FERTILITY AND INEQUALITY DYNAMICS IN MEXICAN INDIGENOUS COMMUNITIES: A SPATIAL AND TEMPORAL ANALYSIS

Abstract

This article provides a comprehensive historical analysis of indigenous fertility dynamics in Mexico across three critical temporal phases: pre-transitional (1930), population growth (1970), and advanced transition in progress (2015). We examine the multifaceted associations among socioeconomic-inequality, geographical determinants, and net fertility in married women aged 15-45 years. Our study challenges prevailing narratives by elucidating how high mortality in indigenous communities could delay fertility decline during the population growth phase. We introduce a novel analytical approach using a bivariate normal distribution to explore associations between inequality and net fertility. Spatial analysis techniques uncover correlations between indigenous subpopulation proportions, socioeconomic-inequality, and net fertility between municipalities. Leveraging spatial visualization tools, our findings inform evidence-based policy formulation tailored to indigenous population needs.

Key words: socioeconomic inequality, indigenous subpopulation, historical demography, spatial analysis, demographic transition.

5.1. Introduction

Recent studies on Mexican indigenous communities highlight socioeconomic challenges like poverty, inequality, and marginalization (Rentería-Gaeta, Valencia-López, et Soto-Hernández 2020). They also address demographic issues including high mortality, fertility, early pregnancies, and migration (Colomé-Hidalgo et al., 2021; Mesenburg et al., 2018). This body of research delineates the plight of the indigenous Mexican population, presently constituting 6.6% of the national demographic landscape (INEGI, 2022), impeding their pursuit of sustainable development. While scholarly investigations reveal discernible patterns in the reproductive behavior of indigenous subpopulations, extending these observations to historical epochs requires substantial empirical validation.

Furthermore, over the past century, the indigenous groups in Mexico have witnessed a significant decline, with its proportional representation in the overall population receding by more than 10 percentage points. Several factors have contributed to this regression, including heightened mortality rates during seminal historical episodes such as the Mexican Revolution (1910) and the Spanish flu outbreak (1918). Social upheavals throughout the 20th century, particularly involving the Yaqui and Mayan communities, have also played significant roles (Hu-DeHart, 2016; Lovell, 1988b). Moreover, the persistent discrepancy in mortality rates between indigenous and non-indigenous subpopulations, which has been evident since the beginning of the 20th century, remains prevalent to the present day (CEPAL, 2005). Another portion of this demographic drop may stem from factors that are more perceptual than substantive, including the decreasing prevalence of indigenous languages and administrative errors in registration (Tamez et Terborg, 2009). Also, to decreases tendency to self-identification as indigenous during after Mexican revolution. Furthermore, indigenous communities tend to be located in remote and difficult-to-access regions, far from developed urban centers (Ulrichs et Roelen, 2012). This geographical gap widens the disparities between non-indigenous communities, mainly concentrated in more developed areas than indigenous communities.

The rise of inequality, as evidenced by economic growth deficiencies and negative impacts on various aspects of development, underscores a critical global challenge (Piketty, 2014). This inequality is linked to undesirable social behaviors and poses a threat to sustainable development (Wilkinson et Pickett, 2009).

This study endeavors to examine the correlation between net fertility and socioeconomic inequality within the indigenous population across three pivotal periods: 1930, 1970, and 2015, mirroring distinct stages of the Mexican demographic transition. By scrutinizing these temporal points, our research seeks to furnish novel insights into the indigenous population's dynamics throughout its pre-, mid-, and in progress-transitional phases. Through the utilization of historical census microdata, we operationalize an array of individual-level, family-level, and community-level variables to explore the intricate interplay between socioeconomic-inequality and net fertility (number of children under 5-year-old) on married women aged 15–49 years, delineating the shifting nature of these associations across temporal and spatial dimensions. Given the unique socioeconomic and geographic circumstances of indigenous subpopulations, we expect their demographic transition to differ from that of non-indigenous groups. This temporal difference likely influences the current population size and fertility behaviors observed in Mexico's indigenous population. However, identifying the factors driving fertility decline in indigenous communities presents challenges similar to those encountered in broader demographic transitions (Colleran, 2016). Cultural factors play a significant role, further complicating the analysis. We present a probabilistic analysis using the bivariate normal distribution of net fertility and a socioeconomic-inequality index. We also performed spatial models Besag-York-Mollie model to measure the “risk” of net fertility at municipal level.

5.2. Background

5.2.1. Indigenous population changes

During the early 20th century, Mexico experienced declining mortality rates, leading to rapid population growth. However, indigenous populations saw slower growth, causing their proportion in the overall population to decline from 16% in 1930 to 6.6% in 2015 (Zolla et Márquez, 2004). The slower population growth among indigenous groups during the early stages of demographic transition, coupled with their diminishing share of the overall Mexican population, stems from a complex interplay of health, social, cultural, and economic factors. Contributing factors such as higher fertility rates, lower life expectancy, and elevated infant mortality rates have been documented (T. B. Heaton et al., 2007; Leyva-Flores et al., 2013). Studies conducted by (Haines et Steckel, 2000) underscores the notable health disadvantages faced by indigenous subpopulations in Mexico compared to non-indigenous groups, a trend evident as early as 1930. Furthermore, indigenous communities have historically grappled with socioeconomic marginalization, geographic isolation, and extreme poverty (Canedo, 2018). Predominantly situated in rural areas with lower rates of school attendance, indigenous subpopulations experience heightened mortality rates (INEGI, 2022). These factors elucidate why indigenous infant mortality rates in Mexico remained notably elevated in 2000, with 58 deaths per 1000 births, compared to 31 deaths among non-indigenous individuals (CEPAL, 2005)[1]. Yet, the decline in the proportion of indigenous people in Mexico remains puzzling, given their cultural tendencies towards high fertility (CEPAL, 2014). Patriarchal values lead to more unmarried unions and fewer divorces among indigenous women, increasing childbirth risks (T. Heaton et al., 2012). Then, what has caused its share decline? Contemporary interpretations of indigenous fertility patterns often neglect the historical trajectory of the indigenous groups. We contend that factors such as historical inequalities, discrimination, and the spatial distribution of indigenous communities may significantly contribute, first to the slow population growth and later to the slow fertility decline.

The decline in Mexico's indigenous population share cannot be solely attributed to changes in census methodologies, despite their influence. Increasing numbers of indigenous individuals identifying as non-native due to the social stigma challenges language identification in the census (Solís et Puga, 2011), and the strategy of miscegenation that favored the prevalence of the "bronze race" over the "indigenous race" (A. Stern, 2000) reflect only part of the complex picture. Other factors such as economic shifts, rural-to-urban migration, educational dynamics, and social prejudice contribute significantly to the decline; however an important part of this decline may be due to how a person is identified as indigenous..

In Mexico, belonging to an indigenous population is not limited to speaking an indigenous language but also encompasses cultural aspects such as customs, traditions, and worldviews. Flores et al. (2023) identified two forms of crossing ethnic boundaries: transitory crossing and durable crossing, influenced by political and social dynamics. (Villarreal, 2014)Villarreal (2014) highlights that excluding children whose parents identify as indigenous but who do not speak an indigenous language may introduce bias in estimates of inequality. This nuance underscores the importance of considering this variable in indigenous population studies. In our research, indigenous identity was determined by the question "Do you speak an indigenous language?" since the auto-identification variable was not available in the census questionnaire until after 2010. Future

[1] Unfortunately, we do not have infant mortality for indigenous groups before 2000.

research on demographic transitions should add this metric for a more comprehensive understanding of the ongoing demographic transition of indigenous populations.

5.2.2. Inequality and Fertility

The profound poverty, social marginalization, and limited healthcare access experienced by Mexico's indigenous groups underscore their pervasive inequality, characterized by the uneven distribution of resources (J. C. Costa et al., 2022; Mesenburg et al., 2018). This inequality reflects the challenges encountered by these groups, and reductions in inequality over time signify advancements in their social development and individual well-being. According to Amartya Sen, well-being can be accessed through the Human Development Index (HDI), which incorporates factors beyond income, such as access to healthcare, education, and services (Sen, 2003). These factors enable better individual decision-making in regions with valuable development options, fostering collective development. Disparities in the distribution of these factors lead to socioeconomic inequality among subpopulations. During periods of economic growth, socioeconomic-inequality tends to rise as high-wage occupations see faster wage increases compared to low-wage ones, whereas during recessions or social conflicts, the opposite occurs (Piketty, 2014). Political determinants, such as crime rates, social instability, political polarization and health disparities, have also the potential to either exacerbate or mitigate inequality (Wilkinson et Pickett, 2009).

In Mexico, inequality and poverty are the most critical problems facing the country's development (Canto Saenz, 2019). Although various strategies have been implemented, mitigating these problems has been erratic over time and across subpopulations (Cortés, 2013). Even as the rise of the middle class helped to reduce the inequality gap from 1950 to 1984, since 1984, inequality actually increased, and poverty reduction stagnated until 2000 due to economic crises. By 2010, inequality had dropped to the 1984 level thanks to social programs focused on vulnerable subpopulations (Székely, 2005). Economic disparities in Mexico are particularly acute in rural areas and are further exacerbated among women, particularly indigenous women (Barrera-Rojas et al., 2019). Moreover, in states such as Guerrero, Oaxaca, and Chiapas, where inequality impedes social mobility, the situation is especially dire (Chávez-Juárez et al., 2017).

