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Uncertainty in a globalizing world. Livelihood and fertility variance increases in response to rapid change

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Abstract

Objectives: The extreme condition that we address in this special issue is how people adapt to rapid change, which in this case study is instigated by globalization and the process of market integration. Although market integration has been underway for centuries in some parts of the world, it often occurs precipitously in small-scale societies, initiating an abrupt break with traditional ways of life and fostering a keen sense of uncertainty.

Methods: Using cross sections from 30-years of data collected in a Yucatec Maya subsistence farming community, we test the expectation that when pay-offs to pursue new livelihood and reproductive options are uncertain, variance in social, economic, and reproductive traits will increase in the population. Our data span the transition from subsistence farming to a mixed economy, and bridge the transition from natural to contracepting fertility. Exposure to globalizing and market forces occurred when a paved road was built in the early 2000s.

Results: We find that livelihood traits (a household's primary economic strategy, amount of land under cultivation, amount of maize and honey sold), become more variable as new, but uncertain options become available. Variance in levels of education and family size likewise immediately increase following the road, but show signs of settling back down a decade later. Rather than replacing one way of life with another, Maya farmers conservatively adopt some new elements (family planning, wage labor), until the tradeoffs to commit to smaller families and the labor market become clearer.

Conclusion: Our findings highlight that in rapidly changing environments when the payoffs to assimilate new options are uncertain, some households and individuals intensify what they know best, while others adopt new opportunities, driving variance up in the population.

1 | INTRODUCTION

Globalization has transformative effects on small-scale societies worldwide and presents a window into how humans adapt to rapid change. In small-scale societies, globalization increases social and commercial interaction

with nonlocal communities and markets. This process, often referred to as market integration, involves adding new elements into traditional lifeways, such as working for wages, replacing exchange relationships with monetary payment, producing crops, forest goods or crafts for sale, consuming market foods, formalized schooling,

medicalized health care and birthing practices, and assimilating parity-specific contraception into family planning.

Folding new elements into previous lifeways is not unique to the modern context. Humans have made strategic decisions throughout history about whether to adopt previously nontraditional foods, resources, technologies, behaviors and social institutions. Decisions may also be made whether to intensify the extant resource base, replace traditional practices or diversify livelihood portfolios. This is well documented, for example, in the transition from hunting and gathering to agriculture as it occurred both in the past and more recently (Coddington & Kramer, 2016; Greaves & Kramer, 2014; Hitchcock & Ebert, 1984; Smith, 2001; Wilmsen, 1989). Archeologically, prior to widespread intensive farming, many forager populations incorporated small amounts of cultivated foods while maintaining a primary reliance on hunting and gathering (Harris & Hillman, 1989; Piperno & Pearsall, 1998; Richerson et al., 2001; Smith, 2001; Wills, 1995; Winterhalder & Kennett, 2006). Historically, mixed economies (livelihoods that blend elements of different economic systems) are also described, for example when hunter-gatherers are exposed to domestication or wage labor (Blurton Jones, 2016; Kramer & Greaves, 2016; Lupo, 2016; Tucker, 2006), or when subsistence farmers encounter market options to cash crop or work for wages (Hackman & Kramer, 2021a).

In its contemporary context, market integration often occurs precipitously in small-scale societies that previously had sustainable local economies, initiating a break with traditional ways of life and fostering uncertainty in decision making. In subsistence communities, market involvement has cascading effects on children's growth and wellbeing (Godoy, 2001; Godoy et al., 2005; Hackman & Kramer, 2021a, 2021b; Kramer et al., 2021; Mattison et al., 2023; Padilla-Iglesias & Kramer, 2021; Watts, 2010), language use (Padilla-Iglesias & Kramer, 2021), on the structure of social networks (Hackman & Kramer, 2021b; Mattison et al., 2023), fertility (Kramer et al., 2021; Kramer & McMillan, 2006), and on instigating rapid social and economic change (Borgerhoff Mulder, 2009; Ensminger, 1996; Gray et al., 2011; Polanyi, 1957; Schneider, 2015; Watts, 2010). Although these outcomes are well-documented, local responses when market forces first come into play are largely unidentified. What happens at the onset of rapid change is of interest because the payoffs to assimilate new options may be unknown, and individuals may be stymied how to optimize and weigh costs and benefits, particularly if prestigious individuals are also making first-time decisions. This environment of unknown payoffs and uncertainty characterizes the situation that many small-scale societies find themselves in now or the

recent past and is an opportunity to observe how humans respond to rapid change and new behaviors take hold in a population.

1.1 | Defining uncertainty

Uncertainty is an understudied, but key variable affecting behavioral responses. While risk and uncertainty are often used interchangeably, they have different implications for decision making. Risk relates specifically to the odds of a particular outcome, which is assessed by a known probability distribution, where the chances of success or failure of a particular decision can be known. However, when faced with uncertainty, the likelihood of an outcome's success or failure, and thus its payoff structure, is unknown. As such, the degree of knowledge or predictability about different outcomes, is expected to shape behavioral responses (Knight, 1921; Tversky & Kahneman, 1974). Responses to risk often involve rational, informed decision-making based on calculations of probabilities and expected values, whereas responses to uncertainty may involve heuristics, biases, and emotional or intuitive reactions (Lerner & Keltner, 2001; Loewenstein et al., 2001).

