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Market Integration and Reproductive Transitions Among Indigenous Shuar and Neighboring Nonindigenous Ecuadorians in Amazonian Ecuador

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ABSTRACT

Objective: Global reproductive transitions are well documented, yet less is known about how neighboring populations with divergent histories and exposure to market integration (MI) experience them. This study examines how sociocultural and economic proxies of MI predict variation in reproductive outcomes among indigenous Shuar and nonindigenous Ecuadorian mestizos (Colonos) from Amazonian Ecuador, focusing on menarcheal age, age at first birth, parity, breastfeeding duration, and contraceptive use.

Methods: Reproductive histories were collected from 360 Shuar and 205 Colono women (ages 15–90) between 2008 and 2014. General linear and Poisson regression models were used to assess effects of ethnicity, birth cohort, and MI indices (household-, market-, traditional-style-of-life) on reproductive outcomes; logistic regression determined predictors of contraceptive use.

Results: Shuar women experience earlier age at first birth ($p \leq 0.05$) and higher parity ($p \leq 0.001$) with little secular change. However, within more market-integrated Shuar households, earlier menarche ($p = 0.04$), and lower parity ($p \leq 0.001$) were documented. By contrast, Colonos show secular increases in age at first birth and declines in parity (both $p \leq 0.05$). In both populations, breastfeeding duration decreases over time ($p = 0.006$) and higher contraceptive use is associated with more market-integrated households ($p = 0.03$).

Conclusions: Reproductive transitions in Amazonian Ecuador unfold at differing rates, reflecting different histories and degrees of MI. Colonos show clear secular shifts characteristic of reproductive transitions, whereas Shuar show emerging transitions only among more market-integrated households. Results support the context-specific nature of reproductive transitions and highlight value in disaggregated analyses to understand their dynamics.

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1 | Introduction

Reproductive transitions,[1] typically characterized by declining parity, rising age at first reproduction, and falling menarcheal age, have been well documented for many global populations (Anderson and Hickey 2023; Becker and Lewis 1973; Bongaarts and Hodgson 2022; Bulatao and Lee 1983; Bryant 2007; Caldwell 1981, 1999; Leone and Brown 2020; Ossa et al. 2010). For example, in high-income regions such as Europe and North America, reproductive transitions began in the late 19th century, with the total fertility rate (TFR; estimated number of children a woman will have based on age-specific fertility rates), falling by approximately 40% between 1870 and 1920 (Caldwell 1999; Coale and Treadway 1986; Livi-Bacci 2012). By the mid-20th century, similar trends emerged across parts of Latin America, Asia, and the Caribbean, contributing to a global TFR decrease from 5.07 in 1965 to 2.23 by 2024 (Bhattacharjee et al. 2024; Roser 2024). These fertility shifts typically coincide with significant mortality declines, particularly reductions in infant and child mortality, fueling consequential global demographic transitions (Bongaarts and Hodgson 2022; Omran 1971). Such patterns are also often accompanied by shifts across related reproductive behaviors (e.g., lactation practices, contraceptive use), reflecting the complex and multifaceted ways in which cultural, socioeconomic, and ecological forces differentially interact to shape reproductive outcomes with important implications for maternal/child health and life history (e.g., Anderson and Hickey 2023; InterLACE 2019; Hackman and Kramer 2021; Hoyt and Falconi 2015; Kramer and Hackman 2024; Kramer et al. 2021; Lanza et al. 2013; Matthews and Hamilton 2016; McKerracher et al. 2017).

Comparisons between indigenous and nonindigenous women from the same region exemplify the variable influences of such forces on reproductive biology and behavior, in ways that national-level aggregated data tend to obscure. Several studies show higher fertility, earlier age at first birth, and lower levels of contraceptive use among indigenous women compared to nonindigenous counterparts (Batyra 2020; McNamee 2009; de Ponce Leon et al. 2019; Rodríguez-Vignoli and Cavenaghi 2014), with differences often persisting across generations (e.g., Ossa et al. 2010; Teng et al. 2025). For example, between 2001 and 2012, TFR estimates from Ecuador decreased from 4.7 to 3.1 (World Bank 2022) with provincial-level data from nonindigenous Ecuadorians mirroring these broader national trends (Carr et al. 2006; Goicolea et al. 2008; Ríos-Quituizaca et al. 2021). While limited, existing data from indigenous Ecuadorians indicate a comparatively slower, albeit emerging, decline in fertility. Davis et al. (2015) found that during the same 11-year period (2001–2012), the mean TFR of five northeastern Ecuadorian indigenous groups decreased from 7.9 to 7.0, signaling early stages of a reproductive transition. They argue that increasing market integration (MI; the degree to which people consume from and produce for a market economy; Lu 2007) and exposure to non-indigenous cultures, which commonly prioritize smaller family sizes and more family planning options, are central drivers of this change.

The literature examining the causal determinants of reproductive transitions is extensive, with studies pointing toward a myriad of economic, ecological, and cultural factors as key drivers. For example, economic perspectives have emphasized how globalization and industrialization enhance access to healthcare, nutrition, education, and employment opportunities, factors that, in turn, reshape incentives surrounding family size and fertility decisions (Bongaarts and Hodgson 2022; Bradshaw et al. 2023; Caldwell 1976; Götmark and Andersson 2020; Kirk 1996; Ranganathan et al. 2015). Ecological changes, including shifts in subsistence strategies, alter social dynamics and energetic environments (Gibson and Mace 2006; Gurven et al. 2017; Hill and Hurtado 1996; Lanza et al. 2013; McAllister et al. 2012; Sear et al. 2016), while cultural transformations, such as changing reproductive norms, gender roles, and attitudes toward contraceptive use and family size, further shape reproductive trajectories (Khan et al. 2022; Veile and Kramer 2014).

While there is no singular determinant of reproductive transitions, MI offers a critical umbrella framework for investigating how multiple factors interact to shape reproductive change, as greater engagement with markets often transforms subsistence and labor practices, alters energetic environments through dietary and activity changes, and expands access to health services and family planning, collectively contributing to shifts in cultural norms (Hackman and Kramer 2021; Kramer and Hackman 2024; Mattison et al. 2022). Notably, the magnitude and direction of these effects vary depending on local histories and degree of market participation, contributing to distinct, population-specific reproductive trajectories (Kramer and Greaves 2007). For instance, among Pumé forager-horticulturalists, early stages of acculturation coincided with higher fertility and reduced infant mortality (Kramer and Greaves 2007), whereas in Guatemalan Mayans, proximity to Western immigrant communities contributed to lower fertility and delayed first births (McKerracher et al. 2017). Among the Toba of Argentina, younger generations have more children than earlier cohorts despite cultural shifts, a trend attributed to increased partner availability in formal school settings and Christian prohibitions against abortion and infanticide (Lanza et al. 2013). For the Bolivian Tsimane, fertility remains high despite rapid socioeconomic and cultural development, partly because of related improvements in maternal nutritional status and persistent cultural values emphasizing the importance of large families (McAllister et al. 2012). Similarly, in other subsistence-level communities, developmental initiatives, such as improved water infrastructure without simultaneous access to family planning led to greater parity, resulting in strained familial resources and increased childhood malnutrition and morbidity (e.g., Gibson and Mace 2006; Kramer and McMillan 1999, 2006). Varying influences of MI on other reproductive factors including age at menarche (Leone and Brown 2020; Sumedha and Pathak 2025) and breastfeeding duration (Caicedo-Borrás et al. 2021; Freire et al. 2020; Veile and Kramer 2014) have also been identified. Collectively, these cases highlight that reproductive transitions do not follow a uniform trajectory. Rather, their onset, pace, as well as epidemiological implications, are deeply embedded in local sociocultural and ecological contexts and therefore do not translate to simple universal predictions across other global populations (e.g., Kramer and Hackman 2024; Mattison and Shenk 2019).

