Title: Which measures matter? A behavioral ecology view of “market integration” among the matrilineal Mosuo of Southwest China

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Abstract

Market integration (MI) is a complex process through which individuals transition from relatively subsistence-based to market-oriented activities. Changes associated with MI alter the landscapes of individual health and reproductive decision-making. While the consequences of MI are often easily detected, the specific pathways through which MI affects decision-making are context-dependent and under-investigated. We employed an information-theoretic model selection approach to characterize relationships between multiple indicators of MI and three outcomes commonly associated with MI, waist circumference ($n = 431$), systolic blood pressure ($n = 472$), and age at first reproduction ($n = 974$), among adult matrilineal Mosuo participants from 505 households in six villages in southwest China. Different MI indicators, distributed across individual, household, and community levels of social organization, predicted these three outcomes, demonstrating that individuals' personal circumstances, household structure, and community affect how they experience and respond to MI. We emphasize the importance of identifying and measuring multiple context-appropriate indicators of MI across levels of social organization. Theoretical frameworks that situate hypotheses of MI within specific social, cultural, and historical contexts will be most capable of identifying specific pathways through which multiple elements of MI affect different domains of decision making.

Background

How the changing landscapes associated with market integration (MI) affect humanity has long held the interest of anthropologists from diverse theoretical perspectives. However, how MI is defined and operationalized differs across studies, obscuring trends and hampering theoretical advancement. Here, we present tests of evolutionary hypotheses that link MI to health and reproductive outcomes to investigate whether various common proxies of MI reveal anticipated relationships. An evolutionary framework points to important limitations of characterizations of MI as a quasi-linear process (i.e., comparing 'more' versus 'less' MI); recognizing its mosaic features will be important regardless of theoretical orientation.

What is Market Integration? Researchers use the broad term “market integration” to capture the various processes by which individuals shift away from subsistence activities toward market-oriented activities. MI is often conflated with related concepts (e.g., market participation; integration into markets) and there is remarkably little consistency across studies in operationalization of the concept (Table S1.1). Generally, the concept is meant to encapsulate shifts in production (e.g., wage-labor versus subsistence) and consumption (e.g., market versus garden foods) activities (Lu 2007), as well as variation in ‘acculturation’ to outside influences (Colleran 2020a). Many studies (see Table S1.1) implicitly attribute MI to exogenous processes, for example infrastructural developments such as roads and electricity. An evolutionary ecological view recognizes that endogenous processes also affect MI, via a ‘bottom-up’ approach (Demps and Winterhalder 2019) that focuses on how individuals weigh the costs and benefits of market participation in relation to their specific circumstances and constraints. This theoretical orientation raises the concern that the relevant components of market integration may not be

captured by single metrics such as distance to market (e.g., McAllister et al. 2012) or percent of household calories purchased from markets (Henrich et al. 2010) because each measure reflects only one consideration affecting the costs and benefits of engaging in different opportunities presented by market access.

Studies that operationalize MI using compound indices across levels of decision-making (i.e., individual, household, and community) are likely to be more useful in assessing both general and context-specific features of MI, because they consider both exogenous and endogenous components. Relevant indicators include household or individual ownership of consumer electronics (e.g., Olszowy et al. 2018); aspects of both “traditional” and “material” ways of life (e.g., García et al. 2017); participation in activities related to MI, such as purchasing market foods, or engaging in wage labor (e.g., Liebert et al. 2013), and so on (Table S1.1). Such studies can facilitate theory-building by identifying which aspects of MI are associated with different realms of decision-making and related outcomes, including the importance of indicators at multiple levels of organization (e.g., Collieran 2020a; Gurven et al. 2015). At the same time, Table S1.1 reveals considerable variation in how MI is characterized.

What Predicts Common MI Outcomes? We draw upon evolutionary theory to motivate analysis of three consistent outcomes of MI to evaluate the utility of a range of MI indicators.

First, evolutionary theory generally hypothesizes that MI leads to later ages at first reproduction (AFR). Life history theory anticipates that individuals allocate effort across three fundamental activities to optimize fertility for maximum reproductive success: bodily maintenance (e.g., immune function), growth, and reproduction (Stearns and Koella 1986). According to this framework, AFR represents a transition from investing solely in oneself

(growth and maintenance) to investing in both self and reproduction. Two features of MI can favor later AFR: (i) market opportunities reward investments in education and other forms of 'embodied capital' (e.g., Snopkowski et al. 2016); and (ii) MI incentivizes investments in status competition (e.g., Shenk et al. 2016), requiring additional time to invest in self and thus delaying AFR. Importantly, if market opportunities do not disproportionately favor educated individuals, then increasing access to material resources should lead to *earlier* rather than later AFR (Gurven et al. 2017; Jones and Bliege Bird 2014; Mattison and Shenk 2019), indicating that different markers of MI are relevant for understanding this particular tradeoff.

Second, evolutionary theory predicts that individuals typically prefer market foods and sedentary activity, even if doing so harms their long-term health and survival (Wells 2014). Such changes in nutrition and activity affect waist circumference (central adiposity) and systolic blood pressure (SBP), both of which are commonly associated with MI (WHO Expert Consultation 2011). Reliance on market foods is incentivized because such foods appeal to our evolved preferences for salt, fat, and carbohydrates, and also because they can lower the costs of production and consumption, freeing time and resources to pursue status and reproduction (Lieberman 2006; Wells 2014). As highly-processed market foods supplant traditional foods (low in sugar, higher in fiber, and produced at greater physical effort), metabolic dysfunction and chronic disease result (e.g., Blackwell et al. 2009; Wells 2014). Novel psychosocial stresses associated with culture change, interaction with 'modernized' cultures, increased status competition, and inequality are likely to increase stress-related chronic disease, including hypertension (McDade and Nyberg 2010; see also Wander et al. 2020).

