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SUPPLEMENTARY INFORMATION

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Population structured by witchcraft beliefs

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Suppplementary notes

Our study population w a rural Mosuo community in southwestern China. Agriculture is a primary means of subsistence in this area. Wildlife resources may have been important in the past but are now depleted, and tourism is now a significant source of income for many households. Members of different households help one another during planting and harvesting seasons. Households can also cooperate in the construction of new houses, share funeral costs if the deceased's household cannot afford the ceremony, and jointly invest in economic ventures (1). Whilst many households follow the traditional Mosuo way of life, tourism and more intermarriage with Han people are causing this to shift (2, 3).

The Mosuo (also known as Na) traditionally follow 'walking marriage'; a man visits his partner's house during the night and returns to his natal household at daybreak (4). Once a union is publicly recognised, the male may eat with or give gifts to his partner's family (1). These *Zohoun* relationships may be long or short term. However, since the 1980s, a formal marriage certificate has been a requirement for reproduction throughout China as part of government family planning policy, which also limited family size to three children per women in this area.

So households follow an unusual duolocal, matrilineal kinship system, where husband and wife live apart and children live with their mother and her kin (5, 6). Sisters often breed communally and their brothers usually reside with them, staying in their natal household for life, engaging in 'walking marriage' with sexual partners in other households (1, 6). Dispersal rates both in and out of households, and in and out of villages, is low; hence relatedness is high (7). Households give and receive help on each other's household farms, especially during planting and harvest seasons. Farm help is more likely to come from individuals who are genealogical kin, spouses or partners or other affines, or neighbours (8). Households may thus be in competition both for mates and for help on their farm.

Supplementary methods

Distance in kilometres between households within the same village was calculated from the longitude and latitude GPS coordinates. Household size was calculated as the total number of people living there at the time of the 2012 census. Three seasons of farm observations were aggregated by household.

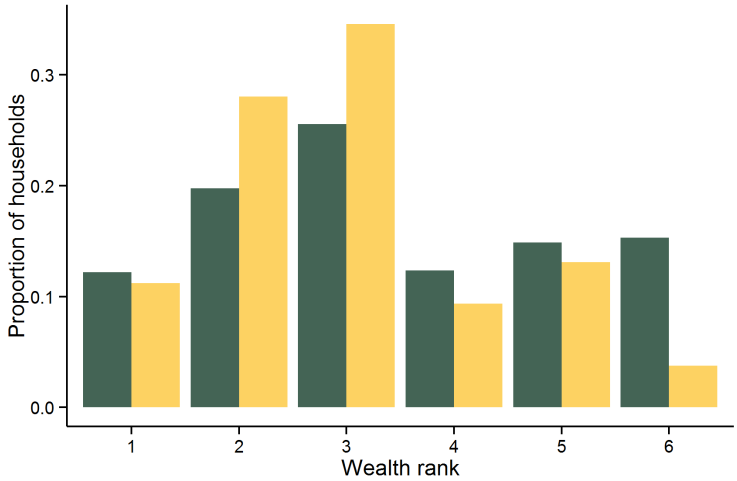
Household dyads were limited to include only those headed by Mosuo people. Binary predictors were coded as 1 for each household dyad if any member of one household:

- was ever observed helping on the farm of another household
- ever gave a gift to any member of another household
- had any children (of any age, not just < 15y) in another household
- had a partner or spouse in another household

Supplementary figures

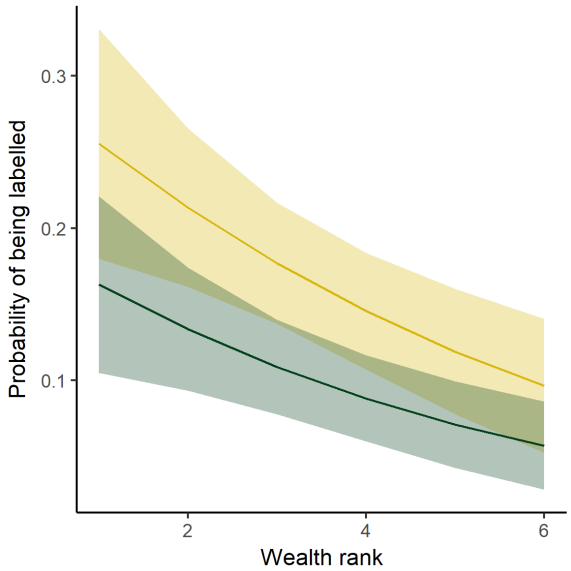
Supplementary Figure S1

Wealth rankings of *zhu* (yellow) and non-*zhu* (green) households. Bars show the proportions of households in each rank compared to the total numbers of *zhu* and non-*zhu* households.



