Socioeconomic development predicts a weaker contraceptive effect of breastfeeding

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The contraceptive effect of breastfeeding remains essential to controlling fertility in many developing regions of the world. The extent to which this negative effect of breastfeeding on ovarian activity is sensitive to ecological conditions, notably maternal energetic status, has remained controversial. We assess the relationship between breastfeeding duration and postpartum amenorrhea (the absence of menstruation following a birth) in 17 World Fertility Surveys and 284 Demographic Health Surveys conducted between 1975 and 2019 in 84 low- and middle-income countries. We then analyze the resumption of menses in women during unsupplemented lactation. We find that a sharp weakening of the breastfeeding–postpartum amenorrhea relationship has globally occurred over the time period analyzed. The slope of the breastfeeding–postpartum amenorrhea relationship is negatively associated with development: higher values of the Human Development Index, urbanization, access to electricity, easier access to water, and education are predictive of a weaker association between breastfeeding and postpartum amenorrhea. Low parity also predicts shorter postpartum amenorrhea. The association between exclusive breastfeeding and maintenance of amenorrhea in the early postpartum period is also found in rapid decline in Asia and in moderate decline in sub-Saharan Africa. These findings indicate that the effect of breastfeeding on ovarian function is partly mediated by external factors that likely include negative maternal energy balance and support the notion that prolonged breastfeeding significantly helps control fertility only under harsh environmental conditions.

Breastfeeding suppresses postpartum fecundity (the capacity for reproduction). This mechanism is critically important to control fertility (actual reproduction) when contraception is uncommon. Whether dependence of the contraceptive effect of breastfeeding on environmental conditions is strong enough to have a significant effect on fertility remains unclear. Analyzing 2.7 million births in 84 low- and middle-income countries over the past four decades, we find a dramatic weakening of the breastfeeding–postpartum amenorrhea relationship that correlates with improved living standards. These results suggest that, in the absence of contraception, the effect of breastfeeding on fertility depends on the level of socioeconomic development.

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Using data on 2.7 million births from 301 demographic surveys conducted in 84 LMICs since 1975 (SI Appendix, Fig. S1), we test two predictions derived from the “maternal energetic status” hypothesis: first, that the breastfeeding–postpartum amenorrhea relationship has weakened over time in LMICs and second, that this relationship is statistically modulated by measures of social and economic development such as the Human Development Index (HDI). These patterns are not incompatible with two other competing explanations, namely a swifter transition to residual breastfeeding and changes in “nursing intensity,” since high nursing frequency might help maintain ovarian function suppressed throughout lactation (22, 23). We therefore additionally test whether the association between exclusive breastfeeding and postpartum amenorrhea has weakened over time. Since cities are known to be forerunners of demographic and social change (7, 24), we assume any hidden changes in breastfeeding practice might diffuse more slowly in rural than in urban populations and inspect the evolution of the exclusive breastfeeding–postpartum amenorrhea relationship in rural regions.

Results

Accuracy of BPF Prediction and Country Trajectories across Time. The BPF systematically overestimates the duration of postpartum amenorrhea except in sub-Saharan Africa (SSA) (Fig. 1). The median deviation from the BPF (BPF prediction − observed duration of amenorrhea) is 1.6 mo (interquartile range [IQR]: 0.1 to 3.5) overall. In SSA surveys, the median deviation is 0.4 mo (IQR: −0.5 to 1.7). By contrast, in Asian surveys, the median deviation is 7.0 mo (IQR: 3.8 to 10.0). The same pattern is observed in all sensitivity analyses (SI Appendix, Fig. S2).

Fig. 1 also shows the trajectory of selected countries across successive surveys. For instance, in Bangladesh, while breastfeeding duration has remained stable, the mean duration of amenorrhea has steadily declined, moving from 15.2 mo (95% CI 14.6 to 15.8) in 1975 to 7.7 mo (95% CI 7.3 to 8.0) in 2017. In some other countries such as the Philippines, the duration of breastfeeding has increased without notable changes in postpartum amenorrhea duration (see SI Appendix, Figs. S3 and S4 for detailed breastfeeding and amenorrhea schedules).