Research Population. We test these hypotheses among the Chinese Mosuo, an ethnic minority

who, since the 1980s, have experienced intensifying integration with regional markets, stemming primarily from increasing domestic and international tourism (Mattison 2010; Walsh 2005). Traditional farming and animal husbandry are increasingly, but unevenly, giving way to lifestyles based on profits from tourism. Villages close to the lake experience the most dramatic effects of tourism, including new opportunities for employment and daily interactions with non-Mosuo visitors. In these lakeside villages, incomes are high, raising the standard of living and increasing emphasis on market-oriented jobs as the Mosuo look increasingly to achieve their ambitions in tourism. The town of Yongning, which is distant from the main tourism center, was historically more important for market activities, housing a central market and providing access to commercial and farmed products brought in from elsewhere. Yongning is also the seat of local government, and contains the local middle school.

Mosuo people have responded to this changing landscape in a variety of ways (Blumenfield et al. 2018; Mattison 2010). We thus examine a suite of “market integration” variables relevant to the Mosuo’s context as predictors of AFR, SBP, and waist circumference, to assess the extent to which one or a small set of variables emerge as relevant indicator(s) of MI.

Materials and methods

Participants and sampling. We administered questionnaires in 505 households in six matrilineal Mosuo villages between January and July 2017. Supplementary material S2 contains details of questionnaire variable parameterization (age, gender, years of schooling, education, age at first reproduction, and income). We calculated road distances from the center of each village to the center of the market town and the main lakeside village using Google Maps ([google.com/maps](https://www.google.com/maps)).

Our dataset contains 11 known or potential indicators of MI at the individual, household, and village levels (Table S1.2).

We collected anthropometric data from household members present at the time of interview. We calculated waist circumference as the average of three measurements taken at 1-1.5 inches above the top of the iliac crest (NHANES 2007). Systolic blood pressure (SBP) was calculated as the average of three estimates using an Omron Series 10 blood pressure monitor.

Data collection protocols were approved by the University of New Mexico Institutional Review Board (06915) and Fudan University conducted additional ethical review. All participants provided informed consent.

Statistical analyses. To assess relationships between MI and our outcomes of interest, we analyzed each outcome separately. We included only adults aged 16 years and older, the earliest age at which people in this society begin to reproduce. Our AFR analysis included 974 individuals (579 women, 395 men, from 292 households). Our SBP and waist circumference analyses included 472 individuals (300 women, 172 men, from 276 households) and 431 individuals (271 women, 160 men, from 271 households), respectively (Table 1); we excluded pregnant women from both analyses. We standardized waist circumference z-scores (waistZ) separately for men and women.

For each outcome, we compared AIC_c values (Burnham and Anderson 2002) across models including all possible combinations of our 11 MI predictors (plus controls for gender, age, and age cohort) to identify a single model that best explains observed variation (details in supplementary material S4). We modeled waistZ and SBP using linear mixed models, and AFR

using a mixed-effects Cox proportional hazards model, and included household as a random effect in all models. We conducted all statistical analyses in R (R Core DevelopmentTeam 2017).

Results

The top-supported models for our three outcomes (Table 2) had little in common, indicating that no single variable or set of variables consistently captures MI in the Mosuo context.

Being male, coming from a household with lower educational attainment, living farther from the market town, and living farther from the tourism center predicted later AFR. Living closer to the tourism center or market town slightly *reduced* the odds of having reproduced at each age. The effect of distance to market town was marginally weaker for older people and slightly stronger for men. Greater household educational attainment *increased* the odds of having reproduced at each age. Age cohort was also predictive (after controlling for year within cohort): AFR was earlier for all cohorts between 26 and 75, but later for the oldest cohort (76+).

Being younger, living farther from the nearest market town, and living closer to the tourism center (on Lugu Lake) were associated with having larger waist circumference. On average, each additional kilometer from the tourism center predicted a 0.04 *decrease* in waistZ, while each additional kilometer from the market town predicted a 0.02 *increase* in waistZ.

Being older, being male, having more education, living in a smaller household, and having fewer migrants in the household predicted higher SBP. On average, SBP was 1.84 mmHg higher for each additional year of schooling, 1.15 mmHg lower for each additional household member, and 0.88 mmHg lower for each additional household migrant. The effect of formal education on SBP was slightly weaker for older people.

Discussion

Theory suggests that market integration as a general process should typically induce transitions to later age at first reproduction (AFR) and higher morbidity due to metabolic load and chronic disease. At the same time, empirical evidence reveals limited consistency across studies in the effects of specific measures of MI or the level at which MI is measured on these and related outcomes (Table S1.1). This presents three immediate possibilities: 1) certain specific indicators of MI are more relevant than others; 2) relationships between indicators and outcome variables are context- and stage-dependent; and 3) publication biases belie true complexity in the causes and consequences of MI. Our results, combined with a healthy dose of scientific skepticism, provide evidence in support of the second and third possibilities.

Is There a “Best” Measure of MI? Our analyses of Mosuo communities suggest that there is no obvious “best” indicator or set of indicators of MI that is consistently related to all analyzed outcomes. Individual-level predictors appear in top models for all three outcomes; household-level predictors appear in models of blood pressure and AFR, but not waist circumference; and community-level predictors appear in models of waist circumference and age at first reproduction, but not blood pressure. Moreover, there is no combination of variables that supports our predictions across the board. Individuals residing closer to the tourism center have larger waist circumferences, as predicted, but this variable was not significant in the top model for AFR and did not appear at all in the top model predicting systolic blood pressure. Indeed, the most consistent effects are of age and sex. Thus, our results appear biologically valid, and also consistent with Lu (2007) in finding limited coherence among measures of MI.

