The distribution of reproduction during a fertility transition: Declining spread of parenthood in Brazil

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Abstract

A fertility transition is defined broadly as the process of population change from high levels of childbearing to lower levels. Demographers have a rich understanding of the fertility transitions that have been observed in many contexts across the globe. Yet, we lack evidence to show whether long-run declines in fertility levels are accompanied by simultaneous changes in reproductive variability. This is an important gap because reproductive variability—the concentration and dispersion of childbearing—may help demographers to better explain fertility trends and predict population change. Here, we address this gap with an empirical case study of Brazil, which is a well-known and well-researched example of a fertility transition, with available microdata on fertility by education for cohorts of women born from 1910-70. We contribute new knowledge using multiple measures of variability in levels of completed fertility. We study how these measures change over time during an entire fertility transition, how they relate to cohort fertility rates, and how this evidence varies by education. In general, reproductive variability declines across the Brazilian fertility transition—for measures of concentration and dispersion—although this is less evident when using a measure of dispersion that adjusts for levels of children ever born. We also find considerable heterogeneity by education, as well as evidence that several measures of variability are predictive of fertility decline, highlighting a promising avenue for future research. In addition, our findings suggest that conclusions based on one measure of reproductive variability may only provide a partial understanding of population dynamics.

Keywords: *Fertility, reproduction, transition, variability, concentration, dispersion, population dynamics, education, Brazil*

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Introduction

The fertility transition is one of the most prominent concepts in demography. There is debate about the extent to which we can refer to a single fertility transition ('the' transition) or whether there are different types (Bongaarts 2017; Bongaarts and Casterline 2013; Bongaarts and Hodgson 2022; Frejka 2017; Timæus and Moultrie 2020). However, there is little debate that the majority of countries across the globe have experienced a process of population change from relatively high levels of childbearing (fertility) to relatively lower levels, as compared with their historic population trend (Bongaarts 2002; Bongaarts and Hodgson 2022; Dyson and Murphy 1985; Frejka 2017; Timæus and Moultrie 2020; UN 2009). Knowledge about this transition is important because it helps to explain how societies have changed and to predict how they will change in the future (Casterline 2001; Chesnais 1990; UN 2009). This is not only with respect to future fertility trajectories, where it remains to be seen whether a similar transition will occur in every nation (Bongaarts and Hodgson 2022) and questions remain about post-transitional fertility (Lee and Reher 2011; McNicoll 2013), but also with respect to the social trends and population processes that are driven by fertility. For example, knowledge about fertility transitions can help researchers, policy-makers, and others to understand the future demand for services, population ageing, and the structure of societies in years to come (Bongaarts and Hodgson 2022).

Prior research provides a rich description the fertility transitions that have occurred across the globe. Typically, these transitions have been documented using average national fertility rates, such as crude fertility rates, period total fertility rates, and average numbers of children ever born (Bongaarts and Hodgson 2022; Dyson and Murphy 1985; Frejka 2017). Many of the causes and consequences of these fertility transitions are also well known, including with respect to health, family dynamics, economic factors, and education (Dyson 2010). Given our knowledge, it is perhaps surprising that demographers are not better able to explain or predict national fertility trends, such as stalling fertility declines or sustained levels of low fertility. Naturally, one reason why we struggle to explain or predict fertility is that all explanations are subject to uncertainty. However, another reason may be that we still have sizeable gaps in our knowledge about fertility transitions and the population dynamics that underpin their development over time.

One notable gap in our knowledge, which we focus on here, concerns reproductive variability at the population level, and how it changes over time during a fertility transition. By 'reproductive variability at the population-level' we do not refer to 'variability' in a general sense, for example how average fertility rates vary between groups. Instead we refer to the concentration and dispersion of childbearing, as typically studied using measures that summarise the distributional variation of childbearing within a given population (Lutz 1989). We are far from the first to propose the benefits of studying fertility using these measures (Lutz 1989; Vaupel and Goodwin 1987). However, we note that such measures have rarely been used to examine how changes in the distribution of childbearing accompany the changes in fertility levels that are essential to diagnosing a fertility transition (c.f. Hruschka and Burger 2016).

Prior research on 'the' fertility transition suggests that its defining feature is a permanent decline in 'levels' of childbearing—i.e. the quantum of fertility (Dyson 2010; Dyson and Murphy 1985). This can be measured in different ways, but the focus on permanence suggests the need to avoid measures that may be distorted by variations in the tempo (timing) of fertility (Bongaarts 2002). Perhaps the most reliable measure is therefore average numbers of children ever born (CEB) at the end of people's reproductive lives, i.e. the completed cohort fertility rate (CFR, see: Frejka 2017), although other measures may be very useful in understanding fertility transitions, and their causes and consequences (Timæus and Moultrie 2020). Much attention has been given to describing fertility transitions in different countries, alongside attempts to study their determinants, including economic change (often linked to theories of development and modernisation), social change and stratification (e.g. urbanisation, changes in gender equity, or educational expansion), and health transitions (notably declines in mortality) (Bongaarts and Hodgson 2022). As more research has accumulated, demographers have also become increasingly aware of the importance of heterogeneity in fertility transitions, not only because they vary in terms of their speed and scope, but also because they vary in terms of the individuals who are involved at different stages of transition (Bongaarts 2017).

As argued here, one source of heterogeneity that rarely been examined is reproductive variability. For example, it remains unclear whether fertility transitions—long-run declines in the quantum of fertility—are accompanied by simultaneous changes in reproductive variability. There is some evidence to suggest that low levels of completed fertility are correlated with low levels of reproductive variability, based on cross-sectional evidence measuring variance in completed fertility (Hruschka and Burger 2016). However, there is evidence that suggests there is no association, or only a weak association, when analysing different measures of reproductive variability (e.g. the concentration ratio, often called the "Gini coefficient": Shkolnikov et al. 2007). Other evidence, by contrast, showed higher levels of reproductive variability at lower levels of completed fertility (e.g. Spoorenberg 2024, using the proportion of women who have half of the children, the so called "have-half"). Not only is there a lack of research that examines how reproductive variability changes over time (c.f. Barakat 2021; Lichter and Wooton 2005; Lutz 1989; Shkolnikov et al. 2007; Spoorenberg 2024; Vaupel and Goodwin 1987), but it is rare that studies make an effort to examine whether conclusions depend upon the way that reproductive variability is measured (c.f. Barakat 2021; Shkolnikov et al. 2007). Moreover, it is even rarer that studies have focussed on trying to understand how reproductive variability—and its association with fertility levels—changes across different stages of a fertility transition (all the way from the pre-transition to the late transition), and how any trends and associations vary across groups, for example by education. The latter is especially relevant given the commonly cited role of education, and educational expansion, in determining the nature and speed of fertility transitions (Bongaarts 2003).

Here, we seek to address these gaps using an empirical case study of Brazil. This case is chosen as a well-known and well-researched example of a fertility transition (Potter et al. 2010), which allows us to build upon prior research and focus on the role of reproductive variability. The choice of this context also means that there are data available for studying reproductive variability over the long-run, simultaneous to sustained long-run declines in the quantum of fertility. To guide this contribution, we seek to answer the following research questions (which are further motivated below):

1. *How does reproductive variability in levels of fertility change over time during different stages of a fertility transition?*
2. *Does it decline in parallel with average levels of fertility?*
3. *Are these trends and associations the same for different educational groups?*
4. *Do conclusions depend upon the way that reproductive variability is measured?*

Measuring reproductive variability

The idea of studying variation in fertility within specific populations has a long history (Kuczynski 1932; Newsholme and Stevenson 1906; Yule 1906), and the concept of 'reproductive variability' is only one of many aspects of 'variation' that may be of interest (Lutz 1989). Rather than referring to variation in average levels of childbearing between different groups—for example between women and men, or those with different levels of education—reproductive variability refers specifically to variation in childbearing itself—i.e. the distribution of childbearing (Vaupel and Goodwin 1987). More specifically, here we define reproductive variability as referring to the concentration and dispersion of childbearing at the population level (i.e. for an aggregate group of individuals) (Lutz 1989).