Despite this body of research, fewer studies have compared how variation in MI influences reproductive outcomes among

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neighboring indigenous and nonindigenous groups. This gap is most evident in regions where such groups share the same rapidly developing environment (e.g., changing infrastructure, increasing market access) yet differ in cultural traditions and degree of exposure to socioeconomic change. This constrains our understanding of how reproductive transitions unfold across diverse but interconnected populations, and more broadly how these processes contribute to global variation in reproductive biology. The current study contributes insight through a comparison of indigenous Shuar of southeastern Amazonian Ecuador, a population increasingly integrating into market economies, and neighboring nonindigenous Ecuadorian mestizos, locally called Colonos. Both populations inhabit the same province, one that is undergoing rapid infrastructural and economic development (e.g., Rudel 2018). Prior research with the Shuar has documented the effects of MI across multiple health domains, including nutritional status (Houck et al. 2013; Urlacher, Liebert, et al. 2016), metabolism and immune function (Urlacher et al. 2021), lipid profiles (Liebert et al. 2013), gut microbiome diversity (Stagaman et al. 2018), helminth infections (Cepon-Robins et al. 2021; Gildner et al. 2020), and biomarkers of chronic stress (Barrett et al. 2025), underscoring the wide-ranging multifaceted influences of market participation on Shuar health and life history. Because rapid MI carries significant health and demographic consequences for indigenous populations, it is also especially critical to extend this lens onto reproduction to identify barriers facing those most vulnerable to health inequalities (e.g., Valeggia and Snodgrass 2015).

To this end, we examine age at menarche, age at first birth, number of live births, duration of breastfeeding, and consider contraceptive use as a proxy of health care access and reproductive decision-making among both Shuar and Colonos. By evaluating how different measures of MI relate to these reproductive variables and by simultaneously identifying possible secular trends, this study aims to shed light on the shared and divergent trajectories of indigenous and nonindigenous groups and provide a more nuanced view of reproductive patterns that may not be gleaned from national demographic data alone. Specifically, our study aims to:

1. determine the extent to which greater participation in the market economy predicts variation in reproductive life history traits and, if so, how different dimensions of MI exert distinct influences.
2. to assess whether secular trends in reproductive outcomes show evidence of a reproductive transition and if features of these shifts differ between Shuar and Colonos.

2 | Ethnographic Background: Brief History of MI Among Shuar and Colonos

The Shuar are an indigenous population primarily concentrated in the Amazon basin of the Morona Santiago province situated in southeastern Ecuador. Prior to the 1930s, Shuar lived in dispersed households as seminomadic forager-horticulturalists, subsisting on fruits, vegetables, and root crops from their gardens, as well as fish and game from the rivers and forests (Harner 1972; Rubenstein 2001). The arrival of nonindigenous Colonos in the first half of the 20th century led to the expropriation of Shuar land and the introduction of infectious diseases like tuberculosis and measles, which eliminated nearly half of the indigenous population in the region (Harner 1972). The Shuar were further disadvantaged by subsequent deforestation of their dispossessed land, which deprived them of valuable hunting grounds, much of which was converted into cattle pastures (Rudel 2018, 2021). In response, some Shuar sought work on Colono farms while others moved from the more populated Upano Valley region eastward into the less densely settled region across the Cutucú mountain range (i.e., the Cross-Cutucú region) (Amaluiza and Segovia 1977).

The pace of colonization accelerated in the 1960s with regional development initiatives stimulating road construction from the Andes into the province, and with most changes occurring in the more accessible Upano Valley (Rudel 2018). During this period, the Shuar population rebounded sharply as intra-tribal conflict became less common and access to medical services and medications expanded (Jokisch and McSweeney 2011). Compared to Shuar in the Upano Valley, Cross-Cutucú Shuar were able to more successfully conserve rainforests and resist further land sales to Colonos, limiting infrastructural development in the region and partly contributing to the highly uneven access to health clinics, villages, schools, and market centers across Shuar territory today (Gildner et al. 2016, 2020; Liebert et al. 2013; Petersson 2012; Urlacher, Liebert, et al. 2016).

Land disputes between Shuar and Colonos continued during the 1960s, as colonists sought to acquire more Shuar land, particularly in the Upano Valley. In some sparsely settled areas of the province, the two groups avoided conflict by claiming adjacent but nonoverlapping lands (Rudel 2018). Encouraged by the Salesian Order of the Roman Catholic Church, many Shuar began adopting more sedentary livelihoods, participating in small-scale agriculture and raising cattle, with some settling into centros or permanent settlements (Jokisch and McSweeney 2011; Rudel 2018). Around this time, Shuar also formed the *Federacion Interprovinciales de Centros Shuar* (FICSH; 1964) to represent their interests through a unified body and resist further land invasions by Colonos.

Throughout the 1970s and 1980s, Shuar and Colonos converted much of the regional rainforest into pastures, with many becoming small-scale cattle ranchers. This conversion facilitated the acquisition of secure land titles, which Colonos successfully obtained and used as collateral for bank loans to purchase cattle. Shuar, on the other hand, obtained collective land titles designed to prevent the sale of their land to non-Shuar entities (e.g., banks). However, this meant that Shuar could not use their land as collateral, inhibiting their access to credit (Rudel 2018). Consequently, Shuar income relied on renting their pastures to Colonos, leading to overgrazing, soil nutrient loss, and declining value and productivity of Shuar-owned land (Rudel 2018).

By the 1980s, the Shuar population had grown to nearly 30 000 (Hendricks 1988) and their numbers continued to rise in the following decades, outpacing growth among Colonos. During the 1990s, diminishing agricultural returns in Morona Santiago led many Colono men to seek employment in urban centers or abroad or in urban centers, resulting in reduced fertility among Colono females (Rudel 2018). Without the resources needed for urban migration, such as income for

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housing or food, many Shuar remained on their family farms, and their population continued to grow. According to one estimate, between 2001 and 2010, the Colono population grew by 4.2%, while Shuar grew by 35.1% (INEC 2010). Because family farms are subdivided across generations, higher fertility rates and lower rates of rural-to-urban migration among the Shuar led to progressively smaller and more fragmented farms (Rudel 2018). This increasing land fragmentation, coupled with degraded soils and limited income opportunities, has entrenched a cycle of poverty that persists among many Shuar today (Barrett et al. 2011; Rudel et al. 2002).

Today, many Upano Valley Shuar live in rural centros, where they practice subsistence agriculture supplemented by cash cropping, small-scale animal husbandry, day labor, or other employment (Barrett et al. 2025; SHLHP unpublished data). The largest centros have intermittent electricity, small health centers with limited supplies, and rudimentary sanitation infrastructure (Jokisch and McSweeney 2011; Lu 2007; SHLHP unpublished data). Access to these resources diminishes in more remote Shuar communities, particularly those located in Cross-Cutucú (Romero-Alvarez et al. 2023). Some Shuar living closer to urban centers are more integrated into the market economy and maintain economic and social ties with non-Shuar, including Colonos. A smaller percentage of Shuar live permanently in market centers. As of 2022, 22.1% of Morona Santiago's indigenous population, primarily comprised of Shuar, was considered urban (INEC 2022). By contrast, most Colonos work wage jobs and live closer to or in major market centers, with approximately 75% of Colonos living in urban settings (INEC 2022), affording them greater access to market goods, infrastructure, and health services. Such access has had broad ramifications, including epidemiological ones, exemplified in morbidity rates that are 2× lower than indigenous counterparts (Pan et al. 2010) and significantly lower rates of childhood stunting compared to Shuar (Blackwell et al. 2009).

However, overall Colonos are not socioeconomically advantaged in absolute terms: Morona Santiago remains Ecuador's poorest province, with an income poverty rate of 65.8% and only 14.6% of the population in adequate employment (De Schutter 2023; INEC 2024). Thus, while Colonos are relatively better positioned than Shuar in terms of market access and economic security, they still live within a province marked by deep poverty and chronic underemployment. In general, both groups continue to remain largely socially and politically divided, with Colonos being comparatively spared from systemic racism, oppression, and exploitation that characterizes indigenous lived experiences (e.g., discrimination, negative stereotypes, extractivist governmental policies) (OHCHR 2017; Petersson 2012; Ríos-Quituizaca et al. 2021; Valeggia and Snodgrass 2015).

