Explaining the Decline of *impal* Marriage among the Karo: An Epidemiological Approach

Geoff Kushnick[1*], Sam Passmore[2,3], Fikarwin Zuska[4], Karmila br. Karo[5], Daniel M.T. Fessler[6,7,8]

[1] School of Archaeology and Anthropology, The Australian National University, Canberra, Australia
[2] Evolution of Cultural Diversity Initiative, The Australian National University, Canberra, Australia
[3] School of Culture, History, and Language, The Australian National University, Canberra, Australia
[4] Departemen Antropologi, Fakultas Ilmu Sosial dan Ilmu Politik, Universitas Sumatera Utara, Medan, Indonesia
[5] Balai Pelestarian Kebudayaan Wilayah II Medan, Indonesia
[6] Department of Anthropology, University of California, Los Angeles, USA
[7] UCLA Center for Behavior, Evolution, & Culture, University of California, Los Angeles, USA
[8] UCLA Bedari Kindness Institute, University of California, Los Angeles, USA

[*] *Corresponding Author:* Geoff Kushnick, email: geoff.kushnick@anu.edu.au

ORCID IDs:

- Geoff Kushnick (0000-0001-9280-0213)
- Sam Passmore (0000-0002-5302-356X)
- Fikarwin Zuska (0000-0001-7642-8546)
- Karmila br. Karo (none)
- Daniel M.T. Fessler (0000-0002-7795-7500)

ABSTRACT

The Karo of North Sumatra, Indonesia, have long expressed a preference for matrilateral cross-cousin (*impal*) marriage, yet the practice has declined sharply over the past century. To identify the demographic and sociocultural factors underlying this change, we applied an epidemiological approach to cultural evolution, using a case-control design coupled with structural equation modeling (SEM). Ethnographic data from 176 married individuals across 62 villages were analyzed to assess the effects of demographic, alliance, religious, cosocialisation, and modernisation variables on the likelihood of *impal* marriage. The model fit was strong (CFI = 0.96, RMSEA = 0.04), revealing significant direct and indirect effects. Marrying an *impal* was positively associated with the number of marriageable *impal* and with arranged or strategically motivated unions but negatively associated with reported religious conflict between spouses. Indicators of modernisation such as schooling and infrastructure were non-significant. These results indicate that the decline of *impal* marriage reflects demographic contraction and the weakening of alliance-based strategies rather than a rejection of the cultural norm itself. Framed within an epidemiological model of cultural transmission, the findings demonstrate how social practices may fade when the ecological and demographic conditions sustaining them erode, even as their normative value persists.

KEYWORDS

Cousin Marriage, Indonesia, Social Change, Case-Control Study, Structural Equation Modeling

INTRODUCTION

The Karo are a *suku* (ethnic group or tribe) from North Sumatra, Indonesia, with a longstanding stated preference for matrilateral cross-cousin (*impal*) marriage (Kipp, 1993; Kushnick, 2006; Kushnick & Fessler, 2011; Singarimbun, 1975; Steedly, 1993). Traditionally, "proper" *impal* marriages encompass both first cousin (MBD–FZS) and second cousin (MFBSD–FFBDS) unions (Figure 1A). This preference is embedded within the broader "circulating connubium" (van Wouden, 1935) or asymmetric alliance systems described by alliance theorists (Leach, 1954; Levi-Strauss, 1949; Needham, 1986), in which "wife giver" (*kalimbubu*) and "wife taker" (*anakberu*) relationships structure a patrilineal social order (Figure 1B).

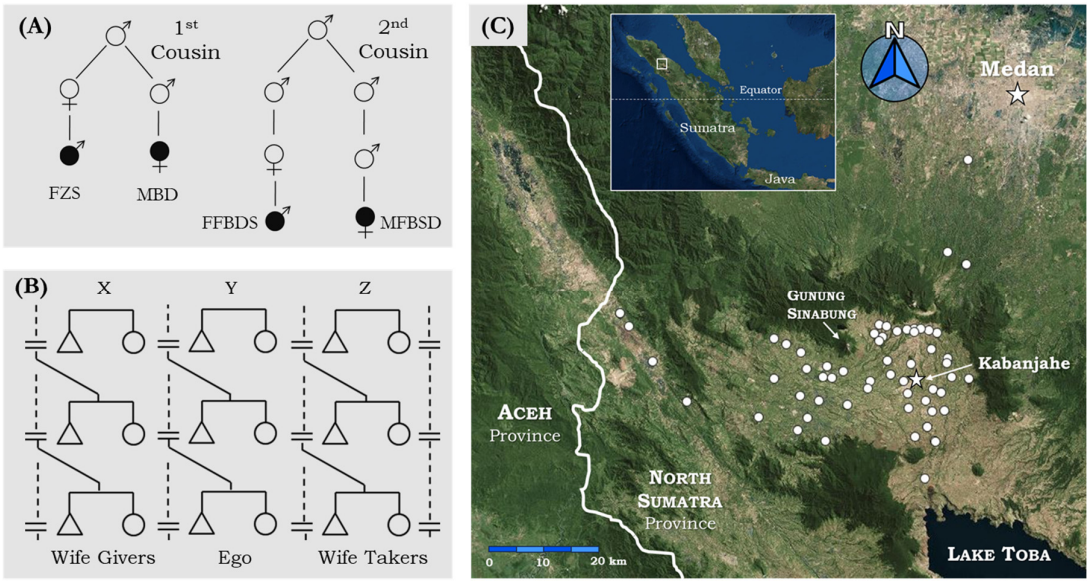

Figure 1. (A) Matrilateral cross-cousin (*impal*) marriage among the Karo are "proper" in both first-cousin and second-cousin forms; (B) it fosters asymmetrical alliance between patrilineage triads, as shown where X are wife-givers (*anakberu*) and Z are wife-takers (*kalimbubu*) of Y; and (C) Location of the 62 Karo villages.

Despite its cultural importance, the practice of *impal* marriage has declined markedly over the past century. Archival and village-census data show that while 11-13% of marriages in the 1930s-1960s were *impal* unions, this proportion fell to just 3-5% between the 1990s and 2014 (Kushnick et al., 2016). Since Karo customary law prohibits marrying an *impal* if one's sibling has already done so (Singarimbun, 1975), the maximum historical prevalence was always constrained by demographic realities (Kushnick & Fessler, 2011). Contemporary Karo fertility rates are around 3 to 4.5 children per woman (Kushnick, 2010). Such a moderate to low fertility rate would significantly limit marriage opportunities with one's *impal*. If those rates were higher in the past, which may well have been the case but remains an open question, they would have been even more limited.

