individual with strategy *p* in a resident population with strategy $\hat{p}$:

$$w_r\big|_r (p, \hat{p}) - w_r\big|_{ur} (p, \hat{p}) = C_{ur} - C_r > 0. \tag{21}$$

Result 2. Whenever positive feedbacks act on responsiveness, at any ESS $\hat{p}^*$, individuals that are responsive in the first stage have a higher tendency to be responsive in the second stage than individuals that are unresponsive in the first stage, that is

$$p_r^*\big|_r \geq p_r^*\big|_{ur}. \tag{22}$$

The inequality being strict when, at the ESS, both responsive and unresponsive individuals occur in the second stage.

Proof. The expected net payoff of a rare mutant with strategy p in a resident population with strategy $\hat{p}$ is given by (equation (17)):

$$w(p,\hat{p}) = p_r \cdot \left(w_{r,ur} + p_r\big|_r \cdot (w_{r,r} - w_{r,ur})\right) + (1-p_r)\cdot\left(w_{ur,ur} + p_r\big|_{ur} \cdot (w_{ur,r} - w_{ur,ur})\right), \tag{23}$$

or, equivalently (with (18)),

$$w(p,\hat{p}) = p_r \cdot \left(w_{r,ur} + p_r\big|_r \cdot (w_r\big|_r - w_{ur}\big|_r)\right) + (1-p_r)\cdot\left(w_{ur,ur} + p_r\big|_{ur} \cdot (w_r\big|_{ur} - w_{ur}\big|_{ur})\right). \tag{24}$$

Now note that from the definition of positive feedbacks (19) follows that $w_r\big|_r - w_{ur}\big|_r > w_r\big|_{ur} - w_{ur}\big|_{ur}$. To see that Result 2 follows from this consider the following three possibilities. (1) $w_r\big|_r - w_{ur}\big|_r < 0$. This implies that $w_r\big|_{ur} - w_{ur}\big|_{ur} < 0$. At such an ESS, $p_r^*\big|_r = p_r^*\big|_{ur} = 0$, being unresponsive is a dominant strategy in the second stage. (2) $w_r\big|_r - w_{ur}\big|_r = 0$. This implies that $w_r\big|_{ur} - w_{ur}\big|_{ur} < 0$. At such an ESS $p_r^*\big|_r \geq 0$ and $p_r^*\big|_{ur} = 0$. (3) $w_r\big|_r - w_{ur}\big|_r > 0$. In this case $w_r\big|_{ur} - w_{ur}\big|_{ur}$ might either be positive, zero or negative. At any ESS with $w_r\big|_{ur} - w_{ur}\big|_{ur} > 0$, $p_r^*\big|_r = p_r^*\big|_{ur} = 1$, being responsive is a dominant strategy in the second stage. At any ESS with $w_r\big|_{ur} - w_{ur}\big|_{ur} = 0$, $p_r^*\big|_r = 1$ and $p_r^*\big|_{ur} \leq 1$. At any ESS with $w_r\big|_{ur} - w_{ur}\big|_{ur} < 0$, $p_r^*\big|_r = 1$ and $p_r^*\big|_{ur} = 0$. This establishes Result 2.