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Bayesian spatial modelling of contraception effects on fertility in Mexican municipalities in 2020

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Abstract

The prevalence and use of contraceptive methods is an essential element to explain the behaviour of fertility and population growth. The objective of this study was to analyse the spatial correlation between the use of contraceptive methods in women of childbearing age and fertility levels observed in Mexico's municipalities in 2020. Data on contraceptive use are from the National Survey of Demographic Dynamics (ENADID) 2018, while fertility rates were estimated from vital statistics and population census data. Three Bayesian spatial models including fixed effects, random effects and spatial effects were employed. The models were estimated using the integral nested Laplace approximation (INLA) package available in the R language. The results reveal the existence of important regional inequalities associated with the use and prevalence of contraceptive methods, which generate marked differences in observed levels of fertility between municipalities.

Introduction

The increasingly widespread use and prevalence in developing countries of contraceptive methods have resulted in a generalized decline in fertility rates; however, both adoption of contraceptive methods and its counterpart, fertility decline, have occurred heterogeneously in different geographic spaces (Bongaarts and Casterline, 2018). The first seminal demographic theory that explains the long-term evolution of fertility (and mortality), known as the demographic transition theory (Notestein, 1945) states that reduction in fertility levels observed in European countries at beginning of the twentieth century arose in response to a decrease in infant mortality, directly related to greater economic development leading to better food and health quality (Caldwell, 1982). The variables associated with these changes are the generalized incorporation of women into labour market and the delay in age of marriage and age at first childbirth. These transformations allow us to understand changes experienced in terms of nuptiality and fertility (Watkins *et al*., 1987). In other words, demographic transition implies the passage from a regime of high and stable mortality and fertility to a regime with low and stable mortality and fertility rates. The transition occurs in pre-transitional societies where women's fundamental role is centred on reproduction (Zavala de Cosío, 1992).

The first stage of transition begins with a period of destabilization caused by a significant decline in mortality, which eventually leads to a drop in fertility that marks the beginning of the second stage of transition, *i.e.* rational control of fertility driven by the widespread use of contraceptive methods. Finally, population growth subsides and a modern demographic regime is consolidated in an advanced stage of transition. As can be seen, this theory does not consider biological, social or cultural dimensions of fertility (or mortality) (Chesnais, 1992).

The determinants of fertility approach, proposed by Davis and Blake (1956), establishes that fertility is influenced by a set of intermediate variables known as proximate determinants, which include: age of sexual debut; permanent celibacy; voluntary abstinence; frequency of coitus; involuntary sterility; contraception; sterilization; involuntary foetal mortality and abortion (Bongaarts, 1983). It also establishes that proximate determinants act at key moments of the reproductive process, delaying, reducing or eliminating exposure to coitus, conception and pregnancy. From a sociological point of view, intermediate variables have promoted the emergence of important changes in reproductive behaviour derived from their knowledge, availability and social acceptance by couples and families (Stover, 1998).

The proximate determinants model makes it possible to separate biological aspects from social behaviours associated with reproduction by clearly identifying, for the first time, biological aspects of human reproduction. It is thus possible to evaluate the effect on the evolution of fertility levels in different societies, where lack of knowledge and/or lack of control over the proximate determinants is a fundamental factor in explaining the existence of high fertility levels; in other words, knowledge and application of proximate determinants makes it possible to observe low fertility levels. Women who know and use appropriate means of

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controlling the proximate determinants are better able to take care of their health and decide on children they wish to have (Stover, 1998), but they will also have a greater capacity to decide when to have a partner and what kind of partner they wish to have.

From an economic perspective, demographic transition posits that fertility (and mortality) decline is a consequence of social modernization understood as a combination of economic development, urbanization and industrialization (Notestein, 1945). However, changes in family formation and reproduction, as a phenomenon typical of developed countries, have been synthesized in a second theory of demographic transition, whose objective is to describe consequences of major transformations in marital and reproductive behaviour (Lesthaeghe and Van de Kaa, 1986; Van de Kaa, 2002) and how these translate into below replacement level fertility rates, high levels of singleness and the postponement and/or cancellation of marital union. Widespread access to the first modern contraceptive methods began in the early 1930s with mass production of condoms in the United States, and in the late 1950s with the dissemination of the first contraceptive pill (Tone, 2002). Twenty years later, the first birth control programs based on the concept of population explosion emerged, which later became family planning programs; a less aggressive approach but with similar meaning. It was at the International Conference on Population and Development in Cairo (UN, 1994) that the notion of family planning was reformulated by integrating concepts such as development, gender equity and respect for human rights (specifically sexual and reproductive rights) (Sen, 2001; Garg, and Singh, 2014). Thereafter, family planning included access to sexual health, maternal and reproductive health.