In a stable natural fertility, subsistence society (no use of parity-specific contraception, and an economy where production and consumption are largely balanced), livelihood and reproductive decisions would be characterized by risk-profiles. That is, the costs and probabilities of certain outcomes are roughly known. With respect to reproduction for example, parents would know the value of goods and services and could make informed decisions about the number of children they can support based on their goals for child success, anticipated food requirements, and the labor needed to produce food and other resources. However with rapid market integration, this once known payoff structure is replaced with uncertainty where parents cannot estimate the payoff that novel investments (e.g., education) will have on child outcomes relative to their cost. Parents who have no previous experience with formal education or exposure to outside social influences (e.g., through wage labor, internet, TV, or cell service), lack a priori knowledge to weigh the benefits to school their children versus the costs to relinquish their economic production (Jensen, 2010).

Similarly, uncertainty surrounds whether to commit to new livelihoods. In market integrating economies, a choice commonly arises whether to become a wage laborer, which may entail migrating temporarily or permanently, leaving behind known social support networks, giving up a secure traditional livelihood, and being susceptible to job market volatility with no

fallback. For first-time wage laborers, these costs are unknown relative to the benefits.

1.2 | Relationship between uncertainty and increased variation

One anticipated initial response to rapid change and uncertainty is increased variation. Biologists have noted a relationship between environmental uncertainty and phenotypic variance (Lerner & Libby, 1976; Lewontin & Levins, 2007). In unpredictably fluctuating environments, for example, parents may vary their investments and reproductive output in attempts to match offspring phenotypes with alternative future circumstances (Donaldson-Matasci et al., 2008; Meyers & Bull, 2002). Building on these associations, we propose that during market integration, when new subsistence and family planning options become available but their costs and benefits are unknown, one likely consequence is increased variance at the population level as new strategies and their payoff spaces are explored.

To evaluate this proposal, we use a case study where rapid change was instigated by an abrupt event, the building of a paved road (see Reyes-García et al., 2020 for Indigenous people's attitudes toward road building). Our aim is to describe at multiple scales how individuals and households respond by mapping the distribution of economic and reproductive traits across time. To do so, our analyses use cross sections from 30-years of longitudinal household economic data and individual education and fertility data spanning the transition from a subsistence to a mixed economy and from natural to contracepting fertility. We test two expectations: (i) a change in the distribution of household- and individual-level traits is detectable as an increase in variance at the population level; (ii) the variance of some traits will diminish over time as uncertainty is transformed into clearer payoffs through trial and error, social learning and accrued generational knowledge. Our focus is on variance rather than central tendency, which can mask underlying shifts in the structure of a trait in a population. This structural change we suggest is a central, but under-examined characteristic of market integration, and more generally of decision making under uncertainty.

2 | ETHNOGRAPHIC BACKGROUND

The indigenous Maya study population who live the Puuc region of the central Yucatan Peninsula, hereafter referred to as the Yucatec Maya, live in small farming

hamlets and villages, and in the few larger market and administrative towns. Multigenerational demographic, reproductive history, economic and social network have been collected in the study community since the early 1990s (Kramer, 2005; Kramer & Boone, 2002; Kramer & McMillan, 2006; Lee & Kramer, 2002).

Prior to 2003, all families made their living as subsistence farmers. Because of the lack of roads and vehicles, little means existed to engage in cash cropping, formal schooling, wage-labor, health care, or the regional economy. The need for and access to cash was minimal, and wealth was measurable by the amount of land under cultivation and size of the household, which is the primary economic unit of production and consumption.

2.1 | Uncertainty in livelihood decision making

A paved road was built into the community in the early 2000s and initiated sweeping changes (Figure 1). In brief, it facilitated the transportation of crops to market, children to schools, women to hospitals and adults to wage labor, which together stimulated sundry other social, economic, technological and demographic changes. The road and subsequent access to market towns, opened up cash cropping, wage labor and craft production as alternative ways of making a living. However, pursuing these new economic options is clouded with uncertainty. Although the Maya have been successful maize farmers for millennia, the payoff to intensify agriculture for commercial sale is unknown because it involves investment in mechanization and costly inputs (tractors, vehicles to transport supplies and surpluses to market, hybrid seed and fertilizer), novel market forces (credit, price fluctuations and debt to repay inputs are bought on credit). For example, when the market price of maize halved in 2015, families who had committed to mechanized farming were in large amounts of debt and unable to repay loans, driving them further into debt. While the Maya plan for occasional crop failure, having had little previous experience selling maize, they could not have anticipated the market's volatility. The requirements to intensify also create a more rigid farming system, which limits the effectiveness of traditional means to respond to interannual climate variation (Kramer & Hackman, 2023). Additionally, new enterprises have been introduced by state and national governments, NGOs and commercial agencies, with varying degrees of success. Vegetable gardening, nut orchards and cattle herding, for example, have failed as commercial ventures, while honey production is currently thriving. The undetermined costs to intensify are compounded by unknown benefits to sell crops, or become a wage laborer.



FIGURE 1 The road being built in 2003 (Top). Five generations of Maya women (Bottom) photo credit: Amanda Veile.

Prior to the road, men occasionally (several days or weeks per year) did field or construction wage work in neighboring towns as the need arose to pay for supplies, school fees or medical treatment. The road facilitated more frequent travel to wage labor jobs, which are available only outside the community. Some young adults, including women, for the first time began to work in commercial agricultural enterprises or a maquiladora several hours away. Others work as shop keepers, nannies or in skilled jobs in larger towns, returning nightly or weekly. While some households make their living through agriculture, a few turn to wage income and forgo agricultural activities all together. Still other households combine both agriculture and market-based livelihoods as adult members explore new economic opportunities, navigate successes and failures, and adjust their activity portfolios in response to others.

