Different forms of uncertainty differently affect the evolution of social learning

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Introduction: Uncertainty and learning

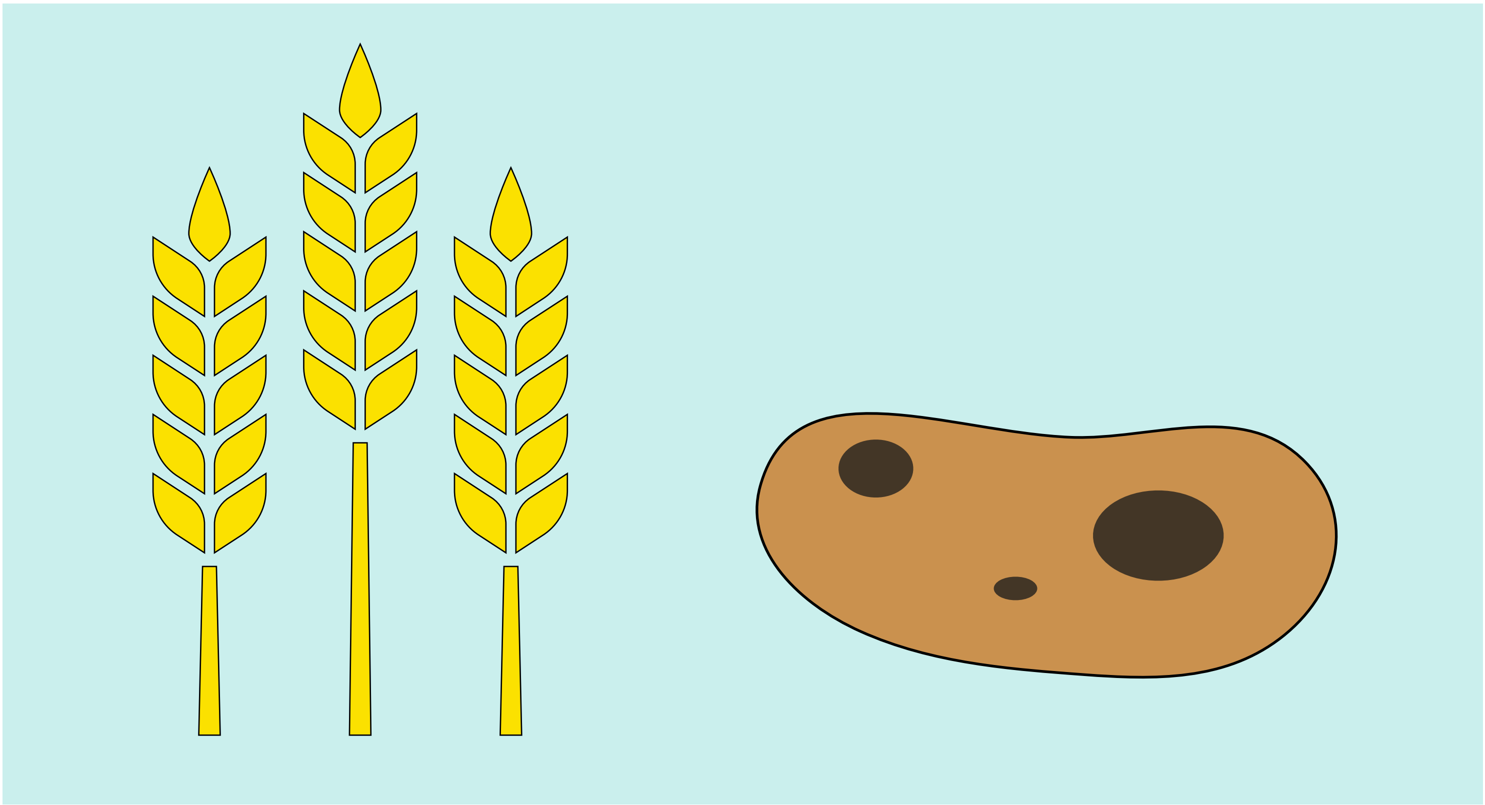
- We face unprecedented uncertainty: how does social learning evolve to address uncertainty?
- Social learning is beneficial when individuals are uncertain about which behavior is optimal.
- We know excessive environmental variability can deprecate and devalue social information.
- But which other forms of uncertainty are important, and how do they affect social learning?

Varieties of uncertainty

1. **Environmental variability:** a measure of how frequently or in what way behavioral payoffs change over time.
2. **Payoff ambiguity:** a measure of how discernible expected payoffs are from performing different behaviors.
3. **Selection set size:** the number of behavioral options available.
4. **Effective lifespan:** number of opportunities for individual learning.

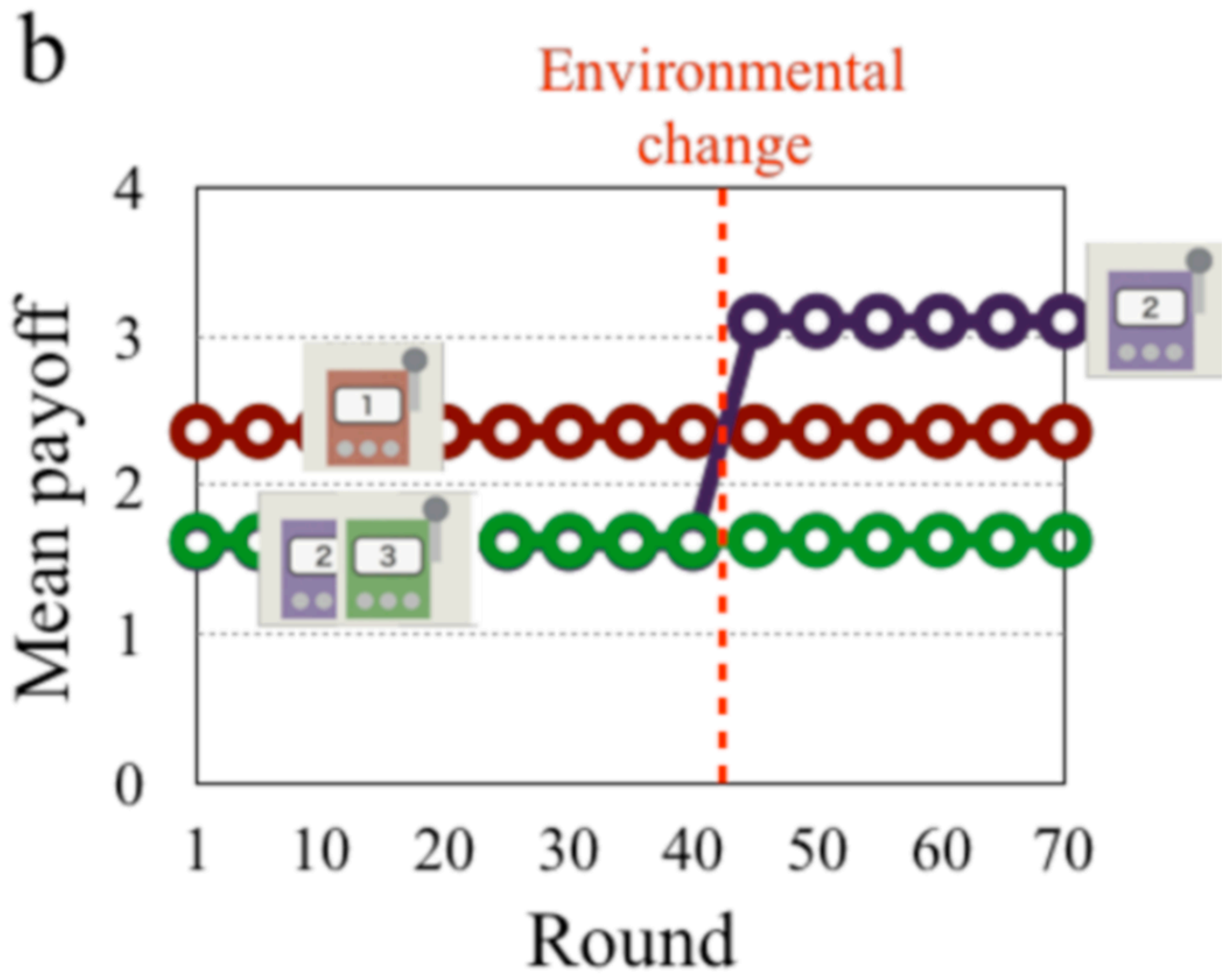
Uncertainty parameter 1: environmental variability

Sub-variety A: Change occurs with some probability at each time step (i.e. change is Poisson-distributed).



McElreath, *et al.*, (2005) prompt participants to choose between planting virtual wheat or potatoes in a computer-based experiment; which is more beneficial changes randomly with probability 1/20.