Breastfeeding–Development–Postpartum Amenorrhea Relationship. We assess the role played by development in these deviations from the BPF by estimating a metaregression of mean duration of postpartum amenorrhea. Given the patterns revealed by Fig. 1, we analyze separately Asia-Pacific, SSA, and the rest of the world. The breastfeeding–postpartum amenorrhea relationship is found statistically modulated by the HDI (SI Appendix, Table S1 and Fig. S5), for example, in SSA, where each 0.1 increase in HDI value is associated with a 0.07 (95% CI 0.02 to 0.13) reduction in the slope of the breastfeeding–postpartum amenorrhea relationship (baseline slope at HDI = 0.2: 0.56 [95% CI 0.39 to 0.74]).

To further investigate the role of development, we focus on groups of births defined by characteristics hypothesized as relevant for maternal energetic status (e.g., access to electricity; see Methods and SI Appendix, Fig. S6). Adding these “standard of livings” characteristics to the metaregression’s predictor, we again find a strong negative modulation of the breastfeeding–postpartum amenorrhea relationship (Table 1). For example, in energetic status groups from the Asia-Pacific region, each 0.1 increase in HDI reduces the slope of the breastfeeding–postpartum amenorrhea relationship by 0.06 (95% CI 0.03 to 0.09); access to electricity is found everywhere significantly associated with a reduced slope and/or intercept. Interestingly, the model leaves unexplained a clear SSA–Asia-Pacific difference in the duration of postpartum amenorrhea: ceteris paribus, amenorrhea duration is longer in SSA (see Fig. 2, Left).

Consistent with the maternal depletion hypothesis, higher parity is also found associated with longer postpartum amenorrhea. For instance, for a breastfeeding duration of 20 mo, a birth of order four or above is expected to increase amenorrhea duration by similar amounts in Asia (1.0 mo [95% CI 0.7 to 1.3]), SSA (1.2 mo [95% CI 1.0 to 1.4]), and the “other” regions (0.9 mo [95% CI 0.5 to 1.2]) compared to a birth of order two or three.

Breastfeeding–Development–Total Fertility Rate Relationship. To explore the demographic significance of these findings, we simulate the postpartum infecundability index $C_i$ for different values of our standard of livings variables and fixed realistic values for the other predictors. In all regions, we find a large effect of development on $C_i$ (Fig. 2, Right). For example, in Asia, an HDI of 0.3, rural residence, maternal absence of education, no electricity, and a distant water source predict a $C_i$ value of 0.65 (95% CI 0.63 to 0.68) for a breastfeeding duration of 30 mo. By contrast, an HDI of 0.5 combined with urban residence, maternal education, electricity, and a nearby water source corresponds to a $C_i$ value of 0.73 (95% CI 0.70 to 0.75). This change in $C_i$ in turn leads to a 12% total fertility rate (TFR) increase (95% CI 9 to 15). For SSA, the corresponding model prediction is a 24% (95% CI 20 to 27) TFR increase.

Exclusive Breastfeeding–Postpartum Amenorrhea Relationship. Studying the same groups of countries across surveys (SI Appendix, Tables S2 and S3), we find a rapid weakening of the association between exclusive breastfeeding and early postpartum maintenance of amenorrhea (Fig. 3). In Asian countries, an exclusively breastfeeding woman on average spent 157 d (95% CI 153 to 160) amenorrheic in the first 6 mo after childbirth in the early 1990s but only 129 d (95% CI 127 to 130) in the latest period ($P = 3.3 \times 10^{-5}$). We find a more modest, albeit distinct, decline in SSA countries: time spent amenorrheic was 159 d (95% CI 157 to 161) in the latest period versus 172 d (95% CI 169 to 175) in the early 1990s ($P = 4.5 \times 10^{-13}$). The same result is found when the analysis is restricted to rural

regions (SI Appendix, Fig. S8) or when India is removed from the set of countries analyzed (SI Appendix, Fig. S9).

Taken together, our results therefore favor improved maternal energetic status as the most likely of the competing hypotheses explaining the weakening of the breastfeeding–postpartum amenorrhea relationship observed in the past four decades.

