IT IS LOWER THAN YOU THINK IT IS: RECENT TOTAL FERTILITY RATES IN BRAZIL AND POSSIBLY OTHER LATIN AMERICAN COUNTRIES[1]

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Abstract

Understanding emerging patterns of low fertility in middle-income countries is of essential importance. We demonstrate that the use of the P/F Brass method in Brazil to adjust for a presumed underreporting of births has the potential to overestimate the country's 2010 TFR by about 8%. Our preferred fertility-register-based estimate is 1.76, substantially lower the officially reported 1.90. This overstatement of fertility in official statistics has important consequences: compared to our analyses, for example, the UN World Population Prospects (UN WPP) overestimate recent TFR levels, and underestimates additional TFR declines during 2015-30, resulting in a projected 2050 population for Brazil that is 7 million larger and almost one year younger than projections using a TFR of 1.76. Several other Latin American countries are possibly subject to similarly upward-biased official TFRs that result from the use of the P/F Brass method in contexts of declining TFRs accompanied by an onset of fertility postponement. We hence believe several Latin American countries have progressed further in the transition towards low fertility than is reflected in official or UN WPP estimates. Our analyses also suggest that the further use of the P/F method in these countries should be carefully evaluated.

Introduction

Understanding fertility trends in middle-income countries is of essential importance for understanding global population trends and patterns of global population aging. Most middle-income countries have experienced substantial declines in fertility in recent decades, along with improvements in mortality, and many have attained – or are at the verge of attaining – below replacement fertility levels. For example, in South Korea during 1950–2010, life expectancy increased from 47.9 to 80 years, and fertility (TFR) declined from 5.1 to 1.3 children per woman; in Bangladesh during this time period, life expectancy increased from 45.3 to 67.8, and fertility (TFR) declined from 6.4 to 2.4 children per woman. Both India and China saw large fertility declines, Iran holds the record of the most rapid decline in fertility from 6.5 to 1.8 during the period 1980–2010 (Abbasi-Shavazi et al. 2009). Perhaps even more surprisingly, countries as diverse as Argentina, Bangladesh, Mexico and South Africa are expected to *reach* net reproduction rates (NRRs) below 1 – and thus below replacement fertility – within 5–10 years, and by 2015–2020, more than 1 billion persons are expected to live in countries with below-replacement fertility (as measured by NRR) in sub-Saharan Africa, Southern and South-Eastern Asia, and Latin America and the Caribbean alone (57 million in SSA, (6% of total pop), 531 million (21% of total pop) in Southern and South-Eastern Asia, and 484 million (75% of total pop) in Latin America and the Caribbean). Moreover, close to 1/2 billion individuals live in countries that are expected to newly *attain* below-replacement fertility (NRR < 1) in these regions within the next 10 years (all population, fertility and mortality data in this paragraph are obtained from United Nations 2013).

While the above UN Population Statistics indicate a remarkable spread of low fertility in middle-income countries, we argue in this paper that below-replacement fertility may have progressed even more, and that some key middle-income countries may have fertility levels that are significantly below those reflected in recent UN or national TFR estimates. The reason is that in many middle-income countries with fertility rates near or below replacement-level, including for instance Brazil, Colombia, Ecuador, Peru, and Venezuela, fertility rates are estimated from census and related survey data. These census- and survey-based estimates are frequently adjusted using the P/F Brass method for potential underreporting of births. But as we illustrate in the case of Brazil, this adjustment in the context of contemporary low fertility and rapid fertility postponement may "do more harm than good". We show in the case of Brazil that in recent years, estimates of fertility based on census and registration data have become highly reliable, and these sources arguable provide more reliable estimates for national fertility levels and regional differences than indirect methods using the P/F adjustment. For example, our registration-based TFR estimates (with adjustment for minor underreporting) suggest that current TFR levels for Brazil are around 1.76 in 2010, which is 8% below the official TFR estimate of 1.90. Moreover, our analyses suggest that the vast majority of Brazilians—around 70% – reside in states where register-based TFR (with adjustment for underreporting) is below 1.75, substantially more than is suggested based on official estimates that use the P/F Brass method and put this fraction at 40%. Brazil is therefore likely to have attained below-replacement fertility earlier than is indicated by the official TFR estimates, and the decline of fertility is likely to have progressed further than is commonly believed.