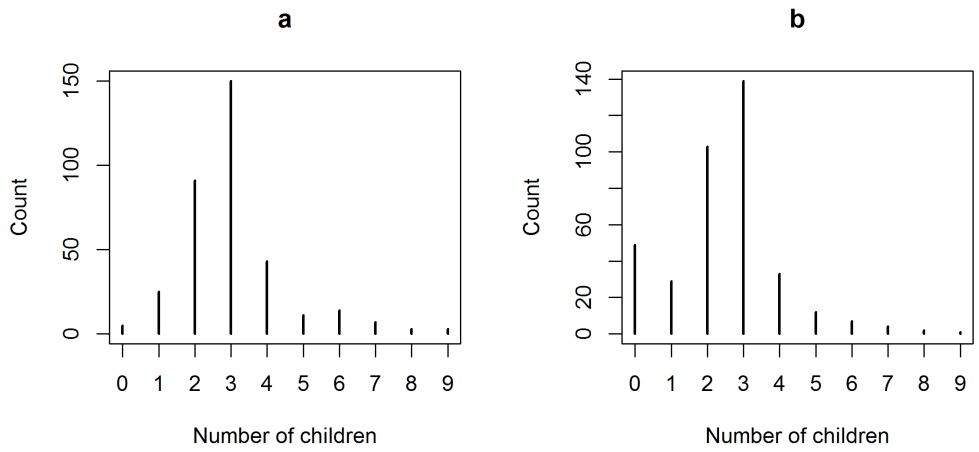
Supplementary Figure S2

Predicted probabilities of a household being labelled *zhu* based on its wealth ranking and sex of household head (yellow = female; green = male). 1 is highest and 6 is lowest wealth rank. Other parameters were held constant at their mean values. See Table S4 for model parameter estimates.



Supplementary Figure S3

Distributions of numbers of children born to (a) female household heads and (b) male household heads. Note that births were limited to three children per woman by government family planning policies that came into effect in the 1980s.



Supplementary Tables

Supplementary Table S1

S1 a) 95% confidence set of models for zero-inflated Poisson regressions on in-degree for households in the farm labour and gift networks. Columns report number of parameters (*K*), differences in AICc relative to the minimum in the set (ΔAICc), Akaike weights (ω_i) and the log-likelihood of each model (LL). Control model includes household size + wealth rank + sex of household head + a categorical variable for village (ref: village B). Intercept-only models were fitted but held none of the Akaike weights and are omitted for brevity.

	Model	*K*	ΔAICc	ω_i	LL
Farm work	Control	14	0.000	0.569	-756.880
	Control + *Zhu*	16	0.555	0.431	-755.060
Gift-giving	Control + *Zhu*	16	0.000	0.685	-677.589
	Control	14	1.553	0.315	-680.463

S1 b) Model-averaged parameter estimates from the best-fitting Zero-Inflation Poisson (ZIP) regressions predicting in-degree (i.e. number of observations) for (i) observed farm work and (ii) gifts received by households. Each ZIP regression fits a Poisson model ('count model'), as well as a logistic model predicting whether a household has Pr = 0 of in-degree > 0 ('zero-inflation model'). Parameter estimates that are statistically distinguishable from zero have been highlighted in bold. In both cases, the response is help or gifts received from all other households in the same village; n = 660.