Access to contraceptive methods allows people to make informed decisions regarding their sexual and reproductive health, as well as to evaluate the advantages of having a small family, which is reflected in the prevention of unwanted pregnancies, reduction of induced abortions and maternal deaths as well as lower infant mortality rates. The advantages range from the possibility of devoting more time to raising each child, to allowing children to remain in school for more years (Pritchett, 1994). In Mexico, the first birth control programs began in the 1970s with the intention to reduce high fertility levels. Thus, contraceptive methods were applied as if pregnancies were an epidemiological phenomenon and it was under this idea that a good part of family planning programs at the time was generated. It was supported by the belief that supply of contraceptive methods would be sufficient to reduce fertility (Juarez *et al.*, 2018). Subsequently, policy turned to demand, *i.e.* it was accepted that fertility would decrease because of rational control of couples, which of course depended on decisions about the number and spacing of children that each couple wished to have (Zavala de Cosío, 1992). The purpose of family planning programs in Mexico is for women to have the number of children they want at the time they want them. That is, programs provide women and/or couples with the ability to decide about their pregnancies, so the society's fertility levels will be a function of the system's ability to provide planning services effectively and efficiently to its population at reproductive age (Juarez *et al*., 2018).

In general, contraceptive methods are classified as modern or traditional, although currently different classifications depend on time and form of use or characteristics and functioning of method. Five types of methods are commonly recognized: definitive, hormonal, non-hormonal, traditional and emergency (de la Vara-Salazar, 2020). Definitive methods are irreversible and include bilateral tubal obstruction known as tubal ligation and vasectomy. Non-hormonal methods prevent sperm from fertilizing eggs through physical or barrier devices. It includes the use of condoms, diaphragm, vaginal spermicides, vaginal sponges, vaginal rings and intrauterine devices (Torres-Pereda, 2019). Hormonal methods consist in using female sex hormones such as oestrogen and progestin that prevent ovulation and therefore fertilization. They include the use of birth control pills, injectables, subdermal implants, body patches, and intrauterine devices with hormones (Grindlay *et al.*, 2021). Traditional methods include a set of techniques that allow couples through knowledge of processes associated with ovulation and adaptation of sexual practices to avoid conception. These include rhythm, calendar, billings or periodic abstinence, withdrawal or *coitus interruptus*, and postpartum amenorrhea. Women who wish to prevent pregnancy use emergency methods after unprotected intercourse, which comprises emergency pills (Mauldin and Segal, 1988).

The National Survey of Demographic Dynamics (ENADID) classifies contraceptive methods as: i) modern, which include definitive, hormonal and non-hormonal methods; and ii) traditional methods, leaving out emergency methods (ENADID, 2018). Now, widespread knowledge and the use of contraceptive methods have made it possible to dissociate sexuality from reproduction in the sense that contraceptive methods comprise a set of strategies that seek to prevent or significantly reduce the probability of fertilization and pregnancy, which depends on efficacy and effectiveness of the method used (Juarez *et al*., 2018). In general terms, efficacy is defined as the probability of an unwanted pregnancy occurring when the method is used the way it was prescribed, and effectiveness measures the total number of unwanted pregnancies when a method is used incorrectly (Shuiling and Likis, 2013). Considering that most modern contraceptive methods achieve an efficacy greater than 90%, while traditional methods are unreliable as a result of their low contraceptive efficacy, and given that the objective is to measure the effects of the use of contraceptive methods on fertility, work will focus on analysing the effects of modern methods (as a whole) and separate the effects of definitive methods, hormonal methods, and non-hormonal methods on municipal fertility levels, in order to reduce the presence of spurious associations (Cavallaro, 2020).

Objective

The research objective was to model spatial variations that differential use of contraceptive methods among women of childbearing age exerts on observed levels of fertility in municipalities of Mexico in 2020.

Materials and methods

Background

The source of data regarding the use of contraceptive methods in Mexico corresponds to ENADID in its 2018 version (ENADID, 2018) that identifies the type of contraceptive method used by women aged between 15 and 54 at the national, state and locality levels. The total fertility rates (TFR), on the other hand, was estimated from data on births and female population from vital statistics and the 2020 general population census, respectively. The percentage of women using contraception observed in 2018 was updated to 2020, under the assumption that contraceptive coverage levels remained constant over the period 2018-2020.

To know the proportion of women users of contraceptive methods by municipality, it was necessary to estimate the total number of users by the size of locality, by all localities in the country (according to their size), and then group the total number of users per municipality as the sum of existing localities in each municipality. To update the TFR to 2020, it was necessary to assume that the proportion of users per locality for the period 2018-2020 remained constant, so the proportion of women users of contraceptive methods in 2020 was estimated as the product of the proportion of women users in 2018 per locality by total female population aged 15-54 resident in the locality in 2020. Finally, users per locality corresponding to each municipality were summed.

