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Variation in Wealth and Educational Drivers of Fertility Decline Across 45 Countries

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Evolutionary demography: the dynamic and broad intersection of ecology and evolution

Variation in wealth and educational drivers of fertility decline across 45 countries

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Abstract

Fertility decline in human populations is an inherent evolutionary puzzle with major demographic, socio-cultural and evolutionary consequences. The individual level predictors of fertility decline are numerous, but the way these effects vary by country and how they are causally mediated by other factors has received relatively little attention. Here we take a multilevel approach to compare similarities and differences in the primary predictors of contemporary fertility declines—wealth and education—across 45 countries in Africa, Asia, Central and South America, the Caribbean, and the Middle East using Demographic and Health Survey (DHS) data collected from 2003 to 2015. We use multilevel models to understand variation in the slopes of these predictors on fertility, and structural equation models to examine the causal pathways by which they take their effects, focusing on four mediating variables: local mortality and birth rates, women's work status, and contraceptive use. We find that associations between wealth and fertility differ substantially across populations, while associations between education and fertility are consistently negative. The mediators also vary: community-level birth rates and women's contraceptive use are important mediators between education, wealth and the number of children born across a wide variety of countries, but community-level mortality rates and women's work status are not. We discuss our results in the context of different causal pathways that reflect cultural and biological evolutionary dynamics as simultaneous and interacting drivers of fertility decline.

Keywords Demographic transition · Demographic and health surveys · Education · Evolutionary demography

Introduction

One of the biggest puzzles in human evolutionary demography is the dramatic reduction in fertility that has occurred during the demographic transition. Fertility decline began in late-eighteenth and early-nineteenth century France and has occurred (or is underway) throughout the rest of the world (Knodel and van de Walle 1979; Chesnais 1992). Given that evolutionary theory predicts that organisms should maximize their reproductive success, why are people curtailing their fertility to such a dramatic degree (Vining 1986; Kaplan 1996; Borgerhoff Mulder 1998; Mace 2014; Colleran 2016)?

There is a fairly clear negative relationship between wealth and fertility rates across countries (Myrskylä et al. 2009; Lutz and Samir 2011). Judging by population level measures including gross domestic product (GDP) and human development index (HDI), wealthier countries, broadly speaking, have lower fertility (Myrskylä et al. 2009). It is often assumed that this pattern of high wealth and low fertility is replicated within countries. And while in Western populations, wealthier and higher status people (particularly women) tend to have relatively lower fertility (Vining 1986; Kaplan et al. 2002), there is clear evidence that this

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is not always the case (Clark and Hamilton 2007; Dribe and Scalone 2014).

Evolutionary demographers study variation in fertility decline to understand how and why people choose lower than optimal fertility in modern contexts. The field has long been interested in the reasons why wealth has a positive association with fertility in most small-scaled and less-market-integrated populations but a negative relationship in large scale market based ones (Kaplan 1996; Mace 1998; Hill and Reeve 2005). This puzzle arises because like all animals, humans are assumed to have translated increased resources into increased reproductive output for most of their history. Within most small-scale subsistence economies, wealthier people tend to have higher fertility. Where wealth comes primarily in the form of food energy, there is a strong association between wealth and reproductive physiology: those with more wealth have shorter birth intervals, greater reproductive success, and improved child survivorship (Kaplan et al. 2002). Where wealth is accumulated through goods, objects, and materials (sometimes described as 'extra-somatic wealth'), this wealth (particularly for men) is often associated with greater reproductive output (Chagnon 1979; Flinn 1986; Cronk 1991; Borgerhoff Mulder and Beheim 2011).

The reasons for a 'switch' in the direction of wealth-fertility relationships are still unclear: how do reproductive incentives change as populations become more market oriented and integrated? And to what extent are these differentially aligned with economic considerations and changing cultural values about reproduction (Kirk 1996; Borgerhoff Mulder 1998; Shenk et al. 2013; Colleran 2016)?

Low-fertility strategies apparently depend on fundamental changes in the prevailing economic system in the course of the subsistence transitions that accompany market integration and economic development, including changes in the types of wealth and status that matter for socio-economic success as well as levels of inequality (Colleran et al. 2014; Shenk et al. 2016), change in inheritance and migration patterns (Colleran 2014), social networks (Madhavan et al. 2003; Colleran et al. 2014) and kin interactions (Newson et al. 2005; Mace and Colleran 2009; Colleran and Mace 2015). But the mechanisms driving the change and the extent to which cultural and economic patterns coevolve in the process remains a major source of contention (Borgerhoff Mulder 1998; Shenk et al. 2013; Snopkowski and Kaplan 2014; Colleran 2016; Stulp and Barrett 2016). Certainly, wealth-generating and wealth-valuing systems differ across subsistence types and cultures. This means that the very meaning of wealth, its uses, economic relevance, cultural value, and the expectations about how it is appropriately used differ depending on a wide range of factors that may be poorly approximated by the measures designed to capture economic development across cultures (e.g., Human Development Index, Gross Domestic Product).

The negative relationship that emerges in the course of demographic transition defies a straightforward evolutionary explanation of reproductive decision-making as the outcome of a fitness-maximizing psychology (Perussé 1993; Borgerhoff Mulder 1998; Low et al. 2002; Alvergne and Lummaa 2014; Colleran 2016). Previous work has clearly shown that individuals who have more children in one generation tend to have more descendants in subsequent generations (Kaplan et al. 1995; Mueller 2001; Goodman et al. 2012). Contemporary high-investing, low-fertility reproductive strategies do not appear to maximize reproductive success over any time span that has yet been studied (Kaplan et al. 1995; Low et al. 2002; Goodman et al. 2012). Yet, despite widespread interest in the factors that may alter the direction of the relationship between wealth and fertility, little research has examined this question cross-culturally as opposed to examining variation at the regional or community level (Low and Clarke 1991; Alvergne and Lummaa 2014; Colleran et al. 2015). An important cross-cultural contribution by Skirbekk (2008) examined broad fertility-status trends over a large array of populations through time, covering a time span of over 700 years. This impressive study was able to show that there is a switch in fertility differentials between high and low status individuals over time (as measured by social class or occupational status): high status individuals switch from having relatively higher fertility to having relatively lower fertility. This work grouped together both educational and income/wealth measures as a general proxy for status. The overall negative relationship between status and fertility was mainly driven by education differentials, which have had more consistent negative associations with fertility than either wealth or income for as long as education has been available (Skirbekk 2008). Collapsing wealth and status into a single parameter is an important limitation from the perspective of evolutionary behavioural scientists, who often conceptualise wealth and status as different parameters (Hopcroft 2006; von Rueden et al. 2008; Huber et al. 2010; Bowles et al. 2010; Borgerhoff Mulder and Beheim 2011; Colleran et al. 2015), broadly construing wealth as 'resources' and status as 'access to resources'. Moreover, while it is often argued that wealth is a multidimensional construct (Braveman et al. 2005; von Rueden et al. 2008; Colleran et al. 2015) with a great deal more uncertainty in its measurement and effects on fertility than for education [in particular women's education (Lutz and Samir 2011; Lutz and Skirbekk 2013)], in fact education is also multidimensional in its effects (Basu 2002; Colleran et al. 2014; Snopkowski and Kaplan 2014). Among other things, education can be considered to confer social and economic status, to represent a body of knowledge altering women's ability to control both reproduction and mortality (Bicego and Boerma

1993; Glewwe 1999; Pena et al. 2000), or to proxy access to economic and social opportunities and information. Consequently, it is increasingly debatable whether the association between education and fertility is directly causal or mediated by other factors (Lutz and Skirbekk 2013; Snopkowski et al. 2016; Tropf and Mandemakers 2017).