While income and wealth are commonly employed metrics for assessing inequality, additional factors like gender equality, alongside access to healthcare, education, and essential services, constitutes pivotal factors in cultivating greater equality within societies (Cowell, 2011; McGregor et al., 2019). These factors which intricately shape reproductive and childbearing behaviors are also, closely tied to development and equality. Studies conducted in Latin American nations have unveiled the association between socioeconomic-inequality and discrepancies in maternal and child health, as well as reproductive health coverage (Colomé-Hidalgo et al., 2021; Mesenburg et al., 2018). These studies identified Panama, Colombia, Costa Rica, Haiti, Honduras, and Mexico as countries with pronounced economic disparities, particularly affecting their indigenous and Afro-descendant subpopulations. Furthermore, they concluded that reducing socioeconomic-inequality and the poverty gap could mitigate maternal and infant mortality while enhancing access to education, reproductive health services, and contraceptives – critical factors in fertility decline. Despite extensive studies on historical inequality experienced by indigenous communities, there remains a notable lack of insight into how this inequality intersects with recent demographic trends, specifically fertility. By exploring this relationship, we seek to shed light on crucial factors influencing fertility dynamics.

We want to highlight that in this research, socioeconomic inequality is measured as the distribution of wealth within a given population—specifically, within municipalities. While this measure provides insight into the welfare conditions of the municipality, it primarily reflects wealth distribution, which is more closely associated with the variance of the data rather than with central tendency indicators such as the mean or median. In this regard, it is essential to recognize that the issue is not merely whether a municipality possesses superior services or infrastructure, but whether these resources are accessible to the entire population in an equitable manner. That is, the focus is on the fair distribution of existing infrastructure. Therefore, we hypothesize that greater socioeconomic equity corresponds to a more balanced distribution of the resources that constitute the *InSoc* index, such as literacy, property ownership, and equal access to employment opportunities. In our view, the equitable distribution of resources will foster social stability and contentment, which in turn will create the conditions necessary for individuals to access quality information, enabling them to make more informed decisions regarding their personal and economic development. In summary, socioeconomic equity will be associated with reduced fertility rates in the later stages of the demographic transition.

5.2.3. Challenges in Measurement and Data Acquisition

The acquisition of population microdata spanning multiple decades presents a significant hurdle in studies pertaining to inequality and demographic trends (Cowell, 2011; McGregor et al., 2019). Historical census data, utilized for analyzing socioeconomic disparities, faces obstacles due to fluctuating data quality and availability, particularly concerning economic indicators like income. Challenges in data usage encompass harmonizing variables across different census cycles to enable temporal comparisons, as well as computing and interpreting the inequality index itself (Alvaredo et al., 2013; Piketty, 2014). To address these gaps, some studies utilize welfare indicators based on property ownership, housing materials, and access to basic services (Colomé-Hidalgo et al., 2021; Mesenburg et al., 2018). Although important advances have been made in compiling information on wealth and income in developed countries (Alvaredo et al., 2018), useful income data for developing countries in Latin America is only available for the last two decades of the 20th century.

5.2.4. Spatial Distribution and Inequality

Since pre-colonial times, Mexico's geographical diversity has resulted in varying degrees of socioeconomic development across regions. Factors such as climate, geography, and vegetation patterns contribute to this spatial heterogeneity, leading to divergent socioeconomic contexts. Each state's per-capita income level reflects disparities within the Mexican Republic (Gallup et al., 2003). According to Bebbington et al. (2016) and Garza (2000), several mechanisms exacerbate inequality in Mexico, including geographic characteristics, health infrastructure, market access, and disparities between rural and urban areas. In particular, the southern states, characterized by their reliance on agriculture and forestry, often experience slower rates of development (Ulrichs et Roelen, 2012). These regions typically exhibit higher levels of socioeconomic-inequality, alongside lower life expectancy and reduced school enrollment rates (Esquivel, 2000). This behavior is sometimes “diffused” across neighboring municipalities, i.e. a municipality with low equality surrounded by others with higher equality will be able to close the inequality gap faster than one surrounded by inequitable municipalities (Suárez et al., 2012).

Spatial analysis has been implemented fruitfully in the study of fertility variations and their socioeconomic determinants. For example, studies of low fertility in developed countries such as Korea and Serbia demonstrated that fertility rates vary spatially in terms of their direction and magnitude (Jung et al., 2019; Lović Obradović et Vojković, 2021). Other research has revealed that geographic distribution and socioeconomic factors are closely associated with adolescent pregnancy in India, Mexico and Costa Rica (Collado Chaves, 2003; Singh et al., 2017). Meanwhile in (Núñez, 2022), fertility rates across Mexican municipalities from 1970 to 2020 were analyzed using spatial models (Besag-York-Mollie) to test the diffusion hypothesis. The study found no association between spatial distribution and municipal total fertility rate. However, Núñez suggested that future research should incorporate socioeconomic and contextual factors into the analysis to further investigate diffusion effects. Spatial analysis in fertility studies provides insights into demographic behavior dissemination. Findings offer guidance for crafting targeted policies to promote fertility in some regions and address early pregnancies in others. Using spatial analysis on historical census microdata will elucidate the geographic distribution of socioeconomic disparities and their link with reproductive behaviors during Mexico's demographic transition, considering ethnic diversity.

5.3. Methodology

5.3.1. Data

The data used in the research draw upon three national-level census databases for Mexico. These include the 10% microdata sample of the 1930 census of Mexico (200.8 thousand women), the 1% microdata sample of the 1970 census (0.67 thousand women) and the 10% microdata sample of the 2015 intercensal survey (1.84 million women). The 1930 sample is from the Mexican Institute of Statistics and Geography (Zamudio et al., 2015) while the 1970 and 2015 samples come from IPUMS-I project (Ruggles et al., 2018). The subjects of our study are married women aged 15–49 years old. The utilization of the 1930 census data marks a notable advancement in understanding the demographic transition of the indigenous Mexican population. These data had not been previously utilized, because of information on relationships with the household head are not available for that census year. In our research, we conducted pioneering work by inferring these relationships through text mining analysis. In order to demonstrate the extensibility of our methodology, we also utilized a dataset from *The Encuesta Nacional sobre la Dinámica de las Relaciones en los Hogares* (ENDIREH 2015) data, provided by INEGI (2017) was used to examine the total number of children and the age at first sexual intercourse among married Mexican women aged 15-49 years in 2015, specifically for the six states that make up the indigenous region analyzed.

5.3.2. Variables

For, our dependent variable, we employ net fertility, which quantifies the number of own children under five years old, as our fertility measure. This choice stems from the unavailability of total fertility data from the 1930 and 1970 censuses, along with the absence of specific mortality information for the indigenous subpopulation. However, several demographic research projects carried out with microdata justify net fertility as outcome variable (Dribe et Scalone, 2014; Jennings et al., 2012; Willführ et al., 2022). Dribe and Scalone (2014) highlight that net fertility is a robust measure for understanding demographic transitions and its association with socioeconomic status. However, they acknowledge potential underestimation in high-mortality groups. In our research. this limitation is particularly relevant for indigenous populations, where high mortality rates may lead to an underestimation of net fertility. To address this, we enhance our analysis by examining mortality patterns with secondary data and discussing how these patterns affect the understanding of socioeconomic associations in our discussion.

The indigenous status was used as independent variable which was determined by the following criterion: A family was classified as indigenous if at least 50% of its members aged over 5 years speak an indigenous language. A municipality was classified as indigenous if at least 50% of families speak an indigenous language. We acknowledge the existence of other criteria, such as "self-identification as belonging to an indigenous group," which was introduced in the 2010 census. However, due to the constraints of data availability across the three datasets analyzed, we have opted to utilize the "native language speaker" criterion. We acknowledge that this choice may result in an underestimation of the indigenous population. Therefore, the incorporation of the "self-identification as indigenous" variable, which was introduced in the 2010 census, will be important for analysing the ongoing indigenous demographic transitions.

Another independent variable is the socioeconomic status index (*InSoc*). *InSoc*, developed by (Zamudio et al., 2018), measures family socioeconomic status through six components: employment, employment sectors (agriculture, manufacturing, services), dependency ratio, index of family age, property ownership, and literacy rate. It ranges from 0 to 1, with 1 indicating highest well-being and 0 signifying deprivation. The inequality index (*EqZ*) and spatial distribution as independent variables will be detailed in subsequent sections.

5.3.3. Measuring Inequality

Several different measures of inequality are commonly used in social science research, such as the Gini, the Atkinson and the Theil indexes. The Theil and Atkinson indexes, although commonly used, are less intuitive and they rely solely on the population mean or an estimate thereof, which diminishes their sensitivity to differences, a crucial aspect when measuring inequality. The Gini index is a prevalent measure for income inequality. It compares each decile of the population with what the population should theoretically earn based on the ideal (equal) income distribution of each decile. Gini-i is very useful, but it may be less sensitive to differences compared to the *EqZ* index (Zamudio et Jiménez, 2022), the one proposed in this research. We utilize the *EqZ*, derived from socioeconomic status (*InSoc*), to depict family socioeconomic-inequality among married women aged 15–49 at the municipal level. This index is computed relative to the maximum value (M_{aj}) of socioeconomic status, representing the highest level of family *InSoc* (x_i) identified within the same municipality *j*: ($M_j = max\{x_i: i = 1,2, \dots n\}$). Then, M_j is compared to each other observed value of *InSoc*, i.e., $I_{qi} = M_j - x_i$. The comparison results in a distance measure that quantifies the difference between each observation and the observation characterized by the highest value of *InSoc* (M_j). The result of this calculation is then weighted by the number of observations in the observed subpopulation. Equation (5.1) is used to calculate the inequality within each municipality EqZ_j, where $p_i = \frac{1}{n}$ is the weighting value within the municipality, and *n* is the number of families in the analyzed municipality *m*. The *EqZ* offers insights into the inequality existing within subpopulations, in our context, municipalities categorized by their ethno-geographic status. *EqZ* ranges from 0 to 1, with 0 representing the most equitable condition and 1 signifying the most inequitable condition.

$$EqZ_j = \sum_{i=1}^{n} p_i \left(\frac{M_j - x_{ij}}{M_j}\right) \; where \; (i = 1, \dots n) \text{ et } (j = 1, \dots, m) \qquad \dots \text{(Eq. 5.1)}$$

5.3.4. Fertility and inequality: normal bivariate distribution

We used socioeconomic inequality to estimate the average net fertility in the municipality by a normal bivariate conditional distribution. This is possible because net fertility and inequality, as measured by *EqZ* (Eq. 5.1) follow a joint bivariate normal distribution (5.2). To confirm this pattern, we first plot 95% control ellipses shown in Figure 5.1b. As a second method to validate this distribution, we plot the squared distances against the quantities of the χ_2^2 distribution (2 degrees of freedom for the normal bivariate case). We executed these analyses by year (1930, 1970, and 2015) and by ethno-geographic status, i.e., indigenous-rural, indigenous-urban, non-indigenous-rural, and non-indigenous-urban.