Discussion

The energy demands of milk production, about 500 kcal a day for exclusive breastfeeding, are high enough to require a major shift in energy homeostasis (25, 26). Pregnancy is yet another energetically demanding period of a woman’s life. The suppression of ovarian function during lactation thus prevents a situation that would compromise both mother ovarian function during lactation thus prevents a situation that would compromise both mother

Table 1. Metaregression of mean duration of postpartum amenorrhea

<table>
<thead>
<tr>
<th>Region</th>
<th>Duration of breastfeeding</th>
<th>Living standards variables – Interaction with breastfeeding</th>
<th>Living standards variables – Main effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sub-Saharan Africa</td>
<td>0.50 (0.42 to 0.57)</td>
<td>-0.05 (−0.07 to −0.02)</td>
<td>0.54 (0.09 to 0.99)</td>
</tr>
<tr>
<td>Asia-Pacific</td>
<td>0.39 (0.28 to 0.50)</td>
<td>-0.06 (−0.09 to −0.03)</td>
<td>1.61 (0.95 to 2.27)</td>
</tr>
<tr>
<td>Other regions</td>
<td>0.70 (0.51 to 0.89)</td>
<td>-0.03 (−0.07 to −0.00)</td>
<td>0.00 (−0.06 to 0.03)</td>
</tr>
</tbody>
</table>

Parameter mean (95% CI). See SI Appendix, Fig. S7 for the spline functions of calendar time. In SSA, easier access to water is associated with a 0.04 (95% CI 0.00 to 0.09) reduction in slope and a 0.55 mo (95% CI −0.39 to 1.52) increase in intercept of the breastfeeding–postpartum amenorrhea relationship. Please note that on the range of breastfeeding durations effectively found in SSA (mostly >15 mo), easier access to water is therefore associated with a shorter duration of postpartum amenorrhea (since 15 × 0.04 > 0.55).

*Defined as 10 × (HDI – 0.2).

†Assuming a 0.1 change in absolute value of HDI, the posterior mean for the combined modulation effect is simply the sum of the coefficients for individual living standards variables.

While the potential abandonment of breastfeeding in LMICs long remained a matter of concern (38), it became clear in the early 1990s that there was not much evidence for such a trend (39). Thanks to information campaigns on its health benefits, breastfeeding has even being increasing since then (40). At the same time, many LMICs have rapidly developed, thus creating situations of both extended breastfeeding and improved nutritional status. A pioneering study conducted in intensely breastfeeding, well-nourished women of an Argentinian indigenous group for instance found a mean duration of postpartum amenorrhea of only 10 mo (19).

We showed here that the breastfeeding–postpartum amenorrhea relationship at the population level is much more sensitive to environmental conditions than previously thought. Our results therefore resolve the longstanding apparent contradiction between demographic evidence and reproductive ecology findings (41). To the best of our knowledge, all previously published cases of mean durations of postpartum amenorrhea above 20 mo either suffered from methodological limitations (e.g., relying on implausible reports) or pertained to deprived populations where prolonged lactation combines with other severe energetic constraints. Perhaps the most puzzling finding of the study is the unexplained difference between SSA and Asia. The HDI is not specifically centered on energetics but rather a summary measure of socioeconomic development. Defining energetic status groups aimed at moving closer to energetics, but some potentially relevant variables (e.g., the level of mechanization) remain elusive and might drive the unexplained difference. Another speculative explanation relates to social organization. Women of SSA have traditionally been economically independent and have assumed an unusually high share of agricultural work, while by contrast,
Fig. 2. Socioeconomic development predicts a weaker effect of breastfeeding on postpartum amenorrhea. "Low development" is defined here as HDI = 0.3, rural residence, no electricity, source of water 30 min or more away, no maternal education. "Higher development": HDI = 0.5 and the reverse of their low development values for the other variables. (Left) Breastfeeding–postpartum amenorrhea relationship in low and higher development situations (posterior mean and 500 replicates shown) based on a metaregression of mean postpartum amenorrhea duration (see Methods). (Right) Relationship between breastfeeding and postpartum infecundability index (Ci) in low and higher development situations (posterior mean and 95% CI). The theoretical increase in TFR that follows the low → higher development change is simply the ratio of Ci values (right y-axis; posterior mean and 95% CI). NB: the different range of breastfeeding durations chosen for the “Other regions” group reflects the range effectively observed as shown on Fig. 1.
contains detailed questions on the births within the last 5 or, for few DHS, 3 y. The mother is asked whether she still breastfeeds the child and whether her menstrual period has returned. The World Fertility Surveys (WFS) program, the forerunner to the DHS program, conducted about 40 surveys in developing countries between 1974 and 1983, a fraction of which investigated postpartum amenorrhea (9).