2.2 | Uncertainty in reproductive decisions

The road has also had several impacts on reproductive behaviors. Tubal ligations, the predominant form of birth

control in Mexico, and the first and most common form of family planning in this community, became available when women began to deliver in birthing centers, and hospitals, which were difficult to travel to prior to the road (Veile & Kramer, 2018). As a consequence, Maya parents are making first-time decisions about whether to adopt family planning and limit family size.

Parents are also making new decisions about whether to send children to school and forgo their time and labor contributions to the household. A rudimentary school, grades 1–4 has existed in the community since 1978. Grades 5–6 were added in 2003–2006, followed by grades 7–9 in 2009. About 50% of teens elect to attend high schools, which are located in other towns where students board, a monetary cost paid by parents, and are expenditures that compete with other ways to spend money. Parents articulate the changing economic and fertility environment in describing the quantity-quality tradeoff. Parents clearly say, if they have fewer children, they could afford to send more of them to school. But they also express their uncertainty whether advanced schooling is worth the expense, whether it will have long-term social or economic benefits for children, and whether children will be happy leaving their family and the community. If the cost and benefits to adopt birth control, have a smaller family or to commit to wage labor or cash cropping to pay for education are unknown, the path forward to adjust family size may be unclear (Kramer et al., 2021).

3 | METHODS

Analyses draw from the Longitudinal Maya Life History Project, which has collected over 30 years of biological, demographic, economic, and social network data in the Yucatec Maya study community.

3.1 | Study sample and livelihood measures

Livelihood data were collected at several time points from both households and individuals through structured and open-ended surveys, and behavioral observation. Both household and individual data are important because while individuals spend their time in certain ways, they do not exist in economic isolation. They contribute to and draw food and resources from the household of which they are a part (e.g. pooled energy budgets {Kramer & Ellison, 2010 #664}. For example, each individual does not cultivate his or her own land. Rather households are so defined because their members jointly

share in both the production and consumption of food, resources, and the monetary gains made by crops sales or wages. Individuals within households adjust their economic activities in response to household needs and what other members are doing.

3.1.1 | Household-level variables

Economic traits are parameterized at the level of the household to capture its primary economic strategy, the amount of land under cultivation, and income from the sale of maize and honey. The household is defined as one or more biological families who self-identify as a sharing group and are observed through detailed social network and economic interviews to share food, labor, capital, and resources. Male and female household heads were interviewed together using the same methods and question prompts at three time points. The 1992 data, the pre-market baseline, was collected in 1992–1993 during a year-long study and consisted of a village census of 316 individuals living in 52 households. The 2012 data were collected from 2010 to 2013 and consists of 483 individuals in 72 households. From 1992 to 2012, 259 individuals stayed in the community (82% of the original sample), 224 new individuals were born or moved into the community and 57 individuals died or left (Figure S1). The 2017 data were collected in 2017 and 2018 and include 551 individuals living in 93 households. Of these, 491 were represented the 2012 dataset (90%) with 102 new individuals entering either through birth or immigrating at marriage between 2012 and 2017 and 42 individuals exiting the census (either through death or emigrating). At each time slice, data collection covered 94%–98% of community households (see Figure S2 for age-sex pyramid of the three time periods).

A household's primary economic strategy is a categorical variable based on three criteria: the amount of land under cultivation; the primary economic activity of the household head; and the total number of full-time wage-laborers in the household. Household economic strategy is coded as one of four categories: (i) subsistence agriculture if the amount of land cultivated is less than 3.0 ha (the minimum maize needed to sustain an average household of 8–10 individuals for a year; one hectare produces an average of two metric tons of maize); (ii) intensified agriculture if more than 3.0 ha are under cultivation; (iii) wage labor if the household head works full-time for a salary (no female household head works for wages); (iv) mixed strategy if the household maintains an agricultural base, but one or several household members (but not the head-of-household) is a full-time wage laborer. To arrive at (iii) and (iv), each adult

member over the age of 15 is coded as a wage laborer (binary variable 0,1) if he/she spends at least 20 days a month working in another community for at least 32 weeks during the study year.

Land under cultivation, a measure of agricultural intensification, was determined both through economic interviews with household heads and accompanying farmers to their fields and taking GPS measurements of the perimeters of their cultivated fields. Maize and honey are sold following the harvest once or twice a year, and account for the majority of agricultural goods produced for sale. Quantities of maize and honey sold were recorded during household interviews.

3.1.2 | Individual-level variables

An individual's education is parameterized as the number of years of schooling that an individual has completed. To observe meaningful change over time, individuals in the most recent census (2017) are subset into three education cohorts. Individuals in Cohort 0 (C0) were born before 1980 and would have completed education prior to the construction of the road, and is the premarket education baseline. Cohort 1 (C1) individuals were born between 1980 and 1989, and completed their education bridging the road's construction. Cohort 2 (C2) individuals were born between 1990 and 1999, and completed their education a decade or more after the road. We exclude individuals born after 1999 since they would still be school-aged in 2017.

3.2 | Study sample and measures of fertility

To assess how the distribution of fertility changes over time, variables were derived from reproductive histories collected annually from all women living in the community, alive in or born since 1992. From these reproductive histories, women who either had completed or were near completion of their reproductive careers by 2017 were retrospectively stratified into three cohorts. All women in the community are included except those who emigrated and censused out of annual reproductive surveys ($n = 3$), who were very elderly in 1992 and whose reproductive histories could not be confirmed in later censuses ($n = 2$), or who had known fertility issues (no child born after 5 years of marriage; $n = 4$).