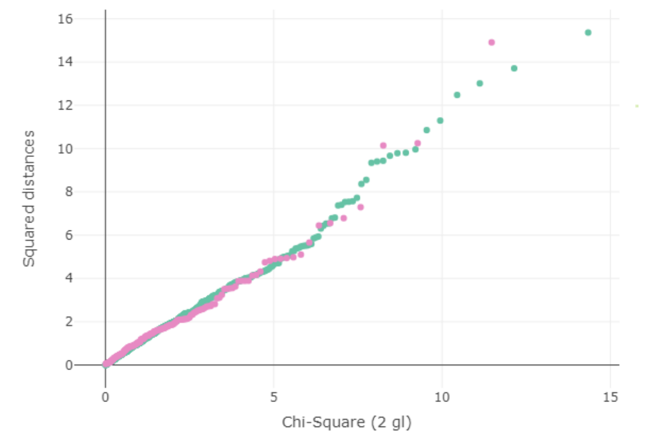
$$\binom{x_i}{y_i} \sim N\left(\binom{\mu_x}{\mu_y} \quad , \quad \begin{pmatrix} \sigma_x^2 & Cov(x,y) \\ Cov(x,y) & \sigma_y^2 \end{pmatrix}\right) \qquad \text{… (Eq. 5.2)}$$

Figure (5.1a) illustrates that the non-indigenous-urban subpopulation (pink dots) exhibits approximately a single bivariate normal distribution, confirmed by the compact ellipse. In contrast, the green dots representing the indigenous-rural subpopulation are dispersed into two groups in figure 5.1a, with one group characterized by smaller (x, y) values and the other by larger values. However, the largest ellipse encompassing 95% of the green dots compared to the ellipse formed for the non-indigenous urban subpopulation in 5.2b further supports the possibility of multiple ellipses in the latter case, indicating two distinct reproductive behaviors within the indigenous-rural subpopulation. In this document, we exclusively present the results for these two subpopulations to clarify interpretations. Similar patterns were observed in all cases. You may access interactive graphs for other subpopulations and analyzed years via the following link: BivariateFit. Once it was confirmed that the control ellipses contained at least 95% of the points, and the distances were consistently close to the quantities of the χ_2^2 distribution, we computed with the equation (5.3), the distribution of net fertility given a municipal inequality measure. Both (5.2) and (5.3) are recognized results of multivariate analysis extracted from (Casella et Berger 2001).

$$y_i|x_i \sim N\left(\mu_y + \rho_{xy}\frac{\sigma_y}{\sigma_x}(x_i - \mu_x) \quad , \quad \sigma_y^2\left(1 - \rho_{xy}^2\right)\right) \qquad \text{… (Eq. 5.3)}$$

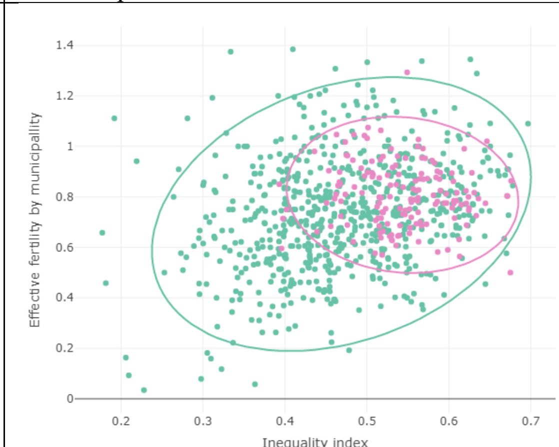
Figure 5.1. Normal bivariate distribution test for 1930: Comparative analysis within indigenous-rural (green dots) and non-indigenous urban population (pink dots)

5.1a. Q-Q plot



Note. Linear data alignment suggests adherence to bivariate normal distribution. Subpopulation analyzes were conducted independently and overlaid on a single graph for comparison.

5.1b. Ellipses at 95% confidence level



Note. If 95% of the data points fall within an ellipse, it suggests adherence to a bivariate normal distribution.

While estimates derived from a bivariate normal distribution may be less precise, we observed instances of multiple ellipses within certain ethno-geographic categories in specific years. To improve accuracy, we employed the R-Mclust package (Scrucca et al., 2016), which allowed us to identify multiple clusters within the same subpopulation. In this context, we make the following assumption:

$$X|k \sim N(\mu_{xk}, \quad \sigma_{xk}^2)$$

Then, the marginal distribution with k=1,…,K is in Eq. 5.3b and K are the total number of clusters in the mixture and $p_1,\ldots,p_K$ are the proportions associated with each cluster.

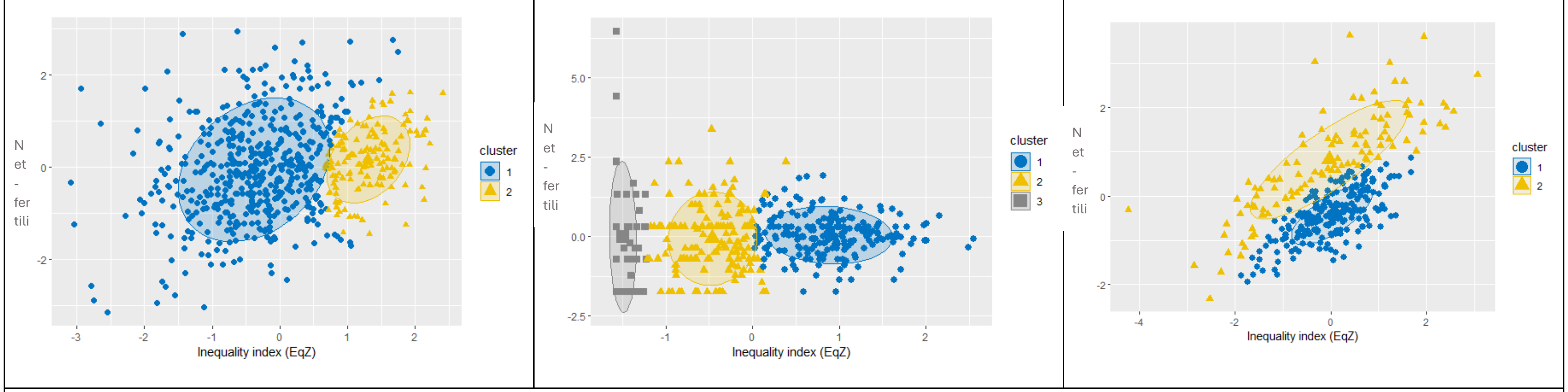
$$E(Y|x) = \sum_{k=1}^{K} \frac{E(Y|k,x)P(x|k)p_k}{\sum_{l=1}^{k} p(x|l)p_l} = \sum_{k=1}^{K} \left(\mu_{xk} + \rho_{xy,k} \frac{\sigma_{yk}}{\sigma_{xk}} (x - \mu_{xk})\right) \frac{P(x|k)p_k}{\sum_{l=1}^{k} p(x|l)p_l} \ldots \quad \text{(Eq. 5.3b)}$$

We present the results for a bivariate normal distribution coming from 5.3 to illustrate its application, but we use the equation in 5.3b to identify the mixture of bivariate normal distributions. Thus, we obtained at least one set of estimators (mean, correlation, and variance-covariance matrix) to compute net fertility for each ethno-geographic subpopulation with equation (5.3b). Figure 5.2 delineates the clusters observed within indigenous-rural subpopulations for the years 1930 (5.2a) and 1970 (5.2b). In 1930, municipalities characterized by low levels of inequality and net fertility are represented by blue dots, whereas those with higher levels are depicted by yellow triangles. The analysis for 1970 reveals three distinct clusters, with high net fertility evident across all levels of inequality. This observation suggests a discernible shift in demographic patterns over the analyzed period. In 2015 (figure 5.2c), blue dots signify municipalities with lower net fertility and inequality, while yellow triangles represent higher levels of both. Tighter ellipses indicate reduced inequality and net fertility, with some municipalities showing extremely low levels of both[2]. For brevity, we only present this subpopulation, the graphs for the rest of the subpopulations and the 3D graphs can be examined at the following link: Mclust.

[2] Note that the values presented in the graphs are standardized. Consequently, larger values indicate heightened levels of net fertility or inequality.

Figure 5.2. Net fertility Distribution and Socioeconomic Inequality Among Mexico’s Indigenous Rural Subpopulation (1930-2015): Insights from Mclust Classification.

5.2a. 1930 | 5.2b. 1970 | 5.2c. 2015



Note. The *x* and *y* axes are standardized by their means and variances.
In 5.2a. The blue cluster represents municipalities with low inequality, while the yellow cluster includes municipalities with high inequality and higher net fertility.
In 5.2b. The blue cluster denotes municipalities with higher inequality, and the yellow cluster represents those with lower inequality.
In 5.2c. The blue cluster comprises municipalities with lower inequality and lower net fertility, whereas the yellow cluster consists of municipalities with higher inequality and higher net fertility.