The specific data to estimate the total fertility rate at a municipal level come from birth statistics and the general population census 2020, are both available from the website (https://www.inegi.org.mx/) of Instituto Nacional de Estadística, Geografía e Informatica (INEGI), *i.e.* the National Institute of Statistics and Geography. The fertility rate of women of age x (between 14 and 54 years old) residing in the municipality at midyear was estimated as the quotient of:

$$f_x = \frac{\textit{births of women aged } x}{\textit{Total no.of women aged } x \ (1/2)} \quad (1)$$

Therefore, the TFR was calculated as the sum of the specific fertility rates:

$$TFR_i = \sum_{x=12}^{49} f_x \quad (2)$$

which represents the average number of children a woman would have after her reproductive stage, provided that the reproductive pattern present in municipality i remains constant (Pressat, 2020).

Exploratory data analysis

Figure 1 shows the evolution of Mexico's TFR for the period 1950-2030. It can be seen that the fertility decline began in 1967, prior to the application of the first family planning programmes derived from the implementation of the General Population Law of 1974 (Palma, 2005). The result of the Law's application was reflected in a sharp decline in fertility over the next 30 years, when between 1975 and 2005 the fertility rate fell from 7 to 3 children on average per woman (Figure 1). By 2020, Mexico finally reached the desired level of intergenerational replacement; however, marked differences remain between its states. Figure 2 shows the distribution of the TFR of the municipalities that make up Mexico's 32 states. By 2020, all municipalities in Mexico City had fertility rates below the replacement level, while only 4.9% and 9.6% of municipalities in the states of Guerrero and Chiapas, respectively, had fertility rates below the replacement level (Figure 2). Moran's index allows establishment of the presence of spatial autocorrelation by identifying patterns of concentration/dispersion of a variable in space. It is understood that a variable is spatially autocorrelated when it presents values that form non-random patterns of the same variable in specific spatial regions. Thus, Moran's index of spatial autocorrelation in its local version classifies spatial clusters as: i) High-High (HH) when high values are clustered; ii) High-Low (HL) when high values are surrounded by low values; iii) Low-High (LH) when low values are surrounded by high values; iv) Low-Low (LL) when low values are clustered; and v) non-significant when no spatial autocorrelation is observed.

Local Moran's index for Mexico's TFR or the year 2020 can be seen in Figure 3. It shows the presence of some HH fertility clusters, especially in the states of Chiapas, Guerrero and Chihuahua, while central Mexico (Puebla, Tlaxcala and Estado de México) presents a mix of municipalities with LH and HL patterns. It is important to note that the scarce presence of LL clusters may be due to the fact that the fertility decline in most of Mexico's municipalities has not yet been consolidated.

The Bayesian spatial model

The spatial modelling uses a random variable $y(i)$ as the response variable, which represents the estimated total fertility rate in municipality i, for i=1,2,3,...,2454, through which it defines an indexed stochastic process given by:

$$Y(i) = \{y(i) \mid (i) \in \Re^2\} \quad (3)$$

which allows the variable $y(i)$ to be georeferenced according to the geographical position of the municipal capital located at coordinate $(i) \in R^2$ (Moraga, 2019). At the same time, $y(i)$ follows the distribution:

$$y(i) \sim Normal(\mu_i, \sigma_i^2) \quad (4)$$

with mean μ_i and variance σ^2 so the linear predictor η_i of the spatial model is specified as the expected value of the variable response:

$$\eta_i = E[Y(i)] \quad (5)$$

so the spatial Bayesian model is defined in terms of:

$$\eta_i = \beta_0 + u_i + v_i + \sum_{j=1}^{J} \beta_j x_{ij} \quad (6)$$

where v_i represents the unstructured spatial component and where u_i component is the part of the model that captures the structured spatial effects (Gómez-Rubio, 2020), which follows a distribution:

$$u_i \mid u_{-i} \sim N\left(\frac{1}{\#\mathrm{N}(i)} \sum_{j=s}^{n} c_{ij} u_j,\ \sigma_i^2\right) \quad (7)$$

where c_{ij} captures the neighbourhood criterion; $c_{ij} = 1$ whenever i and j are neighbours, otherwise $c_{ij} = 0$, while the variance of structured effects, defined as, are weighted by the number of neighbours $N(i)$. The unstructured spatial component v_i is modelled through a *Normal* $(0, \sigma_v^2)$ distribution with zero mean and variance σ_v^2 (Riebler *et al.*, 2016). When u_i is defined in terms of Eq. 7, the Bayesian spatial model takes the Besag-York-Molliè (BYM) form (Schrödle and Held, 2011).