One of the prime goals of cultural evolutionary theory is to understand what factors and causal mechanisms drive social and cultural change (Boyd & Richerson, 2024), and to explain why behaviour changes when the norms driving it remain unchanged (Boyd & Richerson, 1985; Mesoudi, 2011). Within this framework, culture is treated as a system of socially transmitted information that evolves through differential learning, imitation, and payoff-biased adoption. Hypotheses about cultural change are typically tested by examining how variation in transmission pathways, ecological conditions, or social networks alters the frequency of beliefs and behaviours across generations (Henrich & McElreath, 2003; Richerson & Boyd, 2006). Some approaches have focused on people's perceptions and representations, focusing on how ideas and values spread, mutate, and persist even when behaviour diverges from stated norms (e.g., González, 2025). Other approaches emphasise observable behaviour, drawing on methods from human behavioural ecology and demography to study actual choices, actions, and fitness outcomes (e.g., Harris et al., 2021).

Adopting the first of these two approaches, Kushnick et al. (2016) examined Karo perceptions of *impal* marriage through a factorial vignette experiment exploring the effects of demographic and sociocultural factors on attitudes toward marrying an *impal*. Variables included age, gender, cosocialisation with one's *impal*, availability of marriageable kin, practical alliance advantages, and church opposition. Findings revealed several unexpected patterns: cosocialization increased both the perceived likelihood of marrying an *impal* and reduced disgust at the prospect; age influenced male and female respondents' disgust judgments in opposite directions; and female respondents placed greater weight on alliance considerations than males. Taken together, these results suggest that the decline of *impal* marriage cannot be fully accounted for by the Westermarck Effect—where sexual aversion develops through negative imprinting (Fessler, 2007; Kushnick & Fessler, 2011). Instead, the pattern appears to reflect a complex negotiation among multiple evolutionary conflicts: sexual conflict between men's and women's mating interests, parent–offspring conflict over the timing and choice of marriage partners, and sibling conflict arising when brothers and sisters have competing reproductive or alliance-related goals. Because cousin marriage involves the interests of the spouses' parents, who are siblings, it represents a unique social domain where these conflicts intersect and may be resolved simultaneously (Chagnon et al., 2017; Kushnick, 2023; Kushnick et al., 2016).

To investigate these processes beyond perceptions alone, we melded ethnographic and epidemiological approaches to study cultural change, applying methods typically used in public health to the analysis of marriage practices. Epidemiology has long recognized parallels between disease processes and culture, whether in how culture shapes disease risk (e.g., food habits, beliefs about treatments) (Dressler, 2004) or in the analogy between cultural transmission and the spread of contagion, as in Sperber's (1985) "epidemiology of representations." Our approach draws on a third parallel—using epidemiological research designs to study cultural practices themselves.

Specifically, we employed a case-control design, a method well suited to studying rare outcomes (Gamble, 2014; Thiese, 2014), to compare marriages involving *impal* (cases) with those that did not (controls). This design allows efficient retrospective analysis of multiple risk factors without requiring large longitudinal samples or waiting for outcomes to emerge. Given the likely interdependence among variables, we paired the case–control approach with structural equation modeling (SEM) to disentangle direct and indirect effects within a unified framework (Amorim et al., 2010; Beran & Violato, 2010; Kline, 2016). While SEM carries strong assumptions, such as potential unmeasured confounding, its exploratory power has been demonstrated in numerous studies integrating case–control designs with complex causal modeling (Gili et al., 2013; Le et al., 2017; Lyu et al., 2016; Oliveira et al., 2019; Porru et al., 2014). Applying this combined approach enabled us to quantify the social, demographic, and cultural factors shaping the decline of *impal* marriage in Karo society.

METHODS

Data Collection

From March to July 2014, we conducted fieldwork in 62 randomly selected Karo villages across 19 sub-regencies in the Karo and Deli Serdang regencies of North Sumatra (Figure 1C). For brevity we refer to 'we' throughout this section. For clarity, a credit statement at the end of the manuscript provides more details on the specific contributions of each co-author. In each village, the village head identified individuals ever married to an opposite-sex *impal* (currently or previously). We interviewed the available spouse (husband, wife, or both) and then randomly selected volunteers from the same village who had never married an *impal* for comparison. In total, 278 individuals were interviewed: 152 who are or were married to their *impal* and 136 who were never married to their *impal*. For analysis, we created a subsample of 176 respondents by excluding those with multiple marriages, retaining only one spouse per couple, and matching the two groups by age class and gender across all sub-regencies as shown in Table 1. This comprised 88 cases (those ever-married to *impal*) and 88 controls (those never married to *impal*) (Gamble, 2014; Thiese, 2014). Interviews, conducted privately and lasting one to one and a half hours, collected information on marriage histories, *impal* relationships, and motivations for, and familial sentiment towards, marital choices. Data were recorded using ODK Collect (v1.3) on Android devices (Hartung et al., 2010).

Table 1. Sample by gender and age class.

Age Class (years old)	Male		Female		Total
	impal	Non-*impal*	*impal*	Non-*impal*	
30 or less	6	6	9	9	30
31-40	13	13	14	14	54
41-50	17	17	8	8	50
51-60	3	3	8	8	22
61 or more	4	4	6	6	20
Total	43	43	45	45	176

Probit SEM Models

We are using SEM with probit family link. since the main endogenous variable—Is your marriage with a proper *impal*? (bion)—and others, are binary (Kline, 2016, p. 44). Probit, like logistic (a.k.a. logit) regression, aims to predict the likelihood of a binary outcome and is expected to give similar results for substantive effects (Aldrich & Nelson, 1984; Hoffmann, 2016). Probit regression coefficients have a different interpretation to logit regression coefficients, and cannot be transformed to odds ratios, so we analyse them by indicating significance (α=0.05) and sign of effect and then produce marginal effects to aid interpretation. We used the lavaan package in R for SEM analyses which drove the decision to use probit rather than logit models (Rosseel, 2012).

There are two types of variables in an SEM model, endogenous and exogenous (Amorim et al., 2010; Beran & Violato, 2010; Kline, 2016). An endogenous variable is any measured variable that can be treated as a response somewhere within the model. That is, any measured variable that has an arrow pointing into it. An exogenous variable is any variable that does not have an arrow pointing into it and is treated like an independent variable in a regression. SEM models often also contain unmeasured or latent variables, but we do not use them here. The advantage of SEM is that we can pool variance across the paths of the equations. Rather than treating each predictor as independent, the equations are structured in such a way that variance is considered along the structural paths, providing us with better estimates for the relationships of interest.

A limitation of our SEM models is that potential confounding variables were excluded. Given the constraints of the sample size, incorporating too many parameters would have risked overfitting and estimation instability (Kline, 2016; Wolf et al., 2013). While the model prioritizes theoretically central variables, the omission of additional confounders means that some residual bias cannot be ruled out (Arif & MacNeil, 2023; Greenland et al., 1999).