	Farm labour			**Gifts**		
Count model:	**B**	**95% CI**		**B**	**95% CI**	
Intercept	-0.012	-0.563	0.539	-0.566	-1.271	0.139
Zhu house (ref: no)	-0.121	-0.460	0.217	2.788	-13.929	19.504
Household size	**0.047**	**0.005**	**0.090**	-0.207	-0.608	0.193
Wealth rank	-0.023	-0.109	0.063	0.030	-0.027	0.086
HH head's sex (ref: female)	**0.238**	**0.027**	**0.449**	0.434	-0.028	0.896
Village (ref: b)						
Village c	0.365	-0.028	0.759	0.085	-0.027	0.197
Village d	0.202	-0.175	0.579	**-0.552**	**-1.088**	**-0.016**
Village e	**0.816**	**0.443**	**1.189**	-0.312	-1.033	0.410
Zero-inflation model:						
Intercept	**1.245**	**0.331**	**2.159**	0.039	-0.290	0.369
Zhu house (ref: no)	-0.116	-0.576	0.343	1.024	-0.379	2.428
Household size	**-0.167**	**-0.248**	**-0.086**	-2.354	-19.521	14.813
Wealth rank	-0.014	-0.161	0.134	-1.464	-4.665	1.738
HH head's sex (ref: female)	**0.496**	**0.095**	**0.897**	2.407	-14.538	19.352
Village (ref: b)						
Village c	0.664	-0.029	1.358	-0.033	-0.273	0.208
Village d	-0.520	-1.251	0.211	-0.339	-0.758	0.079
Village e	0.008	-0.673	0.688	1.942	-14.635	18.518

We found that households headed by men received more instances of help on the farm compared to female-headed households (Table S1). In addition, larger households received more help on their farms. Household size or having a male head was not associated with gifts received in the gift game.

Supplementray Table S2

S2 a) Sets of candidate generalised estimating equation (GEE) models predicting whether one household helped on another household's farm. The first pair of columns refers to models fitted to a subset of household dyads where the potential helping households were labelled zhu (n = 16,731 dyads); the second pair of columns refers to models in which potential helping households were not labelled zhu (n = 111,351 dyads). In all models, the potential recipients of help were any other household within the same village. The control model contains predictors for distance between households (km), relative wealth rank, and number of people in each household in the dyads. Ego refers to the household providing help; alter is the household receiving help on its farm. All models are clustered on ego household IDs. The full model specifications are shown in Table S2b and c.

	Ego is *zhu*		**Ego is not *zhu***	
Model	**ΔQIC**	**ω_i**	**ΔQIC**	**ω_i**
Full	0.000	1.000	0.000	1.000
Control	193.235	0.000	997.902	0.000
Intercept-only	216.476	0.000	1292.084	0.000

S2 b) Parameter estimates from the best-fitting GEE model predicting farm help in dyads, where ego households were labelled *zhu*. Estimates were standardised over two standard deviations to allow comparison between binary and continuous predictors[1]. Binary predictors are indicated by question marks and the reference category in all cases is 'no'.

Parameter	**Odds ratio**	**95% confidence interval**		**P-value**
(Intercept)	0.002	0.002	0.003	0.000
Ego gave alter a gift?	1.005	0.871	1.159	0.950
Relatedness coefficient (*r*)	2.539	2.053	3.141	0.000
Ego has partners in alter?	1.236	1.093	1.398	0.001
Ego has children in alter?	0.873	0.771	0.987	0.031
Alter is *zhu*?	2.521	1.692	3.755	0.000
Distance (km)	0.531	0.238	1.184	0.122
Relative wealth rank	0.938	0.577	1.522	0.794
No. people in ego	1.639	1.020	2.634	0.041
No. people in alter	1.556	0.958	2.526	0.074
r × alter is *zhu*?	0.867	0.699	1.074	0.192

S2 c) Parameter estimates from the best-fitting GEE model predicting farm help in dyads, where ego households were not labelled *zhu*. Estimates were standardised over two standard deviations to allow comparison between binary and continuous predictors[1]. Binary predictors are indicated by question marks and the reference category in all cases is 'no'.

Parameter	Odds ratio	95% confidence interval		P-value
(Intercept)	0.002	0.002	0.003	0.000
Ego gave alter a gift?	1.095	1.036	1.156	0.001
Relatedness coefficient (*r*)	2.076	1.937	2.226	0.000
Ego has partners in alter?	1.355	1.291	1.423	0.000
Ego has children in alter?	1.006	0.952	1.063	0.827
Alter is *zhu*?	0.750	0.577	0.977	0.033
Distance (km)	0.262	0.175	0.393	0.000
Relative wealth rank	0.805	0.667	0.973	0.025
No. people in ego	1.458	1.202	1.768	0.000
No. people in alter	1.964	1.682	2.293	0.000
r × alter is *zhu*?	1.218	1.069	1.388	0.003

Supplementary Table S3.