3 | Methodology

3.1 | Participants and Sampling Strategy

Retrospective reproductive histories were collected from 565 women living in Morona Santiago between 2008 and 2014 as part of the Shuar Health and Life History Project (SHLHP; www.shuarproject.org), including 360 Shuar (15–86 years old) and 205 Colonos (15–90 years old). A minimum age of 15 years was chosen as it aligns with the local age of consent. No additional exclusionary criteria were applied in order to capture a broad range of participants; however, statistical outliers were removed from analyses (see Section 3.7).

Shuar participants were recruited from peri-urban and rural communities across the Upano Valley and Cross-Cutucú regions. Recruitment occurred over several field seasons in collaboration with *FISCH* and local community leaders. Communities were selected based on informant recommendations and community size with larger populations (> 100 inhabitants) prioritized to maximize sampling. During community-wide meetings, the SHLHP team fielded questions, gathered feedback, and extended an invitation to all community members to reduce potential sampling bias. While most Shuar participants were drawn from communities where the SHLHP team was based, individuals from nearby communities also participated. In total, the Shuar sample represents a minimum of 17 distinct cantons or communities across the Upano Valley and Cross-Cutucú regions. Prior research has demonstrated that socioeconomic and ecological factors differentially shape health profiles across these regions (see Liebert et al. 2013; Stagaman et al. 2018), yet the present study combines regional samples to maximize our resolution of Shuar patterns and to identify secular changes across the population. Moreover, while regional proxies for MI are useful (e.g., Cepon-Robins et al. 2014; Gildner et al. 2016), our utilization of specific household-level MI variables captures the heterogeneity that exists within regions as well as within the Colono sample.

Colono participants were recruited from the area surrounding a centrally located health clinic (*subcentro de salud*) situated approximately 15 km from a major market town in the Upano Valley. This *subcentro*, which served as our base of operations, primarily supports nearby peri-urban and urban communities and is easily accessible by foot or bus from the main road. Collaboration with the *subcentro* doctor and nurses allowed advanced advertisement of the study through posted flyers and word of mouth, and a local radio announcement further encouraged community participation. Colono participants were therefore recruited opportunistically, with at least nine peri-urban and urban Upano Valley communities represented in the total sample.

All participant ages were verified by cross-checking self-reported age against their national identification card (*cédula*), the primary form of identification for Ecuadorian citizens. The *cédula*, often issued upon birth registration and required for access to health services and social security benefits, was presented by all participants at the time of data collection. Among older participants, *cédula* cards may not have been obtained until later in life, raising the possibility of inaccuracies in recorded birth years. To minimize this potential issue, reported ages were further corroborated using additional information from the participants (e.g., age at first birth, current age of their children, birth orders), and/or with other household member data whenever possible.

Differences in age profiles between the two groups are notable. The mean age of Shuar participants is more than 10 years younger than that of Colonos (32.8 ± 14.0 vs. 44.4 ± 18.4 years

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old, respectively). This disparity may partly reflect recruitment strategies given that a portion of the Colono sample consisted of individuals visiting the subcentro during data collection, and these participants were more likely to be older adults. However, mean age differences also align with broader demographic patterns: census data show that Morona Santiago's indigenous population (the majority of whom are Shuar) have a younger age structure, characterized by higher proportions of children and young adults and fewer older adults (INEC 2010). In contrast, Colonos exhibit a more evenly distributed age profile with a relatively greater proportion of adults and older adults (INEC 2010). While such differences could complicate direct comparisons of these populations, our use of age-matched birth cohorts (see Section 3.4) helps mitigate these concerns.

All participants gave individual informed verbal consent, and the study protocol was approved by community leaders, FICSH, and the Office for Protection of Human Subjects at the University of Oregon and the City University of New York (CUNY).

3.2 | Reproductive Variables

Structured interviews were used to collect reproductive histories including age at first menses (i.e., menarche), whether they ever had a child and, if so, number of live births, as well as their age at the first birth, and current age of each offspring. Further, participants reported if they breastfed their children and the approximate duration each child was breastfed. When a woman had breastfed multiple children across their reproductive life, an average of those breastfeeding periods was included in the analysis. Finally, we asked women about their menopausal status to identify participants with completed fertility, a factor relevant to our analysis of parity. Women were asked when they first experienced menopausal symptoms and those who reported that their last menstruation was over 12 months prior (and they were not pregnant or lactating at the time of the interview) were defined as menopausal. For these women, we recorded the age at which they experienced their final menstrual period, although this specific measure was not included in the present analysis.

Participants were also asked about use of biomedical contraceptive use, including condoms, pills, intrauterine devices, injections, and tubal ligation. Since the use of biomedical contraception suggests greater integration into formal healthcare systems, influencing broader reproductive decision-making and access to family planning resources, the few participants ($n=4$) who reported using a traditional remedy (e.g., rhythmic method, herbal plants) were not considered in this sub-analysis. This sample was also too small to perform a meaningful statistical analysis comparing traditional and biomedical contraceptive use. All interviews were conducted in Spanish or Shuar, when necessary, with the assistance of a local translator.

To further contextualize reproductive outcomes and because reproductive capacity (i.e., fecundity) is associated with energetic conditions (e.g., Ellison 2008), we also include height (centimeters [cm]) measured using a portable stadiometer (Seca Corporation, Hanover, MD), and weight (kilograms [kg]) measured using an electronic scale (Tanita Corporation, Tokyo, Japan), and BMI was calculated as weight (kg)/height (meters^2) in the analyses.

3.3 | MI Variables (SOL-Indices)

Following prior studies by SHLHP (e.g., Gildner et al. 2020; Liebert et al. 2013; Stagaman et al. 2018; Urlacher, Liebert, et al. 2016), structured interview data were used to construct three style-of-life (SOL)-indices to assess household-level MI (see Liebert et al. 2013; Urlacher, Liebert, et al. 2016 for a full description of how indices were developed). Components of MI are not well-captured by single metrics (e.g., distance to the market) (Mattison et al. 2022) and thus we constructed this scoring system based on contextual and ethnographic knowledge of the key markers of MI and traditional lifeways in this region. Each participant provided information about their household characteristics and ownership of specific goods, which were then used to develop these indices. SOL-Market reflects ownership of durable goods linked to the market economy (e.g., radio, propane stove, mobile phone, TV, chainsaw, bicycle, refrigerator, motorcycle, car). SOL-Traditional captures reliance on traditional foraging lifeways, measured by the ownership of items such as fishing hook/line, hunting dogs, blowgun, firearm, fishing nets, and canoe. SOL-Household considers household permanence and access to regional infrastructure including floor, wall, and roof materials, total number of rooms and available amenities (e.g., water source, latrine status, electricity). Final SOL scores for each category were calculated as the fraction of total list items owned by each participant household (SOL-Traditional and SOL-Market) or as the sum of items scored (SOL-Household). A high SOL-Market and SOL-Household index suggest greater participation in the market economy, whereas high SOL-Traditional indicates greater participation in traditional subsistence lifeways.

3.4 | Birth Cohorts

As a cross-sectional dataset, identification of secular trends in reproductive patterns requires dividing participants into birth cohorts. The following six birth cohorts, generally defined as 10-year cohorts, were identified: females born (1) before 1950, (2) between 1950–1959, (3) 1960–1969, (4) 1970–1979, (5) 1980–1989, and (6) 1990 and later. Due to smaller sample sizes among older females, participants born between 1920 and 1949 (before 1950) were combined and analyzed as a single cohort. For simplicity, throughout the paper, cohorts are referred to as the following: (1) (before) < 1950, (2) 1950s, (3) 1960s, (4) 1970s, (5) 1980s, and (6) 1990s cohorts. Similar cohort definitions are used in other research on secular trends in reproductive patterns among indigenous groups (e.g., Ossa et al. 2010), and therefore our decisions for cohort cutoffs are also intended to facilitate future cross-population comparisons.

3.5 | Study Expectations

Building on prior research linking MI and reproductive change, we outline several anticipated patterns, while acknowledging

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that these processes are context-specific and nonlinear across populations (e.g., Mattison et al. 2022).

