Competition for resources can explain patterns of social and individual learning in nature

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Supplementary Material

1. Gini index

We used gamma distributions to allocate different resource values to individual patches in our simulations. This allows us to simulate conditions with resource distributions that range from very even to very uneven as illustrated in figure S1. We used the Gini index, G, as a measure of evenness. This quantity is commonly used in economics to measure income or wealth inequality. The Gini index is derived from the Lorenz curve, a graphical representation of the cumulative distribution function [1]. The more unevenly values are distributed, the more right-skewed the corresponding Lorenz curve becomes. The Gini index represents the area between the diagonal ($y = x$) and the Lorenz curve. Therefore, $G = 0$ represents complete evenness, while $G = 1$ means that all resources are concentrated in a single patch. We calculated the Gini index using:

$$G = 1 - \frac{2}{n(n-1)\mu} \sum_{i=1}^{n-1} (n-i) x_i \, ,$$

where n is the number of patches, $[x_1, x_2, \ldots, x_n]$ holds the resource values of each patch in ascending order, and μ is the mean resource value across all patches.

2. Mixed learning strategies

The model reported in the main text assumes that each forager is either an individual learner or a social learner, and uses only the learning strategy of its group. Here, we analyse a second model in which each forager can use a mix of social and individual learning. This model is identical to that reported in the body of the paper in all respects except i) how individuals learn, and ii) how learning strategies are passed from parents to offspring. In the model presented here, in each round that an individual learns, it uses individual learning with probability α and social learning with probability (1 - α), where the value of α is specific to the individual. Each individual inherits its value of α from its parent. With probability 0.01, the offspring experiences a mutation to α. In this case, the offspring's value of α is equal to the parent's value of α plus a random value drawn from a distribution N(0, 0.01). Values of α that drop below 0 or exceed 1 as a result of mutation are rounded back to 0 or 1, respectively. We analysed the model in figure S2 as in analysis 2. Figure S2 reports the proportion of individual learning as a proportion of all learning in the population. The results are qualitatively similar to those reported in figure 2.

3. Different uptake limits *u*

In figure 2 we considered insatiable foragers. That is, a single individual foraging alone could collect the full resource value of its patch. In nature, there may be a limit to how much a single individual can collect or eat in a given time period. We set this limit with the parameter u. Note that u should be interpreted relative to the mean resource value of patches in the system (set to 4 in all simulations, see table S1). For example, if $u = 2$, then a single forager can collect up to 50% of the resources from a patch that offers the mean resource value. In figure S3 we report the results of analysis 2 for $u \in \{2, 4, 40\}$. The results are qualitatively similar to those reported in the main text.

Figure S1. Lorenz curves for even ($G = 0.14$, blue) and uneven ($G = 0.83$, red) resource distributions used in our analyses (*e.g.*, figures 1 and 3). These correspond to gamma distributions with parameters (k = 16, θ = 0.25) and (k = 0.16, θ = 25), respectively. To obtain Lorenz curves, the resources values of each patch are sorted in ascending order, and the sorted vector of resource values is summed cumulatively. The grey line shows the Lorenz curve for a uniform distribution ($G = 0$). The Gini index indicates how strongly the Lorenz curve of a given distribution deviates from a uniform distribution.

