 DOI: 10.1086/703113

Appendix from C. Duncan et al., "The Evolution of Indiscriminate Altruism in a Cooperatively Breeding Mammal" (Am. Nat., vol. 193, no. 6, p. 841)

Supplemental Material

Modeling the Payoffs of Error-Prone Kin Discrimination

The payoffs from the three strategies compared in the model are calculated as follows. Selfish individuals (strategy S) are never altruistic and receive a payoff of 0. Indiscriminate altruists (IA) and kin discriminators (KD) receive payoffs from social interactions according to Hamilton's rule. Both KD and IA individuals receive payoffs from hypothetical interactions with n individuals, their relatedness to whom is randomly sampled from the empirically observed distribution of dyadic coefficients of relatedness between meerkat group mates. The results in figure 4 are based on 50,000 randomly sampled observed coefficients of relatedness between meerkat group mates. These data and the code necessary to reproduce these models have been deposited in the Dryad Digital Repository (https://dx.doi.org/10.5061/dryad.r01cq00; Duncan et al. 2019). IA individuals are altruistic to all of their social partners, such that their payoff is

$$\sum_{i=1}^{n} br_i - c,$$

where b is the benefit to the recipient, c is the cost to the altruist, and r_i is the relatedness between the altruist and the recipient, sampled with replacement from the observed set of coefficients of relatedness between group members. The payoff for kin discrimination with error is defined as:

$$\sum_{i=1}^{n} br_x - c \text{ if } br_x - c > 0,$$

where r_x is a randomly sampled value from a normal distribution with a mean of r_i and a standard distribution of e.

Empirical Analysis

Figures A1–A5 show the results of the models of best fit for the levels of cooperation expressed by individuals, before the inclusion of any terms of relatedness. Results are accompanied by forest plots displaying coefficients and confidence intervals transformed to odds ratios. The model outputs for each measure of relatedness that was subsequently added once the model of best fit had been determined are also displayed but separated from the terms in the base model by a dotted line.