The reasons why the P/F adjustment results in an upward bias in country-level TFR estimates for Brazil are twofold: first, underreporting in census and related surveys has been reduced to improved question framing and recall errors are less common in low-fertility low-infant-mortality contexts. Related, civil registration has improved in countries such as Brazil so that it now provides reasonable coverage of births (94%). Second, the assumptions of the P/F model no longer hold when low fertility is not only due to stopping behavior, but increasingly due to a postponement of fertility that shifts the age pattern of fertility to later ages. Because of the induced biases that result from the violation of assumptions, and the availability of high-quality alternative TFR estimates, we therefore suggest that the P/F method in official TFR statistics should be discontinued in this context.

While we illustrate in the case of Brazil that the P/F adjustment is potentially misleading, indicating a higher level of fertility than we believe is actually prevailing, Brazil is unlikely to be the only country to which this issue applies. Several countries, including Colombia, Peru, Venezuela, and Ecuador, use similar procedures in estimating their official TFR levels as Brazil, and they follow a similar fertility trajectory characterized by a rapid recent fertility decline and an onset of fertility postponement that starts shifting births towards older ages. We therefore believe that recent fertility declines in several Latin American countries have progressed further than is indicated by official TFR estimates and related UN WPP analyses, with important implications for the assessment of future trends in population size and aging.

Brazil is an important country for which to document the importance of accurately estimating TFR. It has the fifth largest population in the world and it is the largest country in Latin America. Based on UN Predictions, it contributes 1.4% and 20% to the global and Latin American population growth between 2010 and 2050 considering the medium fertility variant. Brazil has also a dominating influence to population aging in Latin America. But all of these factors and future trends are in part affected by estimates of recent and current TFR levels, and the resulting forecasts of future TFR trajectories. Our replications of the UN projections for Brazil indicate that a lowering of recent fertility estimates to levels that we perceive are accurate has important implications. For example: using our TFR estimates, and otherwise identical projection methodology, we obtain a national population that is 7 million smaller and almost one year older in 2050 than the predicted by the UN WPP. This is a large difference given that it is 40 years of projection and only a single data point is being changed.

The P/F Brass Method

Total fertility rates are important measures in population projections, and historical and international comparisons. It measures the average number of births a woman would have if she experiences the age-specific fertility rates observed in a specific period throughout her entire re-productive life (ages 15 to 49). Period TFR (TFR) can be very different from cohort TFR (CTFR) (Ryder 1980). Recent research on this topic has focused on the extent to which changes in the tempo of fertility – fertility postponement or acceleration – affect the period TFR and the relation-ship between period and cohort fertility trends (Bhrolchain 1992; Bongaarts and Feeney 1998; Goldstein et al. 2009; Kohler and Philipov 2001; Parrado 2011, Sobotka 2004; Schoen 2004). Notwithstanding the discussion of whether it provides a realistic representation of cohort fertility, the TFR remains widely used in the literature (Myrskylä et al. 2011) and in global population projections (United Nations 2013). The importance of accurately estimating the TFR is undisputed, especially in countries that have experienced fundamental changes in their level and pattern of childbearing.

In this paper, we ask a fundamental question related to the precision of the TFR estimation when using a demographic technique, denominated the P/F Brass method, to adjust the TFR in Brazil. This method was developed by Brass in the 1960s for correcting TFR levels in closed populations with constant fertility rates in countries using surveys, instead of birth registries, to estimate their TFR (Brass et al. 1968; United Nations 1983). Despite the research showing the problems of this technique in countries with rapid fertility decline (Brass 1996; Moultrie and Dorrington 2008; Schmertmann et al. 2013), some countries still use this adjustment in non-constant fertility contexts. Brazil together with Colombia, Peru, Venezuela, and Ecuador are one of these countries in Latin America and the P/F Brass method is used to calculate their official TFR and as input in population projections. The implications of a misleading adjustment in Brazil's TFR are beyond the estimations of the country, but affects estimations for South America and the world since it represents almost half of the population in the region and it is the fifth most populous country in the world (United Nations 2013). Consequently, it is very important to estimate its correct TFR for local, regional, and global population projections.