Sub-variety B: Change occurs once at some given time.



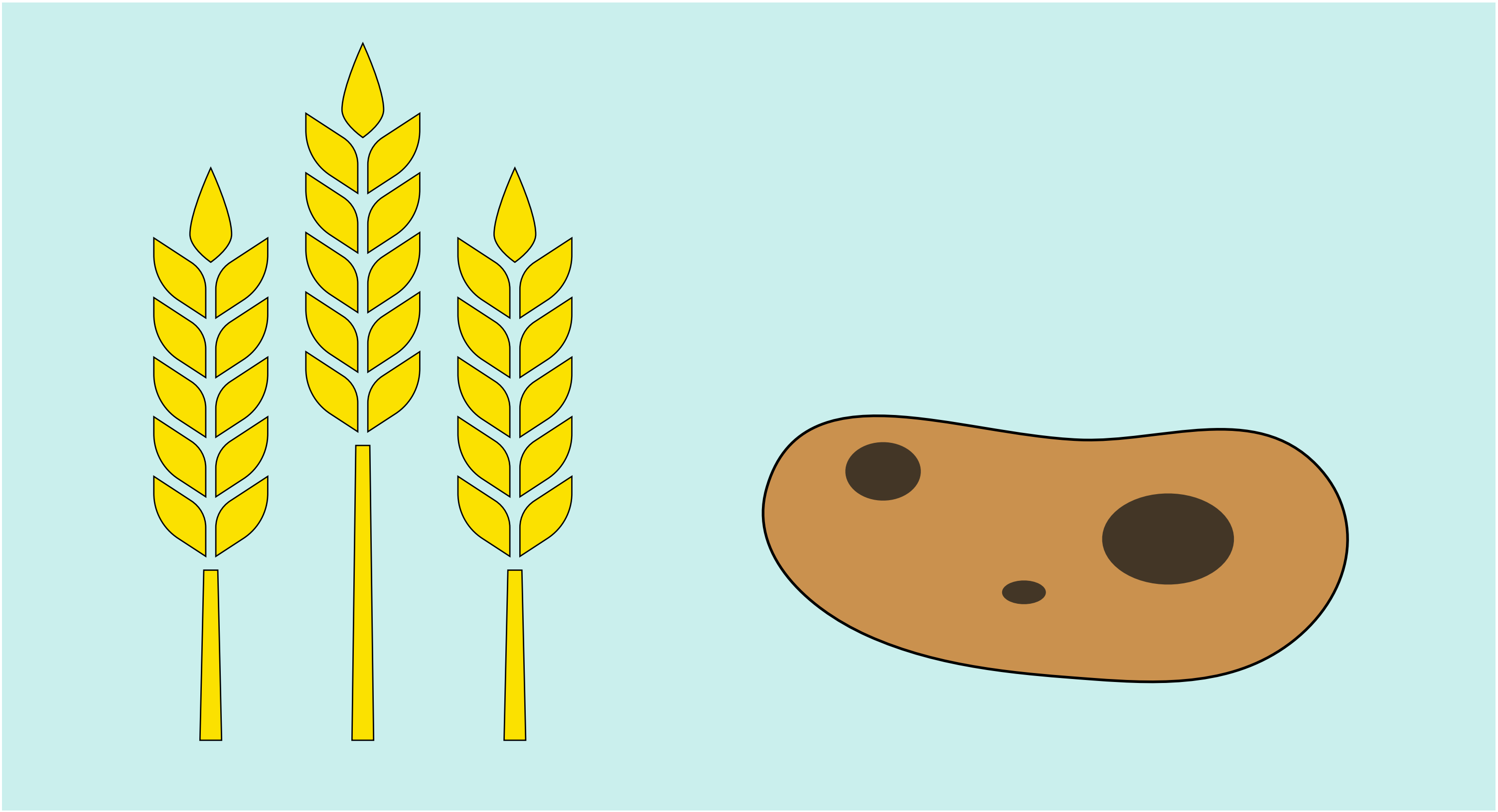
Toyokawa, *et al.*, (2019) designed experiment where one previously sub-optimal behavior became optimal at a certain round.

McElreath, R., et al., (2005). Applying evolutionary models to the laboratory study of social learning. *Evolution and Human Behavior,* 26(6).

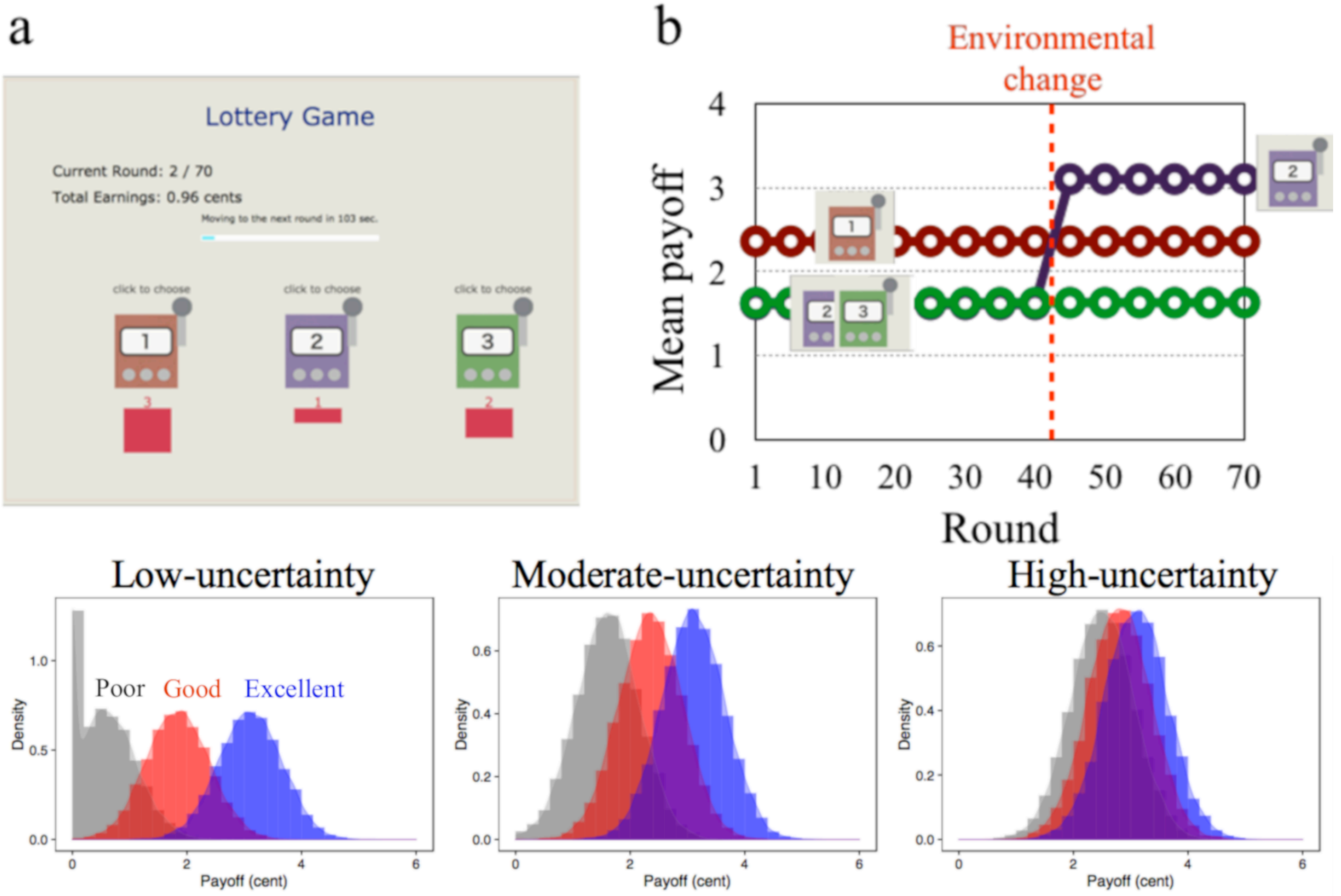
Toyokawa, W., Whalen, A., & Laland, K. N. (2019). Social learning strategies regulate the wisdom and madness of interactive crowds. *Nat. Hum. B.*

Uncertainty parameter 2: payoff ambiguity

McElreath, *et al.*, (2005) assume constant payoff ambiguity for participants deciding which virtual crop to plant: one crop has expected payoff 10 while the other has expected payoff 13, subject to environmental variability.



Toyokawa, *et al.*, (2019) assume three different payoff distributions (bottom row). Closer means translates to greater uncertainty.