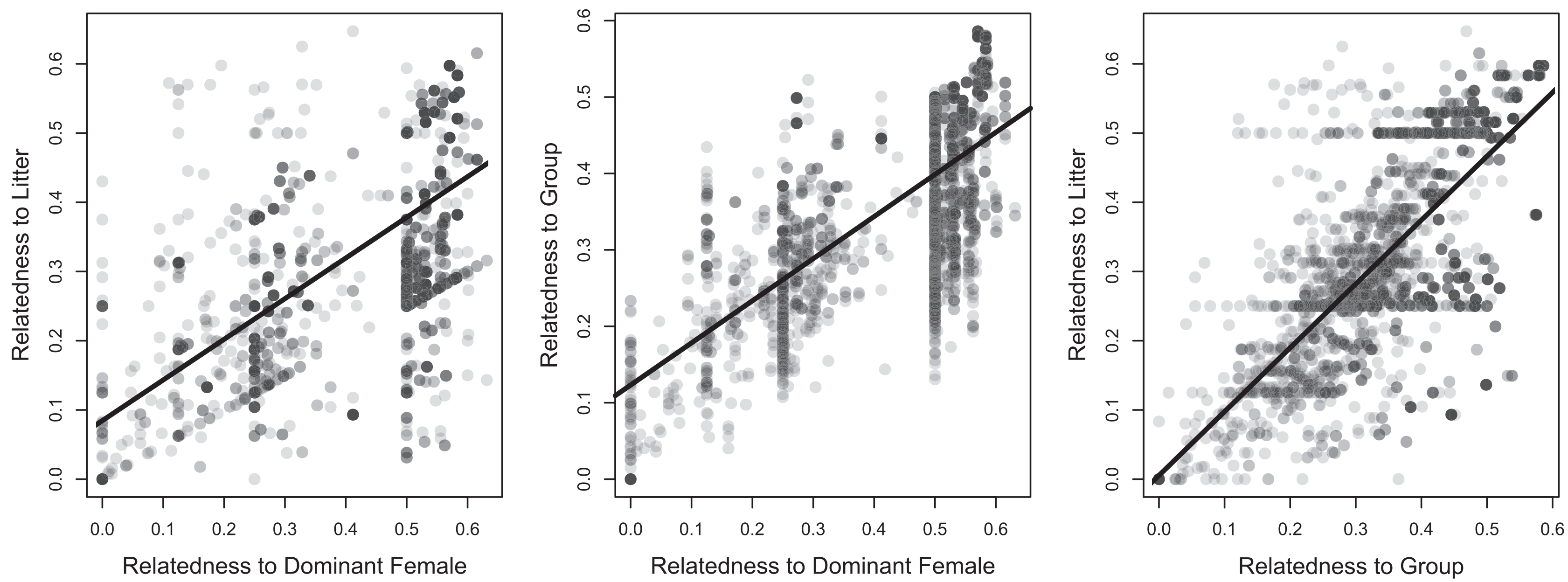

Figure A1: Correlations between the different measures of relatedness included in the models. Spearman's rank revealed significant correlations between an individual's relatedness to the litter and the dominant female ($r_s = 0.581$, $P < .001$), the group and the dominant female ($r_s = 0.683$, $P < .001$), and the litter and the group ($r_s = 0.736$, $P < .001$). Raw data are plotted as gray circles, and the line of best fit is plotted as a solid line. The data for these graphs were derived from the data set for the litter-specific cooperative behaviors; group relatedness and dominant female relatedness are similarly correlated in our group-specific cooperation data set ($r_s = 0.677$, $P < .001$).

	Coefficient	SE	z value	p value
Age (Months)	0.805	0.036	22.63	<0.001
Age² (Months)	-0.277	0.024	-11.41	<0.001
Group Size	-0.973	0.048	-20.36	<0.001
Group Size²	0.266	0.078	3.42	<0.001
Weight	-0.208	0.024	-8.51	<0.001
Foraging Rate	-0.072	0.024	-3.02	0.002
Litter Size	0.239	0.04	5.9	<0.001
Sex (♀ vs ♂)	0.389	0.043	8.99	<0.001
Age:Sex	0.504	0.068	7.41	<0.001
Age²:Sex	-0.155	0.051	-3.04	0.002
GroupSize:Sex	0.29	0.059	4.88	<0.001
ForagingRate:Sex	-0.147	0.044	-3.37	<0.001
LitterR	-0.049	0.037	-1.31	0.191
GroupR	0.029	0.046	0.63	0.528
DomFemR	0.076	0.042	1.8	0.071

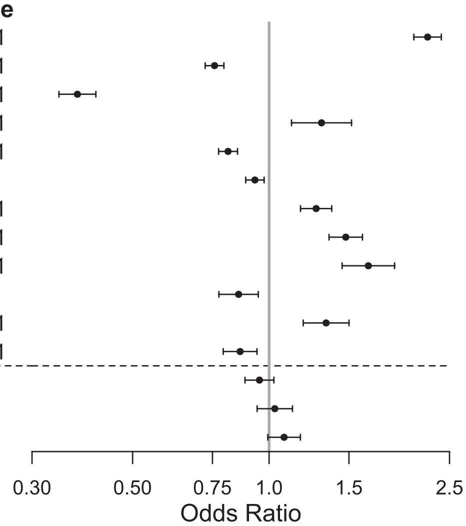

Figure A2: Factors influencing individual contributions to babysitting litters. Contributions of individuals to babysitting on a per-litter basis modeled using a generalized linear mixed model with a binomial error distribution and random effects fitted for the identities of the helper, litter being helped, and the group.

	Coefficient	SE	z value	p value
Age (Months)	-0.269	0.025	-10.94	<0.001
Group Size	-0.836	0.059	-14.09	<0.001
Group Size²	0.28	0.092	3.04	0.002
Weight	-0.097	0.028	-3.52	<0.001
Weight²	-0.156	0.029	-5.39	<0.001
Litter Size	0.131	0.051	2.57	0.01
Sex (♀ vs ♂)	0.26	0.025	10.3	<0.001
Age:Sex	0.129	0.048	2.69	0.007
LitterR	0.024	0.033	0.73	0.465
GroupR	0.032	0.037	0.87	0.385
DomFemR	0.087	0.032	2.72	0.007

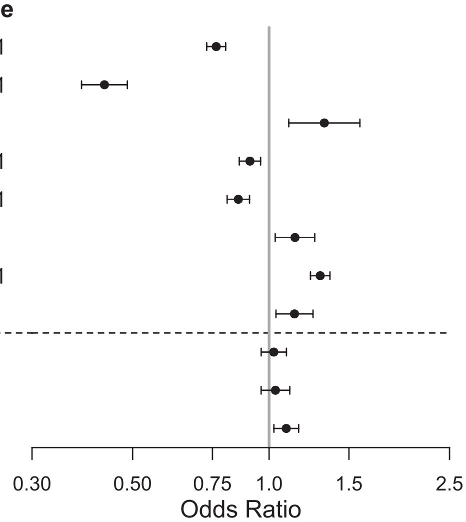

Figure A3: Factors influencing individual contributions to pup feeding of litters. Contributions of individuals to pup feeding on a per-litter basis during the period of peak pup feeding (45 days after the pups start foraging) modeled using a generalized linear mixed model with a negative binomial error distribution and random effects fitted for the identities of the helper, litter being helped, and the group.