The component $\beta_0 + \sum_{j=1}^{J} \beta_j x_{ij}$ represents the model's fixed

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effects part. The term β_0 represents the average total fertility rate, while β_j captures the linear effect of covariates x_{ij}, where j represents the number of covariates (Blangiardo and Cameletti, 2015).

The spatial modelling of fertility in terms of contraceptive use was based on formulation and estimation of three competing Bayesian spatial models: i) a model without covariates (null model) representing a discrete Gaussian Markov Random Field; ii) a spatial model with one covariate: *i.e*. the percentage of women users of modern contraceptives; and iii) a spatial model with three covariates representing the percentage of women using modern contraceptive methods separated into definitive, hormonal, and non-hormonal types (Moraga, 2019).

The spatial Bayesian models were estimated using the integral nested Laplace approximation (INLA) package available in the R language (R Core Team, 2014), which is based on an INLA developed by Rue *et al*. (2009). The INLA package can fit a wide variety of georeferenced data within a broad class of Latent Gaussian models including generalized linear (mixed) models, hierarchical models, spatial models and spatiotemporal models.

In this way, three spatial models were established, defined from the equations:

$$\eta_i = \beta_0 + u_i + v_i \text{ (M0)} \quad (8)$$

$$\eta_i = \beta_0 + u_i + v_i + \beta_1 x_{i,I} \text{ (M1)} \quad (9)$$

$$\eta_i = \beta_0 + u_i + v_i + \beta_1 x_{i,1} + \beta_2 x_{i,2} + \beta_3 x_{i,3} \text{ (M2)} \quad (10)$$

Model M0, defined as a null or covariate model that adjusts the spatial behaviour of response $y(i)$ in terms of spatial effects, was used for comparison, while the M1 model adjusts the behaviour of $y(i)$ in terms of covariate x_I, the proportion of users of modern contraceptive methods, and the spatial effects. Model M2 includes three covariates: the proportion of users of definitive methods (x1); the proportion of users of non-hormonal methods (x2); and the proportion of users of hormonal methods, plus the spatial effects part (x3). The models were estimated using INLA, available in the R-project through the R-INLA package (Rue *et al*., 2009). Its use allowed obtaining fast and efficient estimates for the three proposed Bayesian spatial models.

Since three models were estimated to adjust the same phenomenon from the same data, it was necessary to define a criterion to identify the best model. We chose Akaike's information criterion (AIC) because it uses both the maximum likelihood function and several fitted parameters to estimate a goodness-of-fit measure that weighs the complexity and explanatory power of each model (Moraga, 2019). The AIC selection consists of choosing the model that achieves the smallest AIC statistic. The AIC goodness-of-fit statistics for the models M0, M1 and M2 are presented in Table 1 and indicate that model M0 achieves the best fit.

Results

Although the AIC selection indicates that the M0 model was the best fit to the spatial behaviour of data, this result does not necessarily invalidate the other models, especially when the difference in AIC between M0 and M1 models was only 6.2 percentage points (in relative terms) and since the importance of the M1 and M2 models was fundamental for this research (both models allowed us to evaluate the effect of the use of contraceptive methods on fertility).

Table 2 shows the results of posterior estimates of fixed effects corresponding to Bayesian spatial models M0, M1 and M2. The results include estimates for mean, standard deviation (SD) and first, second and third quartiles. The mean of parameter β_0, estimated in the case of the M0 model, indicated that the average total fertility rate of Mexico's municipalities was 2.7 children (Table 2), which resulted in an unbiased estimate of this parameter. Thus, the average total fertility rate observed in Mexico's municipalities in 2020 was 2.7 (it should be noted that the current TFR at the national level is 2.1).

The estimated mean of parameter $\beta_0 = 6.0$ that corresponds to model M1 (Table 2) represents the TFR that would be observed when the effects generated by application of contraceptive methods or the spatial effect were not considered. The estimated mean

Table 1. The Akaike information criteria applied to the three models.

	Model	AIC
M0	$y_i = \beta_0 + u_i + v_i$	5486.51
M1	$y_i = \beta_0 + u_i + v_i + \beta_{1xi1}$	5831.48
M2	$y_i = \beta_0 + u_i + v_i + \beta_{1xi1} + \beta_{2xi2} + \beta_{3xi3}$	5886.98

Source: Prepared by the author based on R-INLA estimates.

Table 2. Fixed effects posterior estimates, spatiotemporal models.

Model	Parameter	Mean	SD	95% CI
M0	β_0	2.707	0.016	[2.675, 2.738]
Model	**Parameter**	**Mean**	**SD**	**95% CI**
M1	β_0	6.067	0.363	[5.353, 6.778]
M1	β_1	–6.700	0.723	[–8.116, –5.278]
Model	**Parameter**	**Mean**	**SD**	**95% CI**
M2	β_0	5.046	0.373	[4.312, 5.777]
M2	β_1	–5.976	0.864	[–7.671, –4.277]
M2	β_2	0.164	1.416	[–2.612, 2.945]
M2	β_3	–5.660	1.064	[–7.748, –3.569]

CI, credible interval; SD, standard deviation. *Source: Prepared by the author based on R-INLA estimates.*

of parameter β_1, associated with the percentage of female users of modern contraceptive methods, indicates the existence of an inverse relationship where a one-point increase in the percentage of women using modern contraceptive methods would imply a reduction of β_1 to –6.7 percentage points in the total fertility rate.