To assess the models' goodness of fit we use two statistics, CFI and RMSEA (Schermelleh-Engel et al., 2003). The Comparative Fit Index (CFI) is a revised form of the Normalised Fit Index (NFI), which asks whether the target model is an improvement over the independence model (i.e., an unspecified model). A good rule of thumb is a CFI value > 0.9. The Root Mean Square Error of Approximation (RMSEA) is a descriptive measure of overall fit. Values closer to 0 represent a good fit, with values less than 0.5 indicative of models that have a close fit to the data (Xia & Yang, 2019). The p-value presented with RMSEA tests the hypothesis that it is less than or equal to .05 (a cutoff sometimes used for good fit) and thus should be non-significant.

Our approach to building the combined/final SEM model (i.e., with all risk factors and risk factor groups) had elements of exploration. Our original model did not include a connection between Alliance and Cosocialization, treating these groups as independent. This model returned model fit statistics below what is considered satisfactory (CFI = 0.868; RMSEAL 0.083). We added additional links using modification of fit indices. The largest improvement indicated by modification indices was a link from 'friends before marriage' (nnar2) to 'marriage type' (nnr1b), with a modification index of 48.644. Rule-of-thumb estimates suggest adding links of >10 if they support theoretical positions. The added link made sense in terms of the overall causal reasoning used to build the original model (i.e.,

there is a strong link between unarranged marriages being between people who were friends prior to getting married), and it is the only difference between the original and the one used for final inference (see Supplementary Material). Adding this link improved model fits to above the rule-of-thumb thresholds (CFI = 0.962 [>0.9]; RMSEA = 0.045 [<0.05]).

Causal Model

The foundations of an SEM model are the underlying causal assumptions (Greenland et al., 1999; Kunicki et al., 2023). The assumptions of our model are illustrated in the Directed Acyclic Graph shown in Figure 2. It consists of several groupings of risk factors, each with two or more interconnected variables, and one or more causal link to whether the individual had married their *impal* (bion). The specific variables used, and their connections, are justified as follows:

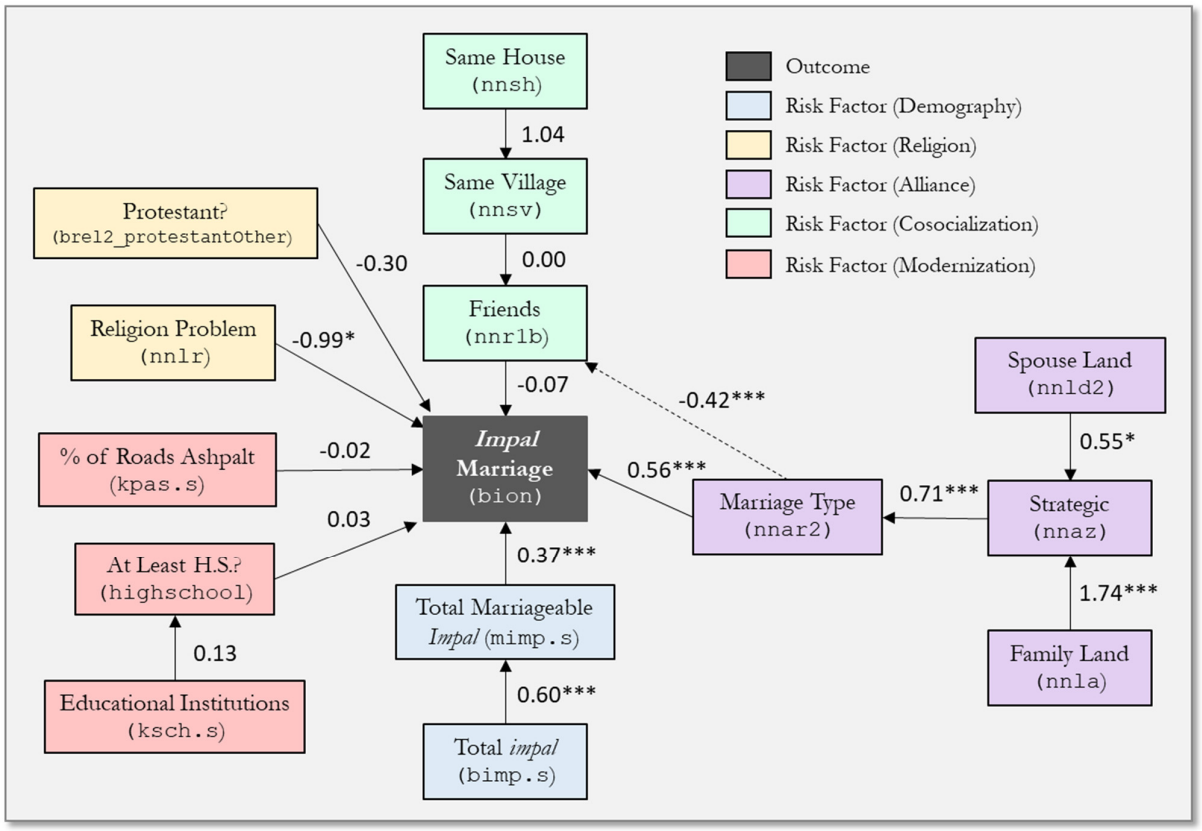

Figure 2. Directed Acyclic Graph (DAG) with coefficients from final SEM model (***p<0.001, *p<0.05).

- DEMOGRAPHY: Whether or not one marries their *impal* should be influenced by the number of total marriageable *impal* they have (mimp.s) which in turn should be influenced by the total *impal* they have (bimps.s) regardless of age difference. This sort of demographic argument has been central to explanations of cousin marriage rates (Kunstadter et al., 1963) and is salient for Karo who have lower fertility rates today than in the past (Kushnick, 2010).
- RELIGION: Religion can play a role in shaping whether one is able to marry a cousin. Although the religious authorities in Taneh Karo have been relatively lenient (Rae, 1994), elsewhere in Indonesia, notably among the Manggarai of Flores, religious authorities have prohibited similar practices (Hicks, 1988). The religion that one practices may shape cousin marriage rates. The Protestant and Catholic churches, for instance, have different stances on, and requirements for entering, cousin marriages. When two potential *impal* spouses have different religious practices, it can also have an effect, such as via causing familial strain and strife.