	Coefficient	SE	z value	p value
Age (Months)	1.186	0.044	26.7	<0.001
Age² (Months)	-0.563	0.025	-22.7	<0.001
Group Size	-0.718	0.039	-18.28	<0.001
Group Size²	0.195	0.054	3.61	<0.001
Weight	0.61	0.023	26.57	<0.001
Foraging Rate	0.155	0.04	3.9	<0.001
Foraging Rate²	-0.145	0.03	-4.87	<0.001
Sex (♀ vs ♂)	-0.402	0.052	-7.76	<0.001
Natal Group	0.753	0.082	9.23	<0.001
Age:Sex	-0.332	0.076	-4.36	<0.001
Age²:Sex	0.327	0.047	6.94	<0.001
GroupR	-0.053	0.049	-1.06	0.287
DomFemR	-0.053	0.049	-1.06	0.287

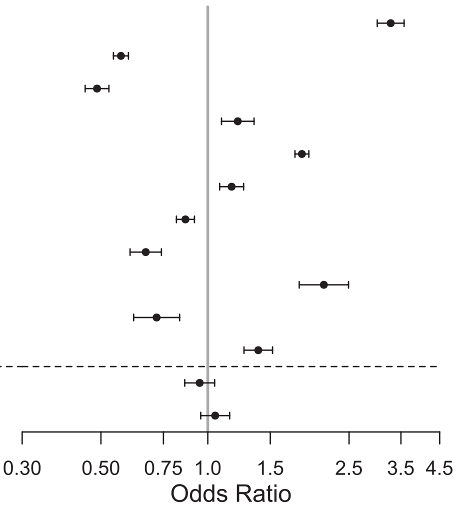

Figure A4: Factors influencing individual contributions to guarding during 3-month periods. Contributions of individuals to guarding during 3-month periods modeled using a generalized linear mixed model with a negative binomial error distribution and random effects fitted for the identities of the helper and the group they are resident at during the 3-month period.

	Coefficient	SE	z value	p value
Age (Months)	0.014	0.037	0.37	0.711
Age² (Months)	-0.124	0.02	-6.06	<0.001
Group Size	-0.63	0.031	-20.57	<0.001
Group Size²	0.284	0.045	6.32	<0.001
Weight	0.527	0.02	25.84	<0.001
Weight²	-0.112	0.026	-4.33	<0.001
Foraging Rate	0.089	0.029	3.06	0.002
Sex (♀ vs ♂)	-0.071	0.031	-2.32	0.02
Natal Group	0.366	0.061	5.96	<0.001
GroupR	0.157	0.034	4.63	<0.001
DomFemR	0.136	0.033	4.13	<0.001

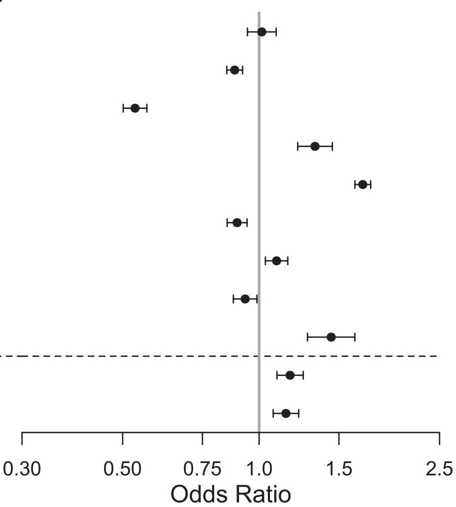

Figure A5: Factors influencing individual contributions to digging during 3-month periods. Contributions of individuals to digging during 3-month periods modeled using a generalized linear mixed model with a negative binomial error distribution and random effects fitted for the identities of the helper and the group they are resident at during the 3-month period.