The P/F Brass method was initially developed to analyze survey data from Africa, in which researchers were detecting systematic errors in its recollections (Brass et al. 1968). The first source of error is related to imprecisions in the reference period based on the question asking whether a person had a birth in the year preceding the Census. Women were reporting events that happened, on average, eight to fifteen months before the Census, leading to distorted values of the TFR. This error should be substantially reduced in recent Brazilian Censuses, because, since the 1991 Census, births in the year preceding the survey are estimated based on month and year of last birth, a question format that is significantly more robust with respect to the reference period error. The second source of error defined by Brass et al. (1968) is the memory error, which suggests that women may forget the total number of children ever born, especially older women, because of low literacy, difficulties in counting the number of births, and high levels of mortality making it more difficult to remember and report births that have died. The memory error would affect the estimated

TFR from the Brazilian Census if women aged 15 to 49 years old were likely to underreport births that occurred in the twelve months prior to the survey.

The adjustment used in Brazil is the P_2/F_2 ratio, which is the total parity in the age group 20-24 in relation to the cumulated period fertility in the same age group. This ratio is multiplied by the TFR or age specific fertility rates, increasing or decreasing its level. The numerator of the ratio, P_2, is the average number of births ever had by women in the 20-24 age group. The denominator of the ratio (F_2) is calculated, first, by acquiring the fertility in the beginning of the age interval, age 20, which is given by $\O_2 = 5 \times f_1$ [from the equation $\O_i = 5 \times (f_1 + f_2 + ... + f_{i-1})$], f_1 is the age-specific fertility rate in the 15 to 19 age group. Next, the average number of births in the 20-24 age group is estimated, but it is not recommended to obtain it by multiplying f_2 by 2.5, because fertility is not constant in the interval, especially in the beginning of the fertility schedule. So, Brass et al. (1968) computed a series of multiplying factors *k* to be interpolated using the observed f_1/f_2 ratio for obtaining k_2. The final value of F_2 is given by the equation $F_2 = \O_2 + k_2 \times f_2$. After obtaining P_2 and F_2, the P_2/F_2 ratio is estimated. This ratio should be one in a population with constant fertility with no errors in data recollection, assuming that the fertility of women who died or emigrated is similar to the fertility of women that survived or immigrated. A P_2/F_2 ratio that differs from one, under the assumptions of the model, indicates that fertility rates are distorted due to reference or memory errors. The TFR is then adjusted by multiplying it to the P_2/F_2 ratio, as suggested by Brass et al. (1968). Importantly, however, the P_2/F_2 ratio can differ from one when the assumptions of the model do not hold, including especially the constant fertility assumption, and in this case multiplying the Census' TFR by the P_2/F_2 ratio can result in a misleading estimate of the TFR.

In Brazil, the estimated P_2/F_2 ratio was 1.12 in 1991, 1.10 in 2000, and 1.19 in 2010. Which means that when the adjustment is applied, the estimated TFRs from Census Surveys are increased by 12%, 10%, and 19% respectively. It is unclear whether these values are generated by the underreporting of births in the Census or by problems in not satisfying the method's assumption. The first hypothesis is not possible to measure using the Census microdata; however, it is unlikely that the underreporting of births would increase with time, as observed with the increase in the ratio from 2000 to 2010, and also that the magnitude of the underreporting of births from women aged 15 to 24 would be so high. A more plausible hypothesis is the unmet assumptions of the method. Brazil is not a population with constant fertility rate, its fertility started to decline in the mid-1960s, but demographers defended that the P/F Brass method could be used because the decline consisted mostly of stopping behavior rather than postponement (Carvalho 1985). So, arguably, the cumulative fertility of the first two age groups (ages 15 to 19 and 20 to 24) and the parity of the age group 20 to 24 should remain constant, not affecting the P_2/F_2 ratio. Nowadays, however, Brazilian fertility is characterized by a postponement of fertility in the first two age groups of the fertility schedule, and so the P_2/F_2 ratio can be distorted, no longer reflecting corrections in births' underreporting.