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200 ***Context-Specificity in Market Integration.*** If our results provide evidence against the notion of
201 universal measures of MI, they may nonetheless provide support for models that account
202 carefully for the context in which market integration is occurring. For example, we suspect that
203 proximity to the closest tourism center is a more appropriate proxy for wage-based than
204 education-based market integration. The tourism center generates significantly more wealth and
205 opportunities for wage labor than the actual market town of Yongning. Thus, the fact that living
206 closer to the tourism center predicted larger waist circumferences is not surprising, given the
207 high nutritional availability and relatively sedentary lifestyles provided by tourism. As
208 introduced earlier, life history theory anticipates this relationship, as well as an earlier AFR,
209 given limited tradeoffs with education and other potential investments in oneself (see also
210 Mattison et al., 2014), particularly within familial contexts of substantial allocare that reduce an
211 individual's costs of raising children (e.g., Thomas et al. 2018) and energetic savings afforded by
212 wage-based occupations (Urlacher and Kramer 2018).

213 At the same time, we were surprised not to find associations between some of the most
214 commonly-studied indicators of MI and our outcomes. Our finding that higher household
215 education was associated with earlier AFR is unexpected for two reasons. First, it contrasts with
216 general patterns across societies in which additional education is associated with later AFR and
217 other reproductive decisions likely to reduce lifetime fertility (Colleran and Snopkowski 2018;
218 Snopkowski et al. 2016; Snopkowski and Kaplan 2014). Second, the salient measure of
219 education is at the household level (highest level of education achieved by any member of the
220 household), not the individual level (years of schooling). This suggests the pathways by which
221 education affects reproduction may be more complicated than simply through an individual's

personal decision to remain longer in formal education, and that the household environment is an important predictor of individual reproductive behavior (Colleran 2020b).

Furthermore, material resources (e.g., individual income, household income, number of cars) did not appear in any of our top-supported models. This may suggest that income and material wealth, per se, are less important to understanding how Mosuo respond to MI than is true in other societies (e.g., Gurven et al. 2015) or that our study failed to capture locally-relevant indicators of material wealth. Nor did household proportion of purchased calories appear in any of our top-supported models, which was unexpected given the importance of diet quality for waist circumference and SBP, and findings from studies in other settings that use consumption of market foods (Dancause et al. 2013; van Horn et al. 2019) or proportion of calories purchased from market (Henrich et al. 2010) as measures of MI. Finally, distance to lake did not predict SBP, which was surprising because tourism is undoubtedly a source of MI for the Mosuo. Instead, smaller households and higher levels of education were the primary MI-related variables associated with higher SBP, suggesting that dietary change and physical activity levels, in the case of the Mosuo, are not the only pathway by which MI affects health or that SBP may not respond to MI similarly among the Mosuo (Wander et al. 2020). It is also possible that publication biases (Smaldino and McElreath 2016) have led us to overestimate the impacts of these specific predictors on health outcomes in formulating our predictions.

Implications for Theorizing Market Integration. Overall, our findings strongly suggest that focusing on a single measure of MI, particularly in efforts to replicate findings across populations, is likely to miss other important elements of MI that impact local outcomes. Rather, the best operationalizations of MI are likely to differ across research settings, and both unique

and universal characteristics of MI are likely to be important at different sites. This context-specificity includes differences in how people experience and respond to multiple elements of MI simultaneously and across levels of social organization.

Taken together, our analyses point most consistently to distance to lake and education as the two most relevant elements of MI in understanding health and reproductive responses in this population. However, to fully understand why these elements of MI are important in this context, we must appreciate the particular context and history of the Mosuo, in which subsistence agriculture and some degree of market integration long predate the more dramatic changes brought by access to tourism. This has resulted in health being affected more among lakeside communities and, unusually, that education does not come at the expense of reproduction. Given this, we (and others) may have over-generalized insights from foraging societies to the context of subsistence agriculture, which is associated with very different nutritional and health environments (Mattison and Sear 2016; Page et al. 2016). Repeating this type of model selection approach using data from different contexts could help identify whether specific indicators of MI exhibit similar relationships with health and reproductive outcomes across societies. Such analyses could provide a more textured picture of the context-specific dynamics of MI and enable powerful comparisons, including whether certain responses to MI correlate with population-level variables such as demography, inequality, subsistence strategy, mobility, environmental conditions, and kinship norms.

Conclusions

Interest in the effects of markets on ‘premodern economies’ is longstanding in anthropology. Our results suggest that research on markets from many theoretical perspectives

may benefit from a more nuanced conceptualization of MI. Despite previously well-established patterns, the dynamics of MI within a given society may be subtle, complex, and potentially unique. We argue that market integration warrants further theorizing to define appropriate measures and levels of analysis for identifying the complex interactions and effects of social processes involved. Theoretical frameworks that situate hypotheses of MI within specific social, cultural, and historical contexts will be best placed to accomplish this task.