The estimates of the fixed effects part of the M2 model shown in Table 2 indicate that the parameter β_0 has the same significance as in the M1 model, while parameter β_1 implies that an increase of one percentage point of users of definitive contraceptive methods would cause a decrease of 5.9 percentage points in the total fertility rate.

The parameter β_2 turned out to be statistically non-significant, so according to the M2 model the covariate x2 associated with the use of hormonal contraceptive methods had no significant effect on fertility behaviour (note that the estimated mean of the β_2 parameter was outside the credible interval). The mean β_3 estimate for the M2 model indicates that increasing the percentage of non-hormonal method users by one point would result in a 5.6 percentage point reduction in the total fertility rate.

Table 3 presents the estimates of structured and unstructured spatial effects for the three models. In all three, the mean estimated value of the parameters corresponding to the structured spatial effect u_i reached a significantly higher relative value than that presented by the unstructured spatial effects v_i. In general, the estimates for u_i were 80% higher than those reached by unstructured spatial effects v_i in all three cases. The importance of the spatial structure when modelling municipal fertility levels in Mexico is thus evident (Wang *et al*., 2018).

Figure 4A and B-D contrast the spatial distribution of the total fertility rate for the Mexican municipalities. The first presents the crude global fertility rate, while the other figures present the mean value of TFR estimated by the linear predictor of the corresponding model, so that a simple visual contrast allows evaluating (at least empirically) the quality of fit of each model in relation to the raw data (Moraga, 2019).

The behaviour of the global crude fertility rate presented in Figure 5 shows a low proportion of municipalities with fertility levels above an average of five children per woman; the municipalities shaded orange-red, while the municipalities in green-blue present fertility rates below the average of two children per woman. It is important to point out that because the estimation of spatial effects was done by weighting the value of the TFR of a municipality with respect to values observed in its neighbouring municipalities; the linear predictor estimation tended to overfit the TFR value and therefore over-smooth the TFR spatial behaviour as observed in Figure 4B-D.

Figure 5 presents the posterior probability distribution for a municipality to achieve a TFR above the national average, that is p(ζi > 2.7 | y). The associated probabilities of the posterior distribution of ζi (defined as the sum of structured and unstructured spa-

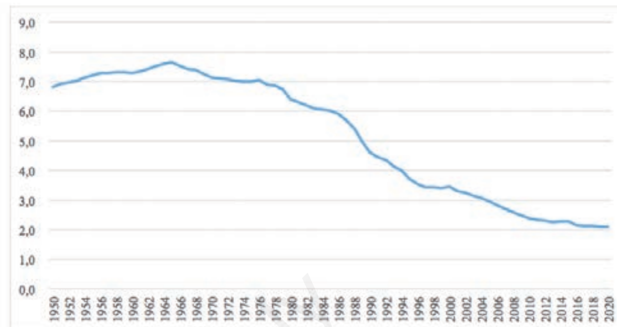

Figure 1. Evolution of Mexico's total fertility rate 1950-2020. ***Source: Prepared by the author based on birth statistics and general population census 2020.***

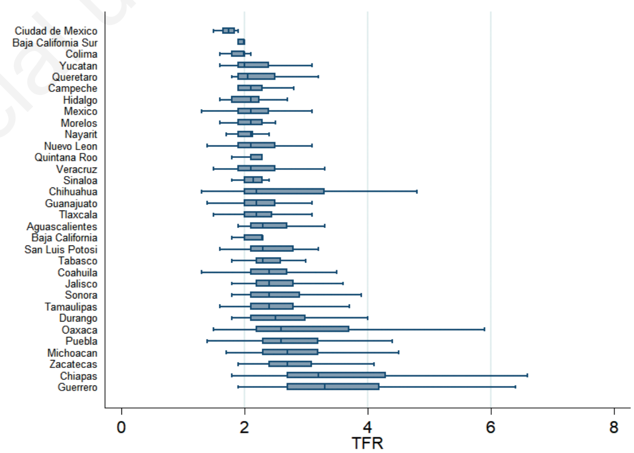

Figure 2. Total fertility rate (TFR) of Mexican States 2020. ***Source: Prepared by the author based on birth statistics and general population census 2020.***

Table 3. Random effects posterior estimates, spatio-temporal models.

