Breast-feeding, inter-birth intervals, and household budgets: a biodemographic framework for linking changes in fertility and obesity in low- and middle-income countries.

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Abstract: Women in low and middle-income countries have simultaneously witnessed a fall in fertility and a rise in adiposity. In a biodemographic framework, these transitions are potentially linked as reproductive age women shift resources from fertility to storing energy as fat reserves. Using demographic and health survey data from 59 countries, we estimate the effect of gestation, lactation, and economic resources on total fat mass (proxied by BMI) among 262865 primiparous and nulliparous women from households in low and middle income countries. Non-breastfeeding mothers uniformly show a post-partum (pp) surplus compared to nulliparous peers—a surplus that increases with increasing household budgets (0.3 to 0.6 kg/m^2). Breastfeeding mothers, on the other hand, can move to a deficit that depends on household budget and the interbirth interval (ranging from -0.6 to 0.0 kg/m^2). These results illustrate how integrating economic and energetic resources in a common framework can help clarify the apparently disparate weight-related outcomes of fertility in different countries.

Body word count: 2750 words.

Introduction

In the past 50 years, women in low and middle-income countries have witnessed two striking transitions—a general reduction in fertility (Bongaarts 2003) and a parallel increase in adiposity (Popkin et al. 2012). If we view fertility and deposition of fat mass as two ways of allocating dietary energy, these transitions are potentially inter-related. Past research has shown variable impacts of fertility on weight gain. In high income countries and among wealthy women in low income countries, higher parity is associated with *increased* odds of being overweight (Davis et al. 2009; Gunderson and Abrams 1999; Kim et al. 2006; Kim et al. 2007; Martinez and al. 2012; Nenko and Jasienski 2009; Winkvist et al. 2003). In low and middle income countries, studies have variously shown that parity increases, decreases, or has no effect on maternal adiposity and nutritional status (Adair et al. 1983; Adair and Popkin 1992; Kim et al. 2006; Kim et al. 2007; Miller et al. 1994; Tracer 2005).

A central challenge in identifying the effect of fertility on adiposity is that pregnancy and childbirth are only one component of the energetic cost of childbirth. Notably, the costs of long-term lactation can far surpass those of pregnancy, and detailed data on both pregnancy and lactation are required to estimate these costs (Jasienska 2009).

In this study, we use data on pregnancy, lactation and anthropometrics from a demographic and health survey (MEASURE DHS) in 59 low and middle-income countries to estimate trajectories of BMI (as a proxy for total fat mass) over the course of pregnancy and through the post-partum period. This pattern is then used to examine the conditions under which deficits or surpluses arise at different stages of the post-partum period under different breastfeeding regimes.

We estimate this trajectory by starting with a prior null model for BMI in low and middle income countries which predicts BMI based on age, household expenditures per capita, urban residence, education, world region and study year (Hruschka and Brewis 2012; Hruschka et al. submitted). To eliminate the unmeasured effects of prior pregnancies and breastfeeding, we focus this analysis by comparing women who are pregnant for the first time or who recently gave birth vis-à-vis women with the same characteristics who are nulliparous.

Data and Variables

DHS datasets. Data on parity, months of pregnancy for pregnant women, months of breastfeeding since last birth, body mass index, wealth category, age, education and rural-urban residence were available for 59 countries from nationally representative, repeated cross-sectional household Demographic and Health Surveys (DHS) datasets, standardized to permit cross-country comparisons. DHS surveys conducted between 1991 and 2011 were included. For each country, there were between one and five surveys conducted in different years (average 2.2 per country), leading to a total of 132 surveys. All collection protocols for DHS surveys are available at measuredhs.com.

Sample: We restricted the analysis to nulliparous and primaparous women who had delivered in the last 24 months, and had either continued to breastfed up until the DHS interview or who had never begun breastfeeding. To maintain maximum comparability between nulliparous and non-nulliparous women, we restricted the sample to women ages 17-29. This sample included 262915 women.

Reproductive status. We coded a categorical variable indicating stage of pregnancy and lactation. The reference category for this variable was nulliparous women who were not pregnant. There were 9 categories for currently pregnant women, one for each month of pregnancy based on self-report (V213). Women classified in their 10^{th} month of pregnancy were excluded. There were an additional 23 categories for women who had continuously breastfed from birth to the study interview, one for each month post-partum up to 23 months. There were an additional 23 categories for women who had never breastfed from birth to the study, one category for each month post-partum up to 23 months. For comparison purposes, we focused on those women who either: (1) did not breastfeed in the first 23 months pp or (2) di breastfeed until the time of the interview (or at least 24 months).