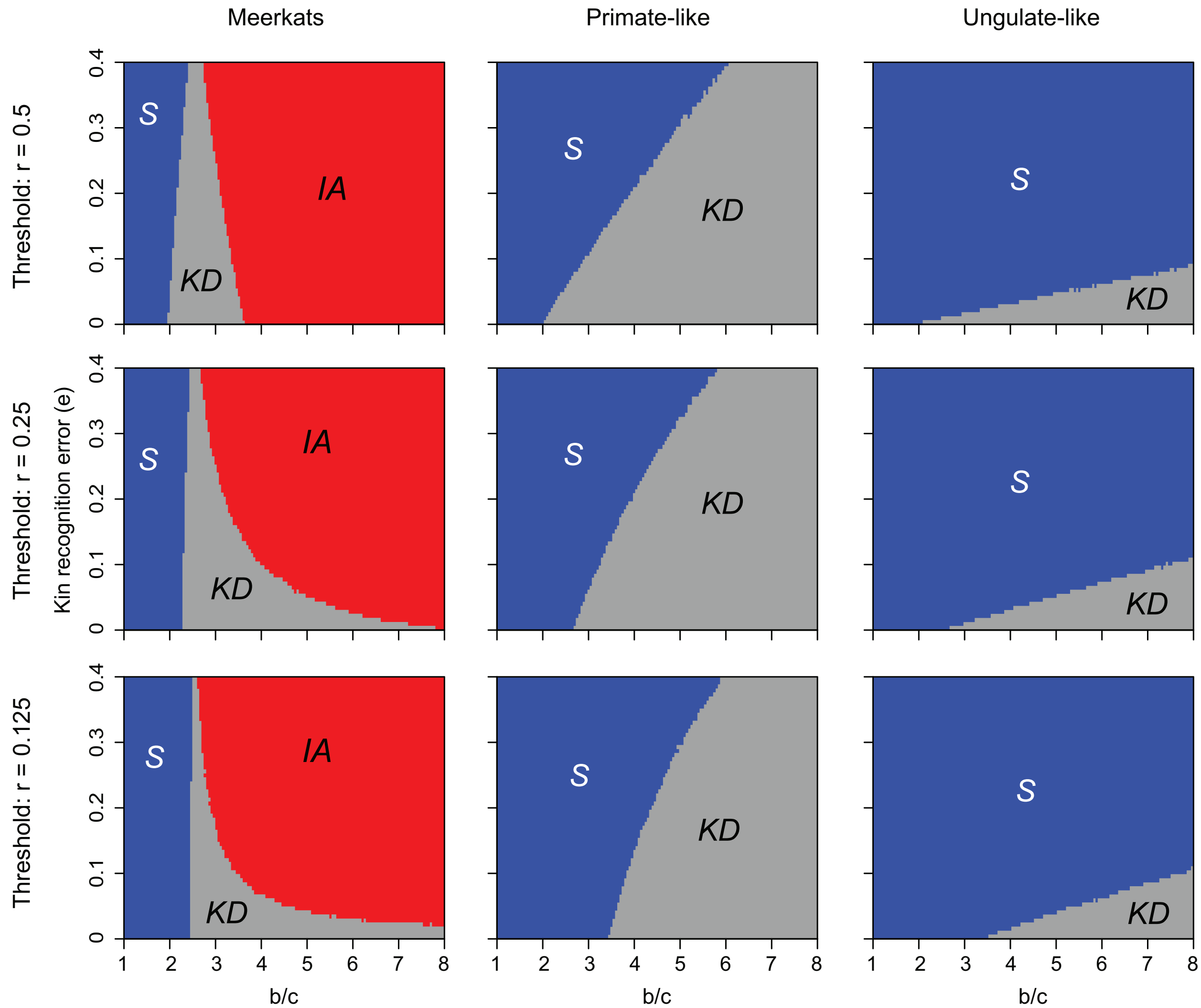

Figure A6: Results of the theoretical model where kin discrimination is discrete. Payoffs for selfishness (S) and indiscriminate altruism (IA) are the same as in figure 3. Payoffs for kin discrimination (KD) are those derived from the altruist having a threshold for recognizing kin of $r = 0.5$ (*top*), $r = 0.25$ (*middle*), and $r = 0.125$ (*bottom*), helping kin but not helping nonkin, and mistaking kin for nonkin and nonkin for kin with probability e.