Model M0		Mean	SD	95% CI
u_i	Structured spatial effect	3.010	0.188	[2.665, 3.666]
vi	Unstructured spatial effect	1.347	0.178	[1.036, 1.734]
Model M1	**Mean**	**SD**	**95% CI**	
u_i	Structured spatial effect	3.388	0.261	[2.923, 3.946]
v_i	Unstructured spatial effect	1.969	0.260	[1.524, 2.543]
Model M2	**Mean**	**SD**	**95% CI**	
u_i	Structured spatial effect	3.646	0.300	[3.115, 4.290]
v_i	Unstructured spatial effect	1.946	0.257	[1.509, 2.514]

CI, credible interval; SD, standard deviation. *Source: Prepared by the author based on R-INLA estimates.*

tial effects) were obtained from the function inla.pmarginal, which takes ζi and a fixed probability value specified by the average TFR as parameters.

In general, Figure 5 shows the existence of spatial clusters that allow the identification of regions with a high or low associated risk of presenting a TFR above the national average (that is, area units in which the posterior probability of reaching fertility levels above the national average are high or low). High-risk clusters occur when the probability associated with the risk of fertility levels above the national average is close to one, as can be observed in municipalities located in the jungle zone of the state of Chiapas, along Sierra Madre Occidental and in some municipalities in the states of Coahuila, Nuevo León, Guerrero and Oaxaca, which are shaded in orange-red tones. Low-risk spatial clusters are presented when the probability of reaching a TFR above the national average is close to zero. These clusters correspond to municipalities located in the Yucatan Peninsula as well as municipalities in the states of Jalisco, Guanajuato, Queretaro and Hidalgo, which are presented in shades of blue in the figure.

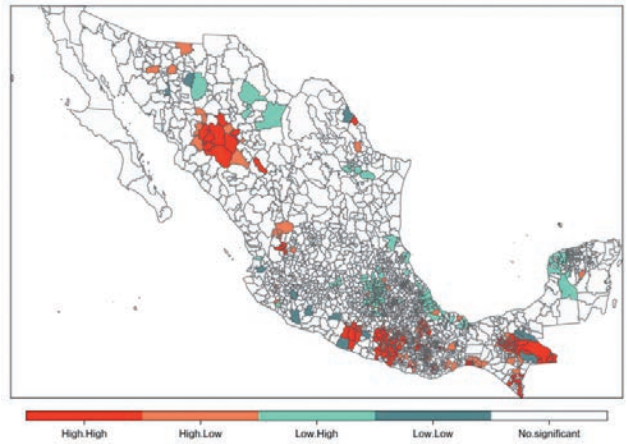

Figure 3. Local Moran index of municipal total fertility rate, Mexico 2020. ***Source: Prepared by the author based on R estimates.***

Discussion

This study addresses the problem of evaluating the spatial effect that the use of contraceptive methods had on the behaviour of total fertility rates in municipalities of Mexico in 2020. We evaluated the joint effect of the use of modern contraceptive methods isolating the effect of the use of definitive, hormonal and non-hormonal methods by applying Bayesian spatial modelling that estimated the fixed effects separately, *i.e.* structured spatial effects and unstructured spatial effects. To our knowledge, there are no papers in the literature devoted to evaluating contraceptive use and its effect on fertility levels at the municipality level using Bayesian spatial modelling.

The M2 model indicates that the use of hormonal methods had a null statistical effect on the behaviour of fertility levels in Mexican municipalities in 2020, which contradicts the very essence of the contraceptive method. Therefore, it would be important to review the elements associated with perception, use and social acceptance of this type of contraceptive method which, on the other hand, could also be used to increase the fertility and fecundity levels of women and therefore cause the opposite effect. In any case, it would be important to deepen the research in this regard (Grindlay *et al*., 2021).

The results presented in Figure 4A suggest the existence of some high fertility clusters, which in comparison to the work presented by Tuiran (2002:504) suggests that the proportion of modern contraceptive users in some municipalities (those in orange-red shade) has been unusually low since 2000. An explanation might be because this period coincides with the presence of high and very high total fertility rates, which coincides with the results presented here. In addition, having a measure of the effect of determinants associated with fertility such as the use of contraceptive methods among women of reproductive age is a fundamental contribution to the design and generation of sexual and reproductive health programs and policies aimed at specific geographic areas.