The 2000s Census rounds already suggested that Latin America's early motherhood imperative was weakening (Rosero-Bixby et al 2009), and the 2010 Census can clearly confirm this trend for Brazil. Rios-Neto and Miranda-Ribeiro (2015), for instance, show that the tempo effect in Brazil was 9% in 2010, which means that the fertility was 9% lower than previous years because of postponement effects. We illustrate this postponement in Fig. 1, which shows the age specific fertility rates for first births per 1,000 women in 1991, 2000, and 2010. In 2000, we can observe a decline in first births starting at age 19, and in 2010, this decline is even more expressive and starts two years earlier in the fertility schedule. In addition, there is a remarkable increase in the rates after age 27, a typical configuration of postponement behavior. In this context of fertility postponement, using the P_2/F_2 ratio is potentially misleading as the underlying constant fertility condition does not hold and the P_2/F_2 differs from one even in the absence of any recall or memory errors in the reporting of births.

A rapid fertility decline in ages 15 to 24 is a sufficient condition for violating the constant fertility assumption of the P/F Brass model and, consequently, for having a P_2/F_2 ratio greater than one even in the absence of underreporting errors. In the case of Colombia, Ecuador, Peru, and Venezuela, Rosero-Bixby et al (2009) show a significant decrease in the percentage of childless women in the 25-29 age group. The decrease was of approximately 10% in Colombia, and around 5% in Peru and Venezuela comparing the 1990s and 2000s Census round. In Ecuador, the change was less expressive being around 2% between the two Census rounds. Esteve et al. (2013) also observe the increase in childless women aged 25-29 in the region and, by controlling for women that has ever been in a union, they find a general increase in childless women in this age range even for Ecuador. Because there is a rapid fertility decline in these countries, and presumably, a significant decrease in fertility before age 24 compared to other years, we believe that the P_2/F_2 adjustment might be overestimating the total TFR of these countries. However, we restrict the following analysis to Brazil because of its central importance for Latin America's population trends and the availability of and access to multiple register-based fertility data that allow us to explore the extent of bias resulting from the application of the P/F method.

The constant fertility assumption can be relaxed with a new variant of the P/F Brass method proposed by Schmertmann et al. (2013). This new method uses a weighted least squares regression to calculate the final adjusted TFR. The regression is given by the equation: $ln(TFR \times P_x/F_x) = \beta_0$

$+ \beta_1 \times (\mu_x - \dot{x})$, with x = 22.5, 27.5, 32.5, 37.5, 42.5, 47.5. The dependent variable is the natural log of the observed TFR multiplied by P/F Schmertmann's ratio, so each age group has a P_x/F_x value that is multiplied by the country's TFR. The independent variable is the time when, in average, the women of age group x had a birth, which is the difference between the mean age of childbearing in each age group (calculated using the M0 and M1 values resultant from the calibrated spline interpolations) and the middle age of each age group (17.5, 22.5, 27.5, 32.5, 37.5, 42.5, and 47.5). The exponential function of the intercept, β_0, provides Schmertmann's final adjusted TFR, which is the fertility at the present time (t=0). An important assumption of the model, represented by β_1 in the regression is that the rate of fertility change in time ($t=\mu_x - \dot{x}$) is the same for all age groups. So, the model assumes an exponential change of fertility in time and within the same period t all age groups have the same rate of change. The authors maintain that this technique performs better in countries with rapid fertility decline than the original P/F Brass method. Empirically it turns out, as we will show below, that this method provides the expected TFRs values for the 1991 and 2000 Censuses, because they are smaller than official estimates using the original P/F Brass and greater than register-based TFRs. However, for 2010, it yields a result that is nearly the same as the official estimate. Consequently, the method does not perform as expected for the 2010 Census, probably because of the model's assumption of a constant annual rate of fertility change (β_1) across age groups in a given year.