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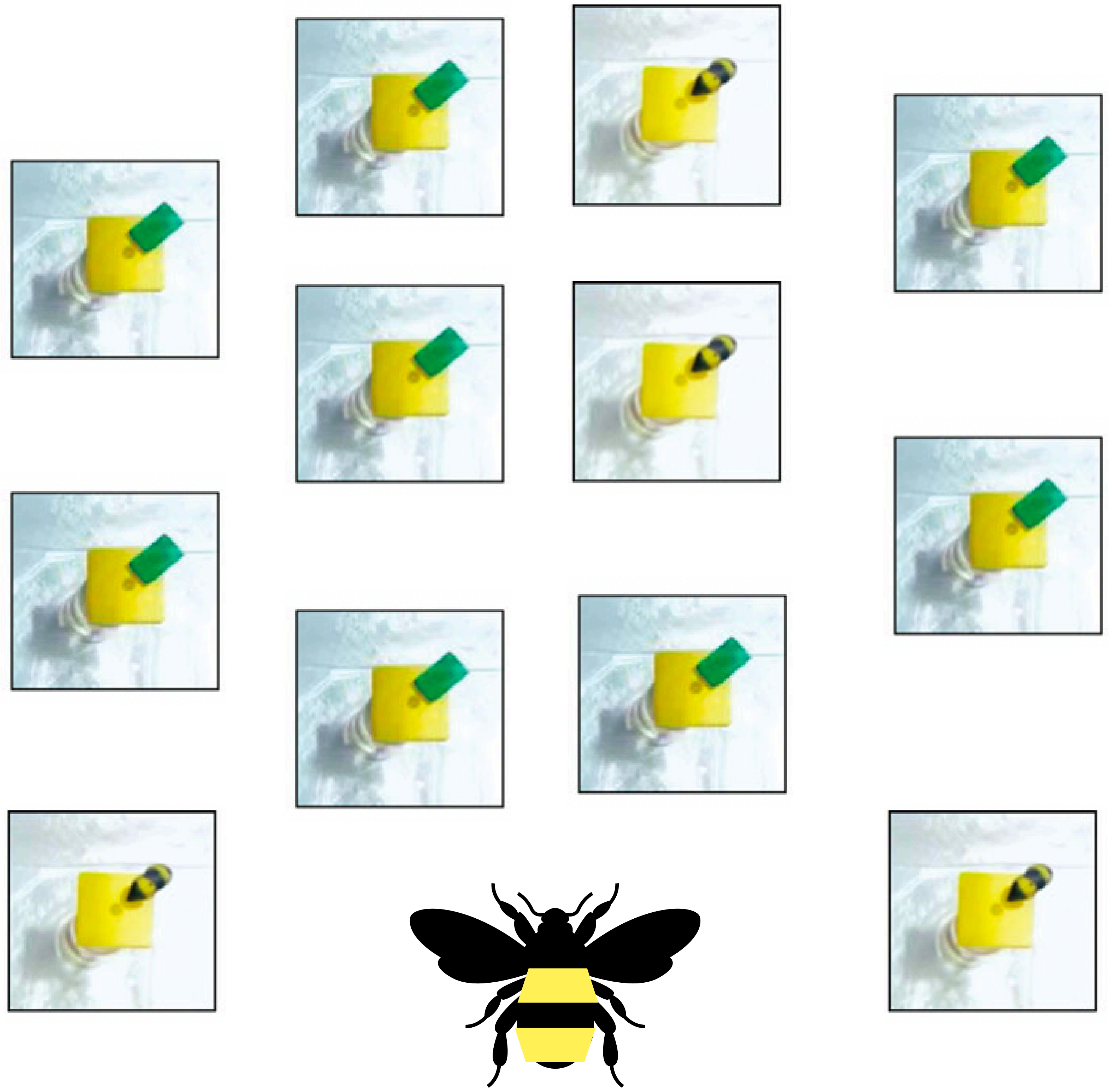
Uncertainty parameter 3: selection set size

Smolla, *et al.*, use insect model bumblebees (*bombus terrestris*) decide whether to use social cues (4 social cues spread among 12 in selection set).

Aplin, *et al.*, have animal model great tits (*parus major*) face a selection set size of 2: they can push a puzzle door on the blue side or red.



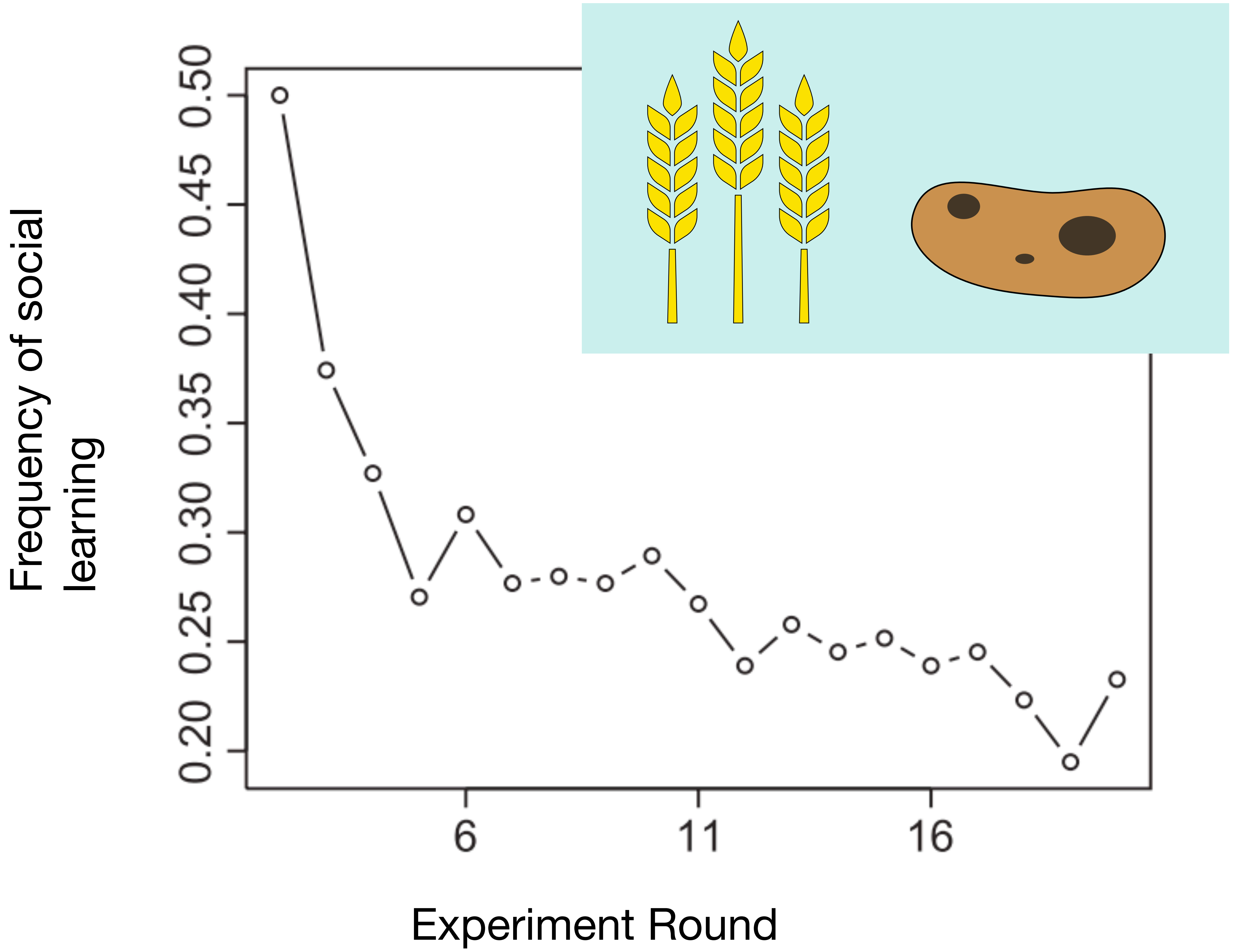
Smolla, M., Alem, S., Chittka, L., & Shultz, S. (2016). Copy-when-uncertain: Bumblebees rely on social information when rewards are highly variable. *Biology Letters*, 12(6).