In this paper we use multilevel models to understand variation in the slopes of these predictors on fertility, and structural equation models to examine the likely causal pathways by which they take their effects. While we cannot match the scope of the data presented in Skirbekk (2008), we address important limitations of this previous work; (1) a consistent, standardised measure of wealth that can be directly compared across populations; (2) use of covariates allowing statistical 'control' of other well-established predictors of fertility decline; (3) an explicit multilevel approach that captures the cross-cultural structure in the data and which can handle varying relationships between wealth, education and fertility by population; (4) use of a structural equation model to identify the mediators of education and wealth on fertility, and (5) an assessment of whether these possible mediators are cross-culturally consistent. Our analysis therefore combines the strength of multilevel varying slope models with structural equation models enabling us to see the path-dependence of these overall effects.

We treat wealth and education as separate conceptual elements in the process of fertility decline, which has important analytical implications. In previous work, we have argued that educational status is likely to influence whether increased wealth is translated into higher or lower fertility (Colleran et al. 2015). In other words, education is claimed to causally determine the effect of wealth on reproductive output (without, of course, being mutually exclusive, since there will always be feedback between them). Increasingly, educational effects on fertility are argued to be a proxy for broader contextual, cultural or familial effects (Colleran et al. 2014; Tropf and Mandemakers 2017) which further supports the distinction we advocate. It also means that we must do more to understand the proximate mechanisms by which education and wealth achieve their effects on fertility, to get a closer approximation of the underlying causal structure of fertility decline (Snopkowski et al. 2016). Earlier work has used standard regression techniques to examine intercorrelations between different predictors of fertility (Martin and Juarez 1995); our approach uses structural equation modelling to more explicitly examine the various pathways by which education and wealth may influence fertility in different contexts. In previous work, we found that the effects of wealth and education differed substantially between 22 different communities of a small-scale farming population in rural Poland (Colleran et al. 2015). We also examined the path-dependence of educational effects on fertility in three different populations for which comparable anthropological data were available (Snopkowski and Kaplan 2014; Snopkowski et al. 2016). We found that education influenced fertility outcomes (both age at first birth and number of births) via several different pathways—although these paths varied by population. For example, education was associated with reductions in fertility via increases in women's labour force participation in Poland, but employment did not have this mediating effect in Matlab, Bangladesh and San Borja, Bolivia. Here, we extend these approaches across 45 countries in Africa, South and Southeast Asia, Central and South America, the Caribbean, and the Middle East.

We examine four likely mediators of educational and wealth effects on fertility at both the community and individual level: child mortality and birth rates in a woman's local community, women's labour force participation, and women's contraceptive use. While there are other variables that might have explanatory value in our models, we selected these variables because they are associated with clear directional hypotheses, were available across our surveys and allowed us to minimize exclusion of subjects due to missing information. For instance, if we had included information related to the husband, we would have to exclude single, divorced, and widowed women.

There are several ways that each of our candidate mediators may channel how wealth and education are associated with fertility. First, purely biologically, child mortality terminates breastfeeding and increases the 'risk' that another child will be conceived, increasing fertility rates when infant mortality is high and thus potentially exacerbating mortality rates too. Second, parents may 'replace' children who die in line with their own or a locally desired family size and/or as 'insurance' against the possibility of future child deaths or support in older age, again more common in areas with high child mortality (Palloni and Rafalimanana 1999). These 'risks' and incentives, which may largely result from exogenous factors affecting mortality, could alter the payoffs to translating wealth or educational status into children. Interestingly, while reduced child mortality is usually observed prior to fertility declines (Mason 1997) and is widely assumed to be an essential prerequisite to fertility change (Doepke 2005; Dyson 2010), empirical evidence actually suggests that the effect of changing child mortality rates on fertility is relatively small (Palloni and Rafalimanana 1999). Local fertility rates in turn can influence women's reproductive output by providing information about locally appropriate reproductive behaviour including the conditions for reproduction, and/or incentives to, or constraints on, higher or lower fertility through social transmission. The cultural transmission of ideas, norms, and information is of course also influential in one's fertility decision-making (Cleland and Wilson 1987; Colleran 2016), especially since individuals may look to others in their local networks and communities to determine appropriate reproductive strategies (Behrman and Watkins 2001; Behrman et al. 2002; Alvergne et al. 2011; Colleran et al. 2014; Snopkowski and Kaplan 2014; Colleran and Mace 2015).

Women's labour force participation may mediate how wealth or education influences fertility outcomes by creating time-constraints on childbearing such that working women are less likely to have additional children (Ermisch 1989; Hoem and Hoem 1989) or through increasing women's decision-making autonomy, which may reveal underlying preferences for lower fertility (Dyson and Moore 1983; but see Moya et al. 2016). Contraceptive use is another possible mediator we examine in our models because its relationship with both wealth and education has been the subject of much research (Ainsworth et al. 1996; McNay et al. 2003; Cleland et al. 2006; Bongaarts 2008). While education likely improves information about contraceptives and wealth appears to increase access to them (Mace and Colleran 2009; Alvergne et al. 2011), previous research in high-fertility contexts has found a positive relationship between contraceptive use and fertility, especially in sub-Saharan Africa, where women who have had many children and want to end their reproductive careers or space future births are often the ones most likely to use contraceptives (Caldwell and Caldwell 1987; Bledsoe et al. 1994; Mace and Colleran 2009; Alvergne et al. 2013).

Methods

We use available data from the standard demographic and health surveys (DHS) that met the following criteria: (1) the country was experiencing fertility decline at the time the survey was conducted (assessed through examining total fertility rates (TFR) the year before and after the survey from https://ourworldindata.org/fertility), (2) the survey was collected using the questionnaire recode IV through VII (earlier surveys did not include the wealth index score we use), and (3) the survey results are publically available. DHS surveys are only carried out in less-developed countries or countries receiving US foreign aid. Countries are surveyed repeatedly, and we examine all applicable survey waves for each country (http://www.dhsprogram.com/). Thirty-six of our sampled countries had multiple waves of data (ranging from two to four waves), generating a total of 85 survey waves that included the necessary variables. The maximum number of waves within a country is four (Bangladesh) but the most common number is two. Given that we compare across countries and within-countries, we have two datasets: (1) a sample of 45 countries with one wave of data per country [the most recent survey completed; $n = 803{,}426$; see Table S1 in Electronic Supplementary Material (ESM)] and (2) a sample of 85 survey waves in 36 countries that include countries with at least two cross-sectional waves in two different years (Table S2 in ESM). Figure 1 displays the sampled countries colour coded by total fertility rate (TFR) at the time of the most recent survey and an indication of

Fig. 1 Map of countries included in analysis. Darker colours represent higher TFR's at the time of the most recent survey. Stars represent countries where multiple waves of data were collected, while triangles represent countries surveyed once. Mapping publishing platform credit to: Harvard WorldMap http://worldmap.harvard.edu

whether the country contributed multiple waves of data. The surveys were collected between 2003 and 2015 and range in total fertility rates (at the time of the survey) from 2.15 (Bangladesh in 2015) to 7.6 (Niger in 2006). Women aged 15–49 were interviewed about their reproductive and marital histories. In 41 countries, women were interviewed regardless of marital status, while in four countries (Egypt, Jordan, the Maldives, and Pakistan) only ever-married women were included (along with Indonesia's 2007 wave). We include all women for whom the necessary data were available in our analyses, to capture reproduction outside as well as inside marriage. We therefore do not restrict our analyses to married women only.