Our interest in this concept derives from the work of Vaupel and Goodwin (1987), who studied the concentration of reproduction in order to understand 'what proportion of women have what proportion of children?' (building on their more general ecological study of the topic: Goodwin and Vaupel 1985a, 1985b, 1985c). At the same time, we follow Lutz (1989) in focussing on—and distinguishing between—both ***dispersion*** and ***concentration*** as two inter-related components of reproductive variability. These two concepts both measure the distribution of childbearing, but the difference between them is that measures of fertility dispersion show how strongly people differ from each other with respect to their childbearing, whereas indicators of fertility concentration show how childbearing is attributed to individual people (see Lutz 1989, in particular Chapter 4).

Commonly used statistical measures of dispersion include the interquartile range, standard deviation, variance, and coefficient of variation (Agresti and Finlay 2013; Wooditch et al. 2021).

Measures like these have been used to study fertility, for example to show that the dispersion of childbearing, (measured using the variance in completed fertility), is positively correlated with mean levels of childbearing (measured using completed fertility, Hruschka and Burger 2016). While some studies have used aggregate measures as the basis for calculating the dispersion of childbearing, for example when analysing the standard deviation of total fertility rates (TFRs) (Dorius 2008), others have used microdata (Hruschka and Burger 2016). Even when it is calculated using microdata, the dispersion of childbearing is an inherently aggregate measure because it is impossible to calculate for individuals (e.g. in contrast to levels of childbearing). However, it is possible to study how the childbearing of individuals compares with that of the rest of a population (or subgroup), for example as has been done using quantile regression (Batyra 2024).

Irrespective of the way that it is estimated, a high level of dispersion indicates that people differ more from each other with respect to their fertility. This is not only true for studies of the dispersion of fertility quantum, but also when measures of dispersion have been used to study fertility tempo, for example the dispersion of age at first birth (Castro Torres et al. 2022; Nathan and Pardo 2019). As noted in prior research (Nathan and Pardo 2019), there may be reasons to choose between different measures of dispersion, not least because each measure summarises reproductive variability in different ways. For example, the standard deviation has a mathematical relationship with the mean, which is not the case with the coefficient of variation because it is calculated relative to the mean. As such, these two measures might lead researchers to derive different conclusions, even when applied to the same data.

There are also a range of different ways to measure the concentration of reproduction (Barakat 2021). The most commonly used are based on the Lorenz curve, as applied to fertility, which typically shows the cumulative proportion of women (x-axis) versus the cumulative proportion of children (y-axis) (Lutz 1989; Vaupel and Goodwin 1987). Although it is of course possible to study concentration by plotting this curve (Vaupel and Goodwin 1987), researchers frequently focus on one or more indicators that summarise this curve, or aspects of it (Shkolnikov et al. 2007). Two examples are the proportion of women who have half of the children in a given population (often called 'have-half') and the proportion of children that are had by half of the women in that population ('half-have'). Another is the concentration ratio (CR), often referred to as the Gini coefficient, which in fertility research is most commonly defined as the *"mean inter-individual difference between women's number of children over all pairs of women relative to the mean number of children"* (Shkolnikov et al. 2007, p. 73). Strictly speaking, all of these are 'relative' measures of the concentration of reproduction, but although it is possible to calculate absolute measures they tend to be of little use for fertility research (Lutz 1989).

When studying either the dispersion or concentration of childbearing quantum, researchers are effectively studying variation across parities, where 'parity' is the number of children born to a person at a given time (e.g. at age 30, age 45, etc.). As such, many studies that use parity-specific analysis, or compare the likelihood of reaching different parities, are implicitly examining the data that underpin many measures of reproductive variability. For example, parity progression ratios (PPRs) measure the different levels of childbearing achieved by different proportions of a population and are therefore indicative of variation in fertility quantum. Indeed, PPRs can be used to plot a Lorenz curve for childbearing quantum and used to calculate measures of concentration (Lutz 1989; Vaupel and Goodwin 1987). However, in contrast to singular (one number) measures (like the standard deviation of children ever born), a single parity progression ratio (for a specific parity) does not measure variability on its own, and can only be used to study variability by comparing with other PPRs. In other words, a PPR is not a summary measure of reproductive variability. This is somewhat analogous to age-specific fertility rates (ASFRs), which can be compared with each other to evaluate variation in fertility by age, but are not measures of variability on their own (unlike, for example, the standard deviation in age at birth). In emphasising this, we are not arguing against the use of PPRs—or any other fertility measure—for studying variation in childbearing. Instead, we are merely indicating the potential benefits of singular summary measures that make it easier to compare and contrast reproductive variability directly. Such measures as especially useful when we are interested in summarising reproductive variability across all parities, as we wish to do here. We also note that there are similarities between our approach and that of mortality researchers, who have gleaned numerous insights from the analysis of summary indictors of dispersion, which are calculated based on age-specific death rates (van Raalte et al. 2018). It is of course equally possible to focus on age-specific rates, which do explain variability, but they are much harder to compare and contrast across populations or their subgroups.

As with the Gini coefficient for lifespan (van Raalte et al. 2018), or levels of income (Ceriani and Verme 2012), the Gini coefficient (concentration ratio) for levels of fertility can also be conceptualised as a measure of inequality (Barakat 2021). However, unlike lifespan or income, researchers may prefer to avoid the term inequality because a high (or low) level of concentration is not necessarily negative (socially, ethically, or normatively). In some cases, it may be that a high concentration of childbearing for a particular group is associated with social disadvantage, just as might be the case if they have high levels of dispersion. Yet, this cannot be assumed. Moreover, measures of concentration like the concentration ratio focus on the attribution of childbearing to groups of individuals, which is in contrast with measures of dispersion, which focus on differences between individuals. Hence, even before we consider whether they produce a different picture of reproductive variability empirically, it is important to recognise that they measure different things. For this reason, in the analysis that follows, we choose to focus on both dispersion and concentration, using two different measures of each: standard deviation (SD) and coefficient of variation (CoV) to measure dispersion; and have-half and the Gini coefficient to measure concentration.

What can we learn from a case study of Brazil?

There are three main reasons why we believe Brazil is an excellent case to study our research questions. The first is that it is a well-known and well-researched example of a fertility transition (e.g. Potter et al. 2010), such that we are able to build upon a range of prior research (outlined below) that has described the transition in Brazil, including its determinants, and how it has varied for different educational groups. The second is that there is high quality data available for Brazil that spans 40 years of censuses and enables us to carry out our study without compromising the ability of our analysis to answer our research questions. In addition, the third reason is that Brazil does not appear to be an outlier in terms of fertility transitions, to the extent to which we can generalise, such that we would hope our findings would be relevant for other contexts (while accepting of course that this is an open question, which we return to in the discussion).

Brazil is one of the Latin American countries that experienced rapid fertility declines from high to low levels during the 20th Century. The period total fertility rate started to decrease from around six children per woman in the 1960s to replacement level around the 2000s, and further to a low level close to 1.6 at the beginning of the 2020s (UN 2024). Cohort fertility – the focus of this study – was stable at a high level of above five children per woman for cohorts born up to around 1925. Subsequently, after a slight decline, completed cohort fertility experienced a dramatic decline, starting with the cohorts born in the 1940s such that it fell to just above two children per woman for cohorts who were born at the beginning of the 1970s (Lima et al. 2018; Rios-Neto et al. 2018). Based on these cohort fertility trends, we distinguish between four stages of transition in Brazil: (a) pre-transition, before the year 1925, (b) early transition, 1925-1940, (c) mid-transition, 1940-1955, and (d) late transition, 1955-1970 (the latest cohorts in our analysis). Although we recognise that the precise definition of these stages is subjective, they are nevertheless based on the commonplace discussion of transition stages in the literature, and are used to facilitate interpretation and discussion, rather than to argue that the stages start and end precisely as defined.

Throughout the last half-century, Brazil has seen a vast educational expansion that contributed to the decline in fertility. Women with high levels of education in Brazil have long had low fertility. The completed cohort fertility rate was already below the replacement level among women born in the 1950s who had more than 12 years of education, while it remained close to five children per woman among those with no, or incomplete, primary education (Rios-Neto et al. 2018). Thus, the fertility differences by women's socioeconomic status in Brazil have been substantial. Cleland (2002) highlighted that Latin American countries exhibited pronounced educational differences in fertility in the early phases of the transition, which, even though decreasing, continued to be larger than in other parts of the world. In Brazil, the strong educational gradient weakened over the course of the fertility transition, primarily due to reductions in fertility levels among women with the lowest levels of schooling (Berquó and Cavenaghi 2005; Rios-Neto et al. 2018). These changes, together with educational expansion, contributed to the decline in fertility to replacement level.