- *MI and reproductive outcomes*: We expect that variation in MI will correspond to distinct reproductive profiles among Shuar and Colonos. While increasing MI has been often associated with earlier menarche and reduced fertility in many economically transitioning populations, evidence from small-scale societies also shows heterogeneous patterns, including fertility increases during early stages of MI (e.g., Gurven et al. 2017; Hill and Hurtado 1996; Kramer and Greaves 2007; Kramer and Hackman 2024; Kramer and McMillan 2006). Considering these mixed findings, we anticipate that MI will be associated with shifts in reproductive timing and investment but that the direction and magnitude of these associations will differ between Shuar and Colonos.
- *Secular trends across cohorts*: We further expect that reproductive change over time will be evident across birth cohorts, although trajectories will diverge by ethnicity. Given their longer history of integration in the market economy, we expect Colonos to exhibit clearer signs of secular changes (e.g., delayed childbearing, reduced parity), whereas Shuar may show more modest or emerging changes. We therefore anticipate that menarcheal timing, fertility, and lactation will vary by both cohort and degree of MI, reflecting complex and context-dependent influences of reproductive transitions.

3.6 | Statistical Analyses

All Shuar and Colono reproductive variables were analyzed separately for normality, with Shapiro–Wilk tests and histograms of residuals ($p \leq 0.05$) indicating deviations which were further supported by slight-to-moderate skewness and kurtosis (Table S1). Separate Breusch–Pagan tests and visual inspections of a plot of studentized residuals versus unstandardized predicted values showed evidence of heteroscedasticity for age at menarche, age at first birth, and number of live births, but not for duration of breastfeeding or contraceptive use in each population. Multicollinearity was assessed using variance inflation factors (VIFs) with all VIFs < 2, indicating no problematic collinearity among predictors. Given these findings, differences in reproductive measures between ethnic groups and across cohorts were assessed using nonparametric Mann–Whitney U tests.

Additionally, general linear models (GLM) were performed with age at menarche, age at first birth, number of live births, breastfeeding duration, and contraceptive use as dependent variables and Ethnicity (Shuar; Colono), Birth Cohort (categorical), and SOL-Household, SOL-Market, and SOL-Traditional as independent variables. Models also included interaction terms for Ethnicity × SOL- (Household, Market, Traditional, separately) and Ethnicity × Birth Cohort. Analyses were pooled across all participants, with Colonos and the oldest cohort (< 1950s) serving as reference categories.

Age at menarche and age at first birth were modeled using a GLM (ordinary least squares [OLS]) regression analysis. Number of live births was examined among participants with completed fertility (i.e., menopausal women), which required collapsing the 1960s and 1970s cohort for this analysis given the small sample size in the latter cohort ($n = 5$); this variable was treated as a count variable and a Poisson regression with log link function was performed to identify significant associations with Ethnicity, Birth Cohort, and SOL-indices. Breastfeeding duration was modeled using a GLM with a Gamma distribution and log link function, because data were heavily right skewed (Table S1). Finally, contraceptive use was coded as a binary variable (0 = never used; 1 = used) for the subset of females who responded to this question (Shuar: 304; Colonos: 200), and logistic regression was used to model the likelihood of contraceptive use.

To account for violations of distributional assumptions, all regression models used heteroskedasticity-consistent standard error estimators (HC3 method; robust standard error) to ensure more reliable p-values and confidence intervals (Wilcox 2005). GLM-OLS results are presented as unstandardized regression coefficients with robust standard errors and corresponding p-values. Poisson regression results are presented as coefficients with exponentiated values expressed as incidence rate ratios (IRR) with 95% confidence intervals and p-values. Logistic regression results are reported as regression coefficients with associated odds ratios (OR), 95% confidence intervals, and p-values. Effects are reported as significant at $p \leq 0.05$. All statistical analyses were performed using IBM SPSS version 29.0 (Chicago, IL).

3.7 | Outliers Removed From Analyses

Outliers were excluded from analyses if their values exceeded 3 standard deviations above the mean for that reproductive variable. In all, five individuals were removed from the analysis including one Shuar and three Colonos who reported age at first birth between 39 and 43 years old, and one Colono female who reported age at menarche at 20 years.

4 | Results

4.1 | Descriptive Statistics

Table 1 presents a summary of reproductive and anthropometric variables for each ethnic group. Shuar, on average, experience their first birth at younger ages (17.9 ± 3.3 vs. 20.2 ± 3.2 years old; $p = 0.001$) and breastfeed children for longer durations (average duration of breastfeeding per child) compared to Colonos (15.7 ± 6.0 vs. 13.8 ± 8.0 months; $p = 0.04$). Shuar participants are also younger (32.8 ± 14.0 vs. 44.4 ± 18.4 years old) and have lower weight and BMIs (all $p = 0.001$).

Cohort-specific descriptive results are presented in Table 2, including intergroup means for each birth cohort (Table S2 shows additional results of Mann–Whitney U test performed across birth cohorts). Visualizations of cohort patterns and reproductive outcomes are represented in Figure 1a–d.

4.2 | Age at Menarche

There was no significant main effect of Ethnicity on age at menarche ($F[1, 415] = 2.41$, $p = 0.12$), with Shuar

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TABLE 1 | Descriptive statistics for Shuar and Colono participants.

	Shuar ($n=360$; 15–86 years old)	Colonos ($n=205$; 15–90 years old)	
	Mean (SD)	Mean (SD)	p
Age	32.8 (14.0)	44.4 (18.4)	0.001***
Height (cm)	148.8 (5.2)	150.1 (6.5)	0.099
Weight (kg)	55.3 (8.6)	62.9 (11.2)	0.001***
Body mass index (kg/m^2)	25.0 (3.5)	27.9 (4.6)	0.001***
Age at menarche (years)	13.3 (1.2)	13.4 (1.6)	0.879
Age at first birth (years)	17.9 (3.3)	20.2 (3.2)	0.001***
Number of live births	4.6 (3.8)	4.2 (2.9)	0.731
Breastfeeding duration per child (months)	15.7 (6.0)	13.8 (8.0)	0.04*

Note: p values derived from Mann–Whitney U test: $^{*}p \leq 0.05$; $^{***}p \leq 0.001$.

($M = 13.3 \pm 1.2$ years old) and Colonos ($M = 13.4 \pm 1.6$ years old) reporting similar ages. Birth cohort shows a significant overall effect ($F[5, 415] = 2.68$, $p = 0.02$) (Table 3), with parameter estimates indicating lower age at menarche specifically in the 1980s cohort compared to the < 1950s reference ($B = -1.11$, SE = 0.42, 95% CI = −1.94 to −0.29, $p = 0.01$) (Table S3). However, no consistent linear change for age at menarche is identified for either population (Figure 1) and no other main effects of the independent variables on age at menarche are found.

Ethnicity × SOL-Household is the only significant interaction effect with age at menarche ($F[1, 415] = 6.08$, $p = 0.01$), such that Shuar with higher SOL-Household have earlier menarche ($B = -0.11$, SE = 0.05, 95% CI = −0.22 to −0.01, $p = 0.04$); a similar relationship is not identified for Colonos.

4.3 | Age at First Birth

As noted earlier, Colonos experience their first birth later than Shuar across all cohorts (Tables 1 and 2 for cohort comparisons). However, after controlling for Birth Cohort and SOL-indices, Ethnicity did not show a significant main effect on age at first birth ($F[1, 365] = 1.5$, $p = 0.22$) (Table S4). The overall effect of Birth Cohort is also not significant ($F[5, 365] = 1.57$, $p = 0.17$), although follow-up parameter estimates indicate that several younger cohorts experience earlier first births (1.9–3.3 years earlier) compared to the < 1950s reference (e.g., 1980s cohort: $B = -2.74$, SE = 0.76, $p \leq 0.001$; 1960s: $B = -1.88$, SE = 0.89, $p = 0.036$) (Table S4).