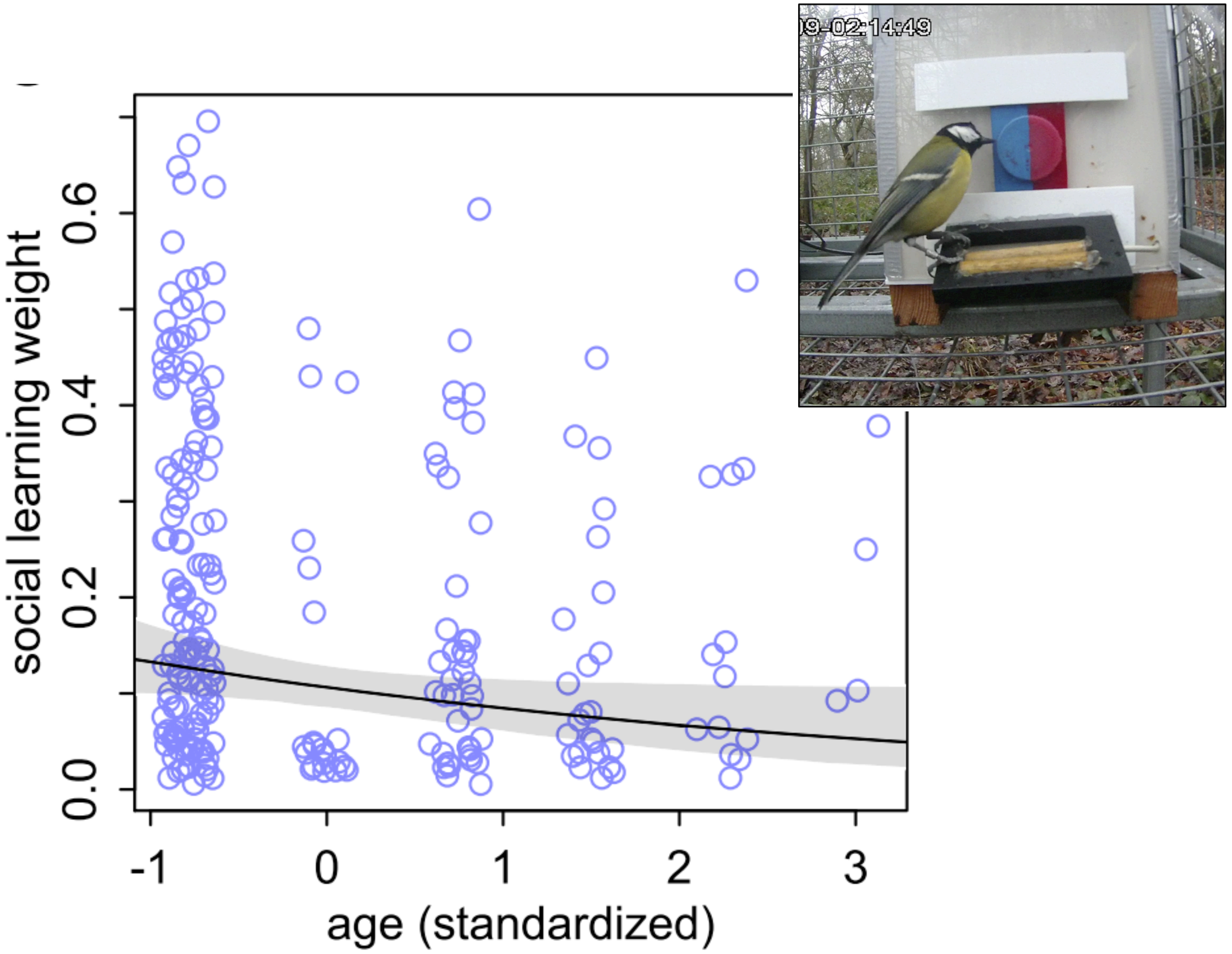
Aplin, L. M., Sheldon, B. C., & McElreath, R. (2017). Conformity does not perpetuate suboptimal traditions in a wild population of songbirds. *PNAS*, 114(30).

Uncertainty parameter 4: effective lifespan

McElreath, *et al.*,observed social learning was utilized more in the first rounds of their multi-round experiment.

Aplin, *et al.,* found that younger great tits were more likely to rely on social information.





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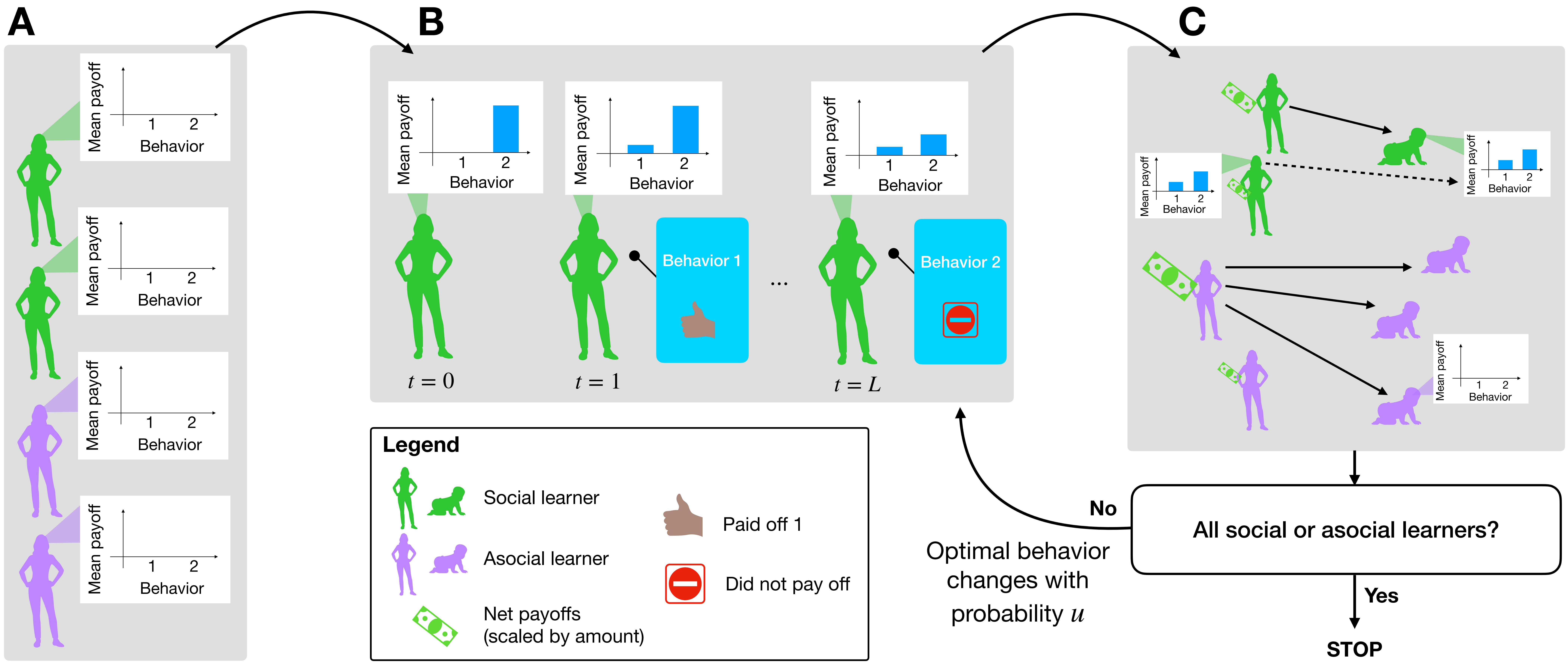
Model