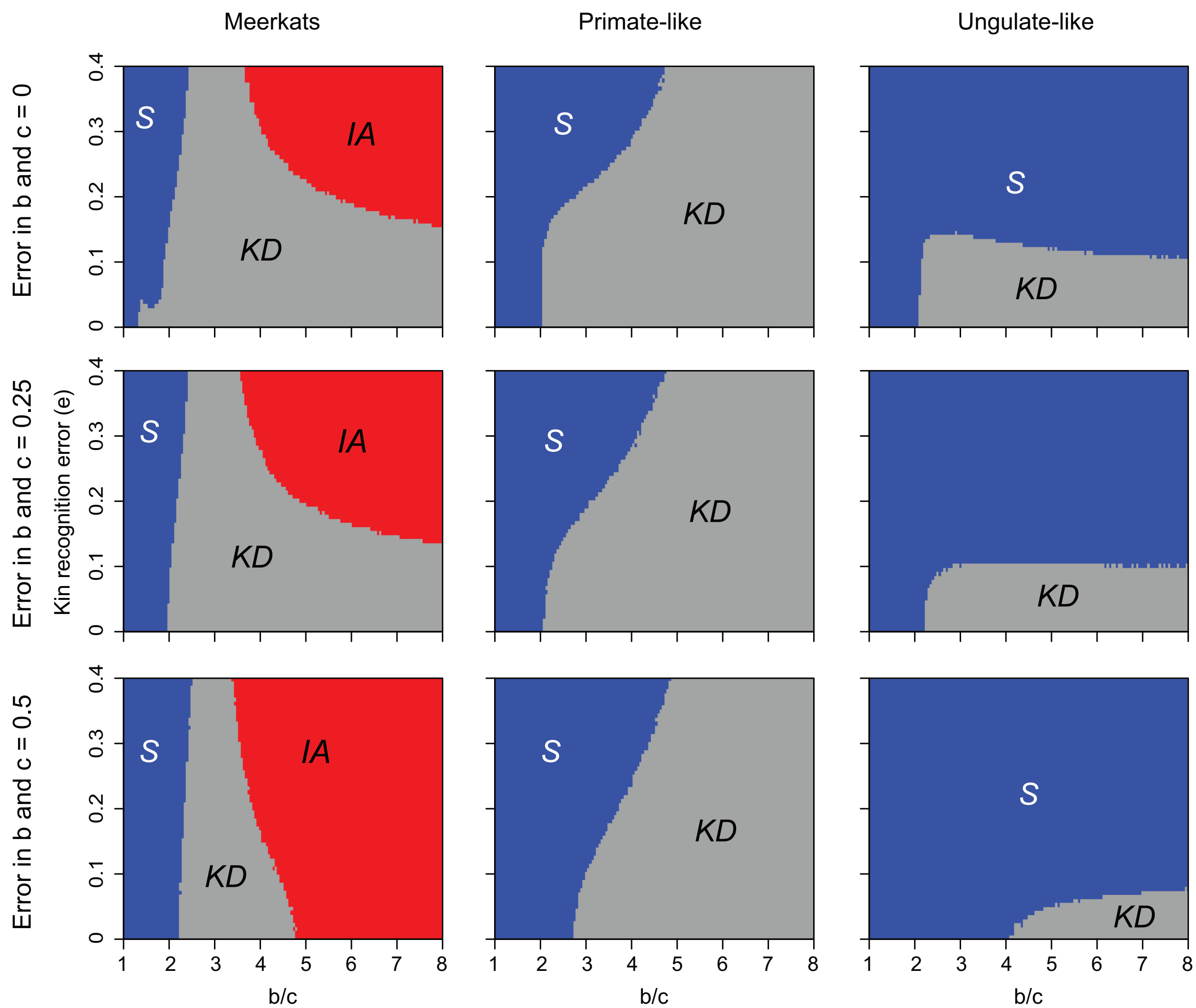

Figure A7: Results of the theoretical model with varying degrees of error in the benefits and costs of altruism. Payoffs for selfishness (S) and indiscriminate altruism (IA) are the same as in figure 3. Errors in estimates of costs and benefits are introduced by sampling from normal distributions with means of the true values of c and b and standard deviations set to a proportion of the true values (e.g., where error in $b = 0.5$, estimated b is sampled from a normal distribution with a mean of b and a standard deviation of $0.5 \times b$). Payoffs for kin discrimination (KD) are those derived from the altruist having a threshold for recognizing kin of $r = 0.5$ (*top*), $r = 0.25$ (*middle*), and $r = 0.125$ (*bottom*), helping kin but not helping nonkin, and mistaking kin for nonkin and nonkin for kin with probability e.