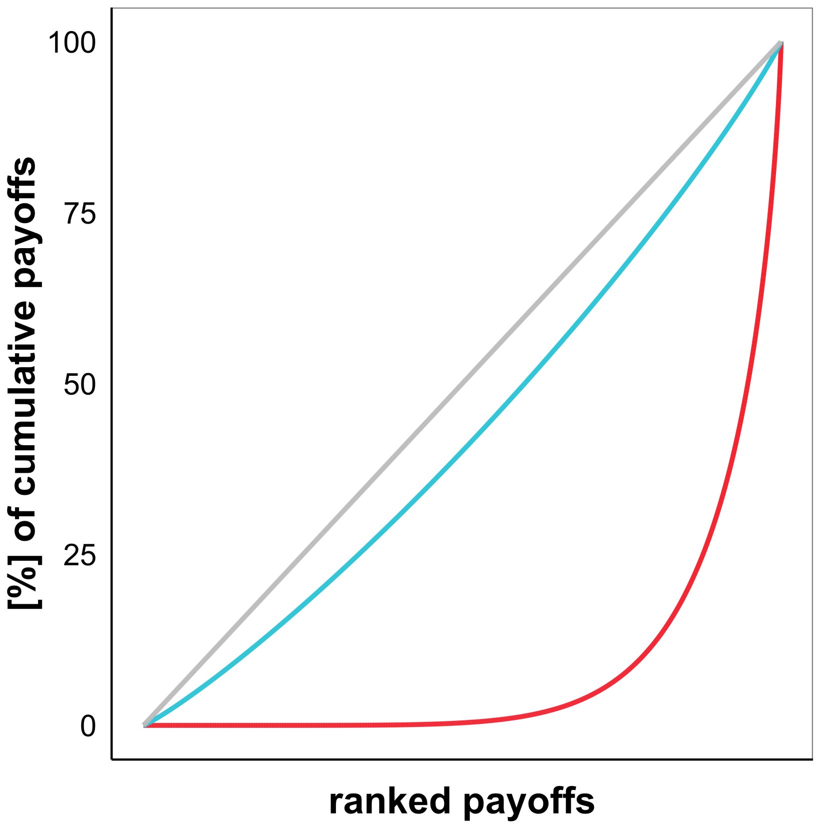

Figure S2. Mean proportion of all learning behaviour that is individual learning, as a function of the evenness of resources among patches (*x*-axis) and the rate at which resources change over time (*y*-axis). The *x*-axis represents increasing unevenness in resource distribution (Gini index *G*), and the *y*-axis represents the probability that the resource value of a patch offers changes in any round. Social learning becomes common when resources are stable and unevenly distributed. Results shown are for $c = 1$ and $u = \infty$.

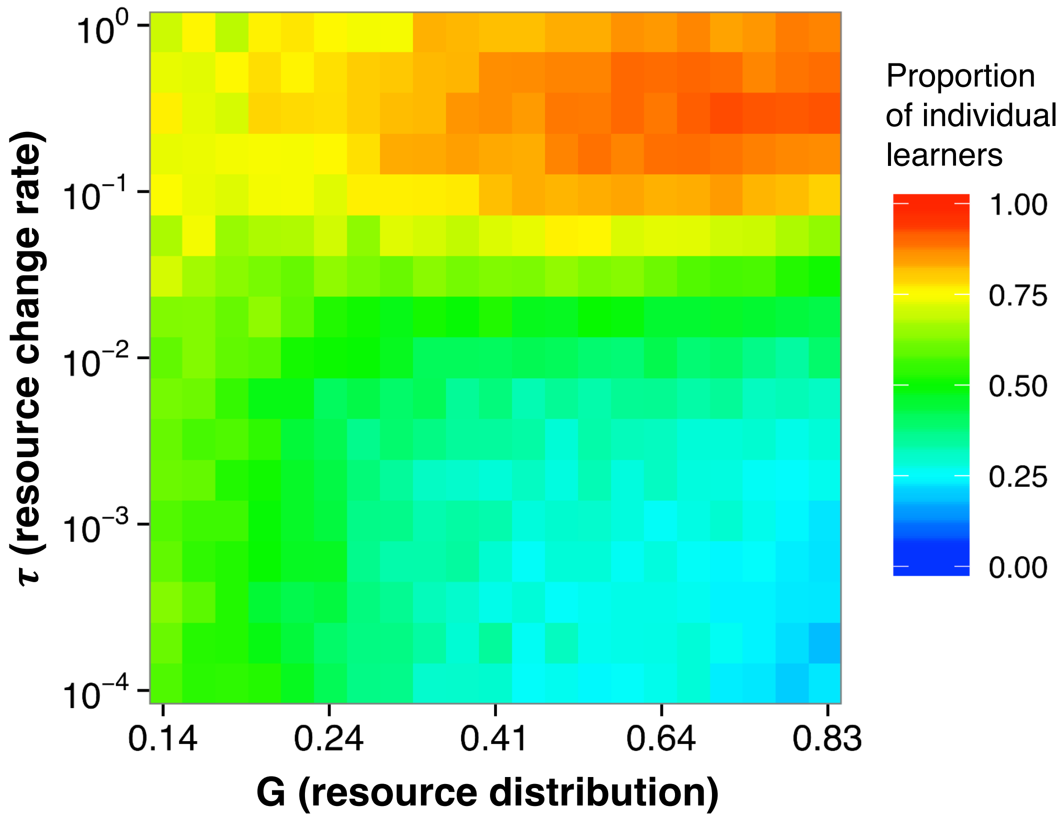

Figure S3. Mean frequency of individual learning as a function of the evenness of resources among patches (*x*-axis) and the rate at which resources change over time (*y*-axis). The *x*-axis represents increasing unevenness in resource distribution (Gini index *G*), and the *y*-axis represents the probability that the resource value of a patch offers changes in any round. Social learning becomes common when resources are stable and unevenly distributed. Simulation parameters are as in analysis 2, except *a* ($u = 2$), *b* ($u = 4$), *c* ($u = 40$).