The use of modern contraceptive methods is considered an essential element to protect women's health and rights in the sense that it is a factor that influences fertility and population growth and therefore helps to promote social welfare and economic development. The results indicate that impact on fertility associated with

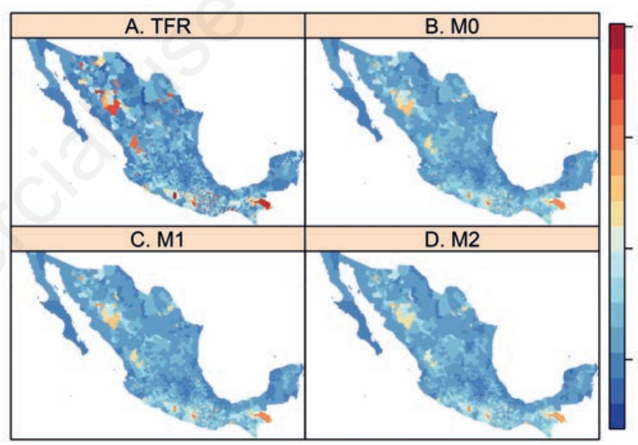

Figure 4. Municipal total fertility rate, Mexico 2020. ***Source: Prepared by the author based on R-INLA estimates.***

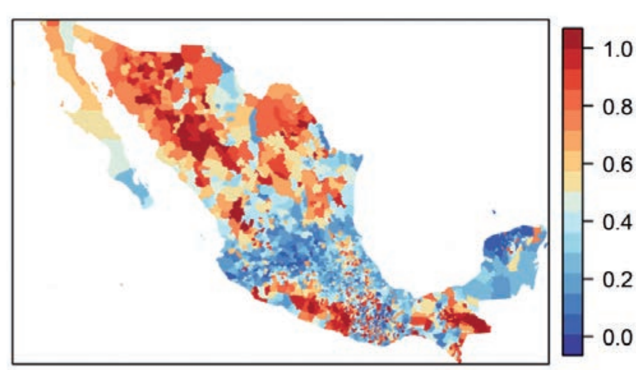

Figure 5. Probability posterior distribution. ***Source: Prepared by the author based on R-INLA estimates.***

the use of modern contraceptive methods in Mexico's municipalities by 2020 is generally effective, except for the use of hormonal methods.

It is important to note that the estimates of the spatial effects (structured and unstructured) of the three estimated models were similar as shown in Table 3. However, given that spatial models for area data are usually defined from the structure of a variance-covariance matrix that depends on the established neighbourhood relationships between areas and that all three models comprise the estimation of structured and unstructured spatial effects, the models can borrow information between neighbouring areas and capture possible overdispersion effects in specific areas. Then the estimates associated with structured and unstructured spatial effects show the existence of a clear spatial trend, as the structured spatial effects parameter clearly dominates the structure of the three proposed models once the variability not explained by the design variables included in each model are considered.

The use of TFR makes fertility levels comparable between municipalities, a fact that allowed us to evaluate differences between crude rates and the rates estimated by models M0, M1 and M2. The municipal distribution of fertility levels as presented in Figure 1A-D are the result of heterogeneous use of modern contraceptive methods in diverse social and cultural contexts, which results in marked differences in fertility, for example, the municipality of Ocosingo located in the Lacandona Jungle in Chiapas that showed a TFR of 7.3 in contrast to the municipality of Benito Juarez located in Mexico City that had a TFR of only 1.2.

Conclusions

Although Mexico's TFR by 2020 has reached replacement level, the differences between municipalities are evident, while municipalities located along the western Sierra Madre, Sierra del Nayar, the Guerrero mountains or Chiapas' Lacandona Jungle have high fertility levels associated with a low level of modern contraceptive use. In addition, another important number of urban municipalities, such as those located in the cities Mexico, Guadalajara and Monterrey, have fertility rates below the replacement level as a result of high levels of access to general health services, particularly reproductive health services.

Throughout the research, we adjusted the behaviour of the TFR using three spatial Bayesian models, which made it possible to evaluate the effect that the use of modern contraceptive methods has on the spatial distribution of fertility in Mexican municipalities. Overall, the models allowed us to quantify the effects of the use of modern contraceptive methods and to identify the presence of some clusters (groups of municipalities) with high fertility levels located in areas of difficult access such as mountains, or jungles, which makes evident the difficulty that these populations have to access any type of goods and services.

It is important to note that fertility behaviour responds to a much broader set of factors than the use of contraceptive methods alone and that their inclusion could certainly improve the explanatory capacity of the models presented here; however, the objective of this research has been to evaluate (isolate) the effect of contraceptive use on fertility. Importantly, this research represents a first effort to quantify the effect of contraceptive use on the spatial behaviour of fertility in Mexico's municipalities.

References

Blangiardo M, Cameletti M, 2015. Spatial and spatio-temporal Bayesian models with R-INLA. John Wiley & Sons, Chichester, UK.

Bongaarts J, Casterline J, B, 2018. From fertility preferences to reproductive outcomes in the developing world. Popul Dev Rev 44:793-809.

Caldwell JC, 1982. Theory of fertility decline. Academic Press, London, UK.