5.3.5. Spatial Analysis

We conducted a Bayesian spatial hierarchical generalized linear mixed Besag-York-Mollie (BYM) model a method known to enhance estimates in small areas (Khana et al., 2018). This model, frequently employed for estimating disease risk, improves local estimates by integrating explanatory variables alongside spatial correlation (Moraga et al., 2021). For estimating and visualizing the results, we utilized the open-source R package R-INLA (Rue et al., 2019), as implemented by (Moraga, 2018). Integrated Nested Laplace Approximation (INLA) is utilized as an approximation technique to conduct Bayesian inferences. INLA is a good alternative method to MCMC (Markov Chain Monte Carlo) because it is easy to use and provides better estimations in small areas. R-INLA and R-leaflet packages facilitate the execution of multi-level models and the production of interactive maps to visualize the model outputs in each unit of analysis, in our case, municipality.

In equation (5.4), we depict the conditional distribution of (Y_i) (net fertility), representing the total number of children under 5 years old in the municipality (i), given a relative risk (θ_i). This relative risk is modeled following a Poisson distribution and its relative to the effects of conditions such as indigeneity, socioeconomic inequality, and the spatial correlations between municipality i and its neighboring municipalities. Additionally, E_i denotes the expected count of net fertility; Expected values are determined using a matrix comprising counts of women's ages within 5-year intervals and their corresponding socioeconomic status (*InSoc*). Subsequently, in equation (5.5), we introduce the model that estimates the logarithm of the relative risk associated with net fertility by municipality. In this scenario, the covariables consist of the proportion of the indigenous families (P_{Ini}) and the inequality index (EqZ_i) in the municipality i; u_i is the spatial structured component, and v_i is the unstructured random effect. The u_i was modeled by a CAR (the conditional autoregressive distribution) as follows,

$$u_i|\mathbf{u_{-i}} \sim N\left(\bar{u}_{\delta_i}, \frac{\sigma_u^2}{n_{\delta_i}}\right)$$

The expression $\bar{u}_{\delta_i} = n_{\delta_i}^{-1} \sum_{j \in \delta_i} u_j$ represents the average u_j values of the zones adjacent to zone i. Here δ_i denotes the set of neighbors of zone i, while n_{δ_i} corresponds to the total number of such neighbors. While v_i follows identically distributed normal variables: $v_i \sim N(0, \sigma_v^2)$.

$Y_i|\theta_i \sim P_0(E_i \times \theta_i)$ … (Eq. 5.4)

$log(\theta_i) = \alpha + \beta_1 \cdot P_{In_i} + \beta_2 \cdot Eqz_i + u_i + v_i$ … (Eq. 5.5)

Spatial analyses were conducted in six states: Chiapas, Oaxaca, Veracruz, Puebla, Yucatán, and Guerrero, collectively representing 70% of the indigenous-speaking population over 5 years old. The same model was replicated for each state individually, allowing for strategies to alleviate inequalities at both national and state geographic levels. The incorporation of geographic dimensions and independent variables into the analysis of net fertility, facilitated by the BYM model, provides the opportunity to quantify the proportion of variation explained by factors such as geographic correlation, indigenous proportion, and socioeconomic inequality. Marginal variances of structured and unstructured effects were computed to distinguish the portion explained by these factors using (*Geo*=*u*/[*u*+*v*]).

5.4. Results

5.4.1. Fertility, socioeconomic development, and inequality

Inequality analysis must consider temporal fluctuations, contrary to expectations of a constant decline in inequality. In reality, inequality fluctuates with economic cycles and social events, potentially impacting its reduction trajectory (Piketty, 2014). In Table 5.1 we show trends in three metrics—socioeconomic status (*InSoc*), socioeconomic-inequality (*EqZ*), and net fertility—across four ethno-geographic subpopulations, with results depicted as municipality averages. In, 1930, net fertility exhibits relative uniformity across subpopulations, with municipal averages ranging from 0.74 to 0.76 children aged under 5 years, except for non-indigenous rural municipalities, where the average net fertility reached 0.87. Non-indigenous municipalities demonstrated superior socioeconomic conditions (*InSoc*=0.37 & 0.30) compared to indigenous-rural municipalities (*InSoc*=0.28 & 0.27). In the same year, urban populations exhibit greater inequality (0.54) than rural populations (0.51 &. 0.47). In 1970, non-indigenous rural subpopulation still had the highest net fertility (1.12), followed by non-indigenous urban (1.05), indigenous-urban (0.96) and indigenous-rural subpopulation (0.87). The highest increase in net fertility between 1930 and 1970 was presented by the non-indigenous urban municipalities (38%) and the smallest by the indigenous-rural municipalities (15%). In this period, we also observed a decrease in inequality in all subpopulations mainly in the indigenous municipalities (-49% &-52%) and a significant socioeconomic advancement, particularly notable among urban subpopulations (74% increase). Finally, in 1970 inequality was higher in both non-indigenous municipalities.

In 2015, mainly as a product of family planning policies and continuous economic development, we observe a sharp drop in net fertility juxtaposed with a continued increase in socioeconomic status (*InSoc*). Thus, indigenous municipalities have more children under 5 years (0.64 & 0.52), the lesser decreases (25% & -46%), than non-indigenous subpopulations (0.50 & 0.43). In terms of socioeconomic factors, the landscape had shifted significantly. Socioeconomic status continued to improve rising by approximately 30% across all ethno-geographic subpopulations. Yet, inequality also increased in almost all groups, except for non-indigenous urban municipalities, where it decreased by 8%. The indigenous-rural subpopulation saw the largest increase in inequality (79%), followed by indigenous-urban (39%) and non-indigenous-rural (35%).

Table 5.1. Municipal mean value of net fertility, socioeconomic status (InSoc), inequality (EqZ) and % change in mean values, by ethno-geographic subpopulation and years: 1930-1970-2015.

					Increase/Decrease (%)	
	Population	1930	1970	2015	1970 Vs. 1930	2015 Vs. 1970
InSoc	**Indigenous- rural**	**0.266**	**0.371**	**0.485**	**39%**	**31%**
	Indigenous- urban	0.283	0.493	0.630	74%	28%
	Non-indigenous - rural	0.301	0.426	0.569	41%	33%
	Non-indigenous - urban	0.366	0.534	0.690	46%	29%
Inrquality EqZ	**Indigenous- rural**	**0.469**	**0.238**	**0.426**	**-49%**	**79%**
	Indigenous- urban	0.539	0.257	0.358	-52%	39%
	Non-indigenous - rural	0.507	0.282	0.381	-44%	35%
	Non-indigenous - urban	0.543	0.349	0.322	-36%	-8%
Net fertility	**Indigenous- rural**	**0.760**	**0.870**	**0.640**	**15%**	**-26%**
	Indigenous- urban	0.740	0.960	0.510	30%	-47%
	Non-indigenous - rural	0.870	1.120	0.500	29%	-55%
	Non-indigenous - urban	0.760	1.050	0.430	38%	-59%

Note. Own elaboration.

5.4.2. Fertility Estimation Given Different Levels of Inequality

Upon verifying the normal bivariate distribution of net fertility and inequality, estimates of net fertility at specific levels of inequality is possible. These estimates can be used to present an overview of net fertility at three inequality levels by ethno-geographic status in 1930, 1970 and 2015 (Figure 5.3). As an example Table 5.2 displays the statistics: means, correlations, and variance-covariance matrices for ethno-geographic subpopulations to produce these estimates. Tables for the years 1930 and 1970 are provided online at BivariateTables.

We estimated net fertility using the estimator as follows:

$$(net - fertility|0) = 0.4628 + 0.5171 \frac{\sqrt[2]{0.0013}}{\sqrt[2]{0.0043}}(0 - 0.3589) = 0.3628$$

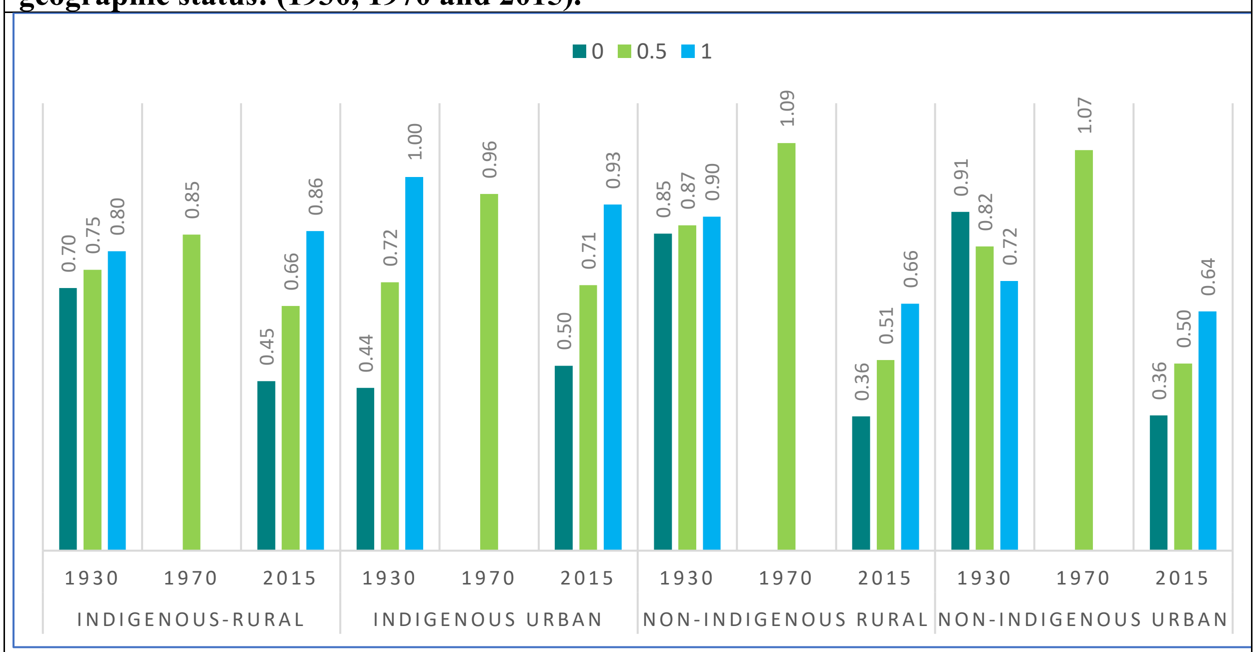
Table 5.2. Estimation of net fertility from normal bivariate distributions for each ethno-geographic subpopulation in Mexico, 2015.