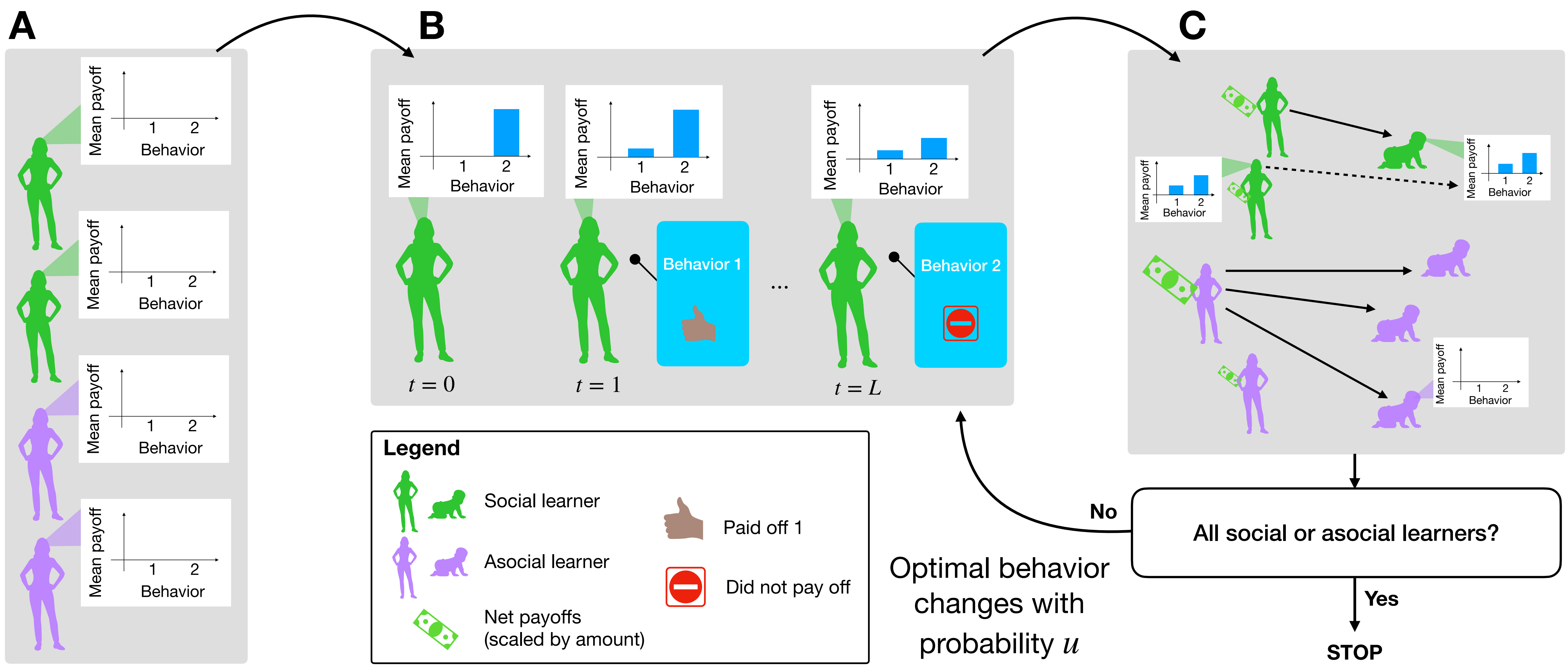


A. Simulated individuals (agents) are initialized as social or asocial learners.

B. All agents learn individually through trial-and-error greedy learning, with behavior selection weighted by softmax normalization. One behavior is optimal, pays off with probability $\pi_{\text{high}} = 0.9$; the rest are suboptimal and pay off 1 with probability $\pi_{\text{low}} \in \{0.1, 0.45, 0.8\}$.

C. A new population is generated by reproducers chosen at random with replacement, weighted by their relative net payoffs.

Computational analysis



Outcome measure:

Frequency of social learning fixation $\langle s \rangle$

- Average over 1000 trials per uncertainty parameter combination.
- Each trial ends after one generation with fixated population.
- 11 u × 3 π_{low} × 3 B × 4 L = 396 total uncertainty parameter combinations tested.

Uncertainty parameters

Symbol	Description	Values tested
u	Probability optimal behavior changes between generations	0.0, 0.1, ..., 1.0
B	Number of behavior options	2, 4, 10
π_{high}	Probability that the unique optimal behavior pays off 1	**0.9**
π_{low}	Probability one of $B-1$ non-optimal behaviors pays off 1	0.1, 0.45, 0.8
L	Time steps per generation	1, $B/2$, B, $2B$, $4B$
N	Population size	50, 100, 200, **1000**

https://github.com/mt-digital/UncMod/tree/CES2022_Pres

Datseris, G., Vahdati, A. R., & DuBois, T. C. (2022). Agents.jl: A performant and feature-full agent based modelling software of minimal code complexity. *Simulation.*

Analysis
Overview

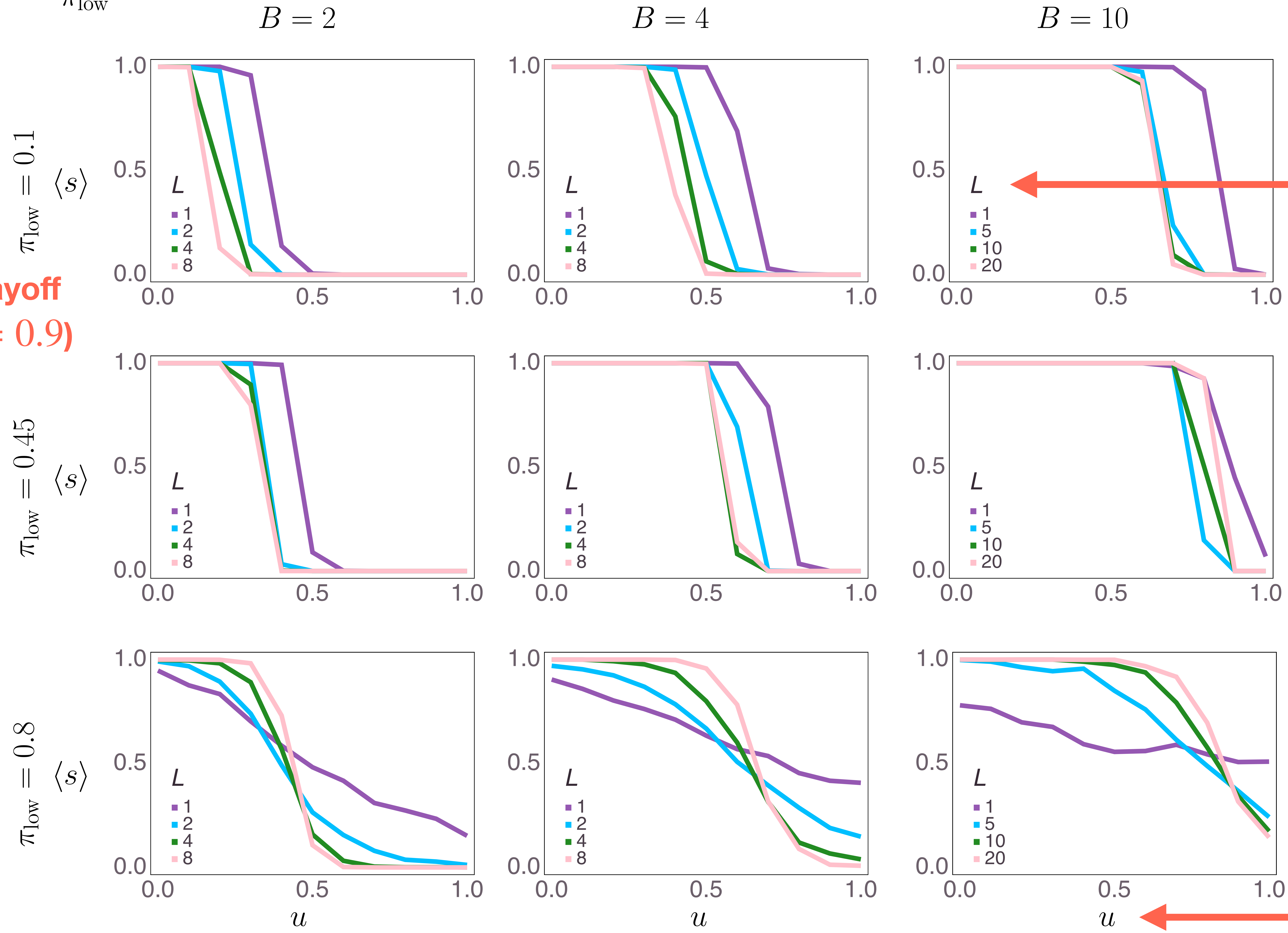
B

π_{low}

Selection set size (# of available behaviors)

Effective life span

Low behavioral payoff (recall $\pi_{\text{high}} = 0.9$)