Assortment on *zhu* tag.
Contingency tables of counts showed significant non-random disassociation between *zhu* households and non-zhu households based on whether or not households contained their partners ($\chi_1^2 = 177.26, P \ll 0.001$) (A), their children ($\chi_1^2 = 264.31, P \ll 0.001$) (B), whether they helped on their farms ($\chi_1^2 = 135.04, P \ll 0.001$) (C), or gave gifts to them ($\chi_1^2 = 112.79, P \ll 0.001$)(D) other households containing *zhu* (or not). Note that 'children' refers to all offspring, regardless of age.

A		**Households containing partners**	
		Non-zhu house	**Zhu house**
Households with partners elsewhere	**Non-zhu house**	455	15
	Zhu house	15	26
B		**Households containing children**	
		Non-zhu house	**Zhu house**
Households with children elsewhere	**Non-zhu house**	489	24
	Zhu house	11	45
C		**Households receiving help on farms**	
		Non-zhu house	**zhu house**
Households giving help to other farms	**Non-zhu house**	443	34
	zhu house	35	46
D		**Households receiving gifts**	
		Non-zhu house	**zhu house**
Households giving gifts to others	**Non-zhu house**	382	34
	zhu house	29	41

***Zhu* households cluster together on social networks but not necessarily spatially**
Using 'join count' statistics we investigated the spatial distribution of the households. In cases where there are more observations of *zhu*/non-*zhu* 'joins' than expected, there is negative spatial autocorrelation, meaning that *zhu* households are dispersed throughout their villages. Where there is positive spatial autocorrelation, *zhu* households cluster together. If the test statistic is not statistically significant then there is no evidence that *zhu* households are not randomly distributed within villages (no spatial autocorrelation). *Zhu* houses were spatially dispersed throughout villages B and C ($p = 0.001$ and $p \ll 0.001$, respectively). In villages A, D and E, *zhubo* and non-*zhubo* households were randomly distributed (i.e. no spatial autocorrelation; $p = 0.326$, $p = 0.352$ and $p = 0.279$ respectively).

Supplementary Table S4

Predictors of being labelled as *zhu*:
Wealthier households (see Fig S1) and households headed by women were more likely to be labelled as *zhu*.

S4 (a) Parameter estimates (log-odds) from a household-level logistic regression where the outcome variable is whether or not a household is said to contain *zhu* (n = 780). 1 is highest and 6 is lowest wealth rank. Note that this is a household-level model, whereas Fig 2 and Tables S5-7 are individual-level models. See Fig S2 for model predictions.

Parameter	B	95% CI		P-value
(Intercept)	-1.004	-2.087	0.077	0.069
No. adults in HH	-0.106	-0.220	0.002	0.060
No. children in HH	0.036	-0.135	0.203	0.674
Wealth rank	**-0.233**	**-0.378**	**-0.093**	**0.001**
Female HH head?	**0.566**	**0.148**	**0.992**	**0.008**
HH head age	0.002	-0.017	0.020	0.852

S4 (b) Average marginal effects (AME) from the logistic regression, showing the magnitude of parameter estimates.

Parameter	AME	95% CI		P-value
No. adults in HH	-0.012	-0.025	0.001	0.060
No. children in HH	0.004	-0.015	0.024	0.674
Wealth rank	**-0.027**	**-0.043**	**-0.010**	**0.001**
Female HH head?	**0.065**	**0.017**	**0.114**	**0.008**
HH head age	0.000	-0.002	0.002	0.852

Supplementary Table S5

Dispersal
Being labelled *zhu* was not associated with dispersal status (χ^2_3 = 7.279; P = 0.064).