A significant Ethnicity × Birth cohort interaction ($F[5, 365] = 2.70$, $p = 0.02$) indicates that cohort patterns differ between Shuar and Colonos (Table 3). Among Colonos, younger cohorts show evidence of delayed age at first birth relative to earlier cohorts, whereas among Shuar, age at first birth remains fairly stable with no indication of a consistent secular change (regression coefficients (B) ranging from 3.77 to 5.99, all $p \leq 0.05$) (Table 3; Figure 1b). Neither SOL-indices nor their interactions with Ethnicity are significant predictors of age at first birth.

4.4 | Number of Live Births

Of the sample, 107 women had completed fertility (i.e., were postmenopausal), including 40 Shuar and 67 Colonos. Among these participants, Ethnicity (Wald $\chi^2(1) = 34.45$, $p \leq 0.001$), Birth Cohort (Wald $\chi^2(2) = 26.09$, $p \leq 0.001$), and their interaction (Wald $\chi^2(2) = 13.52$, $p \leq 0.001$) significantly predict parity.

Shuar consistently exhibit higher parity than Colono women across age cohorts, averaging 7.5–9 births (Table 2; Figure 1c). By contrast, Colonos show greater temporal variability: women in older cohorts averaged 6.3 births, those from mid-century cohorts with 6.9 births, and younger cohorts declined to 3.1 births. Parameter estimates further support this ethnic difference in births, after controlling for Birth Cohort and SOL-indices ($B = 1.23$, SE = 0.25, 95% CI = 0.74 to 1.71, IRR = 3.41, $p \leq 0.001$) (Tables 3 and S5a). Moreover, adjusted model-based predicted means indicate that Shuar women are expected to have approximately 6.8 births (95% CI = 5.66–8.11), compared with 5.3 births (95% CI = 4.68–5.90) among Colono women, an adjusted difference of ~1.5 additional births for Shuar women (Table S5b).

Ethnicity × Birth Cohort interaction reveals divergent secular trajectories with Shuar maintaining high parity across cohorts (e.g., Shuar × 1950s cohort: $B = -0.33$, SE = 0.17, 95% CI = −0.65 to 0.00, IRR = 0.72, $p = 0.05$), while Colonos experience sharp declines in later cohorts (Table S5a).

Higher SOL-Market scores are linked to fewer births across the overall sample ($B = -0.38$, SE = 0.14, 95% CI = −0.66 to −0.10, IRR = 0.69, $p = 0.01$), while higher SOL-Household was associated with fewer births with the most pronounced effects among Shuar ($B = -0.07$, SE = 0.02, 95% CI = −0.11 to −0.03, IRR = 0.93, $p \leq 0.001$). There is no significant effect of SOL-Traditional on number of births, and there are no interaction effects with either SOL-Traditional and SOL-Market.

4.5 | Duration of Breastfeeding

Birth Cohort significantly predicts duration of breastfeeding per child (Wald $\chi^2(5) = 16.40$, $p = 0.01$) suggesting a trend toward reduced breastfeeding in younger cohorts across both ethnicities (Table 3; Figure 1d). However, significant reductions across cohorts are only identified between the 1970s and < 1950s cohort ($B = -0.28$, SE = 0.09, 95% CI = −0.47 to −0.10, $p \leq 0.01$) (Table S6).

There were no significant main effects of Ethnicity and SOL-indices, nor their interaction terms on duration of breastfeeding

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TABLE 2 | Comparisons of cohort-specific means and standard deviations for reproductive and anthropometric measures among Shuar and Colonos.

	Before 1950 (Birth years: <1950)			1950s cohort (Birth years: 1950–1959)			1960s cohort (Birth years: 1960–1969)			1970s cohort (Birth years: 1970–1979)			1980s cohort (Birth years: 1980–1989)			1990s cohort (Birth years: 1990 and after)		
	Shuar ($n=16$)	Colono ($n=48$)		Shuar ($n=20$)	Colono ($n=32$)		Shuar ($n=51$)	Colono ($n=33$)		Shuar ($n=71$)	Colono ($n=31$)		Shuar ($n=95$)	Colono ($n=44$)		Shuar ($n=91$)	Colono ($n=14$)	
	Mean (SD)	Mean (SD)	*p*	Mean (SD)	Mean (SD)	*p*	Mean (SD)	Mean (SD)	*p*	Mean (SD)	Mean (SD)	*p*	Mean (SD)	Mean (SD)	*p*	Mean (SD)	Mean (SD)	*p*
Height (cm)	141.4 (4.5)	146.1 (5.6)	***	149.8 (3.5)	149.4 (7.0)	—	147.9 (5.0)	149.2 (6.8)	—	148.4 (6.1)	152.8 (5.9)	***	150.0 (4.8)	153.3 (5.5)	***	149.4 (4.2)	151.7 (4.3)	—
Weight (kg)	48.6 (7.5)	58.5 (9.3)	***	56.7 (7.0)	66.4 (11.1)	***	56.6 (7.7)	65.6 (10.4)	***	57.9 (9.5)	66.9 (11.1)	***	56.5 (9.3)	62.1 (11.3)	***	52.1 (6.5)	57.0 (12.5)	—
Body mass index (kg/m^2)	24.3 (3.3)	27.4 (4.3)	**	25.3 (2.9)	29.9 (4.6)	***	25.8 (2.8)	29.4 (3.9)	***	26.3 (4.3)	28.7 (4.9)	*	25.1 (3.6)	26.3 (4.1)	*	23.3 (2.4)	24.7 (4.9)	—
Age at menarche (years)	13.3 (1.0)	13.7 (2.0)	—	13.6 (0.8)	14.2 (1.4)	—	13.3 (1.2)	13.4 (1.6)	—	13.6 (1.4)	13.2 (1.3)	—	13.3 (1.1)	12.8 (1.3)	—	13.1 (1.3)	13.4 (1.2)	—
Age at first birth (years)	16.2 (2.1)	21.4 (3.4)	***	18.2 (4.4)	19.1 (3.2)	—	18.5 (4.1)	20.3 (3.0)	***	18.7 (4.1)	20.3 (3.4)	**	17.7 (2.5)	19.4 (2.6)	**	16.9 (2.3)	18.3 (1.5)	—
Number of live births	9.1 (3.4)	6.2 (2.1)	***	8.6 (2.9)	6.8 (2.8)	*	8.3 (3.6)	3.7 (2.2)	***	6.7 (2.7)	2.9 (1.1)	***	3.2 (2.1)	1.6 (0.7)	***	0.9 (0.8)	0.2 (0.4)	***
Breastfeeding duration per child (months)	17.9 (6.1)	16.9 (6.7)	—	19.6 (6.4)	16.2 (7.6)	—	15.8 (6.0)	13.4 (7.7)	—	15.6 (6.3)	13.0 (5.2)	—	14.6 (4.3)	9.8 (9.4)	—	15.4 (7.8)	4.5 (9.0)	*

Note: p values derived from Mann–Whitney *U* test: $*p \leq 0.05$; $**p \leq 0.01$; $***p \leq 0.001$; Additional results from Mann–Whitney *U* test available in Table S2.