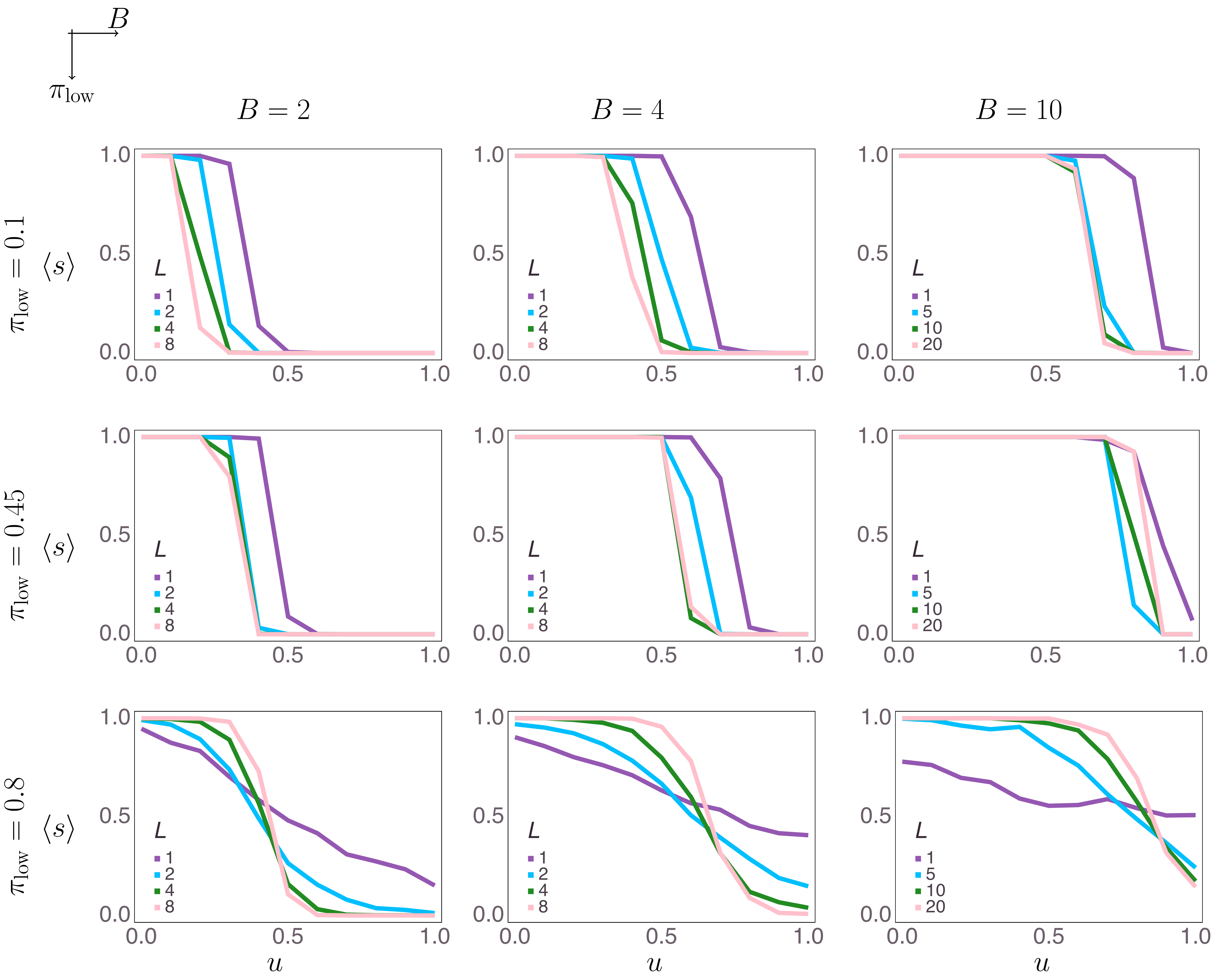


Environmental variability with values

$\{0.0,\ 0.1,\ \ldots,\ 1.0\}$

Analysis

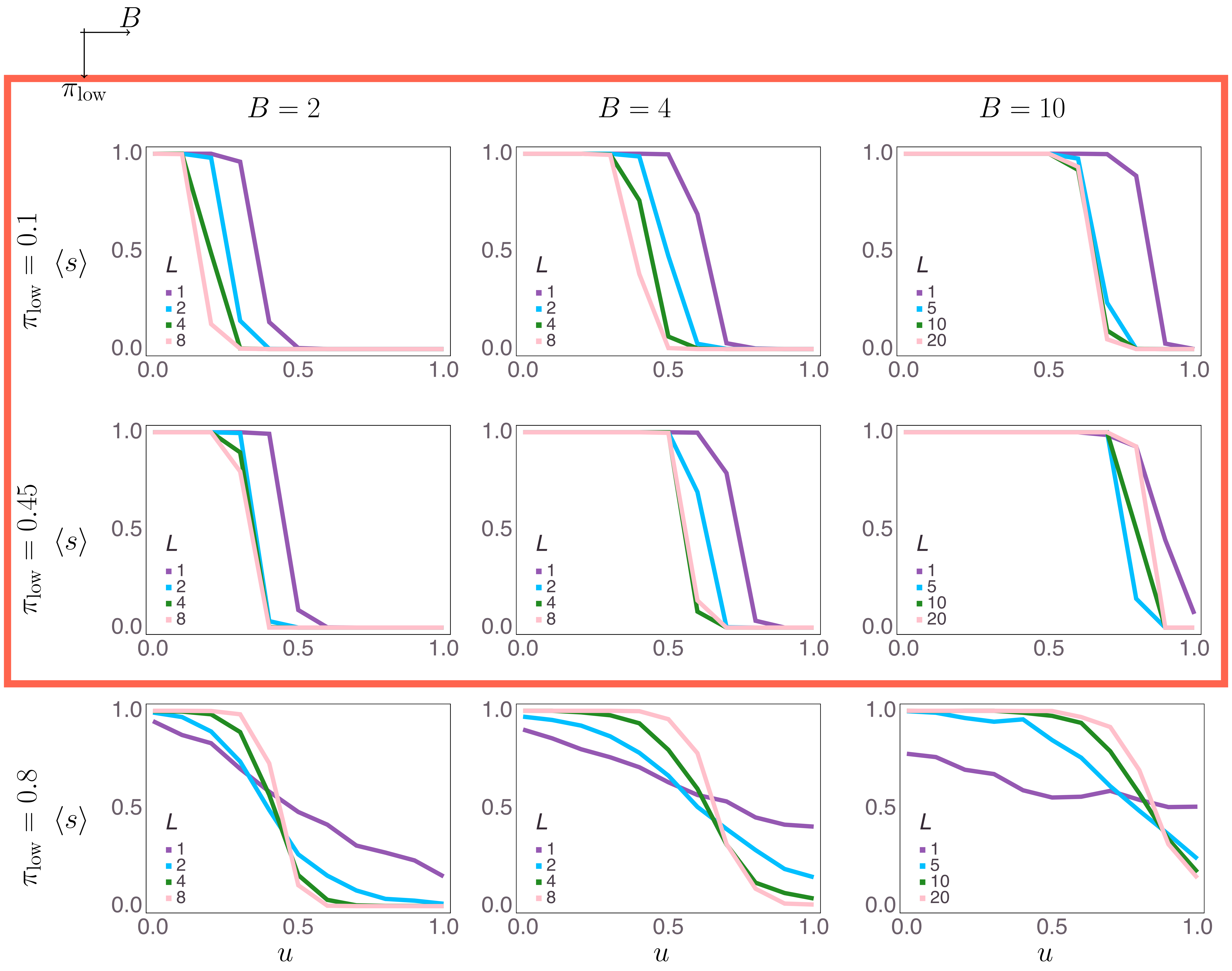
Overview



- The frequency of social learning fixation, $\langle s \rangle$, decreases as environmental variability, u, increases in all cases.

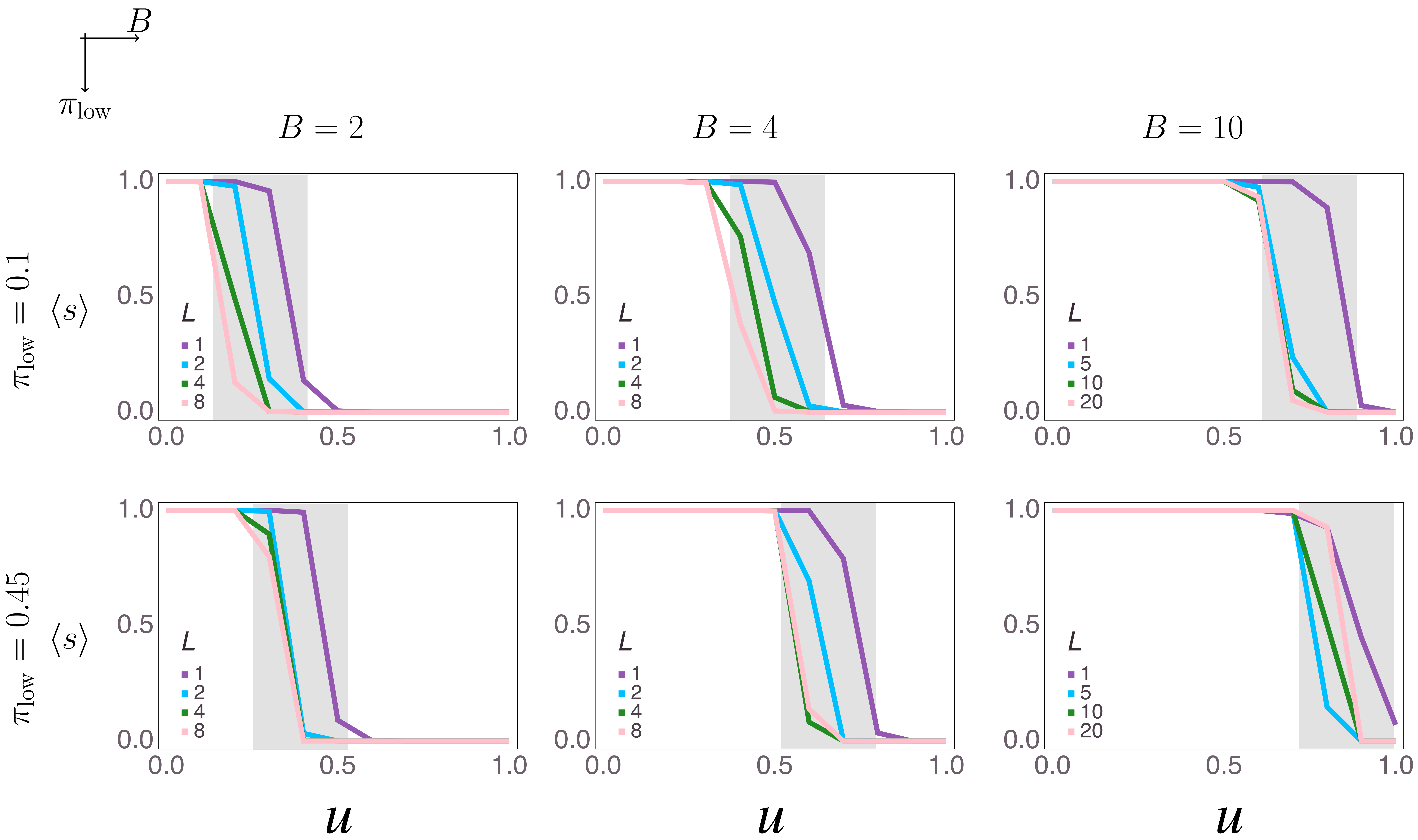
- Different uncertainty parameter settings change the **location** and **steepness** of the point where $\langle s \rangle$ goes from 1 to 0.