- ALLIANCE: The role of marriage in creating and maintaining alliances between descent groups has been central to explaining cousin marriage (Leach, 1951; Levi-Strauss, 1949; Needham, 1986). The necessary prerequisites for alliance-based marriage—arranged marriages, inter-familial variation in lanhdholdings, and the potential for strategically keeping land in the family, for instance—still exist in Karo society, but there may have been changes in its importance which could have driven the decline of *impal* marriage (Needham, 1978; Singarimbun, 1975). As land fragmentation, urban migration, and alternative avenues for social mobility have expanded, the instrumental value of marital alliances has weakened, potentially diminishing both the incentive and opportunity for *impal* marriage.
- COSOCIALISATION: The variable cosocialization reflects the potential influence of the Westermarck effect—the hypothesis that individuals who grow up in close physical and emotional proximity during early childhood develop a form of sexual indifference or aversion toward one another. This could decrease the likelihood of later sexual or marital attraction between an *impal* pair (Fessler, 2007; Kushnick & Fessler, 2011). This will depend on the living arrangements of the two from the pair, and the sort of relationship that develops between them.
- MODERNISATION: Modernisation can reduce the rate of cousin marriage by reshaping educational and urban contexts (Shenk et al., 2024). Greater access to schooling expands social networks beyond kin, elevates individual autonomy, and promotes norms that emphasise personal choice over family obligations. Urbanization disperses kin networks, fragmenting traditional households and opening space for non-kin interactions, reducing the structural incentives for endogamous marriage (Greenfield, 2016). Access to improved roads are a proxy measure for general mobility access to cities. Together, these processes weaken both the supply of suitable cousins (Colleran, 2020) and the demand for kin-based unions, accelerating the decline of cousin marriage in many contexts.

RESULTS

Descriptive Statistics

Tables 2 and 3 summarise bivariate differences between *impal* and non-*impal* marriages across measured and categorical variables. Consistent with demographic expectations, individuals in *impal* marriages report higher mean numbers of both total opposite-sex *impal* and marriageable *impal* than those in non-*impal* marriages (Table 2), indicating greater exposure to eligible cross-cousin partners. In contrast, village-level modernisation indicators (school availability and road paving) show little difference between marriage types.

Table 2. Descriptive statistics for measured variables.

Variable	Meaning	*impal*		Non-*impal*		Total		Missing
		Mean	SD	Mean	SD	Mean	SD	
Demography:								
bimp	Total opposite-sex *impal*	6.05	3.31	4.63	2.57	5.34	3.04	0
mimp	Total marriageable *impal* [1]	2.35	1.67	1.42	1.50	1.89	1.65	0
Modernisation:								
ksch	Total schools in Kecamatan	25.36	14.32	25.30	13.69	25.33	13.97	0
kpas	% of roads paved in Kecamatan	27.73	19.09	25.15	17.36	26.43	18.23	13

[1] Defined as within 5 years of age of each other.

Clear contrasts appear in alliance-related variables (Table 3). *Impal* marriages are substantially more likely to be arranged, strategically motivated, and framed in terms of land retention, whereas non-*impal* marriages are more often described as choice-based and non-strategic. Cosocialisation measures show a mixed pattern: *impal* spouses are more likely to report close or friendly relationships prior to marriage but are not more likely to have grown up in the same village, suggesting that kin-based interaction rather than shared residence underpins early familiarity.

Table 3. Descriptive statistics for categorical variables.

Variable	Meaning	Codes	Freqency			
			Impal	Non	Total	Missing
Religion:						
brel2_prot	Religion categories	0 Catholic 1 Protest./Other	35 53	27 61	62 114	0
nnlr	Were there any problems related to religion in marrying this individual?	0 No 1 Yes	86 2	77 11	163 13	0
Cosocialisation:						
nnsv	Did you and your spouse grow up in the same village?	0 No 1 Yes	55 33	62 26	117 59	0
nnr1b	How close were you with your future spouse while growing up?	0 Not/distant 1 Friend/Close	34 54	12 76	46 130	0
Alliance:						
nnld2	How much land does your spouse's family have relative to the average member of their communities?	1 Below Av. 2 Average 3 Above Av.	14 48 26	16 55 17	30 103 43	0
nnla	Was your marriage entered into for the purpose of keeping land in the family?	0 No 1 Yes	64 22	79 6	143 28	5
nnaz	Was your marriage entered into for strategic purposes?	0 No 1 Yes	16 70	49 39	65 109	2
nnar2	Marriage type	0 Choice 1 Arranged	25 63	81 7	106 70	0
Modernisation:						
highschool	Did you attend senior high school?	0 No 1 Yes	36 52	39 49	75 101	0

Religious affiliation itself differs little between marriage types, but reported religious problems are markedly more common among non-*impal* marriages (Table 3). Taken together, the descriptive patterns indicate that *impal* marriage remains closely tied to demographic opportunity and alliance-based decision-making, while modernization proxies show minimal differentiation. These bivariate associations motivate the multivariate causal modeling presented below.

SEM Model

We evaluated sub-models, one for each explanatory grouping (demography, religion, cosocialisation, alliance, and modernisation) before fitting the full model, which combined all the sub-models into 1 amalgamated model. In the full model, we achieved model fit values exceeding the rule-of-thumb thresholds, with CFI=0.96 and RMSEA=0.04 (p=0.61). The model results, including probit coefficient estimates and p values, are shown in Table 4 and Figure 2. Several effects are significant, including 3 of 7 (43%) direct effects and 5 of 8 (63%) indirect effects. Note that Figure 2 includes one pipe linking two risk-factor groups—from nnar2 (Alliance group) to nnr1b (Cosocialisation group). The rationale for including this pipe is discussed in Methods above; the original DAG, without the additional between-group pipes, is included in the Supplementary Material.

The following direct effects on *impal* marriage (bion) are significant: a marriage is more likely to be with an *impal* if an individual has a larger number of marriageable *impal* (mimp.s); a marriage is more likely to be with an *impal* if the marriage is arranged (nnar2); and a marriage is less likely to be with an *impal* if there was a religious problem between the married couple (nnlr).

Table 4. Coefficients and additional statistics for the full causal path model (Figure 2).