We use the measures of wealth and education created by the DHS. The DHS wealth index is a composite measure of household wealth including information on: the household's water supply, sanitation facilities, floor type; whether the household has electricity, a domestic servant, owns agricultural land, a television, a vehicle (and type); and the number of people per sleeping room. The index is constructed using Principal Component Analysis (Rutstein and Johnson 2004) and details for each survey can be found here: http://www.dhsprogram.com/topics/wealth-index/Wealth-Index-Construction.cfm. Education is defined as the education of the woman in single years and varies from an average of 1.8 years in Burkina-Faso to 10.9 years in Jordan. We standardised these measures of wealth and education within countries to have a mean of 0 and SD of approximately 1 (in the majority of countries the wealth index was already standardised). This allows us to directly compare the predicted effect of a 1 SD increase in wealth and education on fertility across different countries, while allowing wealth and education to have country-specific meanings. Standardising within country (i.e., group-mean centring) means that we measure wealth and education relative to the country of the individual, not on an absolute scale across all countries. It also means that computational models are more likely to converge. For comparison we also ran our analysis using untransformed versions of these variables across the 45 countries. We ran all our analyses on two different dependent variables: "number of births" and "number of living children", which we use as measures of 'fertility'. Our results do not differ substantially by outcome variable. We therefore report only models using the number of live births as the dependent variable. This measures the total number of children ever born and includes children who were born alive but later died but excludes pregnancies that resulted in a miscarriage, abortion or stillbirth. Full details for both outcomes are reported in the supplementary materials (Tables S3–S10). We also report our results based on standardised variables. Again, full details of the unstandardised models are available in the supplementary materials (Tables S5, S6, S9, S10).

Our analysis involves multilevel and standard Poisson regression and structural equation modelling (SEM) techniques, which respectively take care of the non-independence of individuals within countries and the mediators of the relationships between wealth, education and fertility. The multilevel analysis replicates the analysis strategy described in Colleran et al. (2015). Here we explicitly compare the varying effects of wealth and education on fertility across the subsample of 45 countries with one wave each. We then assess whether there is variation between different survey waves within those 36 countries that had multiple waves of data, using standard (i.e., not multilevel) Poisson regression techniques. In other words, we ran a separate Poisson regression model for each wave of data (85 waves from 36 different countries). All regression models control for age and age^2, work status, contraceptive use, and community level mortality and fertility rates. All data handling and multilevel analysis was carried out in R v.3.12 (R Core Team 2014) using the 'lme4' (Bates et al. 2012), 'blme' (Dorie 2013) and 'languageR' (Baayen 2011) packages. 'lme4' has known convergence issues with large datasets (Bates et al. 2012) so we follow the developers' guidelines on scaling and standardising variables as well as using a range of optimisers to aid and assess convergence.

We then develop comparative SEMs across all 45 countries using the maximum likelihood with missing values method in STATA (v. 13), using a similar analysis strategy as found in Snopkowski et al. (2016). All SEM models test a model where education and wealth independently predict community-level mortality and fertility, women's work status, and contraceptive use, which in turn, influence number of live births. Age is included as a predictor of all individual-level variables. Wealth and education also have direct paths to the number of live births to determine the direct effect of these variables after controlling for likely mediators. A visual representation of this structural equation model (also

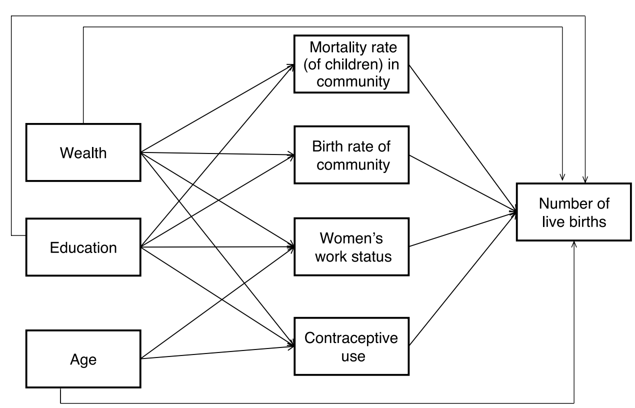


Fig. 2 The hypothesised structural equation model used to analyse the mediating pathways from both education and wealth to the number of births

known as a path model) can be seen in Fig. 2. While we present these models as a series of directed paths, SEM cannot demonstrate causality and all results should be interpreted as correlations.

Community-level variables are calculated at the cluster level; the smallest geographical survey unit for DHS surveys. Clusters consist of a number of adjacent households in a geographical area. In urban areas, this may be a city block, while in rural areas this may be a village, a part of a village, or a group of small villages (ICF International 2012). Community-level mortality is defined as the number of children who died divided by the number of live births of surveyed women (aged 15–49) within the cluster. Community-level fertility is defined as the average birth residual controlling for age within the cluster, calculated by fitting a linear model of number of births by age for each country, calculating the residual for each woman and taking the average residual for all surveyed women per cluster. Communities with higher average residuals have higher fertility (controlling for age) than the overall average for their country. Women's work status is an ordinal variable measured as no work in the past year (represented by 0), works occasionally (1), works seasonally (2), and works all year (3). In the SEMs, we treat this variable as continuous and interpret it as analogous to the intensiveness of a woman's labour-force participation. Finally, contraceptive use is an ordinal variable in the multilevel models measured as no contraceptive use (0), traditional method of contraceptive use (1), and modern method of contraceptive use (2). In the SEMs this was included as a binary variable (no method versus any method).

Results

The association between wealth and fertility varies greatly by country, but education's relationship with fertility is consistently negative

We find that the association between wealth and fertility varies qualitatively as well as quantitatively by country (Fig. 3a), but the association between education and fertility is universally negative (Fig. 3b). A 1 SD increase in wealth, relative to other people in the country, is associated with a range of reproductive outcomes, from a 12% decrease in fertility in the Philippines [$e^{\beta}=0.88$, $\beta=-0.13$, 95% CI(β) (-0.12, -0.14)], β, regression coefficient, CI, confidence interval, (see Table S3 in ESM) to a 3% increase in fertility in Niger [$e^{\beta}=1.03$, $\beta=0.03$, 95% CI(β) (0.04, 0.01)], though flatter slopes in many countries indicate that the relationship is not always strong. These values must be understood in the context of the range of standard deviations in a particular country (see Tables S3 and S4 in ESM): these coefficients translate into widely varying outcomes across countries.