Cavallaro FL, Benova L, Owolabi OO, Ali M, 2020. A systematic review of the effectiveness of counselling strategies for modern contraceptive methods: what works and what doesn't? BMJ Sex Reprod Health 46:254-69.

Chesnais JC, 1992. The demographic transition: stages, patterns, and economic implications. Oxford University Press, Oxford, UK.

Davis K, Blake J, 1956. Social structure and fertility: an analytic framework. Econ Dev Cult Change 4:211-35.

De la Vara-Salazar E, Hubert C, Saavedra-Avendaño B, Suárez-López L, Villalobos A, Ávila-Burgos L, Hernández-Serrato MI, Schiavon R, Darney BG 2020. Provisión y tipo de métodos anticonceptivos en el posparto inmediato en México, 2018-2019. Salud Publ Mexico 62:637-47.

Garg S, Singh R, 2014. Need for integration of gender equity in family planning services. Indian J Med Res 140:S147-51.

Gómez RV, 2020. Bayesian inference with INLA. CRC Press, Boca Raton, FL, USA.

Grindlay K, Wollum A, Karver, J, Grossman D, 2021. Over-the-counter oral contraceptive use among women in Mexico: results from a national survey. BMJ Sex Reprod Health 47:205-10.

Instituto Nacional de Estadística y Geografía (INEGI), 2018. Encuesta nacional de la dinámica demográfica: diseño muestral. INEGI, México. Available from: https://www.inegi.org.mx/contenidos/productos/prod_serv/contenidos/espanol/bvinegi/productos/nueva_estruc/702825188504.pdf Accessed: November 15, 2021.

Juarez F, Gayet C, Mejia-Pailles G, 2018. Factors associated with unmet need for contraception in Mexico: evidence from the National Survey of Demographic Dynamics 2014. BMC Public Health 18:1-8.

Lesthaeghe R, van de Kaa DJ, 1986. Twee Demografische Transities? (Two demographic transitions?). In: D.J. van de Kaa and R. Lesthaeghe (Eds.), Bevolking: Groei en Krimp (Population: growth and decline). Van Loghum Slaterus, Deventer, The Netherlands, pp. 9-24.

Mauldin WP, Segal, SJ, 1988. Prevalence of contraceptive use: trends and issues. Stud Fam Plann 19:335-53.

Moraga P, 2019. Geospatial health data: modeling and visualization with R-INLA and Shiny. Chapman & Hall/CRC Press, London, UK.

Notestein F, 1945. Population: the long view. In: T. Schultz (Ed.), Food for the World. University of Chicago Press, Chicago, IL, USA.

Palma Cabrera Y, 2005. Políticas de población y planificación familiar. UNAM Demos 16:24-25.

Pressat R, 2020. Demographic analysis: projections on natality, fertility and replacement. Routledge, London, UK.

Pritchett L, 1994. Desired fertility and the impact of population policies. Popul Dev Rev 20:1-55.

R Core Team, 2014. R: A Language and Environment for Statistical Computing. R Foundation for Statistical

Computing, Vienna, Austria. Available from: http://www.R-project.org/ Accessed: November 12, 2021.
Rue H, Martino S, Chopin N 2009. Approximate Bayesian inference for latent Gaussian models by using integrated nested Laplace approximations. J R Stat Soc B 71:319-92.
Schrödle B, Held L, 2011. Spatio-temporal disease mapping using INLA. Environmetrics 22:725-34.
Sen A, 2001. Population and gender equity. J Public Health Policy 22:169-74.
Shuiling K, Likis FE, 2013. Women's gynecologic health. Jones and Bartlett Learning, Burlington, MA, USA.
Stover J, 1998. Revising the proximate determinants of fertility framework: What have we learned in the past 20 years? Stud Fam Plann 29:255-64.
Tone, A. 2002. Making room for rubbers: Gender, technology, and birth control before the pill. Hist Technol 18:51-76.
Torres-Pereda P, Heredia-Pi IB, Ibanez-Cuevas M, Avila-Burgos L 2019. Quality of family planning services in Mexico: The perspective of demand. PLoS One 14:e0210319.
Tuiran R, Partida V, Mojarro O, Zúñiga E, 2002. Fertility in Mexico: trends and forecast. Department of Economic and Social Affairs, Population Division, United Nations, New York, NY, USA, pp. 483-506.
Van de Kaa DJ, 2002. The idea of a second demographic transition in industrialized countries. Birth 35:1-34.
Wang X, Yue YR, Faraway JJ, 2018. Bayesian regression modeling with INLA. Chapman and Hall/CRC Press, London, UK.
Watkins SC, Menken JA, Bongaarts J, 1987. Demographic foundations of family change. Am Soc Rev 52:346-58.
Zavala de Cosío M, 1992. Cambios de fecundidad en México y políticas de población. El Colegio de México/Fondo de Cultura Económica, México.