DV		IV	Coeff.	SE	*z*	*p*	95% CI	
							Lower	Upper
bion	~	brel2_protestantOther	-0.30	0.23	-1.34	0.18	-0.75	0.14
bion	~	nnlr	-0.99	0.48	-2.06	0.04	-1.93	-0.05
bion	~	mimp.s	0.37	0.08	4.64	0.00	0.22	0.53
bion	~	nnr1b	-0.07	0.09	-0.83	0.41	-0.24	0.10
bion	~	nnar2	0.56	0.07	8.05	0.00	0.43	0.70
bion	~	highschool	0.03	0.12	0.22	0.83	-0.20	0.25
bion	~	kpas.s	-0.02	0.11	-0.21	0.84	-0.25	0.20
mimp.s	~	bimp.s	0.60	0.07	8.32	0.00	0.46	0.74
nnsv	~	nnsh	1.04	0.65	1.59	0.11	-0.24	2.32
nnr1b	~	nnsv	0.00	0.14	-0.01	0.99	-0.28	0.27
nnaz	~	nnld2	0.55	0.23	2.45	0.01	0.11	0.99
nnaz	~	nnla	1.74	0.40	4.38	0.00	0.96	2.51
nnar2	~	nnaz	0.71	0.09	7.91	0.00	0.54	0.89
nnr1b	~	nnar2	-0.42	0.07	-6.00	0.00	-0.55	-0.28
highschool	~	ksch.s	0.13	0.17	0.78	0.44	-0.20	0.46

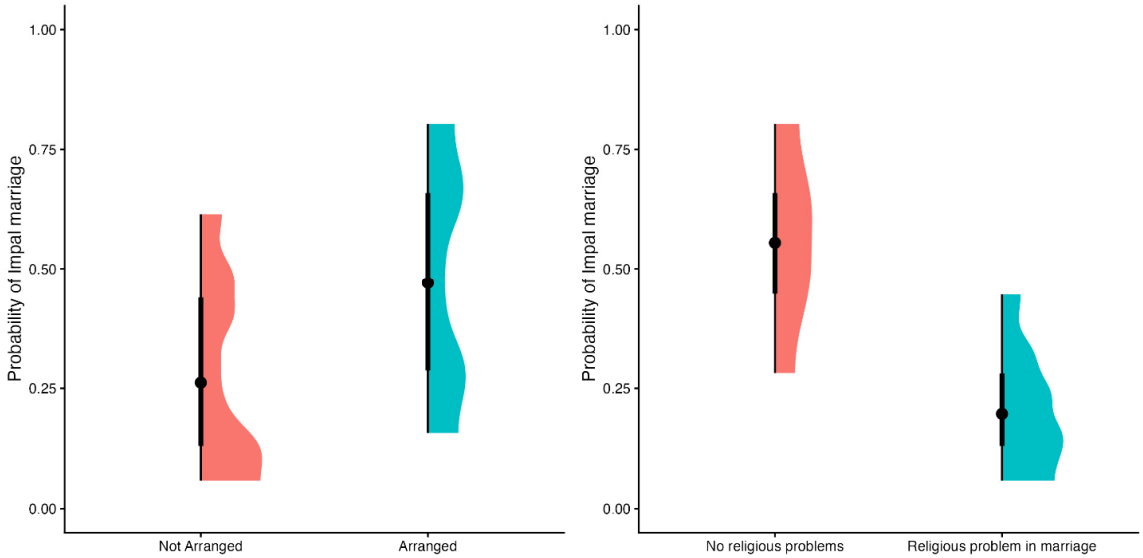

Figure 3. Marginal effects for type of marriage and religious problems.

Using the marginal effect of marriageable *impal* (mimp.s) for the 25%, 50%, and 75% quantiles (approx. 1, 2, or 3 marriageable *impal*), the predicted probability of marrying *impal* is 0.31, 0.38, and 0.46. The other two direct effects are illustrated in Figure 3 and described as follows: if a marriage is arranged (nnar2), there is an approximately 47% chance that it is with an *impal*, but only a 29% chance if it is not arranged; and if there is a religious problem in the marriage (nnlr), there is a 21% chance the marriage is to *impal*, but if there is no religious problem then there is a 55% chance.

The following first- and second-order indirect effects are significant: having more *impal* in general (bimp.s) means individuals are more likely to have more marriageable *impal* (mimp.s); arranged marriages (nnar2) are more likely to occur between individuals who are friends (nnr1b); marriages that were made for strategic reasons (nnaz) are also likely to be arranged (nnarr2); and marriages that were made to retain (nnla) or gain property (nnld2), are also likely to be strategic (nnaz).

DISCUSSION

We used a case-control design combined with SEM to identify demographic, sociocultural, and modernization factors associated with the likelihood of *impal* (matrilateral cross-cousin) marriage among the Karo of North Sumatra, Indonesia. The analysis revealed three key pathways: (1) a demographic chain linking the number of total *impal* to the number of marriageable impal, which in turn predicts the likelihood of *impal* marriage; (2) an alliance chain linking property-related motivations to strategic and arranged marriage decisions, which are strongly associated with *impal* marriage; and (3) a religious pathway, whereby the presence of religious problems between spouses is negatively associated with *impal* marriage. Indicators of modernization, education and infrastructural development, showed no significant effects. Together, these findings suggest that the decline of *impal* marriage can be understood primarily as the product of demographic contraction and the partial erosion of alliance motives, rather than as a wholesale abandonment of the cultural norm itself.

Demographic Constraints and the Shrinking Pool of Marriageable Kin

The strong positive association between the number of marriageable *impal* and the probability of marrying one's *impal* underscores the demographic basis of the practice. In traditional Karo society, moderately sized sibling sets and fertility rates, often exceeding four children per woman (Kushnick, 2010), created ample opportunities for cross-cousin unions. If fertility rates have declined, which we suspect but is undocumented, the pool of eligible *impal* would have contracted, reducing not only actual marriages but also the exposure necessary for such unions to remain culturally salient. This pattern parallels the demographic constraints mathematically modeled by Kunstadter et al. (1963), and the relatively lower fertility rates coupled with lower rates of cousin marriage in Bangladesh and India compared to Pakistan, where fertility and cousin marriage rates are high (Shenk et al., 2024). Demographic effects on cousin marriage extend to kinship terminology as well (Dole, 1969). From an epidemiological perspective, this represents a decline in "exposure opportunities", the equivalent of fewer potential "contacts" through which the practice can be transmitted.

This finding complements earlier ethnographic observations that the Karo system of asymmetric alliance, while ideologically stable, has always been demographically fragile (Needham, 1978; Singarimbun, 1975). The prohibition against marrying an *impal* when a sibling has already done so (Kushnick & Fessler, 2011; Singarimbun, 1975) further constrained prevalence. Our model quantifies this long-theorised demographic limitation: a reduction in total *impal* translates statistically into a reduced number of marriageable *impal*, which in turn lowers the probability of *impal* marriage. Demography, rather than changing values, thus appears to be a principal proximal driver of the decline.

Persistence and Weakening of Alliance Motives

Despite the overall decline, alliance-related variables remain significant predictors of *impal* marriage. Marriages undertaken for strategic reasons or to retain or gain property were more likely to be arranged and, in turn, more likely to involve *impal* partners. This finding reinforces the continuing, though diminished, importance of alliance logic in Karo marriage systems. The *impal* tie has historically served as a mechanism to maintain the reciprocal flow of goods, labor, and ritual obligations between *kalimbubu* (wife-givers) and *anakberu* (wife-takers) (Leach, 1951; Levi-Strauss, 1949; Needham, 1986). Our data suggest that this structural logic persists in some contexts, particularly where property retention remains salient, but that its functional scope has narrowed.