Status	Cluster	No. Obs	Mixing probabilities	Matrix var-cov		Means		Correlation
				EqZ	**Net fertility**	**Net fertility**	***EqZ***	**Net fertility: *EqZ***
Indigenous-rural	C1	110	0.4066	0.0079 0.0097	0.0097 0.0240	0.6256	0.4247	0.7024
	C2	214	0.5934	0.0025 0.0031	0.0031 0.0077	0.4866	0.4263	0.7024
Indigenous-urban	C1	6	0.0828	0.0210 0.0393	0.0393 0.0910	0.6446	0.3435	0.8993
	C2	90	0.9172	0.0027 0.0017	0.0017 0.0057	0.4873	0.3592	0.4229
Non-Indigenous-rural	C1	928	0.7870	0.0021 0.0021	0.0021 0.0069	0.4779	0.3898	0.5448
	C2	116	0.2130	0.0062 0.0061	0.0061 0.0200	0.4756	0.3463	0.5448
Non-Indigenous-urban	C1	543	0.5540	**0.0013** 0.0012	0.0012 **0.0043**	**0.4628**	**0.3589**	**0.5171**
	C2	440	0.4460	0.0008 0.0008	0.0008 0.0028	0.4027	0.2772	0.5171

Note: C1 signifies the cluster distinguished by elevated levels of net fertility, whereas C2 indicates a cluster with comparatively lower levels of net fertility.

Conducting various estimates at different inequality levels indeed facilitates a comprehensive understanding of elasticity or responsiveness of net fertility to inequality for each subpopulation and time. In figure 5.3, we display the estimated net fertility for each ethno-geographic subpopulation within C1 (the highest fertility cluster) at three levels of inequality (0, 0.5, and 1), where 1 represents the highest inequality and 0 the lowest. The findings for 1930 suggest that indigenous subpopulations exhibit higher net fertility with increased inequality, akin to rural non-indigenous subpopulation. Conversely, the non-indigenous urban subpopulation demonstrates lower estimated net fertility with higher inequality. This divergence can be attributed to the historical context, wherein ensuring child survival posed a significant challenge, particularly addressed by families with unfavorable socioeconomic circumstances as it was the case of urban indigenous group. Furthermore, it can be inferred that if the non-indigenous urban subpopulation possessed an *EqZ* of zero in 1930, its average net fertility would have exceeded that of the indigenous-rural subpopulation (0.91 vs. 0.85). In 1970, due to the absence of a clear normal bivariate distribution, we only did it for *EqZ*=0.5. However, by 2015, a discernible positive correlation between inequality and net fertility emerged across all subpopulations. This signifies that as inequality escalates, net fertility tends to rise correspondingly. Particularly noteworthy is the substantial surge in fertility observed among indigenous subpopulations. Notably, even under conditions of heightened equality (*EqZ*=0), fertility levels remain elevated compared to non-indigenous subpopulations. Notwithstanding the responsiveness of indigenous net fertility to declines in inequality, unobserved cultural factors such as traditions or traditions must be considered in the interpretations of theses results.

Figure 5.3. Estimated net fertility for three inequality levels (0, 0.5 & 1) by ethno-geographic status: (1930, 1970 and 2015).



Note. The level of inequality 0 means the greatest equality within each subpopulation, on and one the greatest inequality.

5.4.3. Spatial Analysis

The spatial model (BYM) applied to the indigenous region chosen in this study (comprising six states) offers insights into the impact of geography on net fertility, considering the proportion of indigenous families residing in each municipality and the level of inequality within that municipality. Table 5.3 presents the means and 95% credible intervals for the proportion of the indigenous subpopulation (-0.192, -0.114) and the inequality index (*EqZ*) (0.22, 0.542) for the year 1930. These findings suggest a negative association between the proportion of indigenous people and net fertility, while inequality is positively associated with net fertility. A similar pattern obtains in 1970, but the effects are larger (-0.263) for indigenous proportion and (0.469) for inequality. These results suggest that in the early stages of the demographic transition, the municipalities with the lowest proportion of the indigenous subpopulation and the most inequitable municipalities had higher average net fertility rates. In 2015, a different picture emerges. While a similarly positive association of socioeconomic inequality with net fertility (0.299) is observed, the proportion of indigenous population is now associated positively with net fertility (0.069). Thus, by 2015, the proportion of the indigenous people living in the subject's municipality of residence is associated with an increase in net fertility.

The ratio, $Geo = u/[u+v]$), serves as a metric for assessing the proportion of geographic variation explained by the model. The *Geo*-values are 0.495 in 1930 and 0.245 in 1970, suggesting that the explanatory variables in the proposed model were more effective in estimating fertility in 1970 compared to 1930. The higher *Geo*-value in 1930 indicates a stronger spatial correlation during that period. However, by 2015, we observe a substantial increase in the *Geo*-value, reaching 0.852, denoting an even larger spatial effect compared to previous years.

Table 5.3. Results from the spatial model (BYM) across years (1930, 1970 & 2015): Indigenous region analyzed to estimate the risk of net fertility in the region analyzed.									
				Quantile			**Marginal variance**		
		Mean	**Std. Dev.**	**0.025**	**0.5**	**0.975**	***u***	***v***	***Geo***
1930	**(Intercept)**	-0.215	0.05	-0.314	-0.215	-0.117	0.039	0.040	0.495
	Indigenous	**-0.153***	0.02	-0.192	-0.153	-0.114			
	Inequity	**0.38***	0.082	0.22	0.38	0.542			
1970	**(Intercept)**	-0.297	0.068	-0.431	-0.297	-0.164	0.233	0.716	0.245
	Indigenous	**-0.263***	0.072	-0.403	-0.263	-0.122			
	Inequity	**0.469***	0.2	0.078	0.469	0.861			
2015	**Intercept**	-0.164	0.027	-0.216	-0.164	-0.111	0.026	0.005	0.852
	Indigenous	**0.069***	0.013	0.043	0.069	0.094			
	Inequity	**0.299***	0.062	0.177	0.3	0.421			

Note. * Credibility intervals at 95% confidence. The dependent variable is fertility. Indigenous proportion and inequality (*EqZ*) are independent variables. Where *u* is the spatial structured component and *v* is the unstructured random effect. Geo is the proportion of variability that geographic variable explains. The *u* effect was modeled using the Besag ICAR and v: IID model.
The region analyzed consists of six states with a predominantly indigenous population.

Our spatial analysis has also yielded interactive maps, which can be accessed at Maps-leaftlet. Hovering over municipalities provides details such as independent variable values, estimated net fertility risk, and 95% confidence intervals, offering comprehensive insights into municipal variations. The municipalities colored with reddish tones are the ones with the highest net fertility risk. The mapped relative risk illustrates the likelihood of having a child aged under five, factoring in the proportion of indigenous individuals and socioeconomic inequality within each municipality. In snapshoots presented in figures 5.6, 5.7 and 5.8, we note that the relative risk of net fertility was higher in 1930 and 1970 compared to 2015. Specifically, in 1930, there were elevated net fertility rates observed in municipalities situated along coastal regions. However, in 1970, the pronounced clustering of high net fertility by municipality diminished a result which concords with the low *Geo-value* in 1970 (Table 5.3). Instead, more municipalities exhibited peak net fertility (indicated by red colors) dispersed throughout the interior of the country in a mosaic pattern. This shift in patterns could be attributed to significant population growth across Mexico during this period, resulting in high fertility rates observed nationwide. In the map for 2015, we observe the reddish "spots" were concentrated in just certain places and the reddish tones are fainter. In this scenario, municipalities characterized by a higher proportion of the indigenous families and greater socioeconomic inequality are depicted in reddish colors. It is noteworthy that regions exhibiting the highest fertility “risk” (exceeding 1.20) are situated in the highlands of Chiapas, Guerrero’s central mountainous area, southern Puebla, and other municipalities recognized for their significant indigenous subpopulation. Conversely, other regions display modest net fertility risk rates (below 1.1).