For education the relationships are less varied. A 1 SD increase in education, relative to other people in the country, is associated with a 27% decrease in fertility in Comoros [$e^{\beta}=0.73$, $\beta=-0.31$, 95% CI(β) (-0.29, -0.34)] to a 4% decrease in fertility in Egypt [$e^{\beta}=0.96$, $\beta=-0.04$, 95% CI(β) (-0.03, -0.05), see Table S4 in ESM]. The results are qualitatively comparable when we use unstandardised variables, i.e., treating a 1-year increment in schooling as the unit of measurement instead of 1 SD (Tables S5 and S6 in ESM). So a 1-year increase in schooling is associated

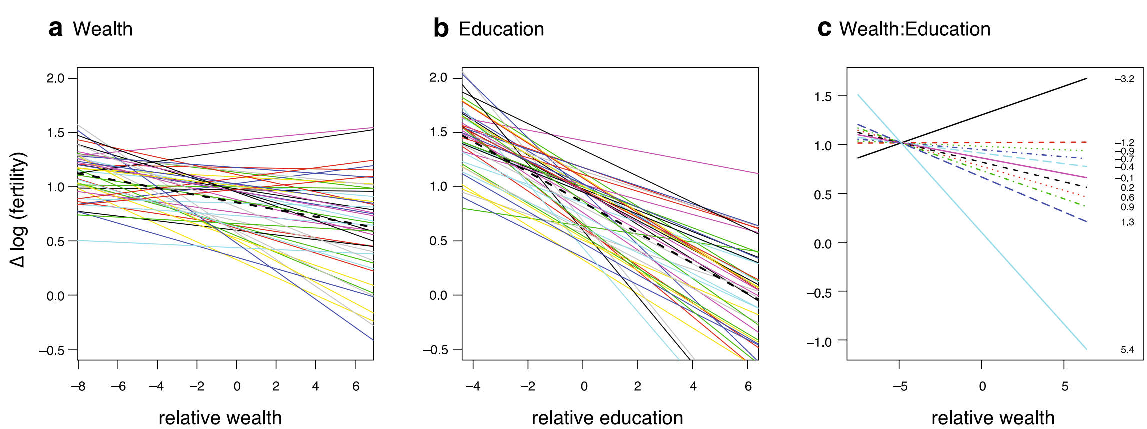


Fig. 3 Varying slopes of **a** wealth and **b** education on fertility across the 45 countries represented by the DHS data. Plots show the marginal (model-adjusted) regression slope of each variable in each country as produced by the multilevel models, with different countries represented by coloured lines. The black dashed lines show the predicted averaged or 'fixed' effect, i.e., the association between wealth or education and fertility when the slopes are not allowed to vary. Note that the variables are centred on zero, which represents the mean value of wealth or education within a particular country. A one-unit interval on the x-axis represents a standard deviation in the predictor variable. **c** Interaction between wealth and education. Here each line represents the relationship between wealth and fertility for a particular point on the scale of education. The numbers attached to each line represent the exact point on the scale of relative education

with a 29% decrease in fertility among women living in the Comoros, where years of schooling range from 0 to 20, whereas a 1-year increase in schooling is associated with a 4% decrease in fertility in Egypt, which is comparable to the estimate from the standardised model, where the range of education is 0–23 years.

We argued that the education level of an individual could alter how wealth influences fertility. In support of this hypothesis, we find a significant interaction overall between wealth and education (Fig. 3c), suggesting that these two variables should not be understood in isolation from each other when considering fertility differentials. For every 1 SD increase in education, the association between wealth and fertility is on average 3% more negative [$e^{\beta}=0.97$, $\beta=-0.029$, 95% CI(β) (−0.027, −0.03)]. Taking the quintiles displayed in Fig. 3c as an example, this interaction implies that among women with the highest levels of education, more wealth is translated into fewer children. The opposite is the case for women with the lowest levels of education: more wealth is translated into more children.

Wealth has a more positive effect in high fertility regimes

Figure 4a shows that in countries with high total fertility rates, the relationship between wealth and fertility within a country tends to be positive, other things equal, whereas in countries with relatively low TFRs, the relationship between wealth and fertility is more negative. This variation probably represents points on a continuum of economic development but also socio-cultural variation that regulates the overall way that wealth is associated with fertility. Notably, although countries located in sub-Saharan Africa are clustered together at the higher end of the distribution of TFR, there is also very clear variation between these countries in how wealth is associated with fertility. In contrast, the relationship between education and fertility, shown in Fig. 4b, is more consistent across countries, in most cases having a small negative association. These results are consistent with those found by Skirbekk (2008). The interaction between wealth and education does not itself appear to vary substantially by country.

Within-countries, the effects vary over time, but not consistently

Our Poisson regression analyses of each wave of data within the 36 countries for which multiple waves were available indicate little variation in the magnitude of the associations between wealth, education and fertility in different survey years, though the patterns are not consistent across countries. In some countries, for example Ghana (3 waves), the association between education and fertility is more negative in later survey years than it is in earlier ones, indicating somewhat steeper negative slopes of wealth and education on fertility as the overall fertility rate declines. A 1 SD increase in education was associated with a 9% [$e^{\beta}=0.91$, $\beta=-0.09$, 95% CI(β) (−0.11, −0.07)] decrease in fertility in 2003 when the TFR was 4.51, a 14% [$e^{\beta}=0.86$, $\beta=-0.15$, 95% CI(β) (−0.17, −0.13)] decrease in 2008 when the TFR was 4.19 and a 13% [$e^{\beta}=0.87$, $\beta=-0.14$, 95% CI(β) (−0.16,−0.13)] decrease in 2014 when the TFR was 3.79. The corresponding measures for wealth, which do not vary substantially across years, are a 7% [$e^{\beta}=0.93$,

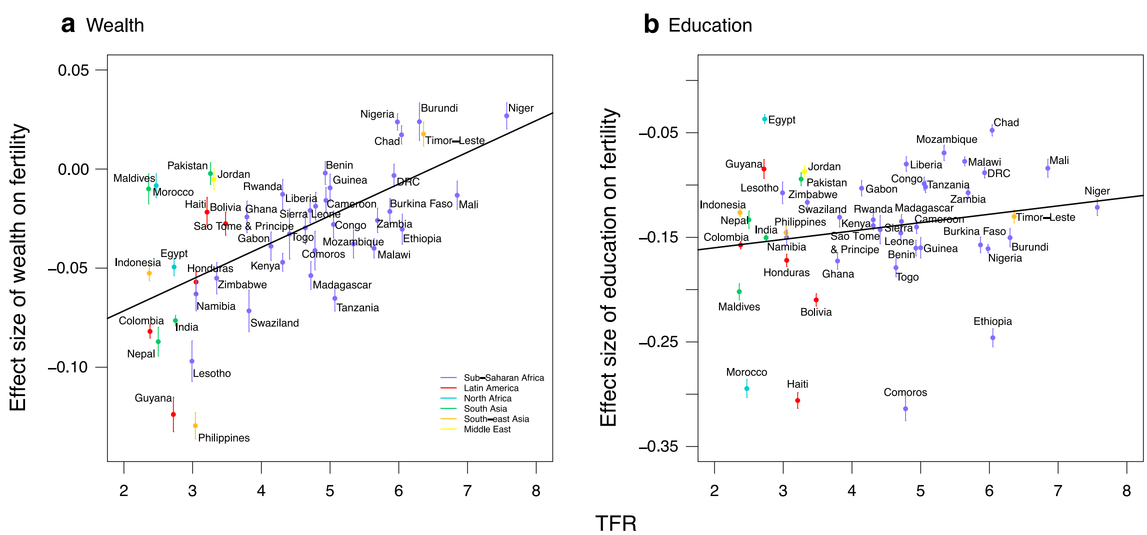


Fig. 4 Varying beta coefficients (±SE) of **a** wealth and **b** education on fertility, shown in order of contemporary total fertility rates and colour-coded to represent different macro-regions. Note that the sign of the beta coefficients for the correlation between wealth and fertility spans both positive and negative values, whereas the corresponding beta coefficients for education are always negative

$\beta = -0.07$, 95% CI(β) (−0.10, −0.04)] decrease in fertility in 2003, a 3% [$e^{\beta} = 0.97$, $\beta = -0.03$, 95% CI(β) (−0.06, −0.01)] decrease in 2008 and a 6% [$e^{\beta} = 0.94$, $\beta = -0.06$, 95% CI(β) (−0.08, −0.04)] decrease in 2014. These results are comparable when using number of living children as the outcome of interest (see Figs. S3 and S4 in ESM).