Given the relative lack of prior research on this topic, there is limited empirical evidence with which to formulate hypotheses about the changes that we may expect to see in reproductive variability across the different stages of Brazil's fertility transition. There also seems to be a lack of relevant theory. However, as noted by Barakat (2021), Lutz provides several explanations for changes that may occur in reproductive variability during a fertility transition, primarily focussed on the role of birth control (1989). His first prediction is that reproductive variability will increase with the onset of a fertility transition, primarily due to an increase in the use of birth control for a subset of the population (who presumably 'lead' the transition). The prediction is that this will then lead to a greater difference in fertility between those who do and those who do not use birth control, and therefore more reproductive variability within the population. His second prediction is that reproductive variability will then decrease as a fertility transition moves towards its later stage, primarily due to the widespread availability and uptake of effective methods of birth control for the whole population. At this point, reproductive variability is predicted to be determined primarily by variation in childbearing intentions and desires, such as voluntary childlessness, as well as ongoing variation in some proximate determinants, such as involuntary childlessness (Lutz 1989).

Here, we test the hypothesis that Brazil follows Lutz's predicted pattern of rising reproductive variability during the early part of its fertility transition, followed by a decline in variability from mid- to late-transition. One the one hand, this might be expected given that Brazil did experience a shifting variation in the use of birth control across the transition, not just via a spread in availability, but also via a spread in attitudes toward contraception (Potter et al. 2002). On the other hand, it may be that reproductive variability does not follow this predicted pattern, for example due to reductions in childlessness at the beginning of the transition (which may be caused by factors that are related or unrelated to the transition in Brazil). Furthermore, it may also be that changes in reproductive variability are not solely explained by underlying changes in individual fertility behaviour. They may instead be caused by changes in the structure of the population, such as educational expansion or other changes across birth cohorts (although educational expansion may change both the structure of the population and individual fertility behaviour). As noted previously, there has been some research that examines how reproductive variability changes over time, or more specifically across cohorts (Barakat 2021; Lichter and Wooton 2005; Lutz 1989; Shkolnikov et al. 2007; Spoorenberg 2024; Vaupel and Goodwin 1987). However, as some of these studies have noted, prior research has been limited by a lack of available data with which to analyse cohort trends in reproductive variability, especially if we wish to analyse almost an entire fertility transition using microdata, as we do here, while also considering a series of measures of reproductive variability and examining differences by education.

Data and methods

This study uses individual-level microdata from the Brazilian Population and Housing Censuses conducted in 1970, 1980, 1991, 2000, and 2010. These data come from the International Public Use Microdata Series (IPUMS) (Minnesota Population Center 2024). IPUMS consists of harmonised, nationally representative samples of Population and Housing Censuses, which for Brazil range from 10% (2010, 2000, and 1991) to 25% (1980 and 1970).

We consider the fertility experience of a cohort to be completed at the age of 40 because few births in Brazil occur beyond that age. We therefore restrict our analysis to women at least 40-years-old at the time of each census (data on men are not available). To reconstruct long-term trends but avoid biases due to increasing mortality with age, we focus on women up to the age of 49 or 50 from each census conducted between 1980 and 2010 and up to 59 from the oldest census that we use (1970). This approach allows us to reconstruct a time series of indicators for cohorts of women born between 1911 and 1970, as shown in Table 1. We obtain information about women's birth year (cohort) by subtracting their age from the census year.

Table 1: Cohort coverage from each census and corresponding sample sizes of women by age

Census	Cohorts		Age at census		Sample size
	Oldest	Youngest	Oldest	Youngest	
2010	1961	1970	49	40	1,342,727
2000	1951	1960	49	40	1,164,112
1991	1941	1950	50	41	783,345
1980	1931	1940	49	40	1,294,145
1970	1911	1930	59	40	1,760,653

Source: Authors' calculations from the 1970, 1980, 1991, 2000, and 2010 Censuses using microdata from IPUMS

The key fertility information in this study is the number of children ever born. We also use information about women's educational attainment and define four educational categories: (i) less than primary completed, (ii) primary completed, (iii) secondary completed, and (iv) some higher completed. Because a negligible number of women completed the entire course of higher education, particularly in the oldest cohorts, the fourth category, namely 'some higher completed', includes all women who completed at least one year of higher education. For simplicity, we refer to these educational categories as: less than primary, primary, secondary and higher when describing the results and in the figures' labels. All the analyses are conducted by yearly birth cohorts for the total population of women, applying individual weights as provided for each census by IPUMS.

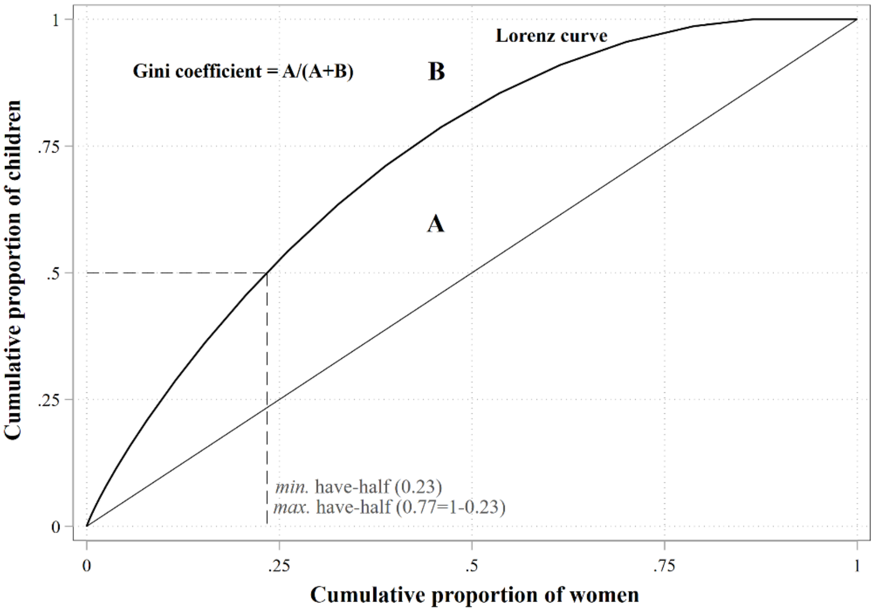
We calculate several measures for each yearly birth cohort based on the information about children ever born. First, we compute the completed cohort fertility rate (CFR), defined as the average number of children ever born (CEB) for women over 40-years-old. Subsequently, we compute four measures of reproductive variability: two measures of dispersion and two measures of concentration. The measures of dispersion are the standard deviation and the coefficient of variation, with the latter computed by dividing the standard deviation by the cohort fertility rate. The two measures of dispersion are thus closely linked, with the difference between the two that, unlike the standard deviation, the coefficient of variation adjusts for the level of fertility. The formulae to obtain these measures for a given cohort of women of size *n* are shown below. The higher the value of the standard deviation or coefficient of variation, the larger the dispersion (and thus more reproductive variability).

$$(i)\ \boldsymbol{CFR} = \frac{\sum_{i=1}^{n} CEB_i}{n} \qquad (ii)\ \boldsymbol{SD_{CFR}} = \sqrt{\frac{\sum_{i=1}^{n}(CEB_i - CFR)^2}{n}} \qquad (iii)\ \boldsymbol{CV_{CFR}} = \frac{SD_{CFR}}{CFR}$$

For concentration, the measures that we use are the Gini coefficient (or concentration ratio) and the 'have-half'. These measures are derived from the distribution of women by number of children ever born within a given cohort. Based on that information, the cumulative proportion of children is computed as a function of the cumulative proportion of women. Such a relationship between these two cumulative proportions gives a Lorenz (concentration) curve. Figure 1 visualises a Lorenz curve (in thick black) for a cohort of women born in 1915 in Brazil. The Gini coefficient is the area between the Lorenz curve and the 'equality line' (i.e., the diagonal, denoting the equal cumulative proportion of children and women) divided by the whole area between the diagonal and the curve (above the diagonal). The more that the Lorenz curve deviates from the diagonal, the higher the value of the Gini coefficient and the larger the concentration (and thus more reproductive variability). We compute the Gini coefficient using STATA command *lorenz* (Jann 2016).