As a check on the persistence of post-partum changes, we also included two additional categories: (1) primaparous women who had delivered at least 24 months prior and who had breastfed for at least 24 months and (2) primaparous women who had delivered at least 24 months prior and who had not breastfed.

Age. We included age as a linear variable centered on 20 years of age.

Household Expenditure. In low and middle income countries, population BMI closely tracks ln(household expenditure) both within and between countries(Hruschka and Brewis 2012; Hruschka et al. submitted). Household expenditure per capita (in purchasing power parity, constant 2005 international dollars) were estimated based on DHS wealth quintile and World Bank measures of gross domestic product per capita (GDP), final household consumption as percent of GDP, and income share across a country's five expenditure quintiles (see Hruschka and Brewis 2012, and Hruschka, Hadley, and Brewis submitted for the general method). All data came from World Bank Indicators, except for Zimbabwe GDP (extracted from James et al. 2012) and final household expenditures for Sao Tome and Principe, Timor-L'este, and Nigeria (extracted from UNDP).

Population differences in basal Body Mass Index. World populations differ substantially in body composition, with some populations having much smaller lean mass relative to height than others (Deurenberg et al. 1998; Hruschka et al. in press; Leonard and Katzmarzyk 2010; Rush et al. 2009). These differences can systematically bias estimates of fat reserves based on body mass index (Hruschka et al., submitted). However, with appropriate correction for these population differences, BMI shows a good fit with total fat reserves, especially among women (R2 = 0.90-0.95)(Hruschka et al. in press). To adjust for these population differences, we include a random effect for mean BMI at the 1st level administrative unit within countries (Hruschka et al., submitted).

Study Year. Survey years covered two decades between 1991 and 2011. We included this as a covariate centered on 2000.

Urban Residence. Researchers have proposed that recent trends in urbanization may play an important role in the dramatic rise of obesity in low- and middle-income countries (Popkin et al. 2012). To examine the moderating effects of urban residence, we stratify analyses by urban residence.

Education. Obesity is regularly patterned by education, though in inconsistent ways across countries (Popkin et al. 2012). We include education as a fixed effect (0 = primary or less, 1 = secondary, 3 = > secondary), the effect of which can vary as a random effect across administrative subdistricts.

Analysis. The null model for BMI is a linear mixed effects regression with the following independent variables: ln(household expenditure per capita), age, age*ln(household expenditure per capita), a categorical variable for education, and study year. We included administrative district as a random effect, and allowed the effect of ln(household expenditure per capita), age and education to vary by administrative district.

To this null model, we added the categorical variable for reproductive status to estimate differences in BMI from an equivalent nulliparous reference at different stages of pregnancy and the post-partum period and whether the mother was currently breastfeeding or not. All models were fit using the linear mixed model in SPSS 20.0 (SPSS 2009; Verbeke and Molenberghs 1997) estimated using maximum likelihood. Inferences about fixed and random effects were based on likelihood tests. The statistical significance level was set at 0.01.

To examine how household expenditures modify the effect of reproductive status on BMI, we fit the model to three sub-samples defined by household expenditures per capita—less than 2 USD per capita per day, 2-6 USD per capita per day, and more than 6 per capita per day.

Ethical Review. The DHS data collection protocol was approved by the ORC Macro Institutional Review Board (Calverton, MD) and by the relevant human subjects review board in each country. Interviewers obtained oral informed consent for the interview/survey from respondents. The analyses presented here were approved by Arizona State University's Institutional Review Board in the exempt category.

Results.

Descriptives. There were 77544 women from households with estimated spending less than 2 USD per day per capita, 104935 with estimated spending 2-6 USD per day per capita and 80386 with estimated spending greater than 6 USD per day per capita. Women from poorer households were more likely to live in rural areas and were less likely to have finished primary education. They were also more likely to report being pregnant at the interview and to report breastfeeding at the time of interview (Table 1).

Table 1. Description of samples.