In other countries, such as Bangladesh [which has the most (four) waves of data], the estimated slopes are comparable in different years, indicating very modest changes over time. There, a 1 SD increase in wealth was associated with a 1% [$e^{\beta} = 0.99$, $\beta = -0.01$, 95% CI(β) (−0.02, 0.00)] decrease in fertility in 2004 when the TFR was 2.7, a 3% [$e^{\beta} = 0.97$, $\beta = -0.03$, 95% CI(β) (−0.05, −0.02)] decrease in 2007 when the TFR was 2.44, a 1% [$e^{\beta} = 0.99$, $\beta = -0.01$, 95% CI(β) (−0.02, 0.00)] decrease in 2011 when the TFR was 2.24 and a 2% [$e^{\beta} = 0.98$, $\beta = -0.02$, 95% CI(β) (−0.03, −0.01)] decrease in 2014 when the TFR was 2.15. The corresponding measures for education are an 11% [$e^{\beta} = 0.89$, $\beta = -0.12$, 95% CI(β) (−0.13, −0.10)] decrease in fertility in 2004, a 10% [$e^{\beta} = 0.90$, $\beta = -0.11$, 95% CI(β) (−0.12, −0.09)] decrease in 2007, a 10% [$e^{\beta} = 0.90$, $\beta = -0.11$, 95% CI(β) (−0.12, −0.09)] decrease in 2011 and a 9% [$e^{\beta} = 0.91$, $\beta = -0.09$, 95% CI(β) (−0.10, −0.08)] decrease in 2014.

Since most countries have only two waves of data, it is difficult to determine significant variation in these estimates with much confidence, or to put forward any strong claims about the cross-cultural variations in this patterning across time. However it does suggest that the cross-sectional between-country differences we observe above are larger than the within-country differences over the available time-spans.

A linear regression shows that TFR accounts for about 20% of the variation in the wealth coefficients (adjusted $R^2 = 0.20$), with a one unit increase in TFR associated with about a 1% [$\beta = 0.012$, 95% CI(β) (0.01, 0.02)] increase in the magnitude of the association (i.e., becoming more positive in the association with fertility). Other macro-level predictors such as GDP (measured both in US dollars and purchasing power parity) are neither correlated with the wealth coefficients nor account for much variance (adjusted $R^2 < 0.03$). We do not observe any comparable correlations between TFR or GDP and the education coefficients (Fig. 5).

Both wealth and education affect the hypothesised mediators of fertility in similar ways—except for women's work status

Figure 6 displays the structural equation model that was executed for each country, where each pathway is designated by the proportion of countries that have either a positive (pink, solid line), negative (blue, dashed line) or non-significant effect (black dotted line) for the given relationship, and where the thickness of the line indicates the proportion of countries where that effect was found. Each line is labelled with the percentage of countries where a statistically significant association was found followed by a symbol to represent the direction of the association. For example, the relationship between education and contraceptive use is positive in the majority (80%) of counties. The remaining 20% of countries either exhibited significant negative associations or non-significant trends. Details for each country (including fit statistics) can be found in Table S11 in ESM.

Consistent with the multilevel models, education has a consistent negative association with total number of live births (significant in all 45 countries) net of controls whereas wealth varies by country: in 55% of countries there is a significantly negative association, in 16% there is a significantly positive association, and in the rest there is no significant association. Both wealth and education are significantly negatively associated with community-level child mortality and birth rates and significantly positively associated with contraceptive use in the vast majority of countries.

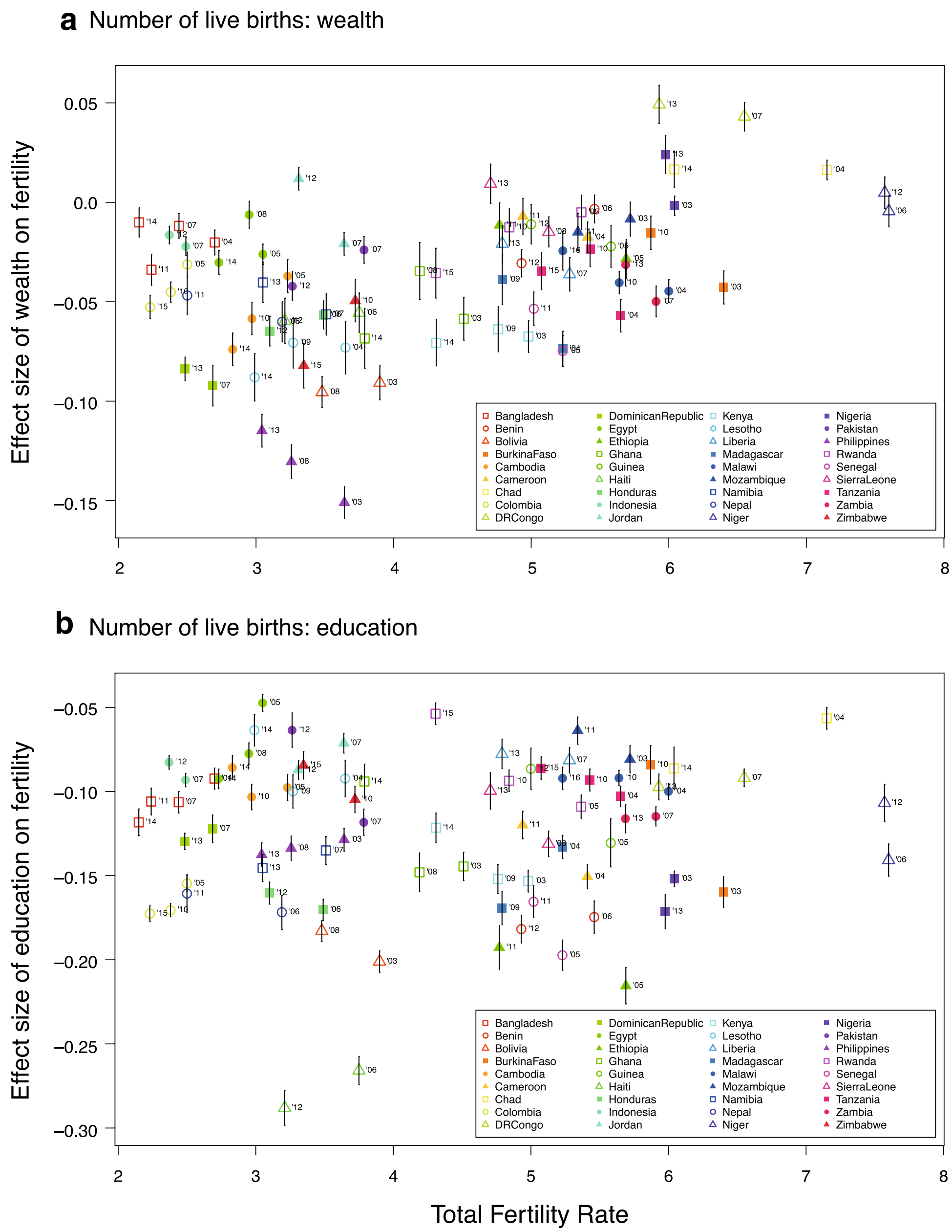
But there are some important differences. Wealth is more consistently associated with women's intensity of labour-force participation across countries than is education. Figure 7a displays these differences across countries. Women in wealthier households tend to work less in over 80% of countries. Women with more education tend to work more in 50% of countries, but in 30% of countries they work less, and in the remaining 20% of countries, education is not significantly associated with women's work status (see Fig. 7b). This pattern seems to be driven by differences between high and low fertility countries. Among the subset of relatively lower-fertility countries (those with TFRs ≤ 3), education is positively associated with intensiveness of labour-force participation (or has no effect in India). In higher-fertility countries (particularly those with TFRs > 4.5), the association between education and labour market participation is highly variable: more countries exhibit a negative association between education and women's work status than a positive one.