We pool together 284 DHS and 17 WFS covering the period 1975 to 2019 for 84 LMICs (SI Appendix, Fig. S1). In order to exploit the large sample size of the four Indian DHS, the six standard zones of India are analyzed separately, yielding 321 “pseudosurveys.”

The interview of 1,816,174 women provided information on breastfeeding and postpartum amenorrhea for 2,663,496 children born in the 5 y preceding survey. We exclude from the main analysis all births to women taking hormonal contraception at the time of interview, since this may have interfered with the normal pattern of menses resumption.

Amenorrhea Status. Though implausible, some women interviewed shortly after childbirth declare menstruation has already resumed. For all populations, we assume all women less than 1 mo postpartum are still amenorrheic. If the mother reported being pregnant at the time of interview, the last period of postpartum amenorrhea is considered over whatever the answer to the question “Has your menstrual period returned?”

Exclusive Breastfeeding Status. Individual questions relate to the foods given to each child in the 24 h preceding the interview (“Was the child given food X?”). If all the answer is no to all of these questions, the child is considered exclusively breastfed. We reconstruct individual-level exclusive breastfeeding status and then recompute median durations of exclusive breastfeeding following the DHS program’s methodology (47) and check that they match routine estimates given by the DHS program (SI Appendix, Fig. S10).

Energetic Status Groups. We define groups of births based on parity (one; two or three; four or more), residence (urban/rural), maternal access to electricity (yes/no), maternal access to water (source for water 30 min or less away round trip: yes/no), and maternal education (no education/primary or more). Defining such energetic status groups is possible for 254 of our 321 surveys. We restrict the analysis to the 4,031 groups with an (unweighted) sample size of 70 individuals or more. We estimate mean durations of amenorrhea, breastfeeding, and exclusive breastfeeding for each of these groups as described below.

Statistical Analysis. Estimation of mean durations. Retrospectively reported durations are known to be unreliable in the WFS and DHS because of recall bias and because of heaping on multiples of 3 mo. For the estimation of mean durations, we therefore predict current status data (e.g., answer to the question “Are you still amenorrheic?” using a spline function of child’s age. Writing $a$ as the probability of still being amenorrheic a month after childbirth, we fit the logistic regression $\ln \left( \frac{a}{1-a} \right) = \alpha (\text{age})$ with $a$ as a monotonically decreasing spline. The mean duration of amenorrhea is then estimated as $E(a|\text{data}) = \int \left( \frac{e^{\alpha (\text{age})}}{1+e^{\alpha (\text{age})}} \right) d(\text{age})$.

To get unbiased estimates of population means, normalized sampling weights are introduced in the model’s log likelihood. We estimate $SE$s using bootstrap resampling.

Breastfeeding–postpartum amenorrhea relationship. We estimate a Bayesian hierarchical multiregression model to assess the breastfeeding (BF)—postpartum amenorrhea (PPA) relationship while accounting for measurement error on breastfeeding and exclusive breastfeeding (EXC) durations. Writing $PA_A$, $BF_A$, and $EXC_A$ as our estimates for survey $s$ and $\sigma_{PA_A,s}$, $\sigma_{BF_A,s}$, and $\sigma_{EXC_A,s}$ as their (estimated) $SE$s, we assume the measurement error models: $PA_A = N(\mu_{PA_A,s}, \sigma_{PA_A,s}^2)$, $BF_A = N(\mu_{BF_A,s}, \sigma_{BF_A,s}^2)$, $EXC_A = N(\mu_{EXC_A,s}, \sigma_{EXC_A,s}^2)$ and a standard linear model linking true durations:

$$PPA_A \sim N\left(\left(\sigma_{BF} + \sigma_{HDI}^{*} \cdot BF_A\right) \mu_{BF}, \sigma_{BF} \cdot BF_A^2 + \sigma_{HDI}^{*}^2 \cdot HDI^2 + \sigma^2\right).$$