Women in Cohort 0 (C0) were born before 1960 and would have been age 40–45 at the completion of the road and serve as the natural fertility baseline. Women in Cohort 1 (C1) were born between 1960 and 1969,

completing their fertility within 10 years after the completion of the road. Women in Cohort 2 (C2) were born between 1970 and 1979 and were influenced by the road's effects for the majority of their reproductive careers. Of the 66 children born in this cohort, two were born after 2012 (~3%) and one in 2017 indicating the majority of women in Cohort 2 had completed fertility by time of data collection in 2017. Total fertility, interbirth interval, age at first and age at last birth are described for the women in these three cohorts (Figure 1).

3.3 | Analytic approach

Several measures are used to observe change in the distribution of livelihood traits across the population and time. First, the change in economic strategies is assessed using a chi-square test for k populations, which determines whether the distribution of a categorical variable statistically differs across the three time points. Second, we use a Gini coefficient, a dimensionless statistical measure of dispersion, to detect shifts in continuous household livelihood variables (the distribution of land, maize, and honey sold). The Gini coefficient is mathematically based on a Lorenz curve, which plots a household's ranked proportional share of the total (land, maize or honey sold) relative to the cumulative proportion. Values range from 0 to 1, where 0 corresponds to complete equality (all households in the population have the same amount of cultivated land, or same profit generated by the sale of maize or honey) and 1 corresponds to complete inequality (one household has all the land or profit).

To test whether changes in variance in both the household and individual traits are statistically significant we employ the Kruskal-Wallis test (KW) and the Feltz and Miller test (FM). The Kruskal-Wallis test is a nonparametric test that is robust to deviations from normality and can detect differences in the medians and raw variance even when the variances of groups are not equal. The FM test is similar to the Kruskal-Wallis test (Feltz & Miller, 1996; Marwick & Krishnamoorthy, 2019) but uses the coefficient of variation (CV), which accounts for differences in variation relative to the mean. The tests together provide complementary information. The FM test is more powerful when the variances of the populations are approximately equal and can detect differences in the spread of the distributions. By using both tests, we gain a more complete understanding of the differences between time points (households) and cohorts (individuals) and determine whether the differences are due to differences in location, spread, or both.

4 | RESULTS

4.1 | Distribution of livelihood measures

Prior to the introduction of labor market livelihood options in the early 2000s, the primary economic strategy for the majority of households (~80%) was subsistence agriculture, defined by the amount of land needed to meet the consumption needs of an average household (Figure 2; Table S1). A small proportion of households were intensifying maize production (13.5% cultivated >3 ha). Few households had a full-time wage laborer (7%), most of whom were adult sons over the age of 18 ($n = 3$, primary strategy coded as mixed). Only one household head was a wage laborer.

Since the early 2000s, the distribution of a household's primary economic strategy has become significantly more varied ($\chi^2 = 100.11$, $df = 6$, $p < .001$). Compared to the baseline where most were subsistence farmers, many more households are intensifying agricultural production (34% in 2017), or pursuing a mixed strategy by maintaining both their agricultural base while one or more adult family members work as wage laborers (39% in 2017).

In 2017, the average amount of land under cultivation more than doubled, from 2.92 ha to 7.62 ha, since the early 1990s. Variance increased by an order of magnitude, with the standard deviation increasing from 1.5 to 7.1 ha. The coefficient of variance nearly doubles, indicating that variance is rising independent of the increasing mean, with a significantly greater spread around the mean ($FM < 0.001$). The change in variance is reflected in the inequality of land distribution across households. The Gini coefficient increased from 0.27 in 1992, to 0.42 in 2017 (Figure 3A). The upper range expanded from 4.5 to 40 ha under cultivation, an eight-fold increase. The greatest increase occurred in the last 10 years, with a 31.3% rise in the Gini coefficient.

In step with agricultural intensification, mean values of maize and honey produced for the market have significantly increased. Moreover, the distribution has changed. Of the 18 households with harvest amounts known in 1992, 10 households (56%) sold an average of 3.75 metric tons, with an upper limit of 6 metric tons sold. In 2017, 41 households sold maize (44%) with an increase in the upper limit to 95 metric tons. Between 2012 and 2017, the coefficient of variance and the standard deviation in maize sold doubled. One insight is that both the total number of households selling maize declined from 2012 to 2017, along with a sharp reduction in the median amount sold, from 8.4 to 3.5 ha (Table 1). These declines alongside the much higher maximum amount sold point

FIGURE 2 Distribution of a household's primary economic strategy across three time points (1992 $N = 52$; 2012 $N = 71$; 2017 $N = 90$). Economic strategies are mutually exclusive categories (see text for description).