Contraceptive use and local birth rates, but not mortality or work status, have independent associations with fertility in the majority of countries

Both contraceptive use and community-level birth rate are significantly positively associated with fertility in more than 95% of countries surveyed. This pattern for contraceptive use is in line with much research in sub-Saharan Africa showing that women who have many children are often more likely to adopt contraceptives, but it is surprising to see that this association is also widespread outside of this region.

On the other hand, community-level child mortality rate appears to have little direct effect on the number of children

Fig. 5 Beta coefficients (±SE) of **a** wealth and **b** education on fertility for all 85 waves in the 36 countries. Coefficients are colour-coded by country, with survey years indicated by the adjacent numbers. Note again that the sign of the beta coefficients for wealth spans both positive and negative values (**a**), whereas the corresponding beta coefficients for education (**b**) are always negative



being born (as opposed to the number of children remaining alive) despite being widely hypothesised to influence fertility outcomes. While in 100% of surveys, there is a significant negative relationship between community-level mortality and number of living children (see Table S12 in ESM), in 75% of countries there is no association between community-level child mortality and number of live births. The remaining 25% of countries are split between significant positive or negative associations (Fig. 8a). For instance, Mali had an estimated under-5 mortality rate of 11.5% in 2016 (World Bank 2017), but community-level child mortality was not associated with the number of live births in our analysis. This seemingly paradoxical result suggests that mortality rates (at least as we have operationalized them here, see "Methods") have little direct impact on actual birth rates across less-developed countries, though they are of course strongly associated with the number of children that survive.

Also surprising was the finding that in 45% of countries, women's work had no association with fertility. Where there is a significant association it tends to be negative (39% of countries). Again we see a difference between low and high fertility regimes: in countries with low TFRs, working women tend to have fewer live births, while in countries with higher TFRs, women's work status has no association with their fertility (see Fig. 8b).

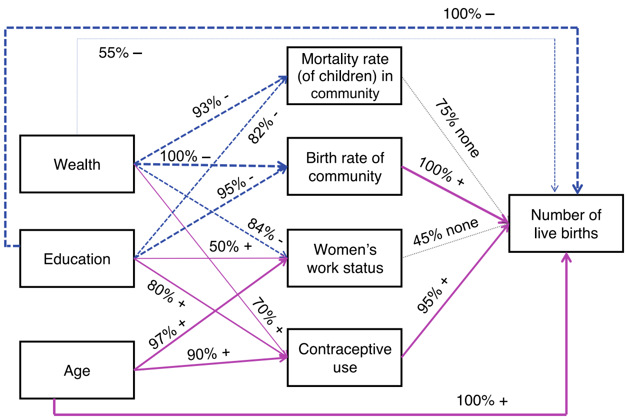


Fig. 6 The structural equation model (SEM) that was executed for each country, where each pathway represents the proportion of countries that have either a positive (pink, solid line), negative (blue, dashed line) or non-significant effect (black dotted line) for the given relationship, and where the thickness of the line indicates the proportion of countries where that effect was found (note that only the most frequent effect is indicated)

Within-country surveys show some pathways change consistently through time

There are 12 countries where surveys were collected three (or more) times over approximately 10 years (refer to Table S2 in ESM for details). This allows us to determine if and how the paths change over time. The full results of these path analyses can be found in Table S13 in ESM. One of the most consistent changes is the path between age and number of births. Not surprisingly, as fertility is reduced (which is occurring in every country included in our survey), the effect size of age on number of births shrinks (see Fig. 9). The magnitude of the association between these variables is decreasing over time. The opposite is true for education. As women have fewer children the magnitude of the negative association between women's education and number of births gets larger. This is happening in 75% of the countries we analysed.

The paths between both wealth and education and contraceptive use are generally positive (see Fig. 6). Wealthier and more highly educated individuals are more likely to use contraceptives, but the size of the effect tends to be reduced across time in 7 of 12 countries we examined, possibly reflecting the diffusion of contraceptive practices over