Figure 5.6. Relative risk to have a child aged under five in 1930

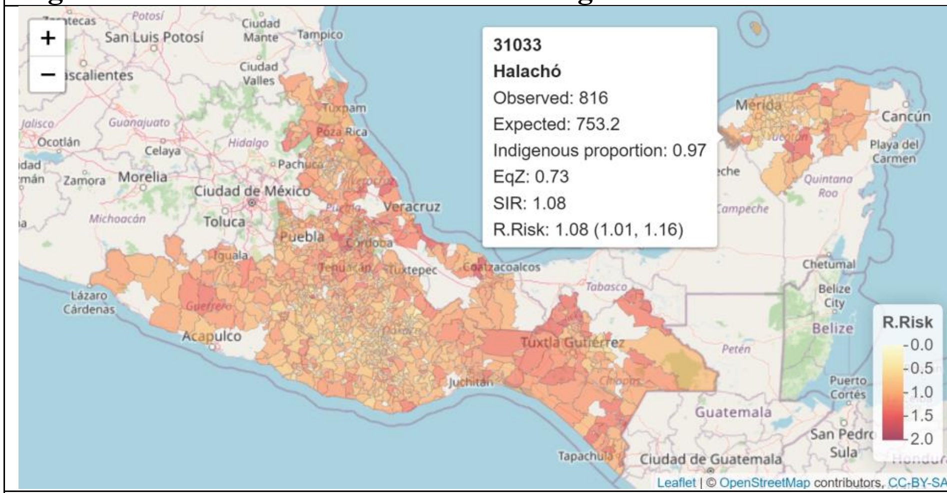


Figure 5.7. Relative risk to have a child aged under five in 1970

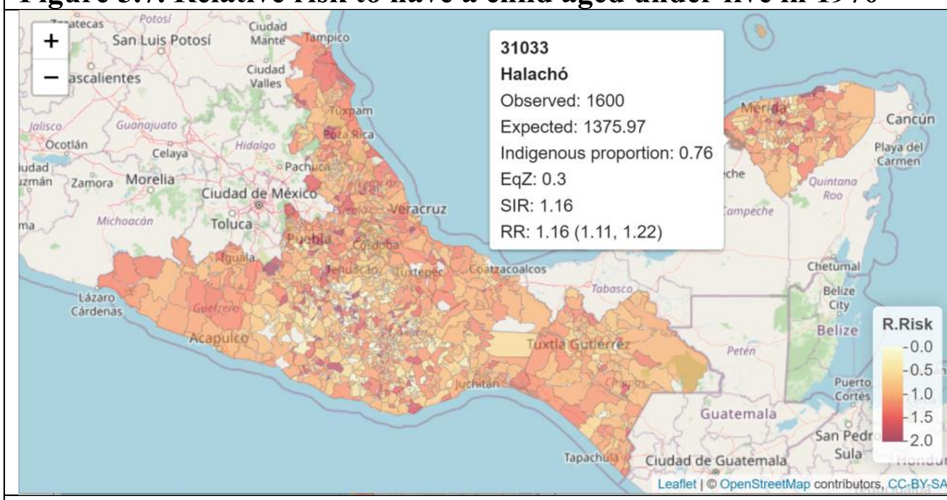
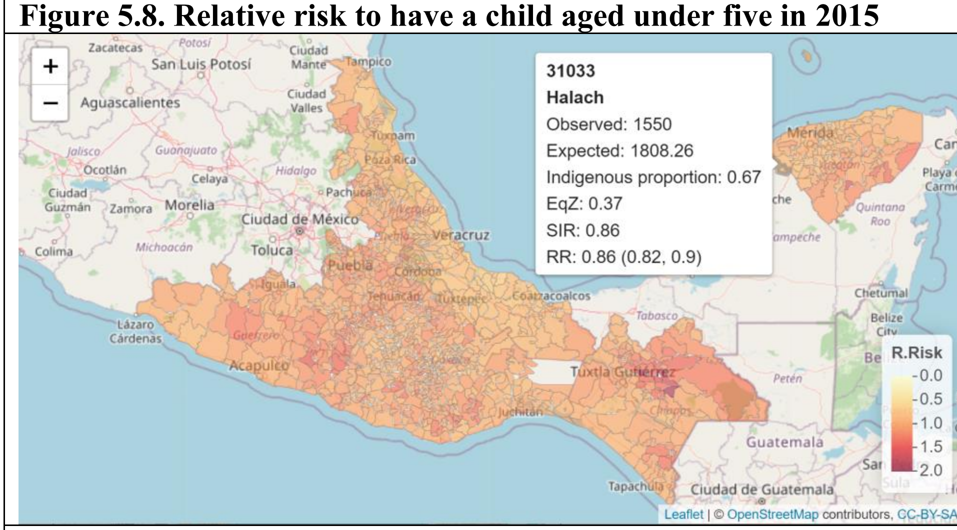


Figure 5.8. Relative risk to have a child aged under five in 2015



Note. In these snapshots, we exclusively present the information for the municipality of Halachó to illustrate the metadata displayed for each municipality in the interactive maps. However it is possible to display the outcomes for each municipality.

5.4.3.1. Spatial Fertility by State

To understand specific spatial patterns of each of the six states analyzed, we repeat the analysis shown in Table 5.3 for the year 2015 only with separate results for each state. Statistically significant estimates are indicated by containing the mean estimate within the 95% credibility interval, denoted by (*). In the state of **Chiapas** (figure 8a), the indigenous proportion shows the highest estimator (0.375), implying a notable association between net fertility and the proportion of indigenous families in thus patriarchal municipality of residence. Conversely, the credible interval of the inequality variable in Chiapas encompasses zero, indicating that municipal inequality does not significantly contribute to explaining net fertility in Chiapas in the year 2015. The indicator (*Geo*=0.551) shoes that spatial correlation plays an important role in explaining net fertility in the region. In figure 5.8a, we observe that municipalities with the highest net fertility risk (depicted in the reddest colors) are concentrated in the mountainous areas of both northern and southeastern Chiapas. The elevated fertility risk in the northern mountainous region (R1) correlates with the proportion of the indigenous families. Notably, among the municipalities exhibiting the highest relative risk are Chanal (1.71), Larrainzar (1.6), and San Juan Cancuc (1.49). Similarly, in the southeastern region of Chiapas (R2), municipalities with the highest risk include La Grandeza (1.19), Motozintla (1.17), Siltepec (1.14), and Mazapa (1.14)[3].

In figure 8b, **Oaxaca** demonstrates clusters of municipalities with heightened net fertility risk (reddish spots) across various regions, suggesting shared reproductive behaviors. Oaxaca notably exhibits a high proportion of variability explained by geography (*Geo*=0.764). In region R1, municipalities like San Agustín Loxicha (1.3), Candelaria Loxicha (1.26), and Santo Domingo de Morelos (1.19) show elevated fertility risk, especially where the indigenous proportion exceeds 60%.

For **Puebla** and **Yucatán**, Table 5.4 reveals no significant contributions from the indigenous proportion or socioeconomic inequality to net fertility. In Yucatán (figure 5.8e), spatial distribution explains a substantial variability (*Geo*=0.996). Municipalities in the southeast, bordering Quintana Roo (region R1), exhibit the highest net fertility risk. Notable municipalities include Tahdzi (1.52), Chichimil (1.39), Chemax (1.31), and Tekom (1.34). Although the indigenous proportion was not statistically significant, all these municipalities have over 90% indigenous population. In Puebla

[3] Access indicators for all municipalities via the interactive maps at the following link: Maps-leaftlet.

(figure 5.8d), geography explains less variability (0.559) compared to Yucatán (0.996). Yet, we still see clusters of high net fertility in the northeast. Region R1 includes Chichiquila (1.16), Chilchotla (1.17), and Quimixtlán (1.08), bordering Veracruz, also showing high net fertility risk.

In figure 5.8c, municipalities in **Veracruz** exhibit a positive association between net fertility and socioeconomic inequality (0.439, Table 5.4). Notably, this pattern is evident in the R1 region, including Ayahualulco (1.32), Villa Aldama (1.27), Altotonga (1.22), Jalacingo (1.16), and Perote (1.13). Another Veracruz region with elevated net fertility risk due to increased inequality is R2, bordering San Luis Potosi, encompassing Tantoyuca (1.35), Chiconamel (1.16), Platón Sánchez (1.15), and Temporal (1.12). In Veracruz model results, the indigenous proportion was not statistically significant, suggesting that net fertility variability in this state is primarily explained by spatial correlation (*Geo*=0.867).

In **Guerrero**, both inequality (0.631) and indigenous proportion (0.112) significantly influence net fertility. In figure 5.8f, region R1 has municipalities with over 90% indigenous population and high inequality, like Cochoapa el Grande (1.33), Metlatnoc (1.28), and Alcozauca de Guerrero (1.21). Region R2 includes municipalities with high indigenous population and average inequality near 0.5. benefiting from a humid temperate climate conducive to year-round agricultural cultivation, display lower levels of inequality, a minimal indigenous presence, and reduced net fertility rates. This pattern elucidates why spatial distribution accounts for only a limited portion of the observed variability (*Geo*=0.08).

Table 5.4. Results from the spatial model (BYM) for 2015 by State to estimate net fertility.									
				Quantile			Marginal variance		
		Mean	**Std. Dev.**	**0.025**	**0.5**	**0.975**	***u***	***v***	***Geo***
Chiapas	Intercept	0.049	0.117	-0.181	0.049	0.278	0.009	0.008	0.551
	Indigenous	**0.375***	0.041	**0.294**	**0.375**	**0.456**			
	Inequity	-0.376	0.264	-0.893	-0.376	0.144			
Oaxaca	Intercept	-0.052	0.056	-0.161	-0.052	0.057	0.024	0.007	0.764
	Indigenous	**0.06***	0.021	**0.02**	**0.06**	**0.101**			
	Inequity	0.051	0.132	-0.209	0.051	0.308			
Veracruz	Intercept	-0.194	0.074	-0.34	-0.194	-0.048	0.025	0.004	0.867
	Indigenous	0.043	0.045	-0.045	0.043	0.132			
	Inequity	**0.439***	0.177	**0.092**	**0.439**	**0.785**			
Puebla	Intercept	-0.106	0.066	-0.237	-0.106	0.022	0.006	0.005	0.559
	Indigenous	0.048	0.033	-0.015	0.048	0.113			
	Inequity	0.255	0.154	-0.045	0.254	0.56			
Yucatán	Intercept	0.107	0.128	-0.145	0.106	0.358	0.046	0.000	0.996
	Indigenous	0.027	0.062	-0.094	0.028	0.147			
	Inequity	-0.371	0.365	-1.087	-0.371	0.346			
Guerrero	Intercept	-0.309	0.079	-0.463	-0.309	-0.154	0.001	0.006	0.080
	Indigenous	**0.112***	0.032	**0.048**	**0.112**	**0.175**			
	Inequity	**0.631***	0.167	**0.302**	**0.631**	**0.959**			

Note. * Credibility intervals at 95% confidence. The dependent variable is fertility. Indigenous proportion and inequality (*EqZ*) are independent variables. Where *u* is the spatial structured component and *v* is the unstructured random effect. Geo is the proportion of variability that geographic variable explains. The *u* effect was modeled using the Besag ICAR and v: IID model.

Figure 5.8a. Relative risk to have a child aged under five in Chiapas: 2015.