Although most rural Karo engage in agriculture to some degree (Kushnick, 2010), many households are increasingly integrated into non-agricultural economies, and landholdings are fragmented by inheritance, sale, and conversion. Under these conditions, the economic incentives for arranged or alliance-oriented marriages diminish (Schaffnit et al., 2023). Yet the statistical persistence of alliance effects indicates that such motivations retain social legitimacy even as their material foundations weaken. This is consistent with cultural evolutionary theory's prediction that norms may outlive the ecological or economic conditions that originally favored them (Boyd & Richerson, 1985; Mesoudi,

2011). The weakening of alliance motives therefore represents not the disappearance of the cultural schema but its adaptive relaxation in the face of new constraints.

Religion and Moral Recalibration

The negative association between religious problems and *impal* marriage highlights the complex role of Christianity in reshaping marriage ideals. While the Karo Protestant and Catholic Churches have historically tolerated cousin marriage to varying degrees (Rae, 1994), Christian doctrine nonetheless introduced a moral and emotional ambivalence toward kin-based unions. Our data suggest that *impal* marriages are less likely when couples experience religious tension, which may reflect disapproval from clergy, kin, or the broader congregation. This pattern differs from regions such as Flores, where religious authorities explicitly banned cousin marriage (Hicks, 1988), but it suggests a gradual normative recalibration within Karo Christianity—*impal* marriage is not forbidden but has become morally "troublesome." Alternatively the documented effect of religious problems may simply be due to those from the same family, such as *impal*, being members of the same religion. Those not marry their cousins, *impal* or otherwise, have an increase probability of coming from different religions even if one spouse converts. That spouse's family of origin may still have diverging religious views.

Interestingly, the direct variable for religious denomination (Protestant/other versus Catholic) was non-significant, indicating that it is not affiliation per se but interpersonal or community-level conflict that constrains such unions. Religion, then, functions less as a top-down prohibition and more as a social friction that subtly discourages cousin marriage by generating discord or reputational risk. This is consistent with the broader anthropological observation that religious change often modifies the emotional valence of practices before altering their institutional legitimacy.

Limited Role of Modernisation

The absence of significant effects for modernisation indicators (i.e., educational attainment and road infrastructure) was initially unexpected, given modernisation theory's emphasis on education and urbanisation as drivers of cultural change (Greenfield, 2016). One possible interpretation is that modernisation in the Karo highlands is now sufficiently widespread that the remaining variation among villages is too small to generate detectable differences. Alternatively, cousin marriage may have declined earlier in the modernisation process, leaving a residual norm that persists independently of current infrastructural conditions. Another possibility is that modernisation exerts its influence indirectly through the very mechanisms already captured in the model (e.g., declining fertility, reduced land dependence, and altered alliance patterns) rendering its direct statistical effect redundant. These results, thus, caution against assuming that modernisation acts as an independent causal force. Rather, it operates through the reconfiguration of demographic and alliance systems, supporting the argument that the erosion of *impal* marriage is best understood as a downstream consequence of broader socioecological shifts. In a sense, conceptualizing modernization as a direct effect on cousin marriage, rather than as a higher-level effect that exerts its influence on the other variable blocks, is a shortcoming of our model.

Cultural Evolutionary and Methodological Implications

By framing cultural change in epidemiological terms, this study illuminates how demographic contraction and structural transformation can jointly reduce the "transmissibility" of a cultural practice. The analogy to epidemiology is more than metaphorical: cultural practices, like pathogens, depend on exposure, susceptibility, and transmission pathways (Sperber, 1985). As the number of potential *impal* declines and alliance-based incentives wane, the "reproductive number" of the practice falls below the threshold needed for its persistence. Yet, crucially, the normative preference for *impal* marriage remains widely acknowledged among the Karo (Kushnick et al., 2016). The behavior thus declines not because the norm is rejected, but because the ecological and social conditions for its enactment have eroded, a pattern akin to a population achieving herd immunity through environmental change rather than deliberate avoidance.

This interpretation bridges cultural evolutionary theory with human behavioural ecology. From a behavioural ecological perspective, cousin marriage historically optimized inclusive fitness by preserving resources within kin groups and reinforcing cooperative ties (Chagnon et al., 2017; Dalzero et al., 2024; Dalzero et al., 2023; Guillot et al., 2015). As market integration and migration diversify resource flows, the fitness payoffs of such marriages diminish. Selection thus favors individuals who adopt alternative strategies, which are likely to vary by sex and other factors (Chagnon et al., 2017; Kushnick et al., 2016), leading to the cultural decline of the practice through differential reproduction of behaviors. The case-control and SEM approach demonstrates how these processes can be empirically modeled in cultural contexts, providing a framework for quantifying the causal pathways of cultural evolution.

Methodologically, this study demonstrates the utility of combining a case-control design, traditionally used in epidemiology, with SEM to explore complex causal networks in cultural evolution. The case-control design efficiently addresses rare cultural outcomes such as impal marriage, while SEM allows simultaneous estimation of direct and indirect pathways among interdependent variables. Limitations include the cross-sectional nature of the data, potential recall bias in self-reports, and the exclusion of some confounders due to sample-size constraints (Kline, 2016; Wolf et al., 2013). Future research could address these limitations through longitudinal designs, demographic simulations, or agent-based models that explicitly track the transmission dynamics of marriage norms.

Conclusion

In summary, the decline of *impal* marriage among the Karo appears to stem less from ideological rejection than from demographic and structural change. The shrinking pool of marriageable kin, the weakening of alliance-based incentives, and the subtle discouragement introduced by Christianisation together reduced the opportunity and desirability of *impal* unions. By integrating epidemiological reasoning with cultural and behavioral ecological theory, this study demonstrates how social practices can fade not because they are culturally repudiated, but because their ecological and social "hosts" have diminished. In this sense, the waning of *impal* marriage reflects the adaptive transformation of Karo kinship in response to modern demographic and economic realities, illustrating how cultural evolution operates through the same causal logic that governs all complex systems of transmission and change.

ACKNOWLEDGMENTS

Thanks to the Karo people who shared intimate details of their lives with us, and the research assistants who helped in the field. A version of this paper was presented at the Cultural Evolution Society 2024 Annual Conference in Durham, UK. Fieldwork permits were provided by Indonesia's Ministry of Research and Technology (RISTEK), with help from the American-Indonesian Exchange Foundation (AMINEF). Human subjects approval was granted by the Human Subjects Office at the University of Washington, Seattle (with approval to use those permissions from the Ethics Office at The Australian National University, Canberra). All participants provided informed consent before being enrolled in the study.