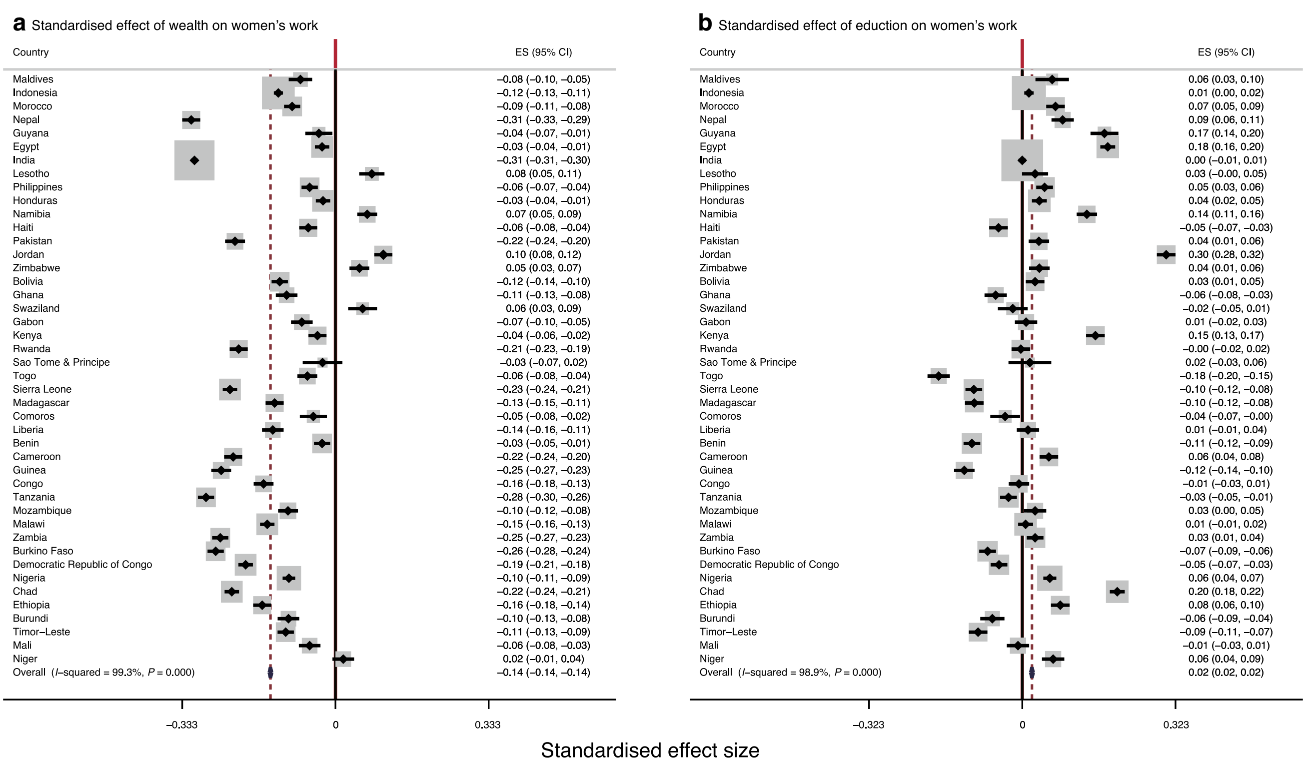


Fig. 7 The structural equation model (see Fig. 6) standardised effect size of **a** wealth and **b** education on women's work by country. Countries are ordered from lowest TFR (at the top) to highest TFR (at the bottom). ES represents "Effect size" with 95% confidence intervals. The area of the grey box is proportional to the weight of the country in determining the overall effect, which is represented by the diamond and dashed vertical line. The solid vertical line represents the null effect (effect = 0)

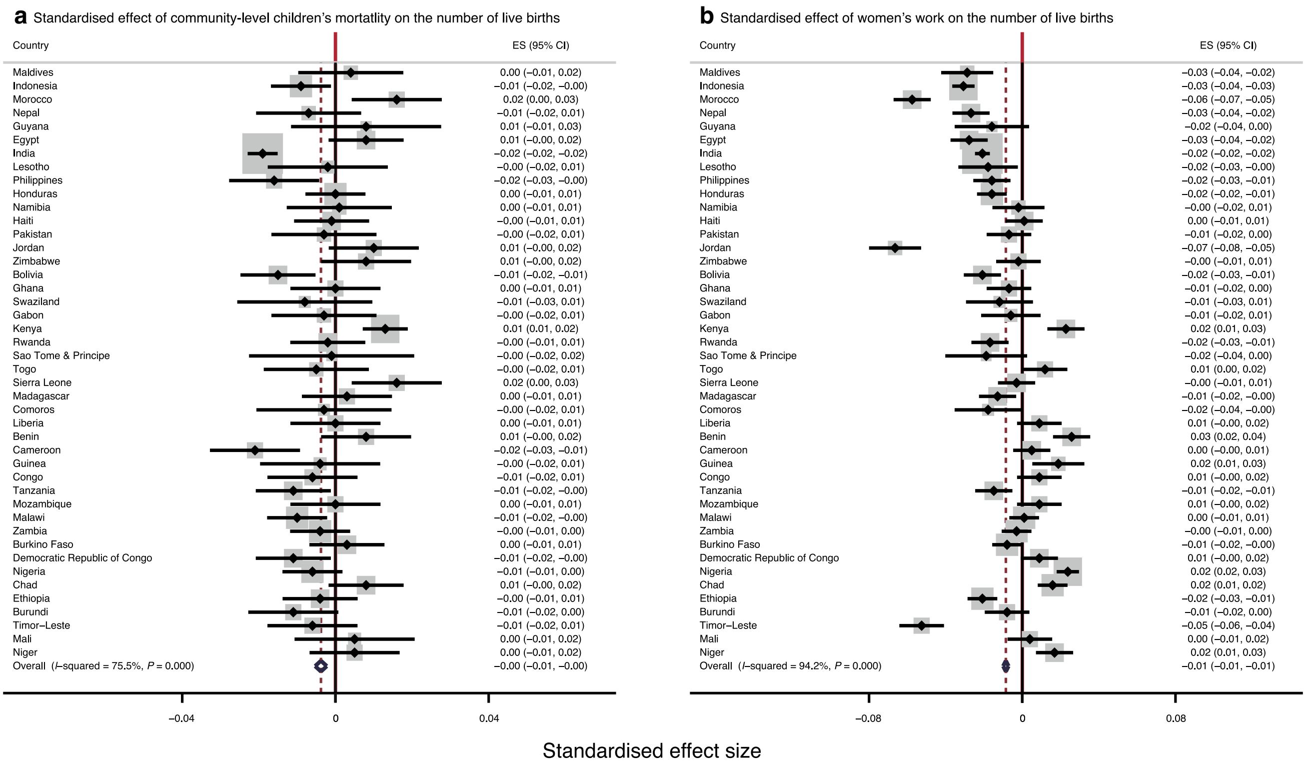


Fig. 8 The structural equation model (see Fig. 6) standardised effect of **a** community-level children's mortality and **b** women's work on number of live births by country. Countries are ordered from lowest TFR (at the top) to the highest TFR (at the bottom). ES represents "Effect size" with 95% confidence intervals. The area of the grey box is proportional to the weight of the country in determining the overall effect, which is represented by the diamond and dashed vertical line. The solid vertical line represents the null effect (effect = 0)

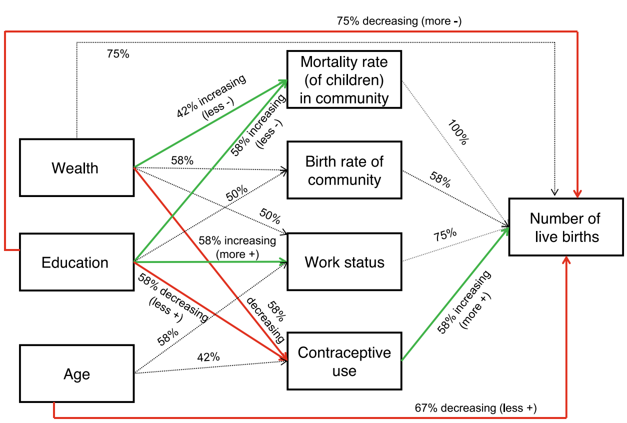


Fig. 9 The structural equation model (SEM) that was executed for countries that have three or more waves of data collection ($n = 12$; for full results, see Table S13 in ESM). Each pathway represents the proportion of countries (out of twelve) that have an increasing effect size over time (green line), a decreasing effect size over time (red line) or inconsistent effect/no change in effect over time (black dotted line) for the given association. It is also indicated (in parentheses) whether the association is becoming more negative, less negative, more positive, or less positive if that effect is consistent. (Note that only the most frequent effect is indicated)

time (see Fig. 9). Again, the size of the association between education and women's labour force participation tends to increase with time. This suggests that as fertility declines, more educated women are more likely to participate in the labour force, mirroring our earlier results. We do not observe any consistent change in the association between women's labour force participation and number of births across the 10-year period covered by the data in most (9) of the countries. This contrasts with the cross-country pattern, where negative associations between labour-force participation and number of births tend to emerge in low fertility contexts.