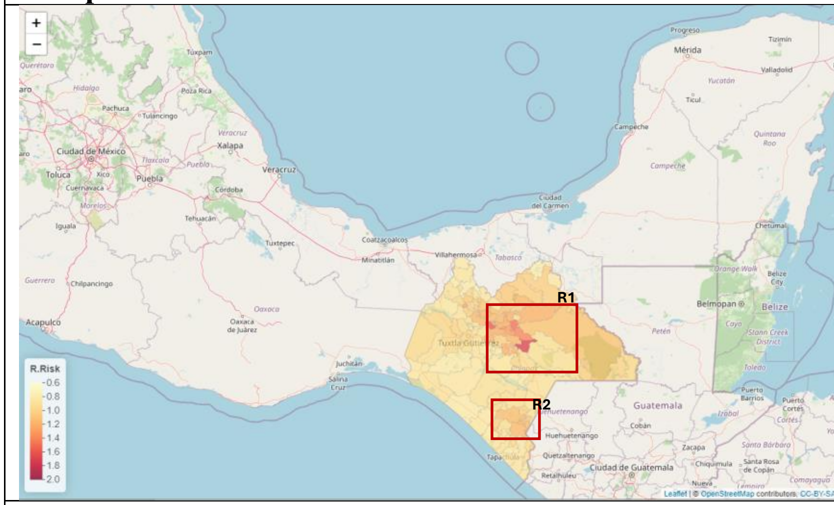


Figure 5.8b. Relative risk to have a child aged under five in Oaxaca: 2015.

Figure 5.8c. Relative risk to have a child aged under five in Veracruz: 2015.

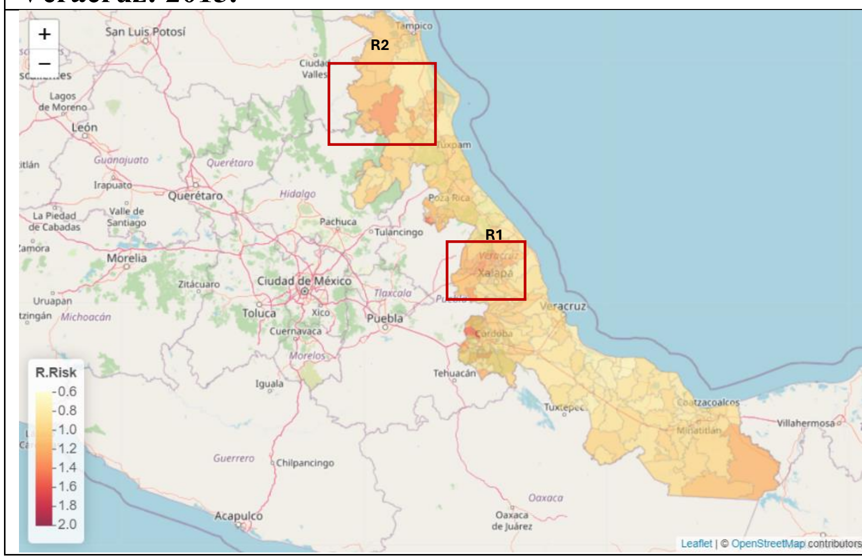


Figure 5.8d. Relative risk to have a child aged under five in Puebla: 2015.

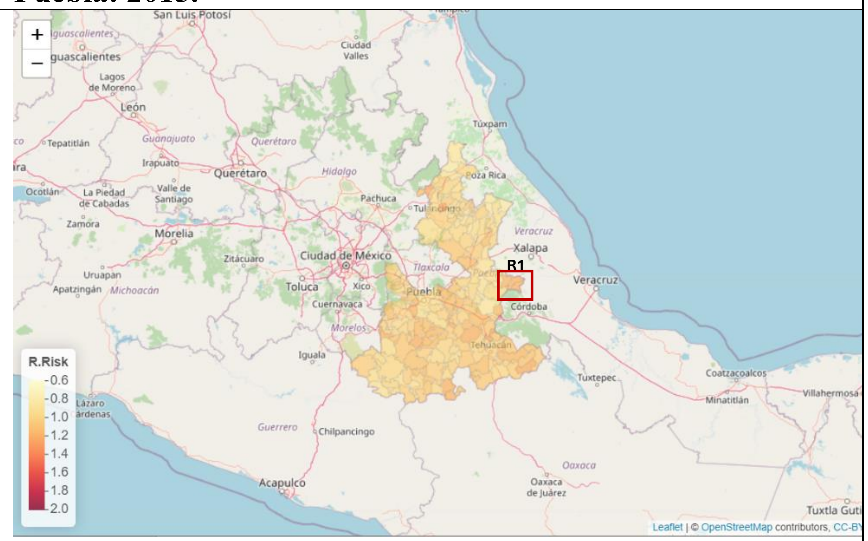


Figure 5.8e. Relative risk to have a child aged under five in Yucatán: 2015.

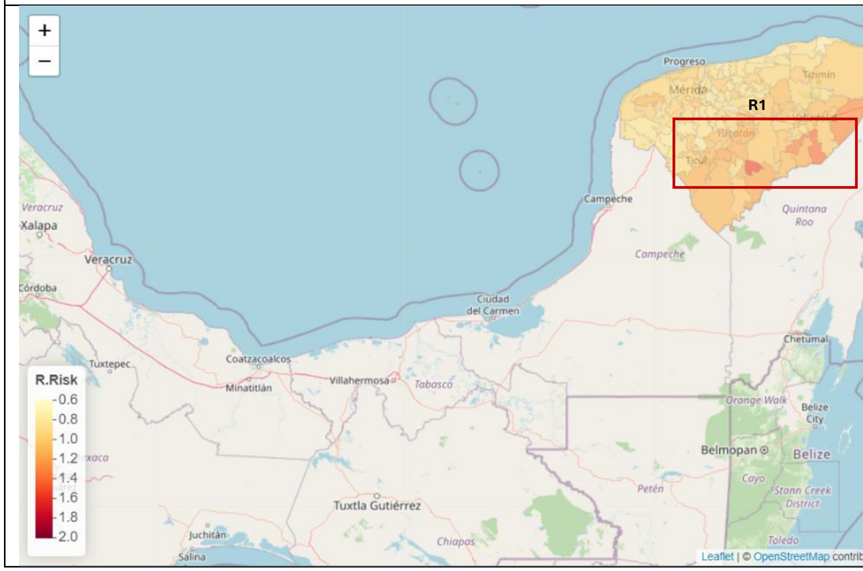
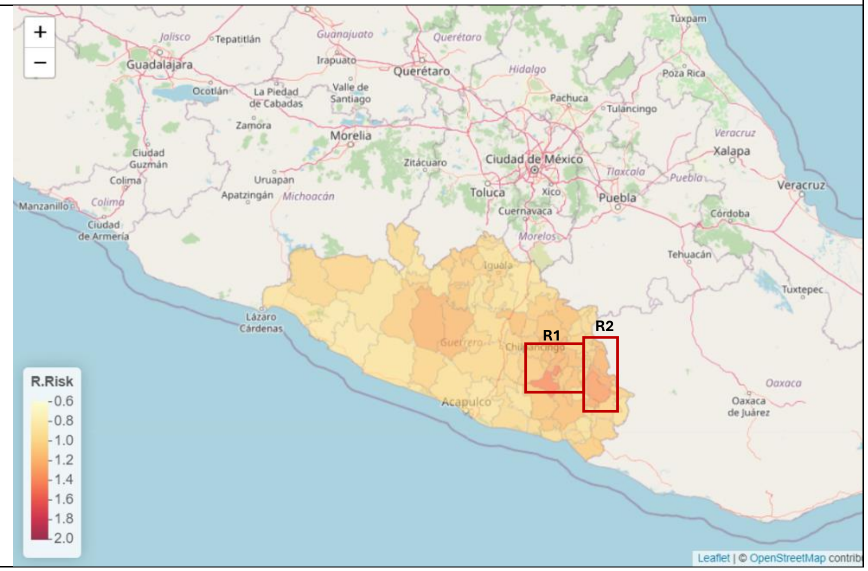


Figure 5.8f. Relative risk to have a child aged under five in Guerrero: 2015.



5.5. Discussion

This article explores Mexico's indigenous fertility dynamics across three pivotal stages: pre-transitional (1930), population growth (1970), and in progress-transitional (2015) phases. Our objective is to offer insights into fertility trends by examining socioeconomic-inequality, cultural, and geographic determinants. Spatial analysis is employed to comprehend the dissemination of reproductive behaviors.

5.5.1. Diffusion of Reproductive Behavior

Our analysis of six Mexican states, representing over 70% of the indigenous subpopulation, highlights the central role of spatial dynamics in understanding Mexico's fertility decline. Thus, we noted changes in the variability of net fertility explained by spatial correlation and independent variables over time (*Geo*= 0.495, 0.245 & 0.852; Table 5.1). In 1930 and 1970, the proportion of indigenous families residing in a given municipality was negatively correlated with net fertility (-0.153 and -0.263, respectively), while in 2015, the indigenous municipal proportion exhibited a positive association with net fertility (0.069). Conversely, inequality consistently correlated with higher net fertility rates across all year examined (0.38, 0.469, and 0.299). This result implies that municipalities spearheading the shift towards lower net fertility initially exhibited higher levels of inequality. However, over time, this inequality diminished (populations tend to homogenize), resulting in increased equality and lower net fertility rates, particularly evident among the urban non-indigenous subpopulation.

Maps in figures 5.6, 5.7, and 5.8 show a reduction in net fertility risk over time. Hence, it is notable that in 1930 and 2015, the propensity for high net fertility was concentrated within specific regions and extended to neighboring municipalities. This indicates the dispersion of concentric reproductive behavior (see figures 5.6 & 5.8). Conversely, such a pattern is not evident in 1970, attributed to the widespread prevalence of high net fertility rates characteristic of the population boom during that period. By incorporating independent variables such as indigeneity and inequality, the BYM model has yielded valuable insights into the analysis of fertility behavior diffusion alongside spatial analysis. This method addresses a gap in the literature identified by Núñez (2022) in their examination of the evolution of Mexican fertility. The spatial trends are more evident and more functional for the realization of public policies when viewed by state, given the state political division of the Mexican Republic.