	Household expenditures per capita per day		
	< 2 USD	**2-6 USD**	**>6 USD**
N	77544	104935	80386
Pregnant at interview	7.3%	6.2%	5.6%
Primaparous < 24 m pp			
Breastfeeding at interview	31.2%	20.8%	14.7%
Did not breastfeed	6.6%	6.5%	7.2%
Primiparous ≥ 24 m pp			
Breastfed to 24 m	1.1%	0.7%	0.3%
Did not breastfeed	1.7%	2.4	3.8%
Nulliparous, non-pregnant	52.0%	63.4%	68.3%
Rural	88.2%	49.8%	18.4%
> Primary education	26.2%	62.1%	86.0%
Age	20.0 (2.8)	20.7 (3.1)	21.6 (3.4)

Null Model. The null models based on economic resources, education, age and rural residence showed significant main effects. The effect of education on BMI depended on a household's economic resources. Among the lowest income households, more education was associated with greater BMI, but among the middle and highest income groups, the relationship between education and BMI reversed. Urban residence only increased BMI among the highest income group (Table 2).

BMI always increased with age, and among the lowest and middle income groups, the effect of age was modified by household resources, with increasing household resources magnifying the effect of age on BMI.

The subdistrict level random effects for the intercept and for the effects of household expenditures, age, and education were all significant (all $p < 0.001$, except for household economic resources among highest expenditure group $p = 0.01$).

Table 2. Effects of key variables from null model on BMI in three income groups. 95% confidence intervals in parentheses

	Household expenditures per capita per day		
	< 2 USD	**2-6 USD**	**>6 USD**
Education*		-	-
Graduated primary	0.2 (0.1,0.3)	-0.2 (-0.3,-0.1)	-0.5 (-0.7,-0.5)
Graduate secondary	0.3 (0.1,0.5)	-0.1 (-0.2,-0.0)	-0.3 (-0.4,-0.2)
Urban residence	0.0 (-0.1,0.1)	0.0 (-0.0,1.0)	0.2 (0.1,0.3)
Household expenditures (ln(USD per annum))	0.4 (0.3,0.5)	0.6 (0.5,0.7)	0.0 (-0.1,0.1)
Age (10 yrs)	0.6 (0.5,0.8)	1.0 (0.7,1.4)	0.2 (0.2,0.3)
Age*Expenditures	0.3 (0.1,0.6)	0.9 (0.7,1.1)	-0.1 (-0.3,0.1)

*did not finish primary school is reference category

Effect of reproductive status on BMI. Figure 1 describes the difference in BMI at different stages of pregnancy and the post-partum period for primaparous women (17-29 yr) compared to non-pregnant, nulliparous women (17-29 yr) controlling for education, household expenditures, urban residence, and age. Each panel shows results for the three household expenditure groups (< 2 USD, 2-6 USD, and > 6 USD per capita per day) for both women who never breastfed the focal infant and those who breastfed until time of interview.

Pregnancy: Each figure shows a large increase in BMI during pregnancy with the 9-month peak varying across expenditure group (+2.6 for the low group, +3.0 for middle group and +4.0 for the high group). Despite showing different weight gain during pregnancy, the groups show similar loss at parturition—approximately 2.5 kg/m^2. This leads women from the high income group to have a 1.25 kg/m^2 greater BMI immediately post-partum relative to both their pre-pregnancy weight and relative to their nulliparous peers. On the other hand, women in the poorest group return to pre-pregnancy BMI levels.

Breastfeeding in the first 24 months: Mothers who do not breastfeed showed a significant post-partum surplus which depends on household expenditures (average surplus 6-23 m post-partum = 0.6 for highest income group and 0.3 for two lower income groups). The BMI of breastfeeding mothers reduces from their post-partum weight to a trough at about 14 months post-partum, which then rebounds in the higher income groups to reach the surplus of non-breastfeeding mothers at about 23 months post-partum. The lowest income group does not experience this rebound and retains a deficit even at 23 months.

Persistence of differences after 24 months: These differences between groups defined by breastfeeding and household expenditures persist after the first 24 months post-partum (Table 3).