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395 **Tables**

396 **Table 1**

Variable	Level of organizatio n	WaistZ sample Mean(sd)	SBP sample Mean(sd)	AFR sample Mean(sd)
Scaled waist circumference	Individual	0(1)	-	-
Systolic blood pressure	Individual	-	116.71(22.67)	-
Age in years at first reproduction	Individual	-	-	24.86(4.98)
Log-transformed individual income (CNY per month)	Individual	737.42 (1657.25)	678.30 (1592.88)	1126.11 (3344.81)
Number of years in school	Individual	3.57(4.78)	3.23(4.54)	5.82(5.25)
Age in years	Individual	49.16(14.51)	51.20(15.35)	42.35(15.91)
Log-transformed household income (CNY per year)	Household	87903.11 (134283)	89484.81 (131785.6)	97661.77 (146468.7)
Highest level of education attained by any household member	Household	3.94(1.30)	3.93(1.11)	4.02(1.07)
Percentage of household calories purchased from market	Household	26.28(25.66)	26.70(25.78)	28.31(26.01)
Number of cars in household	Household	0.92(1.03)	0.94(1.07)	1.01(1.11)
Number of migrants in household	Household	2.05(2.19)	1.94(2.03)	2.33(2.33)
Household size	Household	4.65(1.80)	4.72(1.83)	4.89(1.86)
Road distance to tourism center (km)	Village	8.50(5.76)	8.36(5.81)	8.05(5.98)
Road distance to market town (km)	Village	7.77(5.70)	7.92(5.78)	8.45(6.00)

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401 **Table 2**

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	<i>Sample</i>	<i>Variables</i>	<i>Coefficient (SE)</i>		<i>AIC</i>	<i>AIC_w</i>
AFR	n=974	Age*	0.03 (0.01)	1.04	12614.1	0.063
	579 women	26-35 cohort*	0.71 (0.31)	2.04		
	395 men	36-45 cohort*	0.83 (0.36)	2.29		
	292 households	46-55 cohort	0.78 (0.44)	2.18		
		56-65 cohort	0.84 (0.55)	2.32		
		66-75 cohort	0.52 (0.66)	1.69		
		76+ cohort	-0.63 (0.81)	0.53		
		Gender (male)*	-1.23 (0.12)	0.29		
		Highest household education*	0.08 (0.04)	1.08		
		Distance to tourism center	-0.02 (0.01)	0.98		
		Distance to market	-0.01 (0.02)	0.99		
		Age:Distance to market	-0.00 (0.00)	1.00		
		Distance to market:Gender	0.02 (0.01)	1.02		
WaistZ	n=431	Intercept*	-0.96 (0.23)		1138.7	0.017
	271 women	Age*	-0.02 (0.00)			
	160 men	Distance to tourism center*	-0.04 (0.01)			
	271 households	Distance to market	0.02 (0.01)			
SBP	<i>Sample</i>	<i>Variables</i>	<i>Coefficient (SE)</i>		<i>AIC</i>	<i>AIC_w</i>
	n=431	Intercept*	70.06 (5.14)		4123.0	0.015
	271 women	Age*	0.97 (0.08)			
	160 men	Gender (male)*	6.68 (1.88)			
	271 households	Household size*	-1.15 (0.52)			
		Number of migrants	-0.88 (0.45)			
		Years of schooling*	1.84 (0.62)			
		Age:Years of schooling*	-0.03 (0.01)			

403

404 **Table and figure legends**

405 **Table 1.** Descriptive statistics (means and standard deviations) for samples for each analysis: waistZ sample (n=431, 271
406 women, 160 men; 271 households); SBP sample (n=472, 300 women, 172 men; 276 households); AFR sample (n=974, 579
407 women, 395 men; 292 households). Values are displayed for outcome variables only in the column corresponding to the sample
408 used for their analysis. Incomes reported in Renmimbi (CNY) using July 31 2017 exchange rate (1USD = 6.73 CNY).

409
410 **Table 2.** Top-supported models of associations between outcomes of interest and indicators of market integration (MI). Coefficients
411 and standard errors (SE) show predicted effect of each indicator on scaled waist circumference relative to people of the same gender
412 (waistZ) and systolic blood pressure (SBP). Coefficients for age at first reproduction (AFR) show the predicted effect of each indicator
413 on the probability that an individual has had a child by a given age (positive values thus represent a shift toward younger AFR, while
414 negative values represent a shift toward later AFR). AIC_w is the weight, or relative likelihood, of the top-supported model given all
415 other possible alternative models. Variables with asterisks are significant at a 0.05 alpha level.

416
417 **Figure 1.** Predicted effects of indicators of market integration (MI) and demographic variables on scaled waist circumference (waistZ,
418 panel a) and systolic blood pressure (SBP, panel b) from top-supported waistZ and SBP models reported in Table 2. MI indicators
419 with positive predicted effects are associated with an increase in waistZ or SBP, and MI indicators with negative predicted effects are

420 associated with a decrease in waistZ or SBP. Dashed lines represent intercepts ($z = -0.96$ for waistZ; 70.06 mmHg for SBP). Predicted
421 effects are parameter estimates ± 2 standard errors.

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424 **Figure 2.** Later age at first reproduction (AFR) is associated with living farther from market activities. The probability of having a
425 child by any given age is higher for individuals living farther from the tourism center (panel a) and farther from the closest market
426 town (panel b). Data are from top-supported AFR model reported in Table 2.

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428 **Hare et al.** Which measures matter? Market integration among the matrilineal Mosuo of Southwest China SUPPLEMENTARY
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S1. Definition, operationalization, and indicators of MI

The processes we refer to as “market integration” are described by a range of terms including “integration into the market”, “market intensification”, “market involvement”, “market incorporation”, “market participation”, and “modernization”, often with subtle differences in meaning. In this study we follow a large body of research that employs “market integration” to encompass these various meanings. Our starting point is Lu’s (2007) observation that MI is characterized by individuals producing for and consuming from markets.

Table S1.1. Variation in operationalization of MI across selected studies, organized chronologically (shading indicates reported outcomes related to: **health**, **relationships/cooperation**, and/or **AFR**).