AUTHOR CONTRIBUTIONS

Writing was done by GK with help from SP. Editing and manuscript approval was done by GK, SP, FZ, KK, and DMTF. Research design was done by GK and DMTF. Analytical design was done by GK and SP. Analyses were carried out by SP with help from GK. Fieldwork was done by GK with help from KK. Research permits were arranged by GK and FZ.

FINANCIAL SUPPORT

Funding was provided by grants to GK from the Fulbright Scholars Progam, American Institute for Indonesian Studies (AIFIS), and ANU's Research School of Humanities and Arts, and a grant to DF and GK from UCLA's Center for Culture, Brain, and Development. SP was supported by the Evolution of Cultural Diversity Initiative at the ANU.

Conflicts of Interest

The authors declare no conflicts of interest.

Research Transparency and Reproducibility

For more details about the project, see https://osf.io/pmf4d. The data, a variables codebook, and Supplementary Material, which provides additional methodological details and R code, are available at: https://osf.io/5xwzs/overview?view_only=4691eb38eb4c430cbfb202d4040007db.

References

Aldrich, J., & Nelson, F. (1984). *Linear Probability, Logit, and Probit Models*. SAGE Publications, Inc. https://doi.org/10.4135/9781412984744

Amorim, L. D., Fiaccone, R. L., Santos, C. A., Santos, T. N., Moraes, L. T., Oliveira, N. F., Barbosa, S. O., Santos, D. N., Santos, L. M., Matos, S. M., & Barreto, M. L. (2010). Structural equation modeling in epidemiology. *Cad Saude Publica*, *26*(12), 2251-2262. https://doi.org/10.1590/s0102-311x2010001200004

Arif, S., & MacNeil, M. A. (2023). Applying the structural causal model framework for observational causal inference in ecology. *Ecological Monographs*, *93*(1), e1554. https://doi.org/https://doi.org/10.1002/ecm.1554

Beran, T. N., & Violato, C. (2010). Structural equation modeling in medical research: a primer. *BMC research notes*, *3*, 267-267. https://doi.org/10.1186/1756-0500-3-267

Boyd, R., & Richerson, P. (1985). *Culture and the evolutionary process*. University of Chicago Press.

Boyd, R., & Richerson, P. J. (2024). Cultural evolution: Where we have been and where we are going (maybe). *Proceedings of the National Academy of Sciences*, *121*(48), e2322879121. https://doi.org/doi:10.1073/pnas.2322879121

Chagnon, N., Lynch, R. F., Shenk, M. K., Hames, R., & Flinn, M. V. (2017). Cross-cousin marriage among the Yanomamö shows evidence of parent–offspring conflict and mate competition between brothers. *Proceedings of the National Academy of Science USA*, *114*(13), E2590-E2607. https://psycnet.apa.org/record/2017-15783-001

Colleran, H. (2020). Market integration reduces kin density in women's ego-networks in rural Poland. *Nature Communications*, *11*(1), 266. https://doi.org/10.1038/s41467-019-14158-2

Dalzero, A., Beheim, B. A., Kaplan, H., Stieglitz, J., Hooper, P. L., Ross, C. T., Gurven, M., & Lukas, D. (2024). Cross-cousin marriage among Tsimane forager-horticulturalists during demographic transition and market integration. *Evolutionary Human Sciences*, *6*, e18. https://doi.org/10.1017/ehs.2024.11

Dalzero, A., Ross, C. T., & Lukas, D. (2023). Fitness consequences of cousin marriage: a life-history assessment in two populations. *Evolutionary Human Sciences*, *5*, e3. https://doi.org/10.1017/ehs.2022.55

Dole, G. E. (1969). Generation Kinship Nomenclature as an Adaptation to Endogamy. *Southwestern Journal of Anthropology*, *25*(2), 105-123. https://doi.org/10.1086/soutjanth.25.2.3629197

Dressler, W. W. (2004). Culture and the risk of disease. *Br Med Bull*, *69*, 21-31. https://doi.org/10.1093/bmb/ldh020

Fessler, D. M. T. (2007). Neglected natural experiments germane to the Westermarck hypothesis: the Karo Batak and the Oneida community. *Human Nature*, *18*, 355-364.

Gamble, J. M. (2014). An introduction to the fundamentals of cohort and case-control studies. *Can J Hosp Pharm*, *67*(5), 366-372. https://doi.org/10.4212/cjhp.v67i5.1391

Gili, J. A., Poletta, F. A., Campaña, H., Comas, B., Pawluk, M., Rittler, M., & López-Camelo, J. S. (2013). Is gravidity 4+ a risk factor for oral clefts? A case-control study in eight South american countries using structural equation modeling. *Cleft Palate Craniofac J*, *50*(5), 591-596. https://doi.org/10.1597/11-320

González, R. (2025). The role of norms as promoters of social change. *Political Psychology*, *46*(2), 455-481. https://doi.org/https://doi.org/10.1111/pops.13025

Greenfield, P. M. (2016). Social change, cultural evolution, and human development. *Current Opinion in Psychology*, *8*, 84-92. https://doi.org/http://dx.doi.org/10.1016/j.copsyc.2015.10.012

Greenland, S., Pearl, J., & Robins, J. M. (1999). Causal diagrams for epidemiologic research. *Epidemiology*, *10*(1), 37-48.

Guillot, E. G., Hazelton, M. L., Karafet, T. M., Lansing, J. S., Sudoyo, H., & Cox, M. P. (2015). Relaxed observance of traditional marriage rules allows social connectivity without loss of genetic diversity. *Molecular Biology and Evolution*. https://doi.org/10.1093/molbev/msv102

Harris, J. A., Boyd, R., & Wood, B. M. (2021). The role of causal knowledge in the evolution of traditional technology. *Current Biology*, *31*(8), 1798-1803.e1793. https://doi.org/https://doi.org/10.1016/j.cub.2021.01.096

Hartung, C., Lerer, A., Anokwa, Y., Tseng, C., Brunette, W., & Borriello, G. (2010). *Open data kit: tools to build information services for developing regions* Proceedings of the 4th ACM/IEEE International Conference on Information and Communication Technologies and Development, London, United Kingdom. https://doi.org/10.1145/2369220.2369236

Henrich, J., & McElreath, R. (2003). The evolution of cultural evolution. *Evolutionary Anthropology*, *12*, 123-135.

Hicks, D. (1988). Change, adjustment, and persistence in generalized exchange: a case study from Indonesia. *Anthropos*, *83*(4/6), 395-402. http://www.jstor.org/stable/40463373

Hoffmann, J. P. (2016). *Regression models for categorical, count, and related variables: an applied approach*. University of California Press. http://www.jstor.org.virtual.anu.edu.au/stable/10.1525/j.ctv1wxrfr

Kipp, R. S. (1993). *Dissociated identities: Ethnicity, religion, and class in an Indonesian Society*. University of Michigan Press.