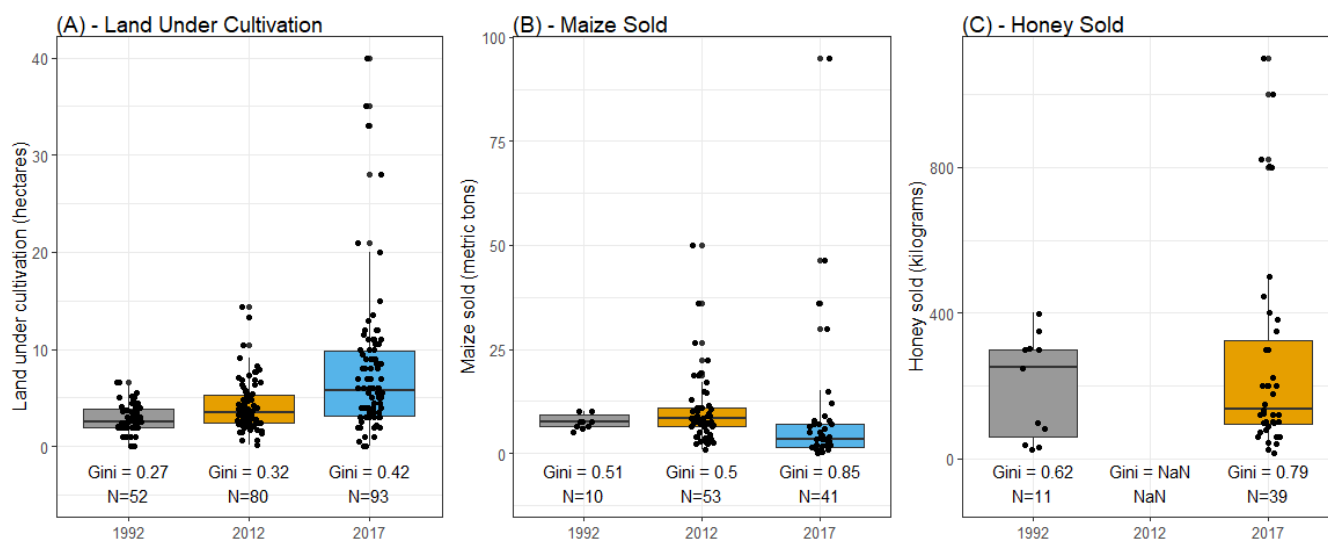
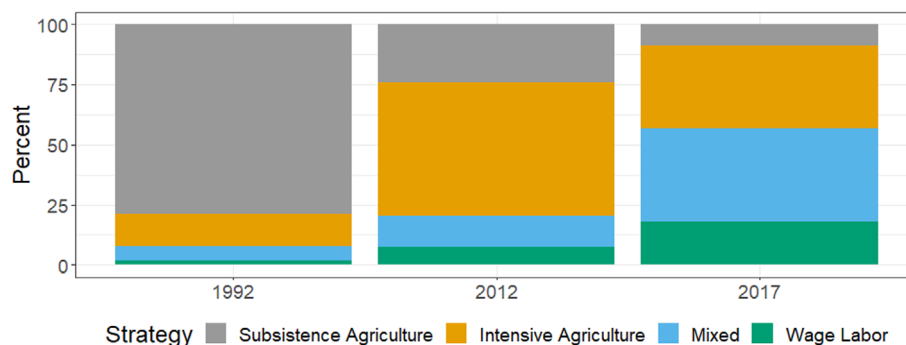


FIGURE 3 Household economic traits across time points. (A) Distribution of land under cultivation (hectares) across three time points (B) Annual maize sales (metric tons) across three time points. (C) Annual honey sales (kilos) across two time points. (B) and (C) include only households that sold maize or honey in the given period.

to increased inequality in maize intensification (the Gini coefficient increases from 0.51 to 0.85 for maize sales; Figure 3B).

We see a similar pattern for honey. In 1992, of the 18 households with known production, 11 households produced honey for sale with a mean of 198 kg (SD = 143) and an upper limit of 400 kg sold. By 2017, 39 households produced honey for sale, with a mean of 262 kg (SD = 279.5) and an upper limit of 1100 kg. Again, the increase in variance, and the coefficient of variance suggest rising inequality, which is supported by the increase in Gini coefficients from 0.62 to 0.79 for honey sales between 1992 and 2017 (Figure 3C).

Average completed years of schooling both increases and becomes more variable over time (Figure 4; Table 2). Mean years of completed education increase from 3.7 in the preroad education cohort (C0) to 10.6 years in Cohort 2, who completed schooling after the road was built and the addition of grades 5–9 to local schools. Immediately after new schools

were built, the variance in years of completed education increases before beginning to decline in 2017. The coefficient of variance suggests that as the mean increases across cohorts, the variance surrounding the mean is beginning to settle down.

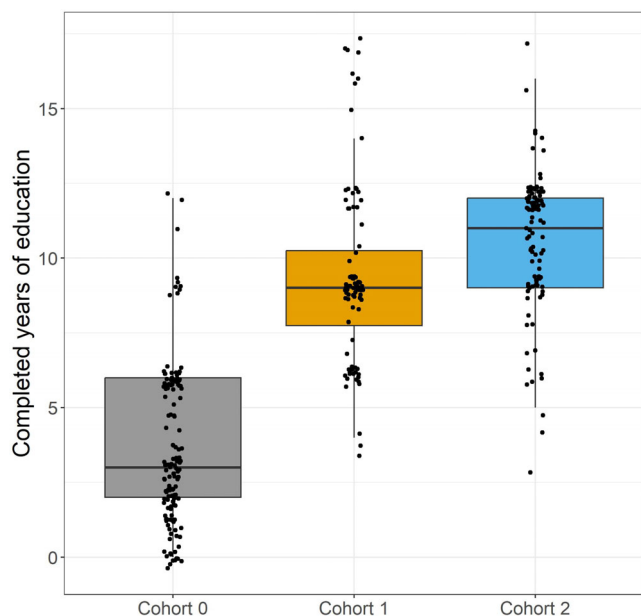
4.2 | Fertility

Total fertility among women in Cohort 0, our baseline for premarket, natural fertility conditions averaged 6.8 (SD = 2.5) with a range from 1 to 11 births. In Cohort 1, the first decade after the introduction of the road and access to family planning, there is an insignificant change in average total fertility from 6.8 to 5.8 children. Yet, the variance nearly doubled, as does the coefficient of variance (Figure 5A, Table 3). The distribution of total fertility expands both at the upper end to 15 children, and the lower end as more women have smaller families. By Cohort 2, both mean and median family size has declined

TABLE 1 Household demographics and economic traits stratified by sampling period.