We define $HD1^* = 10 \times (HDI - 0.2)$ for the interpretability of regression coefficients. $\mu_{BF}$ (respectively, $\sigma_{EXC}$) is the effect of an additional month of breastfeeding (respectively, exclusive breastfeeding) on amenorrhea duration at $HDI = 0.20$, and $\sigma_{BF,HD1}^*$ is the coefficient for the $HD1^*$—breastfeeding interaction. $X_i$ is a vector of covariates, $\beta$ is a vector of coefficients, and $\alpha$ is the SE of the true relationship $\sigma$. $X_i$ includes $EXC$, the mean parity in the sample, and a spline function of calendar time (with six uniformly spaced knots) controlling for unobserved smoothly varying factors. The prior distributions for $PPA_A$, $BF_A$, and $EXC_A$ are chosen so as to approximately

Fig. 3. Proportion amenorrheic among women still exclusively breastfeeding by time elapsed since childbirth survey wave. DHS that were approximately contemporary are grouped for seven Asian countries (SI Appendix, Table S2). Similarly, DHS for 16 SSA countries are grouped (SI Appendix, Table S3). Points are proportions ± SE. Lines are predictions from a logistic regression of current status on a spline function of time elapsed since childbirth.
match the observed distributions of PPA, BF, and EXC. Weakly informative priors are set on the other coefficients.

The same analysis is then repeated on energetic status groups. Group characteristics are added to the linear predictor of PPA. The total effect of development (defined here as moving from rural to urban residence + maternal education + access to electricity and easier access to water + a 0.1 increase in HDI) on breastfeeding–postpartum amenorrhea relationship can therefore be summarized by both $\alpha_{\text{dev}} + \beta_{\text{dev}}$ and $\alpha_{\text{dev}} + \beta_{\text{dev}} + \gamma_{\text{dev}} + \delta_{\text{dev}}$, with $\gamma_{\text{dev}}$ and $\delta_{\text{dev}}$ (slope change) and $\alpha_{\text{dev}}$ (intercept change).

**Effect on the TFR.** We assess the effect of development on the TFR by translating our results on PPA in terms of postpartum infecundity index $\alpha$ that in its simplest form (neglecting age structure and postpartum abstinence) is equal to $20/(18.5 + \text{PPA})$ (6). We set the following values for the other predictors: $EXC = 2.5$ mo; survey year = 1985; mean parity = 2.5. We generate breastfeeding–postpartum amenorrhea relationships from the posterior distribution of the previous model and then translate them into breastfeeding–amenorrhea relationships. We repeat the same exercise for the energetic status groups analysis (same EXC and survey year values, parity set to “2 to 3”).

**Data Availability.** DHS data are freely available at https://www.dhsprogram.com for authorized users. All computer codes needed to replicate the analysis are available in GitHub at https://github.com/ntptodd/BAR.

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**Time spent amenorrheic by exclusively breastfeeding women.** For each group of surveys listed in Table 2, we adjust a logistic regression model for breastfeeding–amenorrhea status on a spline function of child’s age restricted to women exclusively breastfeeding and not taking hormonal contraception. We then compute the mean time spent amenorrheic in the first 6 mo postpartum as $\tilde{\alpha}$ and use bootstrap resampling for SE estimation.

The extraction of WFS data used the wfs Stata command (48). The metaregression model was written in Stan (49). All other analyses were performed in R (50) using the package rafa for the extraction of DHS data (51), the package scan for the estimation of shape-constrained additive models (52), and the package survey for bootstrap resampling (53).

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