Figure 1. Post-conception BMI among primaparous women (either not breastfeeding or breastfeeding to date of interview) relative to non-pregnant, nulliparous women. Panel A: < 2 USD per capita per day, Panel B: 2-6 USD per capita per day, > 6 USD per capita per day. Error bars are standard errors

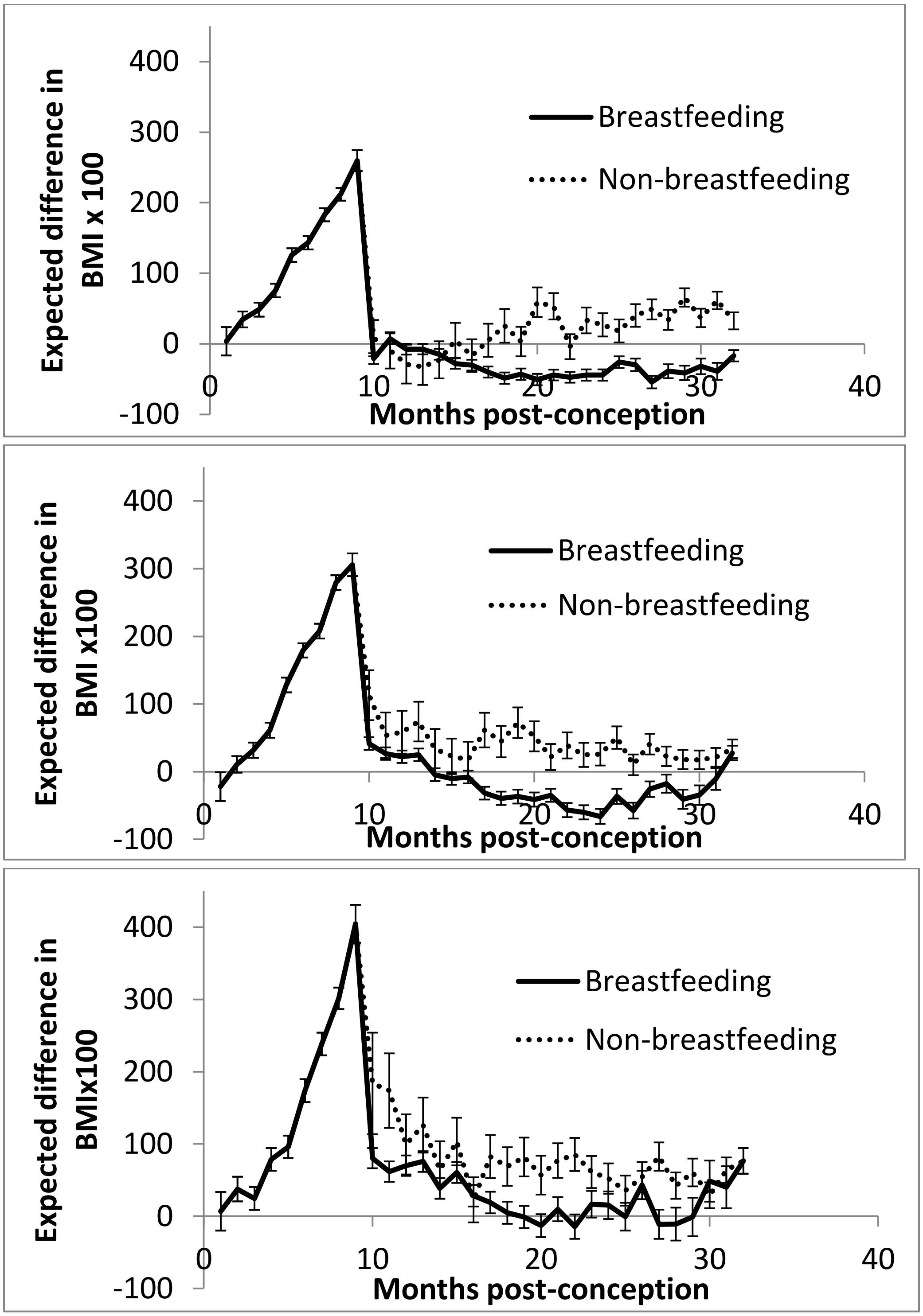

Table 3. BMI of primaparous women at 24 months post-partum and after 24 months post-partum (relative to nulliparous women). 95% confidence intervals in parentheses.