Variable	Year	N	Mean	Median	Min	Max	Variance	SD	CV	KW.p	FM.p
Household adults	1992	49	3.49	3.00	2.00	7.00	2.84	1.68	0.48	.34	.79
	2012	69	4.14	3.00	2.00	14.00	5.77	2.40	0.58	.34	.79
	2017	93	4.03	3.00	2.00	12.00	4.73	2.17	0.54	.34	.79
Age	1992	49	48.08	42.47	23.54	92.58	415.38	20.38	0.42	.94	<.001
	2012	68	44.88	45.32	16.91	68.43	141.32	11.89	0.26	.94	<.001
	2017	93	43.58	45.10	0.00	75.43	287.36	16.95	0.39	.94	<.001
Land under cultivation	1992	52	2.92	2.50	0.00	6.64	2.13	1.46	0.50	<.001	<.001
	2012	78	4.18	3.52	0.16	14.37	6.91	2.63	0.63	<.001	<.001
	2017	90	7.62	5.75	0.00	40.00	50.12	7.08	0.93	<.001	<.001
Maize sold	1992	10	7.65	7.50	5.00	10.00	3.23	1.80	0.23	<.001	.20
	2012	53	10.28	8.44	1.00	49.94	72.29	8.50	0.83	<.001	.20
	2017	41	8.65	3.50	0.14	95.00	282.71	16.81	1.94	<.001	.20
Honey sold	1992	11	197.73	250.00	25.00	400.00	20446.82	142.99	0.72	.72	.97
	2012	-	-	-	-	-	-	-	-	-	-
	2017	39	261.82	135.00	17.00	1100.00	78124.10	279.51	1.07	.72	.97

Note: Household adults = total number of adults over 15 years; Age = average age of household head; Land under cultivation = number of hectares under cultivation during sampling period; Maize sold = number of metric tons sold, only for households reporting maize sales; Honey sold = number of kilos sold, only for households reporting honey sales. Dashes indicated that no information was collected in that year. *N* = number of households with complete data included in analyses; Variance = raw variance; SD = standard deviation; CV = variance relative to the mean; KW.p = p-value for Kruskal Wallance test; FM.p = p-value for FM test.

**FIGURE 4** Distribution of completed years of education across individuals age 17 or older in 2017 stratified by cohort.

significantly, while the coefficient of variance remains high.

Changes in age at first birth, age at last birth and interbirth intervals are also observed (Figure 5B–D). While mean age at first birth appeared relatively consistent across the three cohorts (~20–23 years old), the

upper end of the range increased significantly, from 29 to 40 years. This increase is reflected in all measures of variance, including the coefficient of variance. Conversely, mean age at last birth declined across the three cohorts, with a drop in the upper range from 47 to 41 years old. Finally, variance in interbirth intervals increased across the cohorts, despite the mean being approximately 2 years for each cohort.

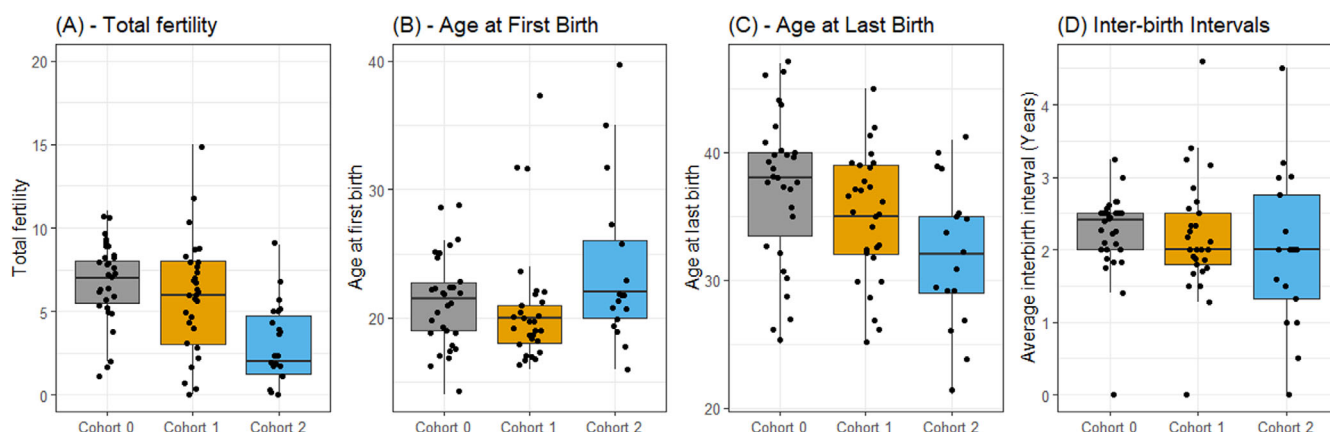
5 | DISCUSSION

While the outcomes of economic and fertility transitions associated with market integration have been extensively described, much less attention has been paid to its effect on a trait's underlying distribution within a population. Here we evaluate the expectation that when new options have unknown payoffs, variance will increase as individuals and households diverge in their reliance on established behaviors or pursue new ones. The opening of a paved road was an abrupt event that exposed the study community to a suite of untested subsistence and reproductive options. From the premarket background of relative homogeneity in how people made their living, the schooling they received and how they built their families, we observe new strategies being tested, rejected, and solidified as they navigate the new socioeconomic environment.