Discussion

It seems obvious that the predictors and mediators of fertility decline will vary in direction and relative magnitude, according to population-level variation, but there is currently a lack of multivariate cross-cultural comparison in different economic and ecological settings to demonstrate this. Our results demonstrate that women's education and wealth are both important predictors of fertility, but when examined separately, it is clear that they have differing effects on fertility and interact with each other. Across all 45 countries analysed, a negative association between education and fertility is evident after controlling for other variables, including wealth. But the association between wealth and fertility is much more variable: it is positive in many high-fertility countries, but negative in many low-fertility countries. Given that education and wealth are usually at least somewhat positively correlated, the positive effects of wealth on fertility may only be observeable when the effect of education is controlled for. Historical and non-European fertility declines indicate that the characterisation of rich families reducing their fertility first in a demographic transition may not be completely accurate (Borgerhoff Mulder 1998; Dribe and Scalone 2014). Taking into account the multidimensionality of wealth and status may help to address these questions more fully in the future.

Skirbekk (2008) documented a switch in status-fertility differentials over time. Based on our models and using more directly comparable data across 45 countries, it appears that the positive association between wealth and fertility switches when countries fall below approximately six births/women. Nonetheless, all of the countries we analysed were experiencing some level of incipient fertility decline at the time of interview.

Moreover, education and wealth interact. Our analyses suggest that this interaction is relatively robust across countries (we did not find that the slope of the interaction varied substantially, result not shown) and shows that among women with the highest levels of education, more wealth is typically translated into fewer children. The opposite is the case for women with the lowest levels of education: more wealth is typically translated into more children. This replicates a similar finding at the community level in our previous work. It also suggests that demographic transitions can be conceptualised as transitions in the nature and effects of wealth and status (Kaplan 1996; Borgerhoff Mulder et al. 2009; Colleran et al. 2015; Stulp and Barrett 2016).

We examined whether the effects of wealth and education on fertility differed over time within 36 countries for which there were repeated waves of data collection. While there does appear to be some change over time, it is neither substantial nor consistent across countries. Differences between countries seem to be larger than differences between waves of data collected within countries. Ultimately, with only two time points in most countries the data are insufficient to fully explore this question. Longitudinal data, analysed on a per-country basis, will undoubtedly shed more light. Nonetheless, we can show that the effects of wealth on fertility co-vary with the country-level TFR, but this is not the case for education.

Our structural equation models demonstrate that the way women's education and wealth influence the number of children born depends partly on both community-level birth rates and contraceptive use, but not on community-level mortality and women's work status. Women's education and wealth increase the likelihood of contraceptive use, which in turn has a positive association with number of births; those using contraceptives have on average, more children. While seemingly counter-intuitive, this effect is well known in sub-Saharan Africa (Caldwell and Caldwell 1987; Bledsoe et al. 1994; Mace and Colleran 2009; Alvergne et al. 2013), where those women who adopt contraceptives are regularly the ones who already have many children and want to space or limit future births and where cultures of high fertility remain strong (Caldwell and Caldwell 1987; Bledsoe et al. 1994; Mbacké 2017). Community-level birth rates likely provide social information about reproductive decisions, and people may adopt the reproductive strategies of others living in their community, as we and others have previously found at lower levels of aggregation (Kravdal 2012; Colleran et al. 2014). Since community level data capture the local social and economic environments that characterise women's daily lives, the characteristics of neighbours and friends may have a larger effect on fertility decline than the same characteristics at higher levels of aggregation (Kravdal 2012). There may also be some selection effect here, as women with more education or household wealth are probably less likely to live in high fertility areas.

In 75% of countries analysed, community-level mortality had no discernible association with births despite the very large sample sizes (over 800,000 women). While some have hypothesised that high mortality rates may have larger effects on fertility in high-mortality contexts (Snopkowski et al. 2016), we do not observe this pattern in our results. It is possible that the type of mortality is very important. When mortality is extrinsic (or unpreventable), individuals may respond by having additional children, but when mortality is intrinsic and can be avoided by particular investment strategies, we may predict increased investment and/or fertility as a response to mortality. Unfortunately, even with detailed information at the community-level, it is hard to determine exactly how much mortality is extrinsic versus intrinsic. Future research should explore whether type of mortality (or specific causes of mortality) can help explain fertility decisions. It is also possible that our measure of community-level mortality rate is too coarse since it is only based on the women who were surveyed in a given cluster. Small variations in local mortality rates may require very large samples to be accurately detectable.

Women's labour-force participation is widely thought to be an important mediator of the relationship between women's education and fertility (Becker 1981; Ermisch 1989; Snopkowski and Kaplan 2014; Snopkowski et al. 2016). But greater education increases the intensity of labour-force participation in only 50% of the countries surveyed, mainly in low fertility contexts. Nonetheless, education appears to have an increasingly important association with women's labour-force participation through time. Conversely, women in wealthier households tend to work less, not more, in 83% of countries. Women's work status was the only mediator that had qualitatively different mediating associations between wealth/education and fertility.

Women's work status is a poor predictor of total number of births, but appears more important in low-fertility contexts. The association between women's labour-force participation and number of live births is not consistently changing across time.

By explicitly examining cross-cultural variation in both the overall relationships between key predictors of fertility decline and the path-dependence of their effects, we highlight that the causal structure of fertility decline will differ under varying ecological, cultural and economic scenarios. This has broad implications for our understanding of the kinds of evolutionary trajectories that drive demographic change over time and especially highlights that the processes themselves may differ depending on the context and the level of analysis. The prevailing cultural and economic institutions in different countries will variably influence the way that education and wealth provide access to opportunities and information for women, making it more or less advantageous to calibrate reproductive strategies to local community dynamics instead of macro level ones. For example, gender norms directly or indirectly restricting women's employment can work against macro-level selective pressures for market-oriented skills and investment in embodied capital. Cross-cultural differences in 'tightness' and 'looseness'—for example, how acceptable deviations from existing norms are, how new norms are received and how open the mass media and information flows are—could influence cultural transmission dynamics both within and between countries (Gelfand et al. 2011). Structural biases in development spending, driven by macro-level interactions in international networks, could cause some areas to more slowly adapt to changing reproductive incentives at the macro-level, or enable them to maintain reproductive strategies that are equilibrated to the local economy.

There has been considerable debate about whether different predictors of fertility decline represent underlying 'economic' or 'cultural' influences on reproduction. Knowing more about the inter-correlations between different predictors, and in particular how those inter-correlations themselves vary across cultures, should help researchers develop a better understanding of the causal structure of fertility decline that avoids simply prioritising one key variable. One of the strengths of this research is that we are able to cross-culturally compare different predictors of fertility, which provides us with macro-level information about the amount of variation in key predictors and mediators of fertility decline. Along with this strength comes the disadvantages associated with large-scale demographic datasets that involve secondary data analysis, including that the survey was not collected to answer our specific question, that there may be non-response bias associated with such a time-intensive survey, and differences in the sampling criteria across countries, for instance, by excluding particular groups of women based on marital status (Stulp et al. 2016). Additionally, there are many additional structural features of these countries that could be built into our models, including ethnic, linguistic and religious sub-groupings, region and sub-region, which may have important influences on fertility behaviour. We ignore these effects for the moment, overlooking the cultural and structured complexity of fertility decline within each country in favour of a broader assessment of the variation between countries. This is because the number and types of such structuring properties vary substantially by country and allowing the slopes of wealth and education to vary within each of these structures would currently present insurmountable difficulties, both computationally and in terms of interpreting the resulting variation in a cross-cultural light. While we are aware that the relationships we report here may vary at lower levels of aggregation (Kravdal 2012; Colleran et al. 2015), these may be better assessed on a country-by-country basis that takes this complexity more fully into account. Future research will surely examine these important aspects in more detail and this study is a first step towards quantifying these differences cross-culturally.

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