Fertility Estimates across Data Sources and Methods

We argue in this paper that the potential errors in census and related data collections do not bias the Brazilian TFR in the magnitude that is suggested by the P_2/F_2 ratio currently calculated for the country. We maintain instead that the magnitude of the ratio and its variation in time is mostly driven by the violation of the constant fertility assumption, which might result in a biased official TFR for the country. In order to contextualize the magnitude of the estimate using the P_2/F_2 ratio, we analyze the consistency of TFR estimates across data sources. Figure 2 shows TFR estimates from 1991 to 2013. The official estimate shown in the figure is the only trend that has the P_2/F_2 adjustment. It uses the fertility information from the Census (1991, 2000, and 2010) and Pnad household surveys and apply the P_2/F_2 adjustment. The civil registry and SINASC (Live Births Information System) estimates presented in the figure correspond to two different information sources on birth registries. If a birth occurs in the hospital, the hospital produces a form and its first copy is sent to SINASC, which is managed by the Health Ministry, the second copy is given to the family to registry their children in public notaries, and the third copy stays in the hospital. The information from notaries is assembled and published by the National Institute of Geography and Statistics (IBGE) and constitutes the civil registry system. If the birth occurs in the household, the first health unit or notary visited sends the information to the SINASC system. Birth estimates from SINASC are usually greater than the civil registry estimates for a given year because of late registration. The DHS data trend in Fig. 2 represents the 1996 Demographic and Health Survey (DHS) and its Brazilian equivalent in 2006, the *Pesquisa Nacional de Demografia e Saúde* (PNDS). Finally, the modified Brass data trend shown in Fig. 2 is the new variant of the P/F Brass method (Schmertmann et al. 2013), explained in section 2.

It can be observed that between 1992 and 1995 the official estimates were broadly consistent with census and survey estimates. For instance, the 1996 DHS presents a similar value to the official estimate, being 2.5 births per woman in 1994-1996 compared to 2.52 of the official estimate in 1995. After 1996, however, official values, which use the P_2/F_2 Brass correction, start diverging significantly and systematically from survey estimates, with the latter being generally lower than the former. In the DHS a decade later, official estimates contrast sharply with DHS estimates, being 2.06 in 2005 compared to 1.80 in the 2006 DHS. In this same year, the Pnad survey shows a TFR of 1.77, consistent with the DHS estimate. In 2010, the official TFR estimate is 1.90 births per woman, and the Census data shows 1.60 births per woman and a confidence interval of 1.53 to 1.66 births. The TFR of the national birth system (SINASC) is 1.71 births per woman in 2010 and the civil registry is 1.65, consistent with the boundaries of the 2010 Census estimate, but very different from official estimates. In general, the estimates across data sources are fairly consistent, but the official estimate, which uses the P_2/F_2 Brass adjustment, is considerably larger than the other estimates.

When considering the new variant of the P/F Brass method proposed by Schmertmann et al. (2013), denominated 'modified Brass' in Fig. 2, the results in 1991 and 2000 are lower than the official estimate and greater than Census estimates, as we would expect when correcting for birth underreporting. In 2000, for instance, the TFR using the modified Brass method is 2.23, which is lower than the official estimate (2.38) and closer to the upper boundary of the Census' confidence interval (2.21). Nevertheless, in 2010, the modified Brass provide a greater TFR than the official estimate, being 1.91 for the former and 1.90 for the latter. The similarity between the classical P/F

Brass method and the new variant of the method in 2010, suggest that the latter may also be influenced by the country's rapid fertility decline and onset of fertility postponement, both of which violate the assumption underlying the P/F Brass adjustment.

What is the Best TFR Estimate for Brazil?

We have observed that TFR estimates from direct methods (SINASC, civil-registry and census) have similar values, but the estimates using indirect methods (Census or Pnad with P/F adjustment) are considerably larger. Nevertheless, it remains unclear which set of estimates are better suited to represent Brazilian fertility, as direct estimates are potentially subject to under-registration of births. Fortunately, we are able to assess the extent of under-registration in administrative records using a question from the 2010 Census. The question asks the type of birth certificate held by children aged 10 or below. The first alternative is the formal birth certificate emitted in notaries, which is the correspondent adjustment for the national civil registry system. The second alternative is the form provided in health facilities, the live birth declaration (DNV), in order to register the birth in the notary, this option together with the first is the correspondent adjustment to births registered in SINASC. The third option is the indigenous birth certificate (RANI), which is not accounted in the civil registry data or SINASC. These adjustments are applied only for the 2010 SINASC and civil registry data, since this question is not available in the 1991 and 2000 Census.