TABLE 2 Individual completed education stratified by cohort.

Variable	Cohort	N	Mean	Median	Min	Max	Variance	SD	CV	KW.p	FM.p
Completed years of education	0	144	3.72	3.00	0.00	12.00	6.95	2.64	0.71	<.001	<.001
	1	88	9.35	9.00	3.00	17.00	9.40	3.07	0.33	<.001	<.001
	2	105	10.56	11.00	3.00	17.00	5.44	2.33	0.22	<.001	<.001

Note: N = number of households with complete data included in analyses; Variance = raw variance; SD = standard deviation; CV = variance relative to the mean; KW.p = p-value for Kruskal Wallace test; FM.p = p-value for FM test.

**FIGURE 5** Distribution of reproductive traits by birth cohort.**TABLE 3** Individual reproductive traits stratified by cohort.

Variable	Cohort	N	Mean	Median	Min	Max	Variance	SD	CV	KW.p	FM.p
Total fertility	0	31	6.84	7.00	1.00	11.00	6.01	2.45	0.36	<.001	.12
	1	33	5.76	6.00	0.00	15.00	12.94	3.60	0.62	<.001	.12
	2	22	3.00	2.00	0.00	9.00	6.29	2.51	0.84	<.001	.12
Age at first birth	0	30	21.23	21.50	14.00	29.00	13.56	3.68	0.17	.08	.13
	1	29	20.79	20.00	16.00	37.00	23.81	4.88	0.23	.08	.13
	2	17	23.76	22.00	16.00	40.00	41.19	6.42	0.27	.08	.13
Age at last birth	0	30	37.27	38.00	25.00	47.00	35.03	5.92	0.16	.02	.48
	1	29	34.97	35.00	25.00	45.00	23.82	4.88	0.14	.02	.48
	2	17	32.12	32.00	21.00	41.00	34.24	5.85	0.18	.02	.48
Interbirth intervals	0	30	2.24	2.41	0.00	3.25	0.33	0.57	0.25	.26	.01
	1	29	2.17	2.00	0.00	4.60	0.65	0.81	0.37	.26	.01
	2	17	1.98	2.00	0.00	4.50	1.21	1.10	0.56	.26	.01

Note: N = number of households with complete data included in analyses; Variance = raw variance; SD = standard deviation; CV = variance relative to the mean; KW.p = p-value for Kruskal Wallace test; FM.p = p-value for FM test.

5.1 | Livelihood and reproductive responses to rapid change

Several summary points can be made about responses to rapid change. Following expectations, livelihoods become more variable with rapid change. The road opened up

access to wage labor and agricultural intensification as a means to generate cash. One consequence is a significant increase in variance among households in how they make their living, the amount of land under cultivation, and maize and honey sold. Some households continue to do what they know best—agricultural production—,

while replace farming with wage labor and commit to buying instead of growing food. Most households, however, straddle these two livelihoods. In doing so, they diversify their subsistence activities (measured by the total number of different activities that members engage in; Hackman & Kramer, 2021a), with some members maintaining the agricultural base while others generate cash through either occasional or full-time wage labor or craft production. By 2017, although the number of full-time wage laborers had substantially increased (from 4 in 1992 to 32 in 2017), households with no land under cultivation remained the same (one in both 1992 and 2017). Thus despite adding in new economic activities, 99% of households retain an agricultural base. Wage laborers commonly either do so occasionally, or opt out after a few years and return to farming. Rather than market integration instigating a shift from one economic state to another, our results suggest that most choose a mixed economy, where combining strategies maintains the broadest array of alternatives, fallback options and minimizes unforeseen failure in either domain.

With market engagement, variance in reproductive measures increases then settles down. In Cohort 1, the introduction of market foods and mechanization relaxes physiological constraints on fertility (Kramer & McMillan, 2006). In response, some Maya parents continue to have large and even larger families. Indeed, subsistence populations undergoing in the first stages economic development exhibit some of the highest fertility documented (Dyson & Murphy, 1985; Early & Headland, 1998; Hill & Hurtado, 1996; Kramer & Greaves, 2007; Kramer & McMillan, 2006). But other women move toward smaller families. The net effect is no initial change in mean total fertility, but a marked increase in variance.

Previous study showed that the increase in variance is attributed to the contrasting effects of traditional determinants of fertility (land and labor) and novel determinants introduced with the road (education and wage-labor). Both education and wage labor are proxies for a household's engagement in the market economy, and are well-documented predictors associated with fertility reduction cross-culturally (Becker et al., 2013; Schultz, 2001; Snopkowski et al., 2016). The increased variance results from the combined positive effects of traditional determinants raising fertility for some, and the negative effects of novel determinants pushing down fertility for others. In cross sectional studies, this same pattern is observed, where the distribution of fertility across the demographic transition moves from relatively low (Sear, 2016) to high variance and then stabilizing back to lower levels (Hruschka & Burger, 2016).