Citation	Definition of MI	Operationalization of MI	Reported Relationships
(Behrens 1992)	‘the formation of cash markets for food and labor’ (p. 436) Synonyms: ‘cash-cropping’,	Selling rice, fish, or foraged wild resources. Level of analysis: cocina (food preparing and consuming unit, multiple households)	‘Cash transactions decrease one’s participation in the traditional kin-based network exchange’ Pay for wage labor reduces willingness to participate in traditional labor exchange .
(Joseph Henrich 1997)	‘the spiral of market participation and dependence through the progressive acquisition of capital technologies which continuously require such things as replacement parts, gasoline, oil, etc.’ (p. 329) Synonyms: ‘market incorporation’, ‘participation’	The number and kind of western possessions owned by each household Level of analysis: household, community	Households and communities experiencing market integration are focusing on more cash cropping and animal breeding.
(Franzen and Eaves 2007)	Wage labor or selling of meat that brings in cash, which can be exchanged for storable goods Synonyms: ‘market access’	Market sales of hunted meat and household purchases of food, supplies, and medicine.	No relationship between selling meat and food sharing .

		Level of analysis: household	
(Lu 2007)	‘The commodification of labor, capital, land, and goods and services.’ (p. 594)	Frequency of commercial transactions (wage labor, sale of cash crops, handicrafts, or domestic animals), percent time spent in commercial activities, proportion of diet purchased, ownership of ‘market-intensive’ possessions, frequency of market purchases, Level of analysis: household, community	Measures of market integration are not ‘related in any straightforward or consistent way’ (p. 599)
(Reyes-García et al. 2008)	Lack of traditional knowledge	Lack of traditional plant knowledge; proximity to market town Level of analysis: individual	Having less traditional plant knowledge is associated with having lower BMI . The relationship between traditional plant knowledge and BMI is reduced among people living close to the market town.
(Blackwell et al. 2009)	‘Increasing integration of indigenous groups with non-native society’ (p. 161); effectively synonymous with: ‘economic development’, ‘acculturation’	Ethnic group proxy for level of acculturation Level of analysis: individual	Shuar children in the market-integrated area were more likely to be stunted than colonial children in the same area and traditional Shiwiari in a less market-integrated area.
(J. Henrich et al. 2010)	Mutually-beneficial exchanges among strangers (p. 1480) Effective synonyms: ‘market norms’, ‘transactions beyond the local group’	‘Average percent of total household calories that are purchased in the market,’ Level of analysis: household	MI predicts increased offers in ultimatum game, dictator game, and third-party punishment game.
(Godoy 2012)	‘Market Integration’: Working for a wage or selling crops. ‘Selling and buying more labor and goods’	Market Integration: ‘wage income’, ‘access to credit’, ‘wealth’,	Slight effects of wage income: decreased number of days of illness ,

	<p>‘Acculturation’: Absorbing the culture of outsiders</p> <p>Synonyms: ‘market participation’, ‘modernization’</p> <p>(chapter 2)</p>	<p>Acculturation: ‘educational attainment’, ‘numeracy’, ‘distance to nearest town’, ‘literacy’, ‘Spanish fluency’</p> <p>(p. 136)</p> <p>Level of analysis: individual</p>	<p>increased BMI, increased self-reported morbidity.</p> <p>‘credit had no discernible effect on subjective or objective health’</p> <p>Numeracy</p>
(Masferrer-Dodas et al. 2012)	<p>‘consumption of goods and services’</p>	<p>Weekly expenditures, annual durable consumption</p> <p>Level of analysis: individual, household</p>	<p>There is no association between consumption and well-being.</p>
(Houck et al. 2013)	<p>Economic growth associated with intensifying resource extraction, accessibility by roads, and development of the physical environment (p. 524, paraphrasing first par)</p>	<p>Level of MI for ethnic communities (in order of decreasing MI: Shuar, Kichwa, Huaorani, Cofan)</p> <p>Level of analysis: community</p>	<p>Best growth outcomes in the Shuar and Cofan, lower growth in the Kichwa and Huaorani</p>
(Liebert et al. 2013)	<p>‘the suite of social and cultural changes that occur with economic development’ (p.228)</p>	<p>‘increased consumption of market-based foods (e.g. soda, rice, and processed carbohydrates), ownership of more consumer goods and residence in a household with modern features’ (p. 229)</p> <p>Level of analysis: individual</p>	<p>MI affects lifestyle and diet: those owning more consumer goods are also more likely to eat market foods and have houses with modern features.</p>
(Snopkowski and Kaplan 2014)	<p>Growing service sector, increasing wages for jobs that require education,</p> <p>Synonyms: ‘modernization’, ‘labor force participation’</p>	<p>‘involvement in paid work’, ‘increased education’</p> <p>Level of analysis: individual</p>	<p>Fertility decreases with increased education.</p> <p>Involvement in paid work is associated with later AFB.</p>