Table 1 shows the type of birth registry for children aged zero in August 1st 2010, and so that were born between August 2nd 2009 and August 1st 2010. We can observe that 93.83% of these children had an official birth certificate from the notary, 3.3% had a live birth declaration (DNV), 0.17% had the Indigenous birth certificate (RANI), and 2.58% had no birth registry. So, a total of 2.86% births in Brazil during the Census period were not registered by the civil registry or SINASC. In order to adjust the SINASC and civil registry data for under-registration, we assume, first, that the under-registration observed for the Census period (August 2nd 2009 to August 1st 2010) can be applied to the 2010 calendar period. Our second assumption is that the information reported by the individuals is correct and the SINASC and civil registration systems accurately process the information once the individuals receive the official birth certificate or the birth declaration (DNV) from health facilities.

The Brazilian TFR in 2010 using the Civil Registry data is 1.65 and 93.83% of births were registered (Table 1). The correction factor for under-registration in the civil registry is, then, 1/0.9383 = 1.0658, which, multiplied by the total number of births in the civil registry, results in a final TFR of 1.7629 children per women. The Brazilian TFR in 2010 calculated with the SINASC data is 1.71 and its coverage is 97.14% (registries from notaries and health facilities), providing a correction factor of 1/0.9714 = 1.029, and the final SINASC TFR is then 1.7632. The two adjustments provide very similar results, which increase our confidence in the data and estimates. These results are significantly lower than the 1.90 children per women calculated with Brass P_2/F_2 ratio from the 2010 Census data, and in greater agreement with the TFR of 1.80 resultant from the 2003-2006 PNDS, the Brazilian DHS's equivalent.

Despite our confidence that the adjusted SINASC and civil registry provide a more realistic estimate of the Brazilian TFR at the national level, this is not necessarily the case for state-level estimates. The classical error incurred when using different data sources in the numerator and denominator driven mostly by interstate migration are an issue. The problem is driven by the fact that the mid-year population assumption for person-years might not be accurate, with more or less exposure to fertility than assumed in the denominator. Places with high inter-state immigration would present the most problematic estimates. In this regard, the state ranking of TFRs presented by the Census unadjusted TFR might be correct since exposure and occurrences are correct, but the levels might be less accurate because of births' underreporting.

Figure 3 presents the total fertility rate across Brazilian states in 2010, ordered from the lowest to the largest TFR estimates from the 2010 Census. Overall, the adjusted SINASC-TFRs present estimates that are within the 95% confidence interval of the Census estimates, the three exceptions are Rio de Janeiro, São Paulo, and Brasília, which are states with high levels of inter-state immigration. Official estimates (Census with the P_2/F_2 adjustment), in contrast, are consistently higher than the upper end of the Census confidence interval, presenting significantly higher estimates across states. In Fig. 3, we can also observe that nearly 70% of Brazil's total population is concentrated in the first eleven states in which the TFRs from SINASC are within the 1.55 – 1.75 range (with adjustment for under-registration). Moreover, half of Brazil's population is in the states of Minas Gerais, São Paulo, Rio de Janeiro, Rio Grande do Sul, and Santa Catarina that present a SINASC TFR of, respectively, 1.55, 1.69, 1.63, 1.57, and 1.58 (Table 3). Studies have shown a bifurcation in fertility regimes across high-income countries (Rindfuss et al. 2015), and some countries present very low fertility levels for sustained periods of time (Kohler et al. 2002). By dropping the P_2/F_2 Brass correction, we can observe that some Brazilian states might have already started in the direction of very low fertility levels, being closer to the lower range of fertility regimes encountered in more developed countries, as classified by United Nations (2013) (e.g., in 2010 fertility levels from more developed regions ranged from 1.22 in Bosnia and Herzegovina to 2.14 in New Zealand).