Finally, we compute the 'have-half' by identifying the cumulative proportion of women (x-axis in Figure 1) who have a cumulative proportion of children equal to 0.5 (y-axis in Figure 1). For the 1915 cohort in Brazil (the example in Figure 1), have-half equals 0.23, which is marked on the x-axis with the grey dashed line. More specifically, this value denotes the *minimum* cumulative proportion of women who have half of the children (*min*. have-half), which is how have-half is commonly defined (e.g., in Vaupel and Goodwin 1987). The further the Lorenz curve is from the equality line (i.e., the larger the concentration), the smaller the value of the have-half (i.e. childbearing is concentrated among a smaller group of women). To assist interpretation of the results, and so that all our measures of dispersion and concentration take higher values as variability increases, we use a definition of have-half pertaining to the *maximum* cumulative proportion of women who have half of the children. This metric is obtained by simply subtracting *min*. have-half from 1 (for the 1915 cohort *max*. have-half equals 0.77=1-0.23). This way, as with the Gini coefficient, the values of have-half increase as concentration increases. These two measures are derived from the Lorentz curve, so they will inevitably be correlated. The key difference in their interpretation is that while the Gini coefficient is a measure summarising the whole Lorenz curve (i.e., the entire distribution), have-half conveys information about a particular point of the curve. Although this might be seen as a potential disadvantage, we not that have-half is often seen as having the advantage of being more readily interpreted, in particular by those who have no familiarity with measures of concentration.

FIGURE 1 Example of a Lorenz curve based on which the Gini coefficient and have-half are derived, 1915 cohort, Brazil



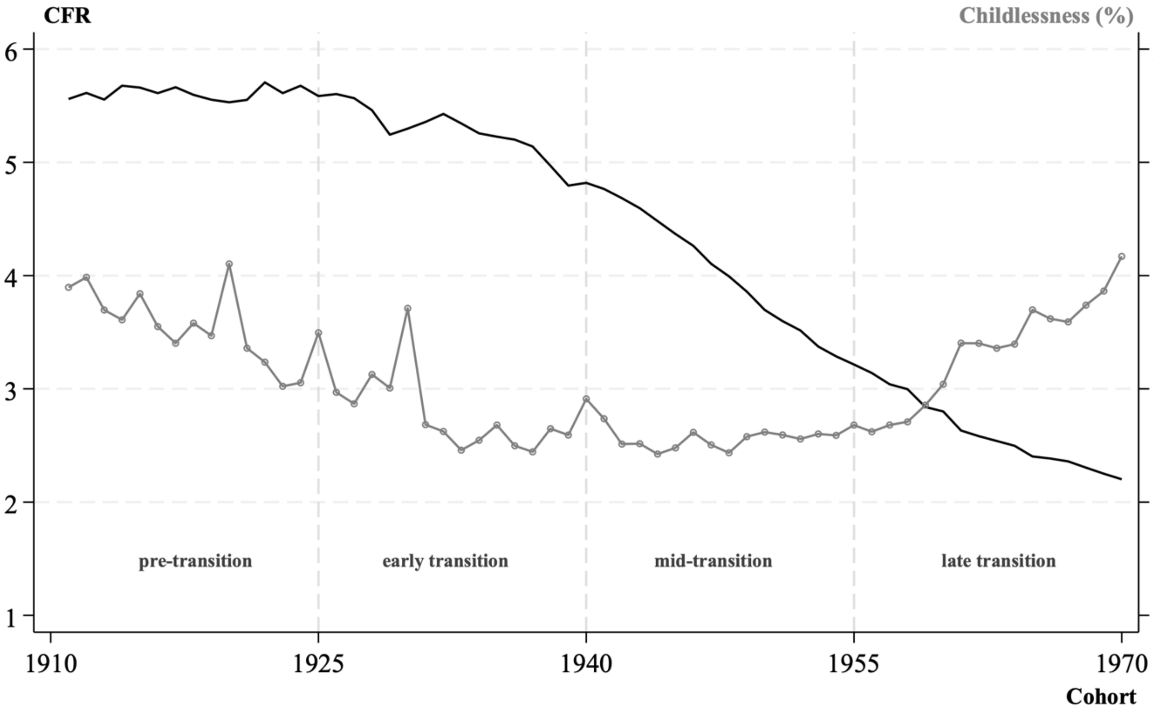
Regarding our strategy for presenting the results, we first show trends in the cohort fertility rate across four stages of fertility transition (as defined in the previous section), alongside aggregate trends in childlessness. Next, to explore patterns and trends in reproductive variability across different stages of fertility transition, we plot each of the four measures of dispersion and concentration (together with the cohort fertility rate in the background to assist comparison). These visualisations allow us to understand how reproductive variability changes as fertility declines, and to examine whether conclusions differ depending upon the measure that we use. Having examined aggregate trends, we then examine trends by education, which highlight how reproductive variability changed within educational groups during the fertility transition in Brazil. Finally, we use linear regression to estimate the relationships between cohort fertility rates and four measures of reproductive variability.

Results

Reproductive variability over the course of fertility transition

Figure 2 provides an overview of the fertility transition in Brazil and shows how the cohort fertility rate declined, starting with women born around 1925 and accelerating during the 1940-50s. Cohorts born at the beginning of the century have relatively high levels of childlessness (around 15% of all women) that decline in the initial stages of fertility transition, stabilise mid-transition (to around 10%) and subsequently increase in the late transition stage (back to around 15%). These trends align with the idea that childlessness may exhibit a U-shaped pattern with increasing development (Poston Jr and Trent 1982; Verkroost and Monden 2022).

FIGURE 2 Trends in completed cohort fertility and childlessness across different stages of Brazil's fertility transition (all women)