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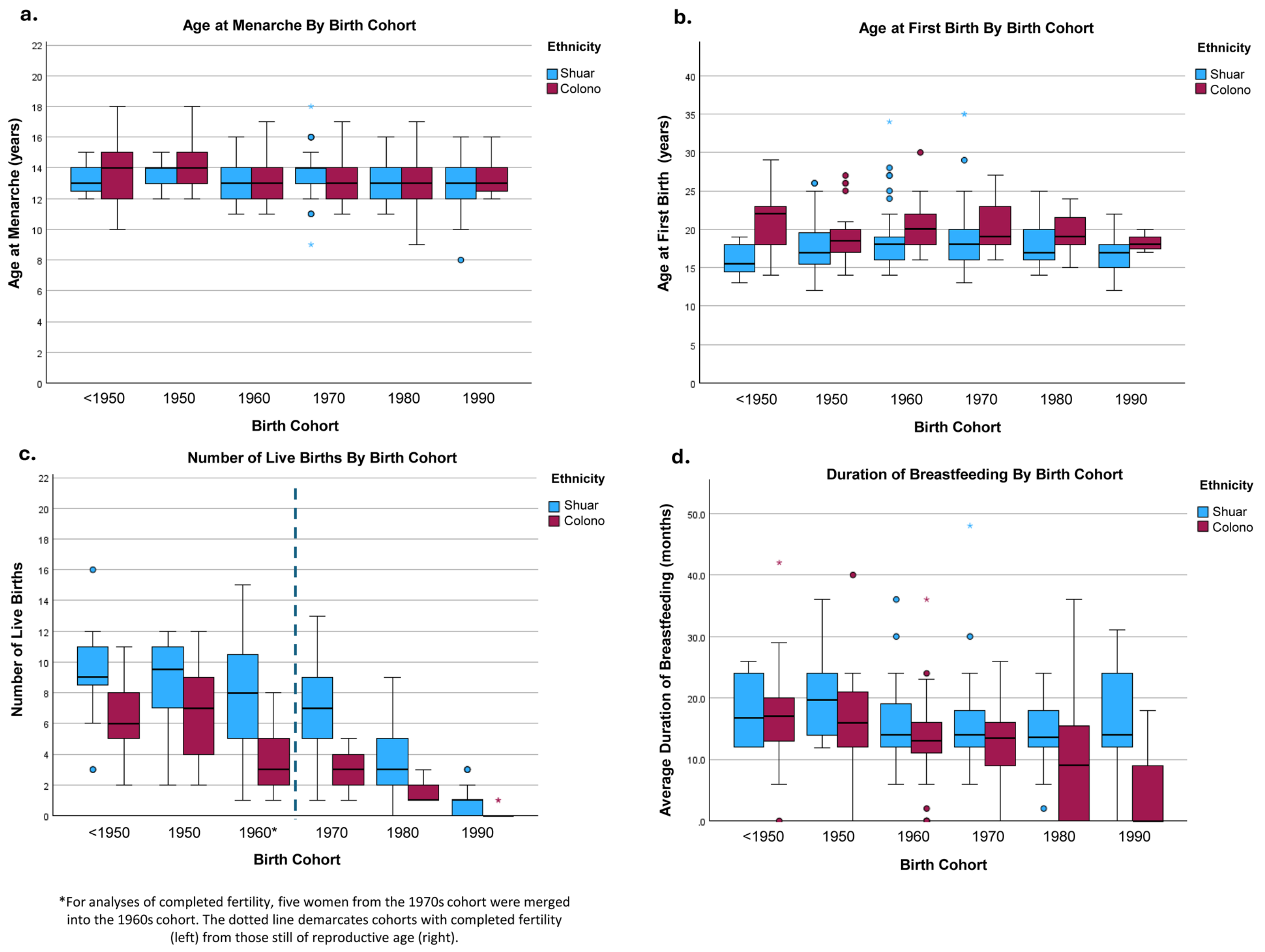

FIGURE 1 | (a–d) Reproductive outcomes by Ethnicity and Birth Cohort. Figures present (a) age at menarche (years), (b) age at first birth (years), (c) number of live births, and (d) duration of breastfeeding (months). Whiskers represent 1.5 × the interquartile range (IQR) extending from the upper and lower quartiles. Points beyond the whiskers represent statistical outliers.

(all $p > 0.12$), suggesting that ethnic affiliation and MI do not significantly predict duration of breastfeeding.

4.6 | Contraceptive Use

Of the subset of females who responded to the question on contraceptive use, 80 Shuar (26.3%) and 84 Colonos (42%) report having ever used some form of nontraditional contraception (Table 4). This result might suggest that Colonos are more likely to use contraception than Shuar. However, contraceptive use is not driven by Ethnicity; in regression models that included Ethnicity, Birth Cohort, and SOL-indices, Ethnicity was no longer a significant predictor of contraceptive use after controlling for other factors.

Birth Cohort exerts the strongest effect on contraceptive use (Wald $\chi^2(5) = 29.76$, $p \leq 0.001$). Overall, women in the following cohorts: 1960s (OR = 6.45, $p \leq 0.001$), 1970s (OR = 10.08, $p \leq 0.001$), 1980s (OR = 10.06, $p \leq 0.001$), and 1990s (OR = 3.38, $p = 0.004$) are associated with greater contraceptive use compared to earlier cohorts. Importantly, relatively low overall usage rates in the youngest cohort (1990s) are more likely reflective of the early stages of their sexual and reproductive life and therefore these results must be interpreted with caution (Table 4).

SOL-Household shows positive associations such that greater investment in household infrastructure predicts higher odds of contraceptive adoption (OR = 1.17, $p = 0.03$); this relationship is not moderated by Ethnicity. No other significant main effects nor interactions are identified.

5 | Discussion

The current study builds upon research on global reproductive transitions by examining how market integration (MI) more and secular changes influence reproductive variables among indigenous Shuar and nonindigenous Colonos from the southeastern region of Amazonian Ecuador. Our findings indicate that both groups are undergoing reproductive transitions, albeit at different paces and trajectories. Shuar women consistently report more births and younger ages at first birth compared to Colonos and demonstrate little secular change in these patterns. However, the effects of increasing MI may mediate reproductive timing and behavior among some Shuar

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TABLE 3 | Significant results from general linear models predicting reproductive outcomes.

Outcome (model)	Predictor	*B* (SE)	95% CI	*t*/IRR/OR	*p*	95% CI for IRR/OR	F/Wald χ^2	df	*p*	Interpretation
Age at menarche (GLM, normal, identity)	Birth cohort (overall)	—	—	—	—	—	$F = 2.68$	5	0.02	Some younger cohorts ↓ menarche than older cohorts
	Ethnicity × SOL-Household	—	—	—	—	—	$F = 6.08$	1	0.01	Higher SOL-Household = ↓ menarche among Shuar
	Ethnicity = Shuar × SOL-Household	−0.11 (0.05)	−0.22 to −0.01	−2.12	0.04	—	—	—	—	
Age at first birth (GLM, normal, identity)	Ethnicity × Birth Cohort	—	—	—	—	—	$F = 2.70$	5	0.02	Cohort trends in age at first birth differed by ethnicity
	Ethnicity = Shuar × 1990s cohort	4.20 (2.14)	−0.01 to 8.4	1.96	0.05	—	—	—	—	Earlier first births in younger Shuar cohorts Later first births in younger Colono cohorts
	Ethnicity = Shuar × 1980s cohort	4.04 (1.11)	1.85 to 6.23	3.63	< 0.001	—	—	—	—	
	Ethnicity = Shuar × 1970s cohort	3.77 (1.30)	1.20 to 6.33	2.89	0.004	—	—	—	—	
	Ethnicity = Shuar × 1960s cohort	4.12 (1.34)	1.49 to 6.74	3.08	0.002	—	—	—	—	
	Ethnicity = Shuar × 1950s cohort	5.99 (1.79)	2.47 to 9.52	3.34	< 0.001	—	—	—	—	
Number of live births (Poisson, log link)	Ethnicity	—	—	—	—	—	$\chi^2 = 34.45$	1	< 0.001	Number of births varies by ethnicity
	Birth Cohort (overall)	—	—	—	—	—	$\chi^2 = 26.09$	2	< 0.001	Birth cohort predicts number of births
	Ethnicity × Birth Cohort	—	—	—	—	—	$\chi^2 = 13.52$	2	< 0.001	Cohort trends differ by ethnicity
	Ethnicity = Shuar	1.23 (0.25)	0.74 to 1.71	3.41 (IRR)	< 0.001	2.10 to 5.53	$\chi^2 = 24.60$	1	—	Shuar have ↑ births than Colonos
	SOL-Market	−0.38 (0.14)	−0.66 to −0.10	0.69 (IRR)	0.01	0.52 to 1.0	$\chi^2 = 6.92$	1	—	Higher SOL-Market = ↓ parity
	Ethnicity = Shuar × 1950s cohort	−0.33 (0.17)	−0.65 to 0.00	0.72 (IRR)	0.05	0.52 to 1.00	3.85	1	—	Consistent high parity in Shuar vs. decline in Colonos
	Ethnicity = Shuar × SOL-Household	−0.07 (0.02)	−0.11 to −0.03	0.93 (IRR)	< 0.001	0.90 to 0.97	$\chi^2 = 14.21$	1	—	Higher SOL-Household = ↓ births esp. for Shuar