Large payoff ambiguity decreases selection strength, increases drift

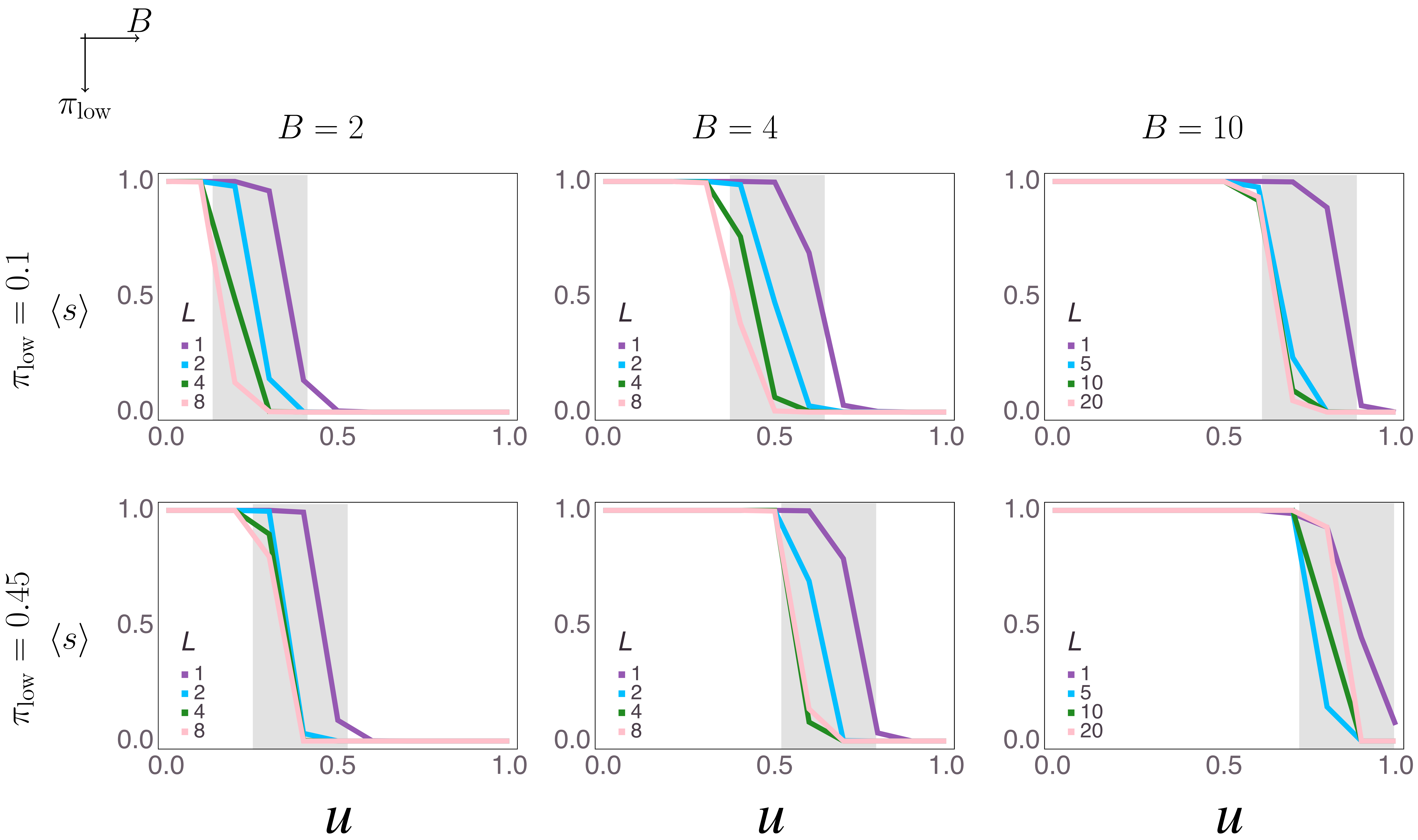


Less drift when $\pi_{\text{low}} \leq 0.45$
(recall $\pi_{\text{high}} = 0.9$)

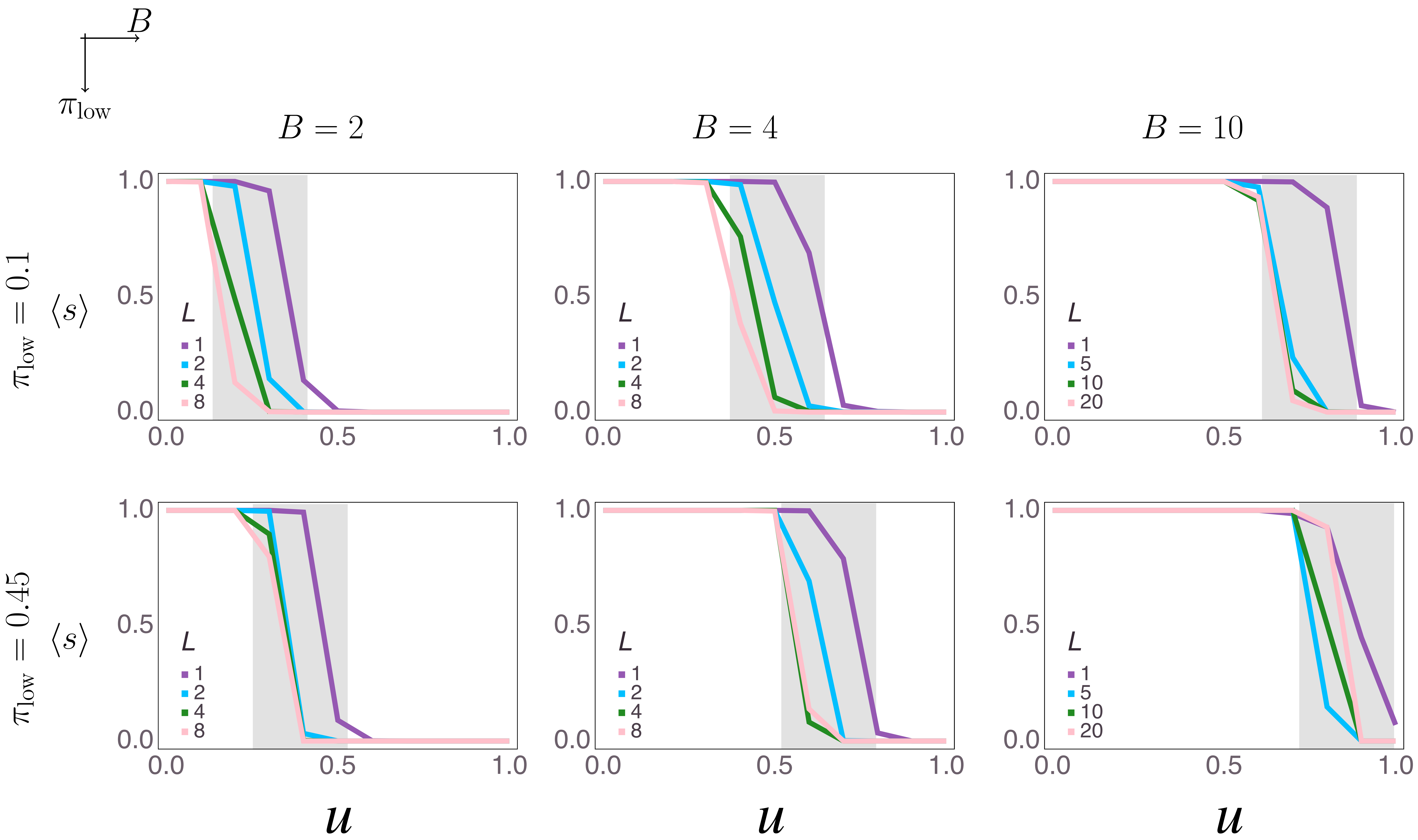
Increased payoff ambiguity supports social learning