(Colleran et al. 2015)	<p>MI occurs when ‘populations consume more, become less self-sufficient and increasingly depend on education as a route to socioeconomic status’ (Abstract, p. 1)</p> <p>Effective synonyms: ‘labour-force participation’, ‘non-farming income/weath’, ‘investment in education’</p>	<p>‘Non-farming wealth’, ‘educational capital’, and employment in market occupations.</p> <p>Level of analysis: individual</p>	<p>Education and market occupations are associated with reduced fertility; non-farming wealth is associated with increased fertility.</p> <p>No measures of education or market integration associate with later AFB.</p>
(Gurven et al. 2015)	<p>‘The ability to store food and accrue savings and credit by alternative means ... for smoothing variance in consumption’</p> <p>Effective synonyms: ‘market involvement’,</p>	<p>‘Market wealth’: material assets and cash income (from wage labor or selling produce)</p> <p>Schooling and Spanish fluency</p> <p>Village proximity to market and mean wealth</p> <p>Level of analysis: household, community</p>	<p>Market wealth predicted greater giving of food (both amount given and number of people shared with)</p> <p>People most fluent in Spanish showed greater giving with higher income. This was not the case for people less fluent in Spanish.</p> <p>Inequality was higher in villages located further from markets.</p>
(Olszowy et al. 2015)	<p>Modernization ‘rapid culture change away from traditional lifestyles as a result of the urbanization, industrialization, secularization, and development of cash economies that accompany economic development.’ (p 832)</p>	<p>Islands that are more/less modernized.</p> <p>Level of analysis: island</p>	<p>Mean body mass and fatness, as well as obesity risk, were higher on islands of increased modernization.</p>
(BurnSilver et al. 2016)	<p>‘Transition away from subsistence-based livelihoods.’ (p. 122)</p> <p>Synonyms: ‘mixed economies’, ‘market dependence’, ‘market transition’, ‘development’</p>	<p>‘Annual income from employment, pensions, dividends, and public assistance’</p> <p>Level of analysis: household</p>	<p>‘high-income households produce more—not less—wild food.’</p> <p>high-income households were no less engaged in food sharing networks, and may in fact have more sharing partners.</p>

(Gildner et al. 2016)	‘increasing production for and consumption from a market-based economy’ (p.1)	Comparison of two regions, one more market-integrated than the other Level of analysis: community	Among females, prevalence of <i>A. lumbricoides</i> was lower in the more MI region; among males, <i>T. trichiuria</i> prevalence was higher in the more MI region.
(Shenk et al. 2016)	Societies that ‘move away from a primary emphasis on agriculture toward increasing integration with a market economy’ Synonyms: ‘industrialization’, ‘urbanization’	Ag or market subsistence strategy: education and occupations of family members, how much cropland the family owns, number of labor migrants in the bari, Level of analysis: individual (women)	Market transition is associated with a shift toward more extensive kinship . Having one or more labor migrants among families in the bari, having a more educated husband, and having a father work day labor reduce the chances of marrying consanguineally . Women with fathers who work a salaried occupation are more likely to marry consanguineally .
(Sun et al. 2016)	Increased energy intake and reduced energy expenditure with increasing use of consumer electronics. Synonyms: ‘economic development’, ‘transition to sedentary lifestyles’	‘Consumer electronics’ Level of analysis: individual	Ownership of consumer electronics was associated with increased adiposity and risk for obesity .
(Urlacher et al. 2016)	‘increasing production for and consumption from a market-based economy’ (p.316)	Household income, ownership of household items related to traditional and market lifestyles, frequency of consumption of market foods in macronutrient groups Level of analysis: individual	Income was negatively related to HAZ and WAZ among females , but positively related to HAZ and BMI-for-age among males. Consumption of market carbohydrates was positively related to WAZ and BMI-for age .

			Traditional lifestyle associated with lower HAZ for females, lower HAZ, WAZ, BMI-for-age among males.
(Abay and Hirvonen 2017)	Access to market foods	Access to local food markets Level of analysis: individual	Children in HHs that are closer to local food markets have greater WAZ WHZ
(Stagaman et al. 2018)	‘producing for and consuming from a market-based economy’	Type of housing construction and infrastructure, proportion of owned items reflecting a traditional foraging lifestyle, proportion of items owned that reflect investment in manufactured goods. Measures translated using factor analysis, into three latent factors called: House modernity, Subsistence Items, Power Usage (necessary for operating owned items) Level of analysis: individual	House modernity predicted lower gut microbiome diversity. Subsistence items did not predict gut microbiome diversity. Power usage interacted with house modernity to affect microbiome diversity.
(Colleran 2020)	‘communities transitioning from subsistence farming to market-dependence’ (abstract, p.1); effective synonyms: ‘urbanization’; ‘industrial intensification’, ‘market-dependent’ versus ‘small-scale’ and ‘mixed subsistence economies’, ‘urbanised market economies’, ‘economic modernisation’, ‘market dependence’, ‘transition to market dependence’	composite index of household members’ occupation, occupational prestige, and employment history individual score is deviation from community mean; intended to capture extent to which household depends on market labor versus farming income; Level of analysis: individual	Personal networks are smaller and less kin-dense in households and communities that are more market-integrated. NB: this includes both household-level and community-level metrics of MI and effects (here, kin density)

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(Lachaud et al. 2020)	Lack of wealth within the cash economy	District accessibility to services and central markets: having an all-season road, distance from service and market area. One “cash economy” dimension of an MCA on DHS asset variables. Education and French literacy. Income, financial stress. Level of analysis: community ,	Living in the mixed or urban area was associated with greater depression and anxiety . Material wealth in the cash economy was less predictive of depression and anxiety than agricultural wealth.
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Table S1.2. Potential indicators of MI used in our analyses, their relationships to market integration (MI), whether they are likely to increase or decrease with MI, and the level of social organization at which they apply.