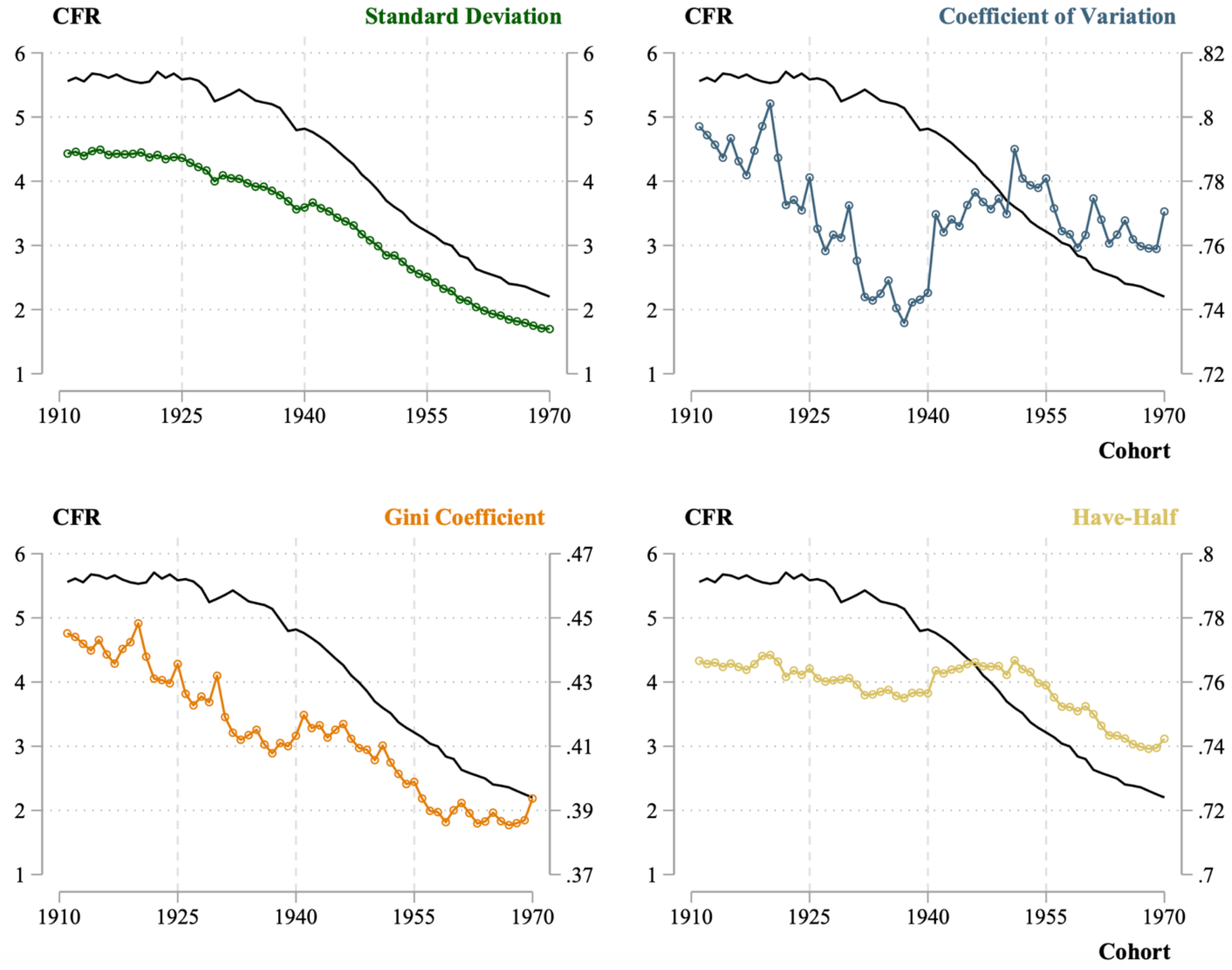


Note: The black line without markers shows the completed cohort fertility rate (CFR). The grey line with markers plots levels of childlessness. Four stages of Brazil's fertility transition are indicated, as defined in the text.

Figure 3 plots the cohort fertility rate alongside four measures of reproductive variability. Measures of **dispersion** (standard deviation and coefficient of variation) and **concentration** (Gini coefficient and have-half) all suggest that reproductive variability is lower in the late stage of the fertility transition compared to the pre-transition stage. However, patterns of change differ depending on the measure. Standard deviation exhibits a general decline over the course of the fertility transition, similar to the CFR change. Although there is also a decline in reproductive variability between the early and the late transition for the coefficient of variation—the measure of dispersion that adjusts for the level of the CFR—the change is less pronounced, and the trend is notably different, occurring in two distinct parts. First, the coefficient of variation declines, throughout the pre- and early transition (among cohorts born before the 1940s). Then, after a marked increase for cohorts born in the early 1940s, the coefficient of variation ceases any obvious downward trend while still exhibiting fluctuations.

The decline in reproductive variability in the pre- and early transition is also visible when looking at the first measure of concentration, namely the Gini coefficient. Indeed, the downward trend in the pre- and early transition stages—particularly in the coefficient of variation but also the Gini coefficient—suggest that the falling values in these indicators may apprehend an upcoming fertility decline. The Gini coefficient continues to fall, albeit to a smaller degree, in the mid-and later transition stages, with some indication that the downward trend has stopped for the youngest cohorts. By contrast, although the second measure of concentration—have-half—also declines over the transition as a whole, it exhibits less evidence of change in the early transition and a more visible drop in concentration in the later stages. Differences in the patterns of change between the two indicators of concentration suggest that conclusions differ depending on whether we focus on a measure summarising the entire distribution of variability (Gini coefficient) or a measure pertaining to one particular point (have-half). For example, the Gini coefficient exhibits a much clearer decline early in the transition, as compared with have-half. Although, as with the Gini coefficient, have-half appears to plateau for the youngest cohorts. Overall, this aggregate population-level analysis suggests that reproductive variability declines across the fertility transition in Brazil. However, each measure of variability exhibits distinct interrelationships with fertility decline across different stages of the fertility transition.

FIGURE 3 Completed cohort fertility rate (CFR) and measures of dispersion (top panel) and concentration (bottom panel), all women



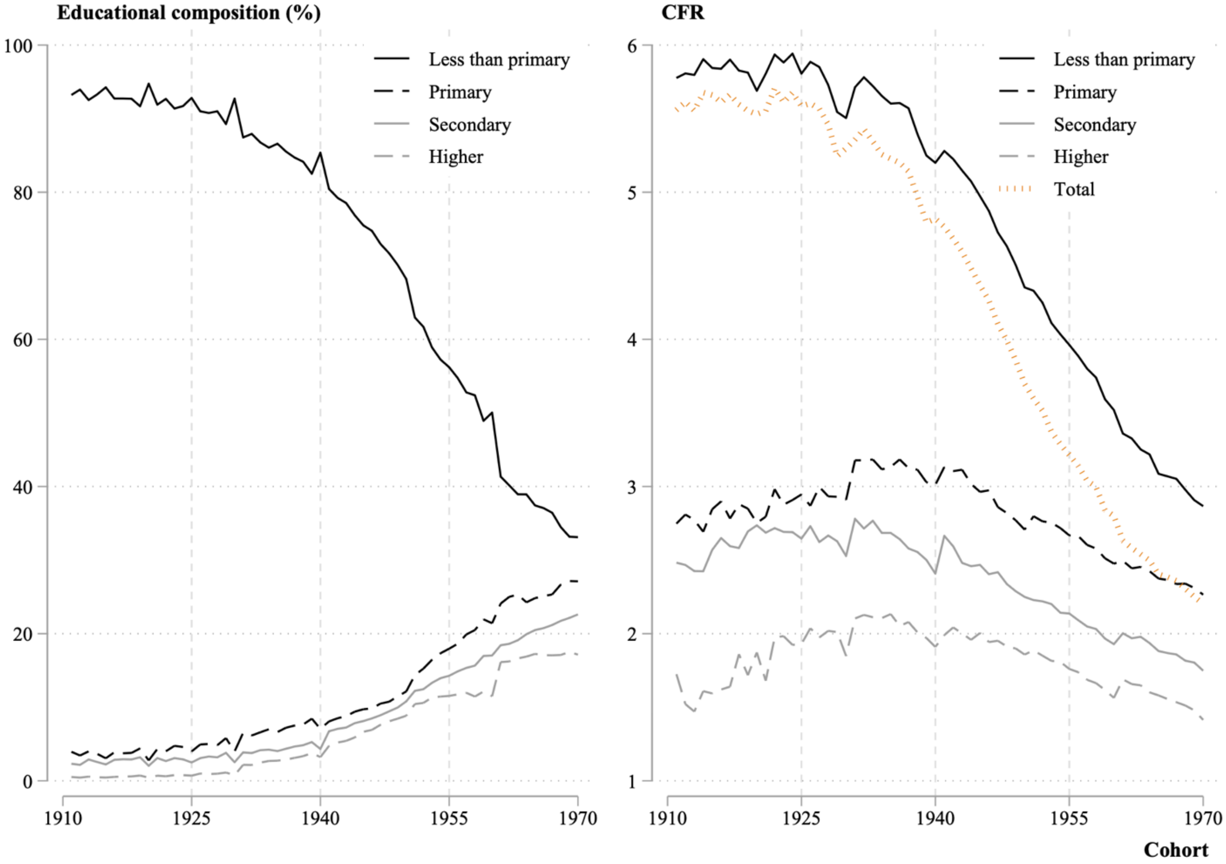
Note: The completed cohort fertility rate (CFR) is the black line without markers and is the same in each plot. The four measures of reproductive variability are plotted separately using coloured lines with markers. Measures of dispersion (standard deviation and coefficient of variation, top panel) and concentration (Gini coefficient and have-half, bottom panel). The scales are chosen to demonstrate changes over time but the magnitude of change in measures of reproductive variability are not necessarily comparable.

Educational differences in reproductive variability

Over the 20th Century, Brazil experienced an immense educational expansion alongside substantial changes in fertility depending on women's educational attainment. Figure 4 (left panel) depicts changes in the distribution of the population by education, with the most notable trend being the declining share of women completing less than primary education. While around 90% of those born in 1910 did not finish primary school, this percentage declined to only 30% for women born in 1970. Between these 60 years, there was a uniform increase in primary and secondary school completion rates and higher education attendance. While very few women completed any form of education among those born at the beginning of the century, roughly 25% of women born in 1970 completed primary school, around 20% finished secondary school and almost 20% entered higher education institutions.