	Household expenditures per capita per day	At 24 months post-partum (kg/m^2)	After 24 months post-partum (kg/m^2)
Breastfeeding	< 2 USD	-0.2 (-0.3,-0.0)	-0.2 (-0.4,-0.0)
	2-6 USD	0.2 (-0.1,0.4)	0.6 (0.1,1.1)
	> 6 USD	0.7 (0.2,1.3)	0.7 (0.3,1.2)
No breastfeeding	< 2 USD	0.3 (0.1,0.6)	0.6 (0.4,0.7)
	2-6 USD	0.3 (0.0,0.6)	1.0 (0.8,1.1)
	> 6 USD	0.7 (0.4,1.1)	1.0 (0.8,1.1)

Discussion

These findings indicate that both the magnitude and direction of the effect of fertility on BMI depends on several factors, including the energetic costs of breastfeeding, the interval between births, and the economic resources available to a household. For example, in a very poor population that fully breastfeeds and has short intervals between births (e.g. 14 months from childbirth to conception), the first child should on average reduce BMI by 0.4 kg/m^2. Even with inter-birth intervals > 24 months, the poorest populations incur a persistent deficit of 0.2 kg/m^2after a first child's birth. On the other hand, in a population that does not breastfeed, the first child should increase BMI by 0.2 to 1.0 kg/m^2 depending on household expenditures. Thus, the effect of fertility on BMI can be either positive or negative depending on breastfeeding, interbirth intervals and economic resources.

These findings are consistent with current knowledge about the energetic costs of reproduction and breastfeeding. As expected, we observe a trade-off between energy stores and fertility, but only among women in low income groups who also breastfeed. Two factors appear to mitigate this energetic trade-off between fat reserves and fertility. First, by not breastfeeding, women in all income categories on average accrue a BMI surplus after their first child. Second, once household resources rise above 6 USD per capita per day, women have sufficient economic resources to accrue fat reserves during pregnancy and to avoid a deficit during the post-partum period whether they breastfeed or not. Interestingly, household economic resources as well as alternatives to breastfeeding appear to do more than decouple the energetic tradeoff between fat storage and reproduction. They also make it possible for women to accrue a BMI surplus while also devoting substantial energetic resources to both gestation and child-rearing.

Notably, this model can account for disparate findings in current work linking fertility and BMI. It explains the increasing odds of being overweight with higher parity in high income countries and among wealthy women in low income countries (Davis et al. 2009; Gunderson and Abrams 1999; Kim et al. 2006; Kim et al. 2007; Martinez and al. 2012; Nenko and Jasienski 2009; Winkvist et al. 2003). The importance of other variables, including breastfeeding and interbirth intervals, can also explain why studies among poor households have variously shown that parity increases, decreases, or has no effect on maternal adiposity and nutritional status (Adair et al. 1983; Adair and Popkin 1992; Kim et al. 2006; Kim et al. 2007; Miller et al. 1994; Tracer 2005).

These findings have a number of limitations. With cross-sectional data on pregnancy status, the estimated trajectory may be biased by unmeasured variables. We have tried to control for these by restricting the analysis to primaparous and nulliparous women within a restricted age range and by adjusting for a null model that has already been shown to strongly predict mean BMI at the population level within and between countries (Hruschka et al., submitted). By relying on self-reports of pregnancy and months of pregnancy, there may be underreporting, especially in the first trimester. However, this should have less of an effect on later trimesters and none on the post-partum period. Additionally, we relied on a coarse-grained measure of breastfeeding, and further attention to the quality of breastfeeding (e.g. exclusive, predominant, etc.) may yield better estimates of how breastfeeding effects BMI in the first 24 months postpartum. By limiting our analysis to nulliparous and primaparous women, it is also possible we are missing physiological adaptations to deficits occurring across pregnancies. For example, the substantial deficit observed in breastfeeding women around 14 months may not carryover through future pregnancies, as there may be powerful checks on further depletion that ultimately shunt energy away from the subsequent child. This proposal is consistent with the observation that mothers with shorter interbirth intervals bear children with lower birthweight (Baker et al. 2009). In future work, we hope to examine these effects by extending the analyses to multiparous women. Despite these limitations, these findings illustrate how considering the energetics of fertility may clarify linkages between key demographic transitions.

Conclusion

Our results show how a biodemographic model which integrates economic resources and the physiology of both reproduction and energy reserves can clarify and organize existing findings on fertility and obesity. It also makes predictions about how population shifts in several key variables, including breastfeeding, length of interbirth intervals, and economic resources, should modify the relationship between these two major demographic transitions. While a biodemographic framework can provide a unified energetic and economic foundation for understanding key demographic processes, the demographic results also contribute to existing models of human biology. Specifically, they provide valuable information about the ways that expected energetic tradeoffs may be decoupled as populations gain more resources or find alternatives to basic physiological processes, such as breastfeeding. In future analyses, we will examine to what degree these effects play a role in changing obesity and fertility rates in low and middle-income countries and how they may interact with infant birthweight.

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