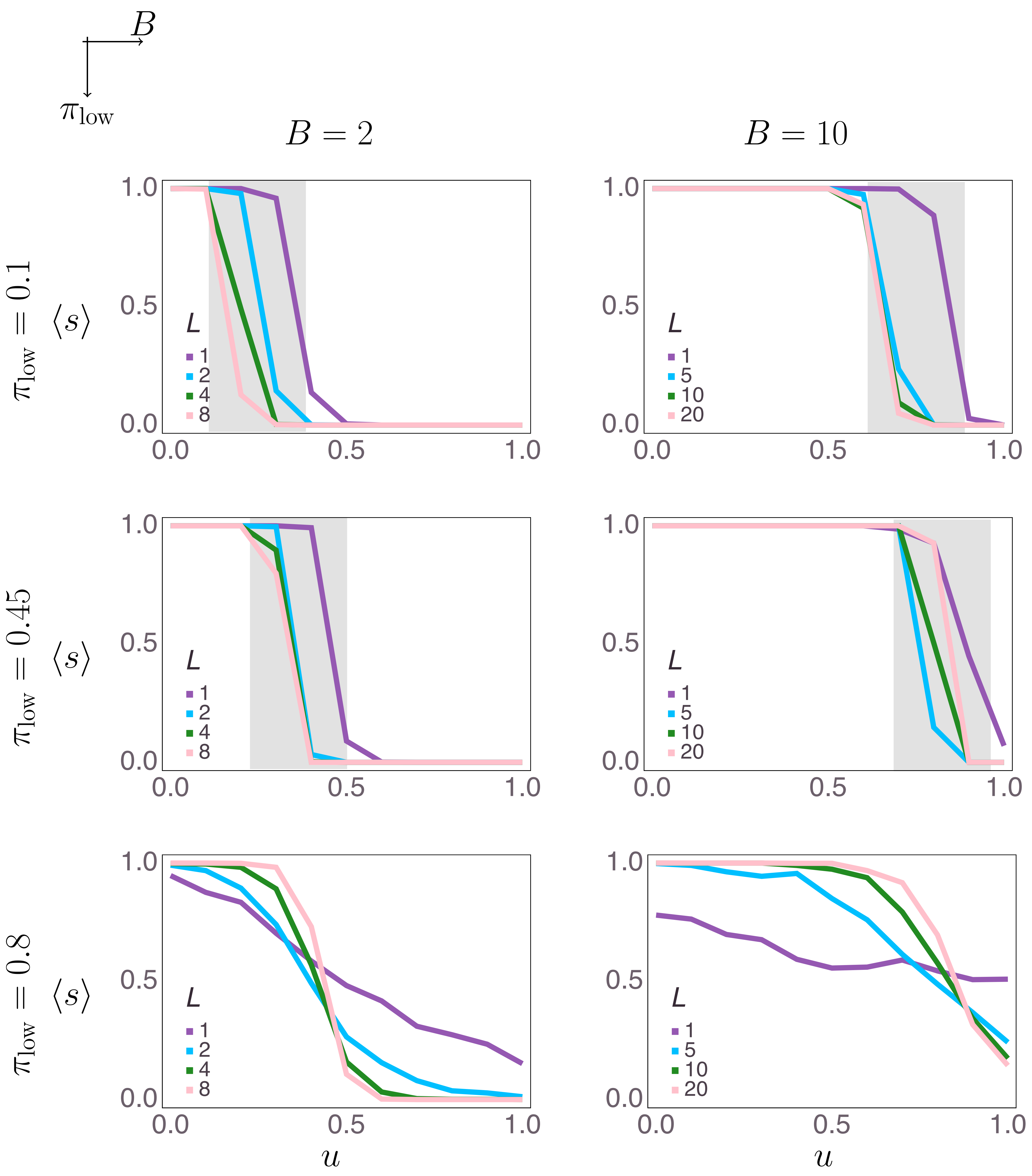
Larger selection set size, B, supports social learning

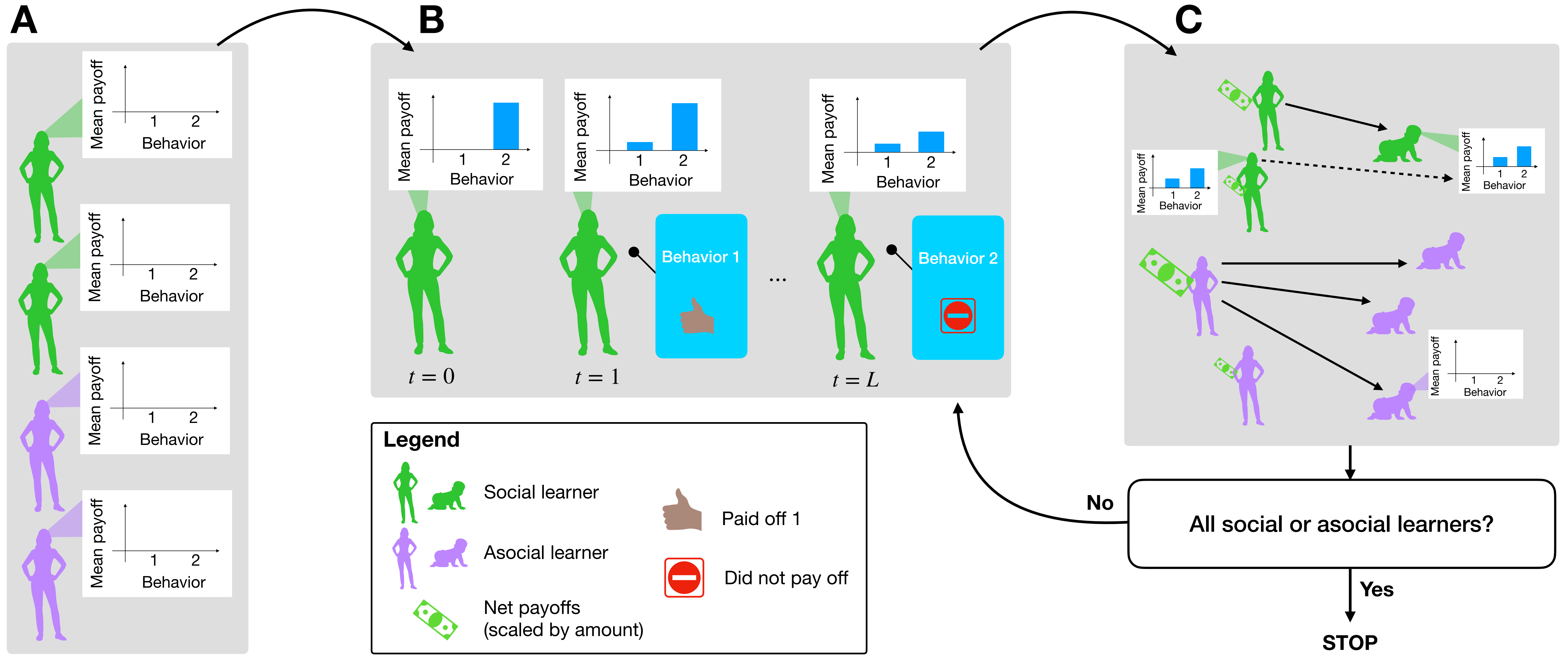


Shorter life span, L, supports social learning



Conclusion





https://github.com/mt-digital/UncMod/tree/CES2022_Pres

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ABM and analysis v1.0:

Turner MA, Moya C, Smaldino PE, & Jones JH (2022). Some forms of uncertainty may suppress the evolution of social learning. *Proceedings of the 44th Annual Conference of the Cognitive Science Society.* https://psyarxiv.com/dzteh/