The right panel of Figure 4 shows trends in completed cohort fertility rates for these educational groups. In line with prior research, we see vast differences in completed fertility between the lowest and highest educated women. While previous studies show that fertility was below replacement level among women with at least some higher education who were born in the 1950s (Rios-Neto et al. 2018), our results show that this was already the case among those born near the beginning of the 20th century. We also show that, for those born during 1910-1940, the fertility decline was confined to women with less than primary education. Among the same cohorts of women with secondary education, completed fertility was fairly stable, while it actually increased for women with primary education (from between 2.5 and 3 to slightly more than 3) and for those with higher education (from around 1.5 to around 2).

FIGURE 4 Cohort trends in educational attainment (left panel) and the completed cohort fertility rate (CFR) by educational attainment (right panel)



Note: Primary and secondary education refer to primary and secondary education completed; higher education refers to some higher education completed (at least one year of higher education), as described in the Data section.

As for all educational groups, these fertility trends are likely to have been driven to a great extent by educational expansion. For cohorts born between 1910 and 1970, Brazil shifted away from being a society where almost all (more than 90%) of women had less than primary education, to a society where this group was only one-third of the population. All other educational strata grew considerably, and for the first time they started to constitute a non-negligible share of the population. The unique nature of this shift may explain why fertility did not decline at first for women with primary, secondary or higher education. It was not until cohorts born after 1940 that fertility fell across all strata. The change was fastest and most pronounced among the least educated, for whom the trend mirrors the pattern of change observed for the total population. Yet, even though initial levels and the speed of decline differ by education, the decline for cohorts born after 1940 concerns all educational groups. As a result, differences in completed fertility between educational groups declined markedly during Brazil's fertility transition. They remain evident for the youngest cohorts. However, over the 60-year period that we observe, the difference between women with higher education and those with less than primary education declined from around 4.5 children per woman to merely 1.5.

In the next part of our analysis, we examine changes in reproductive variability by education. Overall, we find considerable differences in the trends for measures of dispersion (Figure 5) and concentration (Figure 6) depending on education. As for variability at the population level, our four measures most often indicate a decline in variability between pre-and late transition, and this appears to be the case for all educational groups, at least in general. However, trends in variability differ by education, particularly early in the transition, and there are also notable differences between the four measures.

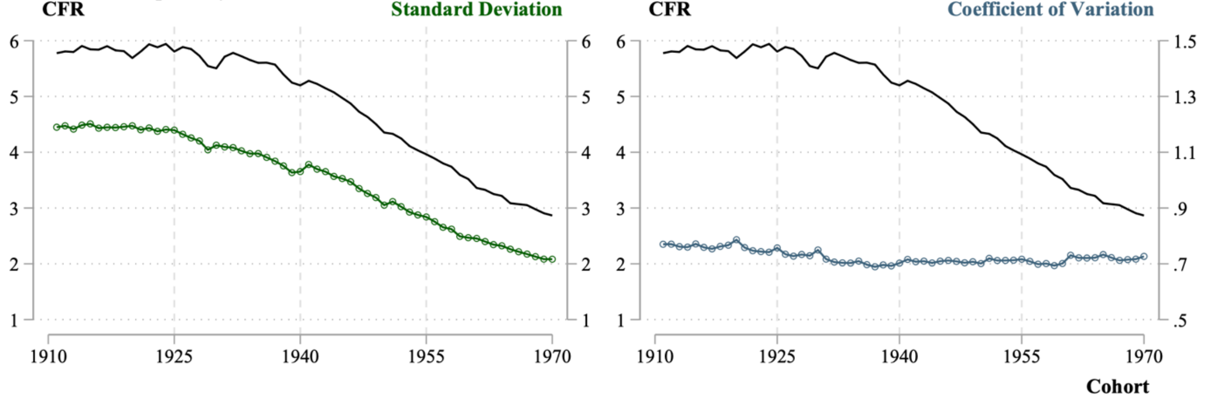
Standard deviation closely follows cohort fertility rates across all educational groups, both in terms of levels and trends (Figure 5, left panels). Overall, the standard deviation tends to be larger for groups with a higher mean (i.e., lower-educated women). By contrast, levels of the coefficient of variation are very different. Contrary to patterns for the standard deviation, dispersion is the highest for higher educated women, especially for older cohorts (Figure 5, right panels). Given that the coefficient of variation measures variability relative to the mean—and thus accounts for the differences in cohort fertility across educational groups—it is perhaps more appropriate for comparisons between groups. At the same time, we note that declines in the coefficient of variation for all four educational groups appear to foreshadow an upcoming fertility decline, as we noted for the total population. This is the case even when completed fertility is increasing, as for the 1910-1940 cohorts with primary, secondary or higher education. The most distinct example of this is among higher educated women, who constituted a very small group for cohorts born before the 1940s. Such rapid declines in variability early in the transition may relate to the selectivity of individuals in more highly educated strata, as well as changes within the strata itself.

Regarding measures of concentration, the Gini coefficient appears to exhibit similar patterns to the coefficient of variation (Figure 6, left panels). There is a tendency towards a greater concentration of reproduction in the higher educated group, and the Gini coefficient declines across all educational groups between pre- and late transition. While a corresponding downward trend is also visible for the have-half measure, the trends are less pronounced than for other measures of variability (Figure 6, right panels). This finding aligns with the population-level analysis showing that have-half exhibits the greatest stability across the Brazilian transition. This may be due to the fact that it refers to a specific point on the Lorenz curve (rather than summarising the entire curve, as with the Gini coefficient), although it remains to be seen whether this explanation for its relative stability over time applies to other contexts (or not).

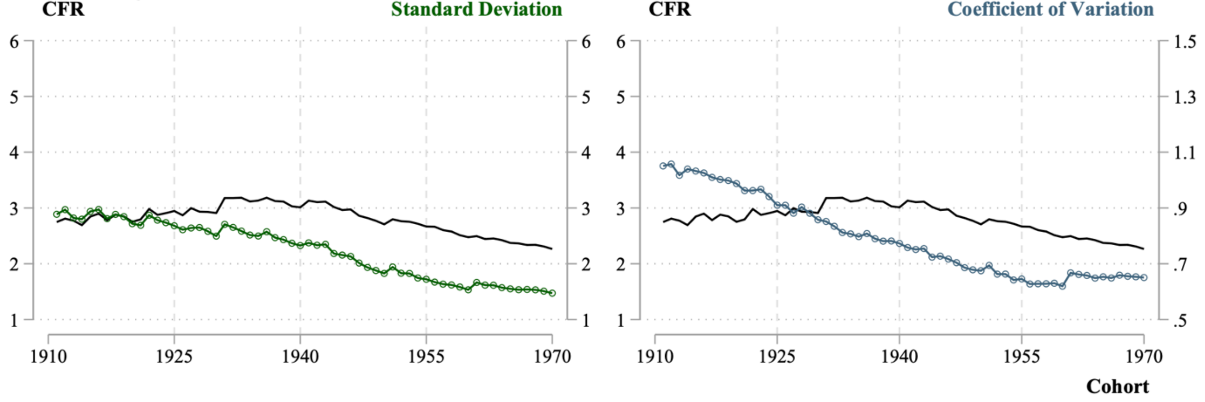
One other potentially interesting finding is the emergence of an upward trend in dispersion and concentration in the late transition stage. When looking at the trends in reproductive variability for the more highly educated groups, there is a notable increase for cohorts born between 1955 and 1970. This is evident for all measures except standard deviation. This reversal in the general trend suggests that declines in variability are neither ubiquitous nor irreversible.