When family planning is introduced, most Maya women (C1) initially are conservative in committing to

small families. Early adopters of fertility control do so at the end of their reproductive careers. Only in the second decade of exposure do women have tubal ligations at younger ages, and completed fertility begins to decline at the population level. The delay we suggest reflects uncertainty to commit to smaller families until parents gain sufficient knowledge to weigh the costs and benefits that small families will have on their agricultural way of life and children's futures. For example, although fertility declines with education, households also must balance low fertility with a family large enough to explore economic diversification (Hackman & Kramer, 2021a).

5.2 | Diversity matters and the benefits of a mixed economy

As a response to uncertainty, diversifying a household's economic portfolio appears protective in a number of ways. Importantly it spreads risks across multiple domains (Hackman & Kramer, 2021a). The Yucatec Maya traditionally reduced the risk of harvest failure by planting crops in different locations to offset geographically patchy rainfall, staggering when they plant across the growing season, and storing maize in different locations (Kramer & Hackman, 2020). Our results show that the Maya further extend existing strategies by diversifying their livelihoods. Diversification allows them to buffer against periodic crop failures brought on by interannual climate variation (Kramer & Hackman, 2023), volatility in the market price of commodities, and against fluctuations in the labor market. For example, during the Covid 19 pandemic, regional commercial agricultural production scaled back, and a main source of wage labor for adult sons disappeared. Many returned to working in their family's maizefields. The protective effect of a varied livelihood portfolio adds to the previous finding that more economically diverse Maya households, which is associated with household size, have a higher income per capita (Hackman & Kramer, 2021b).

A socially diverse household also buffers against fluctuations in a rapidly changing economic environment. Households that maintain strong local networks while also developing social connections outside the community, have both access to institutional support and a broad net that lowers the probability of experiencing a bad economic year (Kramer & Hackman, 2023).

Our results are consonant with other work on small-scale farmers in rural Mexico, which finds that households that both intensify agricultural production while taking advantage of new wage-labor opportunities is an effective means to manage fluctuations in both commercial agricultural and wage-labor (Eakin, 2005). In more

urbanized Yucatec Maya towns, households that have larger agricultural holdings alongside fixed employment and non-agricultural enterprises are ranked as wealthier. Poorer households, in contrast, had little access to agricultural land, relied on subsistence production or seasonal agricultural wage labor (Robles-Zavala & Fiechter-Russo, 2008). More generally, livelihood diversity is recognized as an important survival strategy for rural households worldwide (Ellis, 2000). We extend these findings to suggest that a mixed economy and diversified social and livelihood portfolios are key to navigate a more secure place in an uncertain socioeconomic environment.

5.3 | Uncertainty

While we find abundant evidence for a temporal increase in variance and propose that rapid change and uncertainty are causally related due to the unknown payoffs of new opportunities, we cannot directly measure uncertainty as an independent variable. Uncertainty is suggested by qualitative observations and the number of failures that occur in the pursuit of new ways of making a living that have been introduced by the governmental or commercial organizations. As examples, almond orchards were planted and then burned down by farmers because there was no market for almonds and the land was better used for maize. Cebo trees were speculatively planted to manufacture charcoal, but did not survive. Herds of cattle were purchased that did not thrive in the heat. Several tractors were bought on loan, but fell into disrepair before the debt could be repaid. Commercial vegetable gardening, mechanized tortilla making and worm farming enterprises were unsuccessful pursuits. Each involved financial and social investments, but failed either because of collective action problems, or because there was no means to transport the product to market. People test new ventures the payoffs to which can only be uncovered through trial and error. Some stick, others are fleeting. (This part of rural Yucatan is ethnically homogeneous, with little social stratification; internet and cell coverage are limited to the larger communities.)

A small biological literature points to increased phenotypic variance as an observed consequence of environmental uncertainty. The idea of uncertainty is compelling in generating several new questions. How long does it take to gain knowledge, and build frameworks to assess costs and benefits? Or to transform uncertainty into risk, and find among options how to maximize tradeoffs and economic decisions? How long does it take for parents to learn about the income returns to education, or the profitability to invest in new kinds of production? We have suggested that variance is one observable consequence of

how people move toward optimal strategies when there are no social models or prestigious individuals to follow who have successfully sorted out what might fail and what might succeed.

6 | CONCLUSION

This special issue centers attention on humans at the extremes. The extreme condition we consider is how people in small-scale societies adapt to rapid changes and uncertainty, a situation often brought about by globalization. The Maya respond in a couple of clear ways. First, increased variation is an early response to novel environments where the payoff to pursue new options or retain traditional lifeways is ambiguous. Under these circumstances, individuals and households experiment with different strategies and test different payoff spaces. Some double down on what they know best, others incorporate new alternatives and in time cull those strategies that work and those that do not. Second, rather than a linear transition from a subsistence to a market economy, or from large to small families, we document is more nuanced trajectory. Diversification and having an interest in multiple domains, which is what most households do, attenuates failure in any one sector and threads a more secure position in a rapidly changing environment.

AUTHOR CONTRIBUTIONS

Karen L. Kramer: Conceptualization (lead); supervision (lead); writing – original draft (lead); writing – review and editing (equal). Joe V. Hackman: Data curation (equal); formal analysis (equal); methodology (equal); software (lead); visualization (lead); writing – review and editing (equal).

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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SUPPORTING INFORMATION

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