Variable	Explanation	Relationship to MI	Increases or decreases with MI	Level
Individual income	Log-transformed individual income (CNY per month)	Participation in market-related activities, e.g. wage labor or business	Increases	Individual
Years of schooling	Number of years in school	Participation in formal education	Increases	Individual
MI cohort	Market integration cohort (turned 16 before 1980, 1980-1990, or after 1990)	Born before, during, or after most intensive period of MI	n/a	Individual
Household income	Log-transformed household income (CNY per year)	Participation in market-related activities, e.g. wage labor or business	Increases	Household
Highest household education	Highest level of education attained by any household member (min 0, max 5)	Participation in formal education	Increases	Household
Market calories	Percentage of household calories bought from market	Consumption of food from market	Increases	Household
Number of cars	Number of cars in household	Indicates material wealth	Increases	Household
Number of migrants	Number of migrants in household	May indicate connections to more distant markets	Increases	Household
Household size	Household size	Smaller families generally associated with MI	Decreases	Household
Distance to lake	Road km to tourism center	Proximity to market activity and opportunities	Decreases	Village

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Distance to market	Road km to closest market town	Proximity to market activity and opportunities	Decreases	Village
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S2. Description and Parameterization of Questionnaire Variables

We asked one adult member of each household to provide the age, gender, years of schooling, highest education level, age at first reproduction, and income for all members of the household, as well the number of cars owned by the household and whether any members had out-migrated. We also asked this individual to estimate the typical proportion of household calories purchased from nearby markets. Before analysis, we log-transformed individual income, and calculated household income as the log of the sum of all individual incomes in a household. We calculated household educational attainment as the highest education achieved by any member of the household. Questions were asked in Mandarin Chinese and translated into Naru (the Mosuo language) or the local Chinese dialect when necessary. Because older people will have lived with the effects of MI for a smaller proportion of their lives than younger people, we categorized individuals into seven ten-year age cohorts, as per our prior analyses (Mattison et al. 2018), to capture differences in exposures to Chinese policies affecting health and reproduction, and three MI cohorts (whether they turned 16 before, during or after the period of initial MI, i.e., 1980-90).

467 **S3. Differences in waist circumference for women and men**

468 **Figure S3.1.** Mean waist circumference for women is lower for women than for men in waistZ
 469 sample ($t = -2.36$, $p = 0.02$). Women: mean = 34.53, sd = 3.76. Men: mean = 35.41, sd = 3.77.
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S4. Model construction, model selection, and statistical analyses

We began with a “global” model of the outcome of interest as a function of 14 predictor variables. These 14 predictors consisted of 11 known or potential indicators of MI at the individual, household, and village levels as well as gender, age, and age cohort as demographic controls (Table 1 and supplementary material S1). The global model included main effects for all 14 predictors as well as 14 interactions we considered potentially important in the context of MI. Because multiple individuals in each sample came from the same households, we included household as a random effect in all models.

For all three model selection analyses we began with the same global model, which contains main effects for all 14 predictors (Table S4.1), 14 two-way interactions between predictors, and a random effect of household. This approach allowed us to retain symmetry across analyses, i.e. to ensure that the global model, and all possible combinations of predictors, were consistent in each analysis. Our global model was:

Outcome ~ years of schooling:Age + years of schooling:household income + years of schooling:distance to lake + years of schooling:distance to market + years of schooling:gender + age:household income + age:distance to lake + age:distance to market + age:gender + household income:distance to lake + household income:distance to market + householdincome:gender + distance to lake:gender + distance to market*gender + individual income + age cohort + MI cohort + highest household education + market calories + number of cars + number of migrants + household size + household(random effect)

We selected interactions for the global model by first identifying four distinct “categories” of MI indicators containing more than one variable: education (containing years of schooling and highest household education), material wealth (containing individual income, household income, and number of cars), age (containing age in years, age cohort, and MI cohort), and proximity to market activity (containing kilometers to tourism center and kilometers to closest market town). Market calories, number of migrants, gender, and household size, did not fit within any category.

We excluded interactions between variables from the same category. We selected one representative variable from the education, material wealth, and age categories: years of schooling, household income; and age in years, respectively. We then considered every interaction among representative variables and between representative variables and uncategorized variables using an “opt-in” criterion: only include an interaction if we could justify its inclusion based on our interpretation of the literature and knowledge of our study site. Because our focus was market intensification, we included interactions on both proximity to market town and proximity to tourism center. Using this process, we identified 14 of 91 possible interactions for inclusion in our global model (Table S4.1).

We modeled waistZ and BP using multi-level linear mixed effects models using the “lmer” function from the lme4 package (Bates et al. 2015). Multi-level linear mixed effects models quantify the relative contributions of multiple predictor variables to observed variance in our outcomes of interest. We modeled AFR using a Cox survival model with mixed effects using the coxme package (Therneau 2018). Cox survival models quantify the relative contribution of multiple predictors on the likelihood that an individual will have had their first child by any

516 given age. Our model recognized individuals who had not yet had children and only included
517 them in calculations until their age at the time of sampling.

518 For each analysis, we used the MuMIn package (Bartón 2018) to run and compute AIC_c ,
519 and ΔAIC_c , and AIC_w values for all possible models nested within each global model, including
520 the null (intercept only) model. AIC_c is a variant of the Akaike Information Criterion adjusted for
521 small sample sizes, and estimates the quality of a given model (Burnham and Anderson 2002).
522 ΔAIC_c quantifies the difference in AIC_c values between different models. AIC_w is the weight, or
523 relative likelihood, of a particular model given all other models in a set. We ranked every model
524 in each set (i.e. all models nested within each global model) according to their AIC_c values. To
525 sharpen our results we identified and removed “uninformative” variables (Arnold 2010) from
526 each analysis, except main effects for variables that we allowed to interact with other variables
527 (Leroux 2019). This iterative process produced a single top-supported model (Table 2) and a
528 final set of candidate models (Table S4.2). Top-supported models represent the combination of
529 predictor variables that best explain the outcome of interest, given all other models in the set.
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Table S4.1: Table of interaction terms. Check marks indicate two-way interactions included in global model.

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Table S4.2. Three highest-ranked candidate models for each outcome of interest after iterated model selection process, with top-supported model in bold.