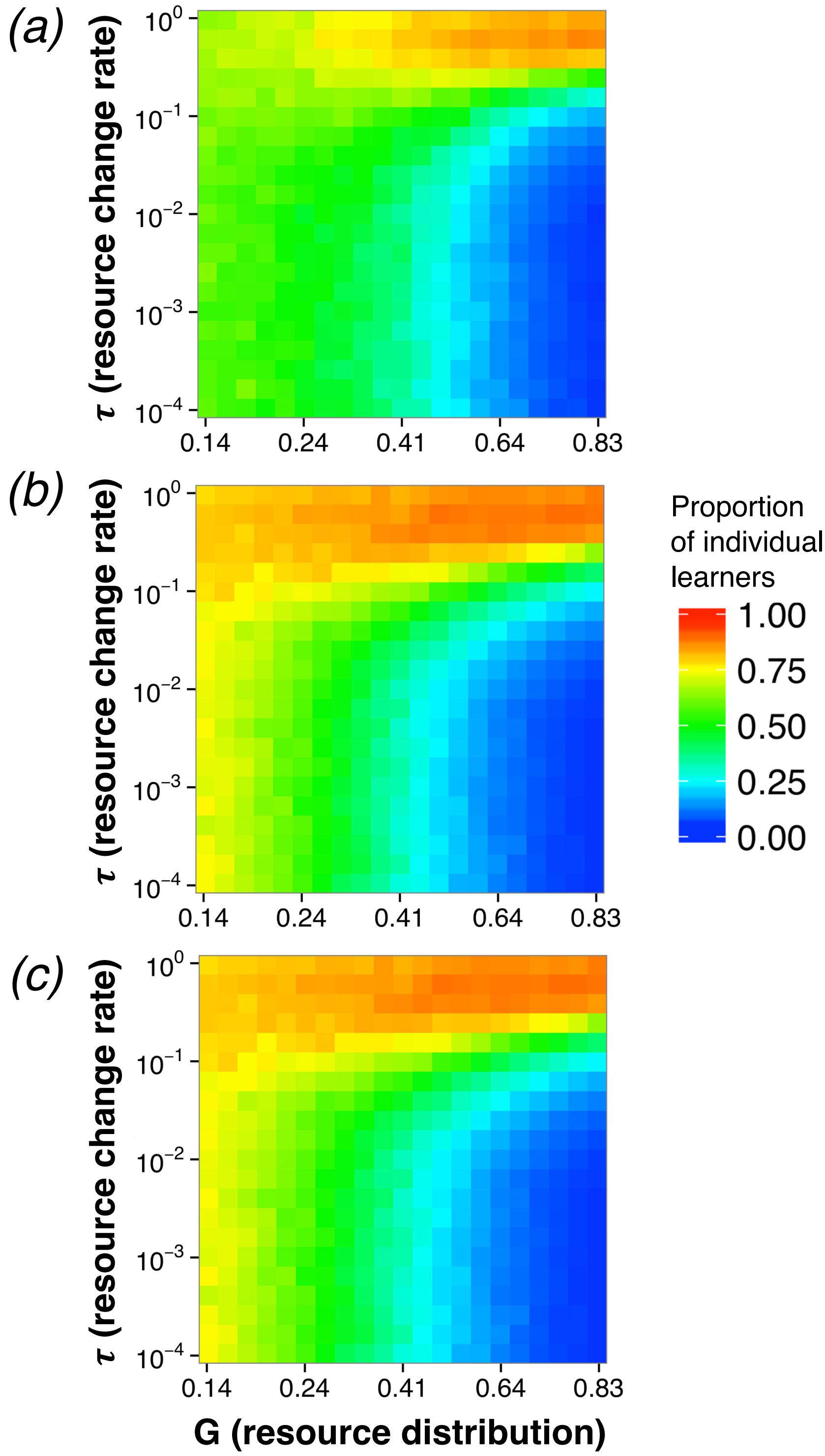

Table S1. Expected resource values in simulations with different resource distributions (even: G = 0.14, uneven: G = 0.83). Minimum, average and maximum values were calculated from 100 randomly drawn values of the corresponding gamma distribution. The results were averaged over 10000 repetitions. (Values ± standard deviation)

Resource distribution	**Average expected resources per patch**		
	Minimum	Mean	Maximum
Even	1.9 ± 0.3	4 ± 0.1	7 ± 0.6
Uneven	≅ 0 ± 0	4 ± 1	62.1 ± 26.2

References

1. Ceriani, L. & Verme, P. 2011 The origins of the Gini index: extracts from Variabilità e Mutabilità (1912) by Corrado Gini. *J. Econ. Inequal.* **10**, 421–443. (doi:10.1007/s10888-011-9188-x)