Kline, R. B. (2016). *Principles and practice of structural equation modeling* (4th ed.). Guilford.

Kunicki, Z. J., Smith, M. L., & Murray, E. J. (2023). A Primer on Structural Equation Model Diagrams and Directed Acyclic Graphs: When and How to Use Each in Psychological and Epidemiological Research. *Advances in Methods and Practices in Psychological Science*, *6*(2), 25152459231156085. https://doi.org/10.1177/25152459231156085

Kunstadter, P., Buhler, R., Stephan, F. F., & Westoff, C. F. (1963). Demographic variability and preferential marriage patterns. *American Journal of Physical Anthropology*, *21*, 511-519.

Kushnick, G. (2006). *Parent-offspring conflict among the Karo of North Sumatra, Indonesia* University of Washington]. Seattle.

Kushnick, G. (2010). Resource competition and reproduction in Karo Batak villages. *Human Nature*, *21*(1), 62-81. https://doi.org/10.1007/s12110-010-9082-4

Kushnick, G. (2023). Marriage: parent-offspring conflict. In T. Shackelford (Ed.), *Encyclopedia of Sexual Psychology and Behaviour*. Springer Nature.

Kushnick, G., & Fessler, D. M. T. (2011). Karo Batak cousin marriage, cosocialization, and the Westermarck hypothesis. *Current Anthropology*, *52*(3), 443-448.

Kushnick, G., Fessler, D. M. T., & Zuska, F. (2016). Disgust, gender, and social change: testing alternative explanations for the decline of cousin marriage in Karo society. *Human Nature*, *27*(4), 533-555. https://doi.org/10.1007/s12110-016-9263-x

Le, A., Zhang, L., Liu, W., Li, X., Ren, J., & Ning, A. (2017). A case control study on the structural equation model of the mechanism of coagulation and fibrinolysis imbalance in chronic schistosomiasis. *Medicine (Baltimore)*, *96*(7), e6116. https://doi.org/10.1097/md.0000000000006116

Leach, E. R. (1951). The structural implications of matrilateral cross-cousin marriage. *The Journal of the Royal Anthropological Institute of Great Britain and Ireland*, *81*(1/2), 23-55.

Leach, E. R. (1954). *Political systems of highland Burma: A study of Kachin social structure*. G. Bell & Sons.

Levi-Strauss, C. (1949). *Les structures élémentaires de la parenté [The elementary structures of kinship]*. Presses Universitaires de France.

Lyu, J., Shi, H., Wang, S., & Zhang, J. (2016). The effect of community stress and problems on psychopathology: A structural equation modeling study. *Compr Psychiatry*, *65*, 24-31. https://doi.org/10.1016/j.comppsych.2015.09.008

Mesoudi, A. (2011). *Cultural evolution: How Darwinian theory can explain human culture & synthesize the social sciences*. University of Chicago Press.

Needham, R. (1978). Classification and alliance among the Karo: an appreciation. *Bijdragen tot de Taal-, Land- en Volkenkunde*, *134*, 116-148.

Needham, R. (1986). Alliance. *Oceania*, *56*(3), 165-180. http://www.jstor.org/stable/40330893

Oliveira, A. A., Almeida, M. F., Silva, Z. P. D., Assunção, P. L., Silva, A. M. R., Santos, H. G. D., & Alencar, G. P. (2019). Factors associated with preterm birth: from logistic regression to structural equation modeling. *Cad Saude Publica*, *35*(1), e00211917. https://doi.org/10.1590/0102-311x00211917

Porru, S., Pavanello, S., Carta, A., Arici, C., Simeone, C., Izzotti, A., & Mastrangelo, G. (2014). Complex Relationships between Occupation, Environment, DNA Adducts, Genetic Polymorphisms and Bladder Cancer in a Case-Control Study Using a Structural Equation Modeling. *PLoS ONE*, *9*(4), e94566. https://doi.org/10.1371/journal.pone.0094566

Rae, S. (1994). *Breath becomes the wind: Old and new in Karo religion*. University of Otago Press.

Richerson, P., & Boyd, R. (2006). *Not by Genes Alone*. University of Chicago Press.

Rosseel, Y. (2012). lavaan: An R Package for Structural Equation Modeling. *Journal of Statistical Software*, *48*(2), 1 - 36. https://doi.org/10.18637/jss.v048.i02

Schaffnit, S. B., Page, A. E., Lynch, R., Spake, L., Sear, R., Sosis, R., Shaver, J., Alam, N., Towner, M. C., & Shenk, M. K. (2023). The impact of market integration on arranged marriages in Matlab, Bangladesh. *Evolutionary Human Sciences*, *5*, e5. https://doi.org/10.1017/ehs.2022.54

Schermelleh-Engel, K., Moosbrugger, H., & Müller, H. (2003). Evaluating the Fit of Structural Equation Models: Tests of Significance and Descriptive Goodness-of-Fit Measures. *Methods of Psychological Research*, *8*(2), 23-74.

Shenk, M. K., Naz, S., & Chaudhry, T. (2024). Intensive Kinship, Development, and Demography: Why Pakistan has the Highest Rates of Cousin Marriage in the World. *Population And Development Review*, *50*(4), 1045-1090. https://doi.org/https://doi.org/10.1111/padr.12678

Singarimbun, M. (1975). *Kinship, descent, and alliance among the Karo Batak*. University of California Press.

Sperber, D. (1985). Anthropology and Psychology: Towards an Epidemiology of Representations. *Man*, *20*(1), 73-89. https://doi.org/10.2307/2802222

Steedly, M. M. (1993). *Hanging without a rope: Narrative experience in colonial and postcolonial Karoland*. Princeton University Press.

Thiese, M. S. (2014). Observational and interventional study design types: an overview. *Biochemia Medica*, *24*(2), 199-210.

van Wouden, F. (1935). *Sociale structuurtypen in de groote oost [Types of social structure in eastern Indonesia]. (Translated by Rodney Needham in 1968)* (R. Needham, Trans.). J. Ginsberg.

Wolf, E. J., Harrington, K. M., Clark, S. L., & Miller, M. W. (2013). Sample Size Requirements for Structural Equation Models: An Evaluation of Power, Bias, and Solution Propriety. *Educational and Psychological Measurement*, *73*(6), 913-934. https://doi.org/10.1177/0013164413495237

Xia, Y., & Yang, Y. (2019). RMSEA, CFI, and TLI in structural equation modeling with ordered categorical data: The story they tell depends on the estimation methods. *Behavior Research Methods*, *51*(1), 409-428. https://doi.org/10.3758/s13428-018-1055-2