Dispersal Status	Not labelled zhu	Labelled zhu
Never dispersed	1,663 (57.2%)	231 (51.0%)
Migrated in from outside Lugu Lake	318 (10.9%)	50 (11.0%)
Dispersed between villages	171 (5.9%)	32 (7.1%)
Dispersed within village	753 (25.9%)	140 (30.9%)

Supplementary Table S6

Female reproductive success

Importance of the label *zhu* on reproductive success of female household heads: Summary of the full candidate set of models predicting number of living children for all Mosuo female household heads (n = 352), including number of parameters (*K*), differences in AICc relative to the minimum in the set (ΔAICc), Akaike weights (ω_i) and the log-likelihood of each model (LL). Control includes age + age^2 + years of education + income from tourism in 2012 (yes/no) + no. livestock in 2012 + household wealth rank. Ages were mean-centred. All models included varying intercepts for villages. The 'Control + *Zhu*' and 'Control' models were averaged; parameter estimates are shown in Fig 3a.

Model	*K*	ΔAICc	ω_i	LL
Control + Zhu	13	0.000	0.631	-580.458
Control	12	1.070	0.369	-582.071
Null model	2	65.420	0.000	-624.689

Supplemenary Table S7

Male reproductive success

Importance of the label *zhu* on reproductive success of male household heads: Summary of the best 95% *a priori* models predicting number of living children for all Mosuo male household heads (n = 379), including number of parameters (*K*), differences in AICc relative to the minimum in the set (ΔAICc), Akaike weights (ω_i) and the log-likelihood of each model (LL). Control includes age + age^2 + years of education + income from tourism in 2012 (yes/no) + no. livestock in 2012 + household wealth rank. Ages were mean-centred. All models included varying intercepts for villages. The 'Control + *Zhu*' and 'Control' models were averaged; parameter estimates are shown in Fig 3b.

Model	K	ΔAICc	ω_i	LL
Control	12	0.000	0.720	-607.745
Control + Zhu	13	1.886	0.280	-607.615
Null model	2	129.618	0.000	-682.964

Variances for village varying intercepts

Variance between villages in the reproductive success models (Fig 3 main text). See captions of Tables S6 and S7 for descriptions of the models.

Model	Females	Males
Null model	0.005	0.008
Control	0	0.001
Control + *Zhu*	0	0.001

Supplemenary Table S8

Age at first birth
S8 a)

Importance of being currently labelled *zhu* on age at first birth: 95% confidence set of models for Cox regressions on age at first birth, including number of parameters (*K*), differences in AICc relative to the minimum in the set (ΔAICc), Akaike weights (ω_i) and the log-likelihood of each model (LL). Control includes age cohort (categorical variable with three levels: born before 1941, between 1941 and 1972, and born after 1972) + no. adult sisters + no. adult brothers + years of education + income from tourism in 2012 (yes/no) + no. livestock in 2012. Intercept-only models were also fitted for females and males (not shown) and had Akaike weights of zero.

Sample	Models	*K*	ΔAICc	ω_i	LL
♀	Control	7	0.00	0.64	-7822.04
	Control + *Zhu*	8	1.13	0.36	-7821.59
♂	Control	7	0.00	0.73	-5639.55
	Control + *Zhu*	8	1.94	0.27	-5639.51

S8 b)

Parameter estimates: Hazard ratios [95% confidence intervals] predicting age at first birth estimated from Cox regressions and averaged over the 95% confidence set of models (Table S6). Models were fitted separately for all Mosuo females (n = 1,625) and males (n = 1,641) aged 15 years and over.

	Hazard ratio [95% CI]	
Parameter	Females	Males
Zhu		
No	1	1
Yes	0.923 [0.781, 1.092]	0.973 [0.805, 1.176]
No. sisters	**0.76 [0.688, 0.841]**	0.939 [0.859, 1.027]
No. brothers	**0.866 [0.808, 0.929]**	**0.895 [0.83, 0.964]**
Education (years)	0.972 [0.95, 0.994]	1.001 [0.985, 1.017]
Tourist income	1.024 [0.91, 1.153]	1.063 [0.929, 1.216]
No. livestock	**1.008 [1.001, 1.014]**	0.998 [0.993, 1.004]
Cohort		
Before 1941	1	1
1941 to 1972	**1.915 [1.566, 2.341]**	**1.493 [1.117, 1.997]**
After 1972	**2.07 [1.657, 2.586]**	**1.605 [1.179, 2.185]**

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