FIGURE 5 Cohort trends in the completed cohort fertility rate (CFR) and measures of dispersion, by educational attainment

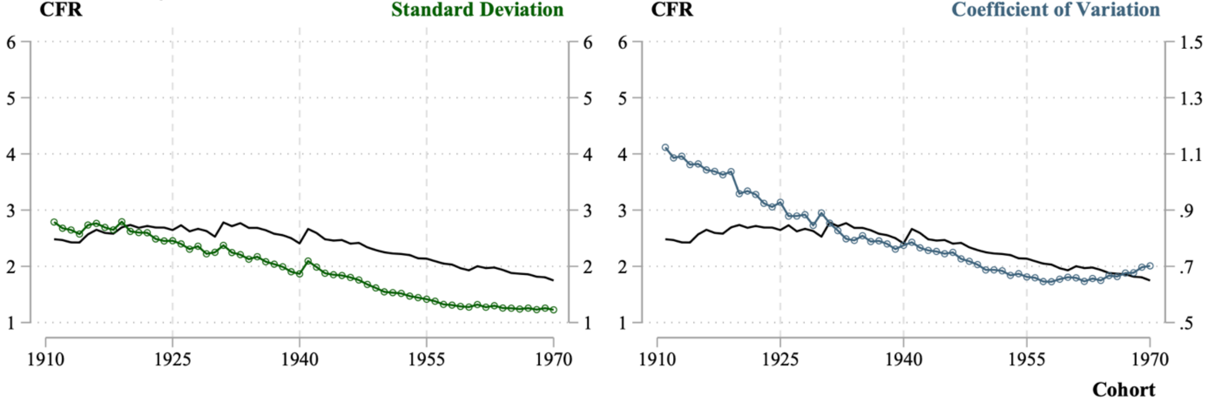
(i) Less than primary



(ii) Primary



(iii) Secondary



(iv) Higher

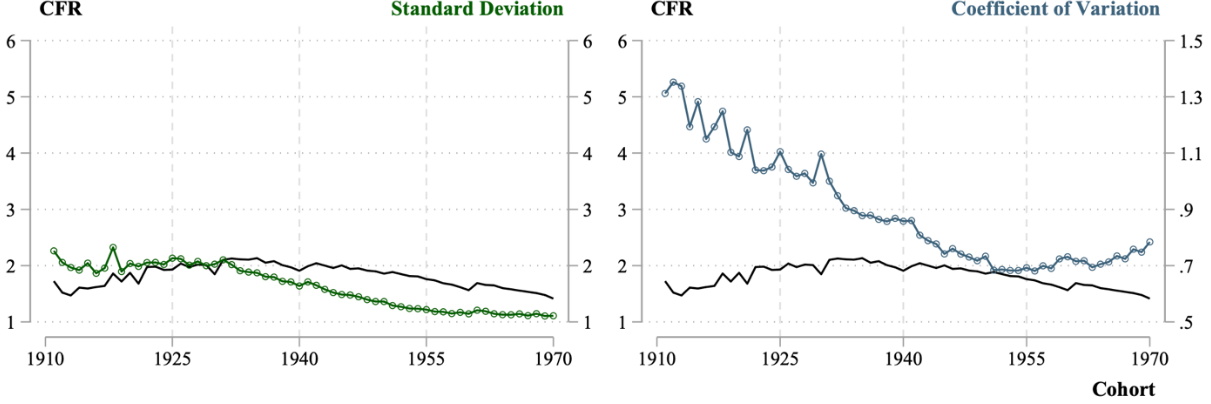
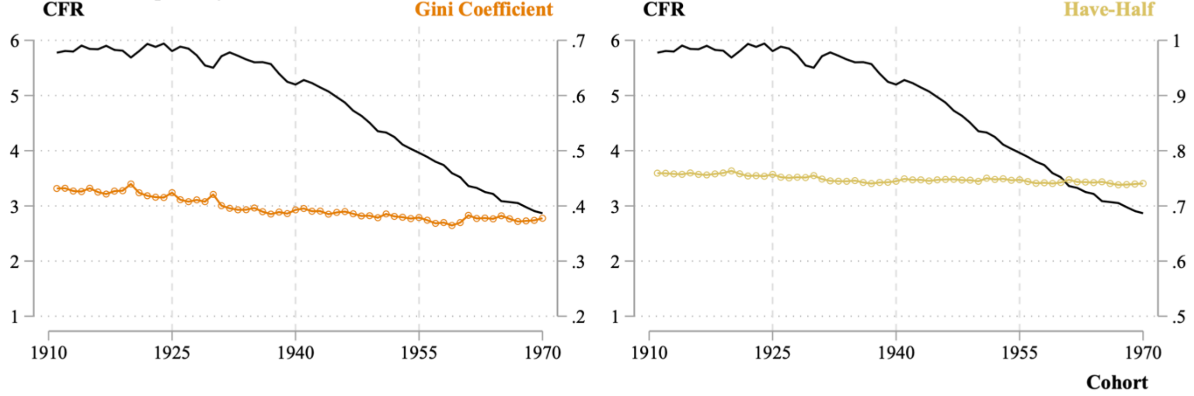
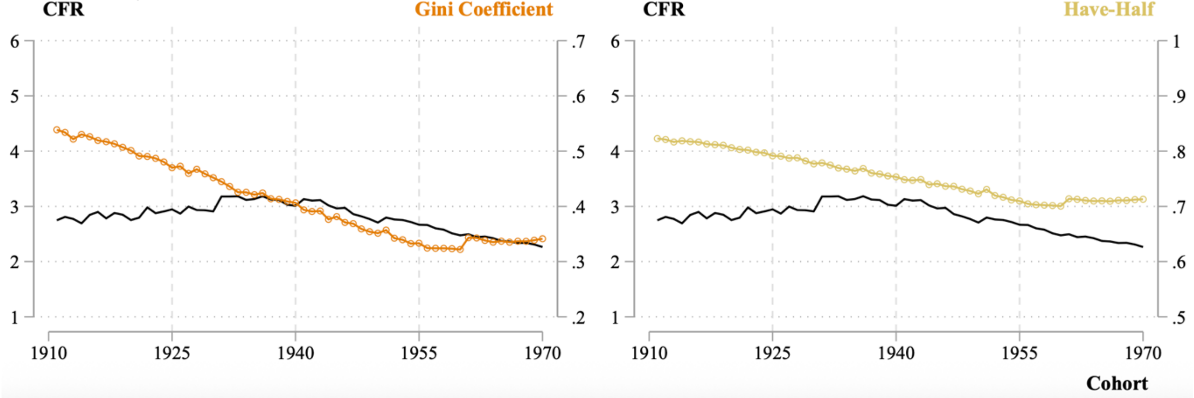


FIGURE 6 Cohort trends in the completed cohort fertility rate (CFR) and measures of concentration, by educational attainment