Outcome	Model	AIC_c	ΔAIC_c	AIC_w
<i>AFR</i>	Age + cohort + gender + highest household education + distance to lake + distance to market + age: distance to market + Gender: distance to market	12614.1	0.00	0.063
	Age + cohort + gender + highest household education + distance to lake + distance to market + age: distance to market	12614.2	0.06	0.061
	Age + cohort + gender + highest household education + distance to lake + distance to market + gender: distance to market	12614.7	0.52	0.049
	Age + cohort + gender + highest household education + distance to lake + distance to market + age:distance to lake + age:distance to market + gender:distance to market			
<i>WaistZ</i>	Intercept + age + distance to lake + distance to market	1138.7	0.00	0.017
	Intercept + age + gender + distance to lake + distance to market	1139.2	0.51	0.013
	Intercept + age + gender + distance to lake + distance to market + age:gender	1139.5	0.78	0.011
	Intercept + Age + distance to lake			
<i>SBP</i>	Intercept + age + gender + household size + number of migrants + years of schooling + age*years of schooling	4123.0	0.00	0.015
	Intercept + age + gender + household size + distance to market + number of migrants + years of schooling + age:years of schooling + distance to market:years of schooling	4123.1	0.10	0.014
	Intercept + age + gender + household size + number of migrants + years of schooling + age:years of schooling + distance to market:years of schooling	4123.7	0.69	0.010
	Intercept + age + gender + household size + number of migrants + years of schooling + age:years of schooling + gender:years of schooling			

Our datasets and analyses contained variables representing potential MI indicators at individual, household, and village levels. For each analysis, village-level variables clustered our data into six groups, introducing the possibility that models with village-level variables might not fit our data as well as models without village-level variables (Whittaker and Furlow 2009). We conducted likelihood ratio tests with a 0.05 alpha level using the ‘lrtest’ function in the lmttest package in R

(Zeileis and Hothorn 2002) to compare model fit based on log-likelihood scores for global models with and without village-level variables, and for top-supported models with and without village-level variables.

For global models, we compared the “full” global model reported in the supplementary material with a “reduced” version of the same model that contained no village-level variables. These reduced models were therefore fully nested within the full global models. For top-supported models, we compared the “full” top-supported models reported in our manuscript with a “reduced” version of the same model that contained no village-level variables. Note that this only applied to the waistZ and AFR analyses because the SBP top-supported model did not contain any village-level predictors.

Likelihood ratio test results for global models

A. WaistZ analysis:

Model 1: Full global model

Model 2: Reduced global model (both village-level variables removed as main effects and interactions)

Model	#Df	LogLik	Df	ChiSq	Pr(>ChiSq)
1	32	-467.41			
2	24	-472.98	-8	11.152	0.19

There is no evidence that the reduced model fits better than the full model ($p = 0.19$).

B. SBP analysis:

Model 1: Full global model

Model 2: Reduced global model (both village-level variables removed as main effects and interactions)

Model	#Df	LogLik	Df	ChiSq	Pr(>ChiSq)
1	32	-1763.6			
2	24	-1766.2	-8	5.332	0.72

There is no evidence that the reduced model fits better than the full model ($p = 0.72$).

C. AFR analysis:

Model 1: Full global model

Model 2: Reduced global model (both village-level variables removed as main effects and interactions)

Model	#Df	LogLik	Df	ChiSq	Pr(>ChiSq)
1	109.66	-4554.2			
2	103.44	-4557.7	-6.21	7.17	0.31

There is no evidence that the reduced model fits better than the full model ($p = 0.31$).

Likelihood ratio test results for top-supported models

A. WaistZ analysis:

Model 1: Full top-supported model

Model 2: Reduced top-supported model (village-level variables removed)

Model	#Df	LogLik	Df	ChiSq	Pr(>ChiSq)
1	6	-536.25			
2	4	-585.02	-2	43.54	< 0.001

There is evidence that the full model fits better than the reduced model ($p < 0.001$)

B. AFR analysis:

Model 1: Full top-supported model

Model 2: Reduced top-supported model (village-level variables removed)

Model	#Df	LogLik	Df	ChiSq	Pr(>ChiSq)
1	127.86	-6167.1			
2	128.52	-6170.0	0.66	7.17	0.016

There is evidence that the full model fits better than the reduced model ($p = 0.016$)

We used the ‘resid’ function in R to investigate the distribution of residual errors for our top-supported models for waistZ and SBP. Residual errors for both models are approximately normally distributed, satisfying the assumption of linearity for linear models.

Figure S4.1. Distribution of residuals from top-supported linear models.

S5. Limitations

Our data are subject to limitations that may affect our results. We collected data from individuals at home during household visits. This sampling strategy meant our analyses were somewhat asymmetric: all of our analyses include more women than men and the people in our anthropometric (waistZ and SBP) samples are on average older than those in our socio-demographic (AFR) sample (Table 1). Our measure of market calories was also based on self-report and subject to considerable error. This may contribute to lack of significance in our results. However, such limitations are common to studies of MI and we believe our samples are large and diverse enough that this difference is not likely to bias our results any more than convenience samples common to similar studies. We also suspect that measures such as percent market calories are more likely to capture real variation in market integration in comparative work than in work measured at a relatively local scale of integration.

Employing composite village-level or community-level metrics of different markers of MI, such as Colleran et al.'s (Colleran et al. 2014) measure of average education, may reveal additional insight into individuals specific experiences of MI, as well as the extent to which community circumstances enable or constrain individual responses. Additionally, more direct measures of nutritional and epidemiological transitions affecting individuals, households, and communities, would shed light on how energetic tradeoffs are shaping outcomes commonly associated with MI (Urlacher and Kramer 2018; e.g., Gurven et al. 2009).

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