5.5.2. Demographic Transition, Socioeconomic Status, and Inequality

During the first quarter of 20th century, Mexico's demographic transition saw a notable population surge, however, indigenous population growth lagged behind non-indigenous growth, doubling compared to a quintuple increase from 1930 to 1990 (M. E. Cosio-Zavala, 2014). Traditional narratives highlighting indigenous cultural norms like patriarchal values and unmarried unions among indigenous women offer a simplified view, masking the complex reality involving multiple factors.

Our results indicate that, in 1930, fertility patterns (Table 5.1) were closely linked to socioeconomic status. The disadvantaged socioeconomic conditions of the indigenous subpopulation led to higher mortality rates, persisting to the present (CEPAL, 2005), impacting their net fertility. Indigenous net fertility was lower compared to non-indigenous rural municipalities (0.76 and 0.74 vs. 0.87), and equivalent to non-indigenous urban (0.76). This observation suggests that a reduction in net fertility was underway among the non-indigenous urban subpopulation characterized by lower mortality rates thanks to its favorable socioeconomic condition (see chapter 3). In this scenario, and after what we observed in the spatial analysis, inequality appears to be a significant driver of demographic change in 1930. It suggests that the most privileged families in non-indigenous urban municipalities with a higher inequality (0.543) are at the forefront of this change, influenced by a prestige bias (Table 5.1) as suggested by Colleran (2016). Essentially, neighboring families begin to emulate their reproductive behaviors with the aspiration of attaining similar "social success". When socio-economic conditions really improve, guided by a conscious decision to reduce fertility. This results in a concomitant decrease in socioeconomic inequality, driven by the decline in fertility rates as we can see in 2015. However, even if we observe a similar reduction in fertility, the underlying causes may differ. Specifically, the change might not be driven by economic development but rather by economic pressure. For instance, the rural indigenous population in 1930 exhibited similar net fertility rates as the non-indigenous population (0.76) and had the lowest level of inequality (0.469). This phenomenon, described by Henrich and Gil-White (2001) as "conformity bias" or by Cosio-Zavala et Leridon (1996) as "Malthusian of poverty," suggests that individuals adopt conservative reproductive strategies in response to challenging living conditions. In 2015, rural indigenous families remain at the bottom of the socioeconomic spectrum (0.485), with the highest net fertility rates (0.64), and greater inequality. This indicates that indigenous families are becoming less similar to each other, thereby increasing inequality. However, under severe poverty, it seems reasonable to think that this population lacks the means to adopt behaviors observed in more economically advantaged segments of the community, as seen in urban non-indigenous populations in 1930 (inverse association- Figure 5.3). In rural indigenous subpopulation in 1930 and in 2015 shows that the absence of significant improvements in socioeconomic conditions is hindering the evolution of adaptive behaviors that could enhance community well-being and lead individuals to make more informed developmental choices. Thus we can see a clear trend towards higher fertility in the face of greater inequality as shown in Figure 5.3 in every year analyzed.

By 1970, Mexico underwent significant social and economic changes due to domestic and foreign investments, alongside new policies (Baca, 2007). Families experienced improved socioeconomic status and reduced inequality (Damián et Boltvinik, 2003; Székely, 2005). Our analysis (Table 5.1) shows a notable increase in net fertility from 1930 to 1970 in every subpopulation, driven by post-crisis repopulation policies. This surge resulted from sustained high fertility rates, fueled by a substantial proportion of women of reproductive age (M. E. Cosio-Zavala, 2022). However, despite efforts to improve socioeconomic status (*InSoc*) through economic policies, the impact was limited among both rural subpopulations: non-indigenous (0.426) and indigenous (0.371). As in 1930, indigenous-rural municipalities had the lowest net fertility rate (0.87) and lowest inequality (0.24), reflecting uniform poverty and fertility distribution, again “The Malthusianism of poverty in Mexico” (M. E. Cosio-Zavala, 2012). Non-indigenous urban areas had higher *InSoc* (0.53), elevated net fertility (1.05), and increased inequality (0.35). Conversely, non-indigenous rural areas, with the second-highest inequality (0.282), had the highest net fertility rate (1.12) after non-indigenous urban municipalities. This suggests that from 1930 to 1970, economic development led to reduced inequality, especially in rural municipalities. This inequality correlated with higher net fertility, particularly in rural non-indigenous municipalities and urban areas. Sustainable development during this period seemed primarily influenced by urban characteristics, followed by ethnic status, with spatial correlation playing a lesser role, as we mentioned before. The adverse correlation between net fertility and indigeneity in both 1930 and 1970 cannot be ignored. This prompts a reflection on (A. Stern, 2000) research, which suggests that governmental policies during that period were influenced, to some degree, by the “Mexican Eugenic Society” emphasis on promoting "mestizofilia" (the blending of white European and indigenous heritage) over the preservation of "pure races" or the admixture with other ethnic groups.

Between 1930 and 1970 structural adjustments, like reduced public spending and privatization, in response to a financial crisis worsened inequality, especially in rural and marginalized regions (Damián et Boltvinik, 2003). In 2015, our results show this trend by an increase in inequality (*EqZ*), particularly conspicuous in indigenous municipalities (79% & 39%), with only non-indigenous-urban municipalities witnessing a decrease in inequality (-8%) (Table 5.1). The prevailing economic conditions have predominantly prompted the migration of both the indigenous-rural and non-indigenous-rural individuals to urban centers. Once located in urban environments, indigenous persons adopt urban behaviors but struggle to maintain customs and traditions. They contribute to modernization in rural areas through frequent returns to their places of origin (Velasco Ortiz, 2007). Table 5.1 indicate that in 2015, every subpopulation saw a significant reduction in net fertility. Urban non-indigenous municipalities had the lowest mean net fertility (0.43), rural non-indigenous followed (0.50), and indigenous had higher net fertility (urban=0.52 & rural=0.64). This decline is attributed to family planning programs post-1974. Once more, in 2015, we observe the diffusion of fertility behavior that is concentric, reminiscent of the patterns observed in 1930. This phenomenon can be attributed to the prestige bias, which is now also identified in indigenous municipalities (figure 5.10).

5.5.3. Inequality and Net Fertility Distribution

Extensive research has explored the inequalities faced by indigenous subpopulations and their developmental implications, yet there is a notable gap in directly linking inequality with fertility. Only few studies have examined the association between inequality and resource distribution for maternal and child health (Colomé-Hidalgo et al., 2021; Mesenburg et al., 2018). Consequently, our study represents a pioneering effort in providing a historical analysis of inequality and its direct correlation with net fertility, shedding light on their intricate dynamics among indigenous subpopulations across time. In 1930, indigenous-rural municipalities display inequality-fertility two clusters (figure 5.2a): yellow triangles signify lower inequality and average net fertility, while blue points denote higher inequality. Within this cluster, we observe a spectrum of both very low and very high fertility rates. This underscores the limitation of conventional measures of central tendency in adequately capturing the complexity of this variable pairing. In 1970 (Figure 5.3b), R-mclust analysis fails to discern a significant association between inequality and net fertility, probably because the small sample we dispose. Instead, independent variables are more closely associated with net fertility. In figure 5.3c, overlapping clusters suggest divergent net fertility rates despite similar inequality levels, indicating additional determinants probably linked to cultural factors. Our findings emphasize the importance of rigorously examining the relationships between socioeconomic-inequality and net fertility, accounting for historical and cultural contexts. This analytical methodology could be useful to explore the association between inequality and net fertility, revealing a significant implication: higher levels of inequality correspond to elevated net fertility in ongoing transitions societies (Figure 5.3). Furthermore, our analysis extends to analyze other demographic variables from current surveys, such as total fertility or age at first intercourse. This comprehensive approach seeks to clarify the direct impacts of inequality on diverse demographic variables, thereby enhancing our nuanced comprehension of fertility behavior within indigenous subpopulations.

5.6. Conclusions

This study comprehensively examines indigenous net fertility dynamics in Mexico across three key demographic periods. It explores the interplay of socioeconomic-inequality, cultural, and geographical factors shaping historical fertility trends. Spatial dynamics are crucial in understanding Mexico's fertility diffusion. This approach integrates independent variables like indigeneity and inequality, confirming that fertility behavior changes through structural shifts, cultural and economic contexts, and the transmission of ideas.

Indigenous subpopulation proportion show varied associations with net fertility rates over time. In pre-transitional Mexico society, higher inequality correlates with elevated net fertility. However; in the ongoing transitions, we suggest a transition towards lower fertility rates as inequality decreases. Moreover, the study challenges conventional narratives on socioeconomic status and fertility outcomes, particularly in pre-transitional and population growth demographic stages. It suggests the significant influence of factors like indigenous mortality rates, miscegenation policies, and cultural factors on fertility dynamics, highlighting the nuanced complexities of Mexico's demographic transition. This study explores the impact of eugenic policies at the onset of the 20th century on the indigenous population, utilizing data gleaned from the 1930 census.

Our research innovatively employs a bivariate normal distribution to analyze the link between socioeconomic-inequality and net fertility. This approach offers precise estimates, facilitating a comprehensive understanding of the elasticity of net fertility in response to fluctuations in inequality levels within each ethno-geographic population. Furthermore, the utilization of interactive maps serves as a pivotal tool in facilitating access to metadata for each municipality. State-specific maps are essential for pinpointing priority areas for development of local interventions. They highlight clusters of municipalities experiencing pronounced inequality and its effects, guiding targeted policy formulation, especially for indigenous municipalities.