(Continues)

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TABLE 3 | (Continued)

Outcome (model)	Predictor	*B* (SE)	95% CI	*t*/IRR/OR	*p*	95% CI for IRR/OR	F/Wald χ^2	df	*p*	Interpretation
Breastfeeding duration (gamma, log link)	Birth Cohort (overall)	—	—	—	—	—	16.40	5	0.01	Younger cohorts = ↓ lactation duration
Contraceptive use (binary logistic)	Birth Cohort (overall)	—	—	—	—	—	$\chi^2 = 29.76$	5	< 0.001	Contraceptive use ↑ in younger cohorts
	1990s cohort	1.22 (0.61)		3.38 (OR)	0.004	1.03 to 11.06	$\chi^2 = 4.05$	1	—	Pronounced ↑ in 1960–1980s cohorts (6–10 times higher odds of use)
	1980s cohort	2.31 (0.51)		10.06 (OR)	<0.001	3.67 to 27.55	$\chi^2 = 20.18$	1	—	
	1970s cohort	2.31 (0.52)		10.08 (OR)	<0.001	3.61 to 28.17	$\chi^2 = 19.44$	1	—	
	1960s cohort	1.86 (0.54)		6.45 (OR)	<0.001	2.26 to 18.42	$\chi^2 = 12.10$	1	—	
	SOL-Household	0.16 (0.07)	—	1.17 (OR)	0.03	1.01 to 1.35	$\chi^2 = 4.54$	1	—	Higher SOL-Household = ↑ contraceptive use in both ethnicities

Note: GLM with HC3 heteroskedasticity-consistent standard errors; *F*-values correspond to Type III Sum of Squares tests.
Abbreviations: IRR, incidence rate ratio; OR, odds ratio.

exemplified by earlier menarche, lower parity, and to some extent, greater use of contraception. Among Colonos, distinct secular patterns emerge with results showing delayed age at first birth, steeper declines in reproductive output, and increasing contraceptive use over time. Notably, few significant associations between MI and reproductive outcomes were found for Colonos, likely because they are further along the MI gradient compared to Shuar as a whole (Lu 2007). Taken together, our findings suggest that Shuar characterized by greater MI are in the earliest stages of a reproductive transition relative to Colonos, while also highlighting that the reproductive effects of MI, and its varied sociocultural and economic influences, unfold in heterogeneous ways both within and between populations.

5.1 | Secular Shifts Among Colonos and MI Influences Among Shuar

Among Shuar but not Colono women, earlier age at menarche was associated with living in more market-integrated housing structures (e.g., those with well/outdoor or indoor pipes, wood or concrete-based housing materials, electrical grid access), despite the absence of a clear secular trend in menarcheal age across both populations. Younger cohorts also reported somewhat earlier menarche than older cohorts, suggesting that the influence of MI on reproductive biology is most pronounced among younger Shuar women, thereby reflecting the effects of more recent socioeconomic change.

As an informative marker sensitive to ecological and nutritional factors, earlier menarche associated with household infrastructure among the Shuar may signal multiple pathways of influence. Household structure and features (e.g., flooring materials, wastewater containment) may reduce pathogen exposure, such as to soil-transmitted helminths that are linked to poor sanitation and direct soil contact (e.g., Cepon-Robins et al. 2014; Gildner et al. 2016, 2020). Prior research has also shown that Shuar with more market-integrated housing are associated with an upregulation of disgust sensitivity, which in turn may motivate higher levels of pathogen avoidance resulting in lower levels of infection (Cepon-Robins et al. 2021). Reduced pathogen exposure through these varied pathways may lower energetic demands on immune function, thus freeing energetic resources for growth and reproduction (Ellison 2008). Urlacher, Blackwell, et al. (2016) and Urlacher et al. (2018) have demonstrated this hypothesized trade-off between growth and immunity among Shuar children helping to explain the high prevalence of stunting (~40%) documented for this population (Blackwell et al. 2009). Collectively, these studies also suggest that chronic energetic constraints shaping growth patterns may be mitigated by more market-sourced housing elements.

Also consistent with current findings, Urlacher, Liebert, et al. (2016) reported that higher SOL-Household scores among Shuar were linked to greater body size in female adolescents, a finding hypothesized to reflect energy savings related to reduced workloads. Specifically, improved access to water and electricity may serve to lessen the time and physical effort required for labor-intensive tasks for which female adolescents are typically responsible, such as hauling water or collecting firewood,

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TABLE 4 | Biomedical (i.e., nontraditional) contraceptive use among Shuar and Colonos.

	Shuar			Colono		
Cohort	**No (*n*)**	**Yes (*n*)**	**% yes**[a]	**No (*n*)**	**Yes (*n*)**	**% yes**
Before 1950	11	1	8.3	38	8	17.4
1950s	13	3	18.8	22	10	31.3
1960s	33	11	25.0	14	19	57.6
1970s	45	21	31.8	9	22	71.0
1980s	54	32	37.2	21	23	52.3
1990s	68	12	15.0	12	2	14.3
Total	224	80	26.3	116	84	42.0

[a]% yes column represents the proportion of women out of the total number of participants in each ethnic group who responded to the question (Shuar: 304; Colonos: 200).

thereby allowing for those energy savings to be allocated to reproductively relevant weight gain (Urlacher, Blackwell, et al. 2016). Additionally, peri-urban Shuar females, who tend to have greater access to these amenities, exhibit lower immune activity and resting energy expenditure compared to rural counterparts, serving to free up additional energetic resources for reproductive function (Urlacher et al. 2021). Both earlier menarche and increased body size thus serve as proxies for improved energy balance, with more MI-associated household infrastructure facilitating these energetic investments (Ellison et al. 2012). Relatedly, household infrastructure has also been linked to shifts in dietary patterns that may further enhance energy availability. Liebert et al. (2013) found that Shuar households with market-associated infrastructure and amenities (higher SOL-Household) are more likely to consume market-based foods (e.g., soda, cookies, rice) as well as refined carbohydrates and beef. Such dietary changes, despite introducing potential longer-term health risks, may improve immediate energy availability during growth, potentially also contributing to the patterns of earlier menarche identified among more market-integrated Shuar.

Menarcheal timing, however, does not fully explain broader reproductive trajectories. While younger age at menarche may be linked to earlier age at first birth (e.g., Hochberg et al. 2011), our findings show that even in the absence of shifts in developmental timing, Shuar women consistently initiate childbearing at younger ages and sustain higher parity than Colonos across all cohorts. Unlike Colonos, who exhibit a clearer secular trend toward delayed first births, Shuar women maintain an age at first birth between 16 and 19 years old (vs. 18–21 years old for Colonos), with little evidence of change over time. These findings align with Pillsworth et al. (2023) who also documented stable reproductive timing within overlapping age ranges (15–22 years old) over a 10-year span across Morona Santiago Shuar. Ethnographic insight can help contextualize this persistence in motherhood timing. For Shuar, cultural norms may serve to reinforce an early start to reproductive life while simultaneously emphasizing the value of large family sizes. Traditionally, Shuar parents have children at a young age, with most births occurring by the time they reach their mid-30s, while larger families offer practical and economic value through collective contributions that benefit the household (Petersson 2012). Having many children is also considered a means of achieving "the good life" (*pénker pujustin* in Shuar), in which offspring strengthen kin alliances in contexts where, especially in the past, constant land feuds and conflicts fostered uncertainty and insecurity (Petersson 2012). Consistent with these cultural norms, Shuar women average 8.1 births across their reproductive lifetimes, more than the 5.9 documented for Colonos.

Our analyses, however, also suggest that traditional reproductive ideals, particularly regarding family size, may be undergoing subtle shifts. Greater ownership of market goods, and especially MI-associated household infrastructure, was linked to reduced parity as well as greater contraceptive use (findings relevant for both groups). For Shuar, such changes could implicate the earliest stages of fertility decline, whereas Colonos, who are currently experiencing later stages along the MI continuum, underwent similar fertility reductions decades earlier (Lu 2007). Importantly, this observed decline in fertility is not necessarily typical of the initial stages of MI, as research among small-scale societies shows considerable variability in fertility outcomes, including some of the highest recorded fertility rates during early transitions to market economies (Hill and Hurtado 1996; Kramer et al. 2021; Kramer and Greaves 2007; Kramer and McMillan 1999, 2006).