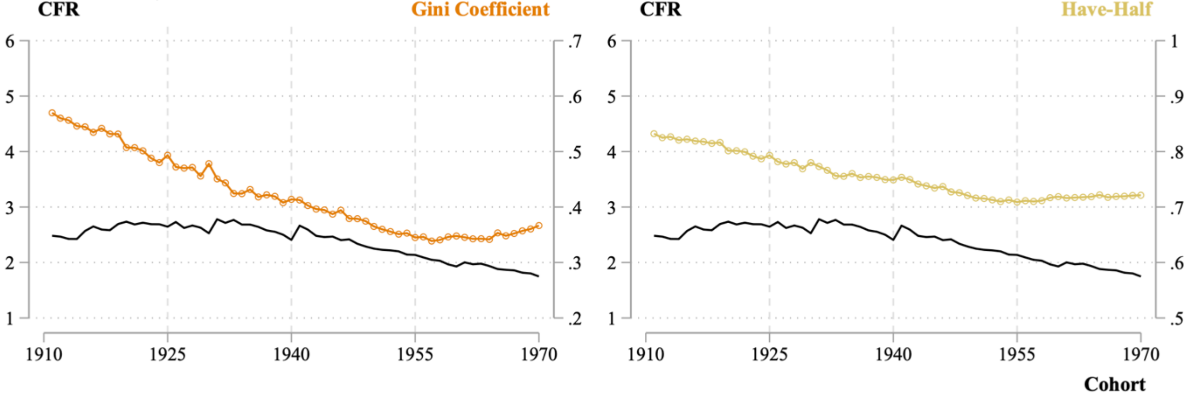
(i) Less than primary



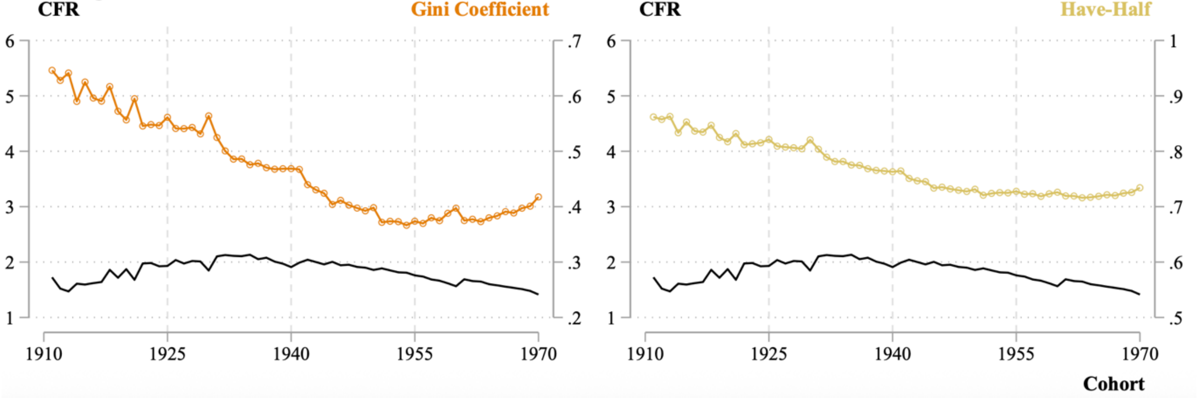
(ii) Primary



(iii) Secondary



(iv) Higher



To conclude our analysis, we examine the association between cohort fertility rates and reproductive variability, for the total population and across educational groups. Table 2 shows coefficients of a series of linear regression models where the outcome is a measure of variability (which differs across columns of the table), and the explanatory variable is the cohort fertility rate. Clearly, the relationship between variability and completed fertility is positive, suggesting that heterogeneity in reproduction is higher when, on average, women have a higher number of children. Conversely, dispersion and concentration are generally lower at later stages of the transition. It is not straightforward to compare the values of coefficients across models, essentially because the units or populations differ. However, it is clear that, the standard deviation is closely associated with the cohort fertility rate—overall and for all educational groups—as we observed in Figures 3 and 5. For the three other measures of variability, we observe a similar positive association, except for women with higher education who exhibit no evidence of an association.

TABLE 2 Regression coefficients describing the association between the completed cohort fertility rate (CFR) and the level of given dispersion and concentration indicator, all women and by educational attainment

Population group	Std. Deviation	C. of Variation	Gini Coefficient	Have-Half
Total population	1.28***	12.05	59.51***	111.78***
Less than primary	1.26***	18.16***	40.86***	114.96***
Primary	0.36***	0.79***	1.71***	3.36***
Secondary	0.51***	1.48***	3.10***	5.65***
Higher	0.24***	-0.01	0.19	0.46

*** $p<0.001$, ** $p<0.01$, * $p<0.05$

Note: Primary and secondary education refer to primary and secondary education completed; higher education refers to some higher education completed (at least one year of higher education), as described in the Data section.

Discussion

This study carried out a case study of Brazil—a well-known and well-researched example of a fertility transition—using microdata on fertility by education for cohorts of women born from 1910-70. We set out to answer four research questions. First, we examined how reproductive variability changed over time during different stages of a fertility transition. In general, we found strong evidence that reproductive variability declined across the Brazilian fertility transition, both for measures of concentration and dispersion. However, this decline was not ubiquitous, and conclusions about the association between reproductive variability and completed fertility—as measured by the cohort fertility rate—differ according to the aspect of reproductive variability that is considered and the way that it is measured.

We compared four different measures, which helped to answer our second research question; whether trends in reproductive variability decline in parallel with average levels of fertility. For some measures, notably standard deviation, they do appear to decline in parallel. However, this is not the case for the coefficient of variation, which is also a measure of dispersion but one that adjusts for changes in mean levels of children ever born. For this measure, and the two measures of concentration that we analysed, there appear to be declines in reproductive variability prior to the transition and in the early-transition phase. However, there also appears to be a step-change increase in reproductive variability between the early- and mid-transition phases, followed by some stability in variability during the mid-transition. Then, in the late transition, there is return to declining variability, albeit with some evidence that variability may stabilise, or possibly even start increasing, for the youngest cohorts in our study.

Our third research question asked whether these trends and associations are the same for different educational groups. In general, we find that the relationship between reproductive variability and completed cohort fertility is not as clear for specific educational groups as it is for the population overall. In part, this can be explained by the fact that cohort fertility rates do not decline monotonically for most educational groups, except those with less than primary education, which is in contrast to the overall trends. The weaker association may also be due to reductions in childlessness in the pre- and early-transition stage, as well as changes in the types of women who achieve primary education or higher. Women with education are a small share of the population prior to the Brazilian transition, and selection into education no doubt changes after the transition commences.

Interestingly, cohort fertility rates often increase in the early stages of the transition for the higher-educated groups, but variability often decreases at the same time. Indeed, variability declines across most of the transition, in all four measures, for all three groups with primary education or higher. In the late-transition stage there is some evidence of an increase in variability in some measures, notably for those with higher education. Nevertheless, levels of variability become more similar over time in all educational groups. Not only do we show that differences in fertility between educational groups have diminished over time—in line with prior research using levels of fertility (e.g. (Berquó and Cavenaghi 2005; Rios-Neto et al. 2018), but we also show that variation has declined both within and between different educational groups in terms of reproductive variability.

Despite the broad clarity of these conclusions, we find clear differences in the patterns that we observe—both overall and by education—depending on the way that reproductive variability is measured. This was the subject of our fourth and final research question, and our findings suggest that conclusions based on one measure of reproductive variability provide at best a partial understanding of fertility dynamics. Moreover, even when we focus on measures of a specific type of variability, either concentration or dispersion, there are differences between measures. It may be important to note here that our study is not exhaustive and there are many other measures of variability that could be considered in future research. These include (but are not limited to) measures of absolute concentration (see Lutz 1989, p. 145) and the Kolm index (Barakat 2021). Nonetheless, our analysis is sufficient to demonstrate that reproductive variability is associated with levels of completed fertility across the Brazilian fertility transition, while this association also differs according to the way that variability is measured.

Further research is required to examine whether our findings would be replicated in other contexts. On the one hand, we might expect to observe similar patterns, at least in contexts where the fertility transition has similar characteristics. On the other hand, it might not always be the case that reproductive variability declines as completed fertility declines, even if both are ultimately driven by fertility behaviour. For example, our evidence would appear to diverge from Lutz's (1989) expectation that concentration increases in the initial stages of fertility transitions. However, Lutz also refers to exceptions, like China, where the association may be linear, particularly when a fertility decline is universal across groups. It could be argued that we also observe a universal fertility decline, at least from the mid-transition onwards. However, like all fertility transitions, the decline in Brazil is unique, and driven by set of proximate and distal determinants that are situated and contextual. Many other countries have not experienced such a rapid expansion of education or adoption of contraception, at the same time as specific policies relating to sterilisation (Caetano and Potter 2004). As such, the patterns that we observe may be different from those in other contexts, and new research would be needed to establish whether this is the case, while also recognising the potential for non-linearities and heterogeneities, not least according to the measures that are analysed.

It is also interesting to note the role of childlessness, which is inextricably linked to reproductive variability by virtue of the fact that it represents the lowest possible value in the distribution of potential completed fertility outcomes. For this reason, we might expect variability to increase as childlessness increases (all else equal), but from the mid-transition onwards we observe a different overall trend, where childlessness increases but variability does not increase, at least not until the very end of our observation period. It would therefore be insightful for future research to examine what happens for younger (completed) cohorts in Brazil, or to examine the whole transition in other contexts, thereby enabling a test of whether reproductive variability increases toward the end of fertility transitions (as suggested in Barakat 2021), or whether it continues to decline. This may include a focus on reproductive variability when completed fertility is low or stable, similar to what is observed currently in many high-income countries (Myrskylä et al. 2013).

Another potential avenue of interest for further research may be to consider our evidence that trends in several measures of reproductive variability are predictive of fertility decline, at least for the population overall. This is particularly noticeable for the Gini coefficient and coefficient of variation, which decline in the pre-transition phase, prior to declines in levels of completed fertility. There is of course a chance that these correlations are spurious, and determined by confounding factors, but it may nevertheless be worth investigating whether—in some circumstances—changes in reproductive variability may predict changes in fertility levels. Such knowledge may be particularly helpful given widespread discussions about the future of fertility globally and recent efforts to predict fertility (McNicoll 2025; Sivak et al. 2024; Van Dalen and Henkens 2021). At the same time, it may be useful for new studies to harness microdata, as we have here, in other to go beyond prior research using aggregate population-level data, and enable research on reproductive variability for specific subgroups of the population.

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