At the outset, our Shuar findings appear to align with Davis et al.'s (2015) assessment of a "delayed fertility transition" occurring among northeastern Ecuadorian indigenous groups (from Pastaza and Napo provinces). Specifically, they found that among Shuar ($n = 110$) between 2001 and 2012, mean parity decreased from 4.5 to 3.7 with MI implicated as the primary determinant of this shift. Yet notably, while Davis and colleagues observed a clear secular decline, our results reveal temporal reproductive shifts only when MI variables are considered. Shuar living in northern provinces have more recently immigrated to the region, often with resources to purchase land, and are described as more market-oriented compared to other indigenous groups in the area (Bremner et al. 2009) whereas participants in the present study are from one of Ecuador's poorest provinces (De Schutter 2023). Compared to northern Shuar, those in Morona Santiago likely face greater barriers to family planning, fewer educational and employment opportunities, and in many areas, have limited access to the market economy. These contextual differences may offer some explanation as to why the population-level fertility trends documented by Davis and colleagues are not yet evident in our sample as a whole. Furthermore, our results illustrate that while traditional norms may continue to emphasize the benefits of large families, structural and economic changes linked to MI are starting to reshape reproductive strategies in ways that hint toward broader demographic shifts in the foreseeable future (Bongaarts and Hodgson 2022; Kramer and Hackman 2024).

In addition to the link between increasing MI and contraceptive use, overall use was lower among Shuar (26%) compared to Colonos (42%), although this difference was not significant after accounting for other factors (e.g., Birth Cohort, SOL-indices). Importantly, because our survey did not inquire about *access to* but rather *use of* contraception, these findings do not distinguish between individuals who have access but choose not to

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use contraception and those who lack access altogether. Secular increases in contraceptive use are evident across later cohorts (1960s–1990s) suggesting that, at least for some participants, access has expanded over recent decades. However, it is clear that barriers to widespread use continue to persist. For instance, Bremner et al. (2009) reported that 68.5% of 144 Shuar women in northeastern Ecuador did not desire more children but had little access to family planning, highlighting a gap between reproductive intentions and contraceptive access. Taken together, these findings lend support that MI, and the access to goods and services it enables, likely facilitates greater contraceptive availability and adoption in our study sample.

Finally, partial evidence of decreasing breastfeeding duration irrespective of ethnicity provides another layer of insight into shifting reproductive behaviors. Among Shuar, while parity has generally remained stable, trends toward reducing breastfeeding bear potential implications for maternal and child health (Prentice 2022; Victora et al. 2016). Although notably, while the youngest Shuar and Colono cohorts reported shorter average durations (15.4 ± 7.8 months, 4.5 ± 9.0 months respectively) compared to some earlier cohorts, these averages, especially among the Shuar, still exceed those of women in high-income countries (Victora et al. 2016). Thus, while both groups may face barriers and/or alternative opportunities that lead them to truncate breastfeeding duration, they continue to exceed the timing that is typical of more industrialized settings. When compared to older cohorts, however, younger mothers may be motivated to shorten breastfeeding duration because of increased exposure to milk substitutes (Caicedo-Borrás et al. 2021; Freire et al. 2020; WHO 2022) and greater reliance on biomedical interventions such as vaccines and antibiotics, which may reduce the perceived necessity of prolonged breastfeeding for infant health and survival (e.g., Veile and Kramer 2014). Because our MI variables do not directly capture these dynamics, future research should more explicitly investigate how access to health services and substitutes mediate breastfeeding strategies.

5.2 | Study Limitations

The current study has several limitations. First, because data were collected between 2008 and 2014, these findings may not be representative of current conditions in the region, particularly given that since the time of data collection, Morona Santiago has undergone substantial infrastructural development (Rudel 2021; SHLHP unpublished data). However, the current study still serves as a valuable point of comparison for future research on Shuar and Colono reproductive trends. Secondly, since this study focused on differences between two ethnic groups living in the same province and in adjacent communities, variability within Shuar and Colonos groups was not examined beyond birth cohorts and SOL-indices. Our study utilized indices that may be meaningful to understand epidemiological and life history patterns among the Shuar but may not capture other important factors associated with reproductive transitions. Future research should further disaggregate these data and examine whether patterns vary across socioeconomic, ecological, and geographic variables such as income, education level, access to nutritional and health resources, and proximity to market centers. Relatedly, the MI variables utilized in this study were developed for Shuar but applied to Colonos to standardize comparisons. More Colono-specific markers of MI may be needed as the effects of MI may be rendered invisible with the current item list. We also do not address participants' perception of healthcare access and reproductive services, which could provide direct evidence of unmet needs for family planning and contraception. Additionally, the recall nature of retrospective self-report data could introduce inaccuracies regarding the timing of key reproductive milestones like menarche, particularly if these events occurred decades prior. Finally, genetic differences between Shuar and Colonos, and their interactions with sociocultural and ecological factors, may contribute to variation in reproductive biology (e.g., menarcheal timing), yet such genetic influences remain unexamined in these populations.

6 | Conclusions

By comparing Shuar and Colono populations, this study highlights the complex determinants of both reproductive change and stasis, demonstrating how MI shapes reproductive variables in subtle and population-specific ways. Among Shuar, greater MI-associated household infrastructure is linked to earlier menarche, likely reflecting improved childhood energetic conditions, while serving to lower completed fertility across the life course. Contraceptive use, while increasing, remains uneven and constrained by barriers to access. By contrast, among Colonos, declining age at first birth and reduced parity mirror patterns observed in many high-income regions, signaling a clear reproductive transition that is not yet evident among the Shuar population as a whole. However, early signs of these shifts among Shuar in more market-integrated households offer further support that global reproductive transitions unfold through varied, locally-contingent pathways.

As with MI, reproductive transitions do not follow a single, cross-cultural trajectory. Future research should continue to investigate this heterogeneity in reproductive patterns by integrating longitudinal datasets, biomarkers, and targeted ethnographic inquiry to uncover the mechanisms driving, or attenuating, reproductive change in indigenous and neighboring nonindigenous populations. Expanding a lens to include intergenerational perspectives and shifting gender dynamics will also be particularly important for understanding how fertility preferences and norms simultaneously shift over time. Ultimately, without place-based perspectives and direct engagement with communities, our understanding of reproductive transitions and their broader demographic and health implications is less robust. Bridging these gaps will be essential not only for advancing scientific knowledge but also for developing reproductive health services and policies that are both effective and equitable for indigenous populations worldwide.

Author Contributions

Felicia C. Madimenos: conceptualization, funding acquisition, data collection and curation, data analysis, methodology, writing – original draft preparation. **Melissa A. Liebert:** funding acquisition, data collection and curation, writing – review and editing. **Tara J. Cepon-Robins:** funding acquisition, data collection, writing – review and editing. **Theresa E. Gildner:** funding acquisition, data collection,

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writing – review and editing. **Samuel S. Urlacher:** funding acquisition, data collection, writing – review and editing. **Richard Bribiescas:** funding acquisition, data collection. **Aaron D. Blackwell:** funding acquisition, data collection. **J. Josh Snodgrass:** funding acquisition, project administration, writing – review and editing. **Lawrence S. Sugiyama:** conceptualization, funding acquisition, data collection, project administration, writing – review and editing.

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Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Endnotes

[1] The term “reproductive transition” is used here in lieu of broader terms such as “demographic transition,” the latter referring to large-scale population shifts in fertility and mortality over time. We prefer “reproductive transition” in this paper as it emphasizes the microlevel behavioral and physiological changes that underlie these macro-demographic patterns.

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Supporting Information

Additional supporting information can be found online in the Supporting Information section. **Data S1:** ajhb70232-sup-0001-Supinfo.docx.

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