An additional possibility for estimating the under-registration of births in SINASC is the data of a proactive search of under registered births in the Northeast and Legal Amazonian Regions (Szwarcwald et al. 2011). A stratified sample of 133 municipalities was estimated and a search of births born in the 2008 calendar year was undertaken in 129 municipalities. The search occurred in health units, notaries, secretaries of social protection, churches, drugstores, midwiferies, and other institutions. Once a birth not recorded in the SINASC system was found, researchers confirmed the occurrence through household interviews. Although the Census survey refer to births from August 2009 to July 2010, the two surveys provide similar results for the regions analyzed. In the Legal Amazonian region (the states of the North region of Brazil and Mato Grosso), the total coverage of SINASC is 91.3% using the proactive search data for 2008 (Szwarcwald et al. 2011, page 91) and 91.1% using the Census data. In the Northeast region, the survey presents a coverage of 93.2% in 2008 and the Census of 95.9% in 2010, a difference of 2.7%. The reason for a greater difference between surveys in the Northeast region is unknown; it can be driven, among other things, by a smaller sample of the proactive search survey, the difference in time-periods, or a greater Census under-enumeration of births[2] in the Northeast region. Nevertheless, the differences are small and the results can be considered consistent.

The results of the proactive search survey in the Northeast and the Legal Amazonian regions were extended to the country as a whole (Szwarcwald et al. 2011). First, the researchers

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[2] The intercensal survivorship ratio is used to estimate the under-enumeration of the population aged 0 to 4 years old in the 2000 Census (IBGE 2013). The 2000-2010 intercensal survivorship ratio is 1.05, so the population aged 10 to 14 years old in 2010 was 5% larger than the population aged 0 to 4 in 2000. Assuming zero international migration and mortality, the under-enumeration of the 2000 Census in this age group is 5%. This under-enumeration can be an issue in our estimations of the SINASC adjustment obtained from the Census question, if the children under-enumerated are, in average, significantly more likely to not have a birth certificate than the children enumerated in the Census.

estimated a logistical regression for the municipalities that participated in the proactive search survey. The dependent variable of the regression was the ratio of births registered using the proactive search. The independent variable was the ratio between the observed births in SINASC and the projected births from the 2008 official population projection (IBGE 2005). Since SINASC births and the projection are available for all municipalities in Brazil, the correction factor of the proactive search is estimated for all municipalities using β_0 and β_1, except for municipalities in eight states[3] that are considered to have a complete birth coverage. The final SINASC coverage calculated with this method is 95.6% for 2008 (Szwarcwald et al. 2011, page 92) and 95.9% for 2010 (RIPSA 2012), and the coverage obtained with the Census question is 97.1%. With the adjustment of the proactive search survey for the SINASC births in 2010, the new TFR becomes 1.786 compared to the 1.763 obtained with the Census adjustment. The adjustment of the proactive search survey provides a TFR that is also significantly lower than the TFR of 1.90 estimated using the P/F Brass method.

At the state level, the differences between the two sources are larger. Table 2 shows the comparison between the SINASC adjustment calculated from the Census survey and the estimations based on the proactive search survey. The largest difference between the two estimates is for the state of Rondônia with the Census showing a SINASC coverage of 97.0% and the proactive search survey of 91.2%. The smallest difference is in the state of Espírito Santo with the Census showing a coverage of 99.14% and proactive search survey of 99.2%. Overall, because the proactive search extends the results of the Northeast and Legal Amazonian region to the rest of the country and are based on population projections of 2008 that can be biased because of an over-

[3] The states that did not have the births estimated by the proactive search survey are Espírito Santo, Rio de Janeiro, São Paulo, Paraná, Santa Catarina, Rio Grande do Sul, Mato Grosso do Sul, and Distrito Federal (RIPSA 2012).

estimation of the TFR when using IBGE (2005), we consider these estimates less reliable than the estimates obtained from the Census data. Consequently, we consider that the best TFR estimate of Brazil in 2010 is 1.763, the adjusted SINASC estimate based on the Census question.

In summary, our analyses suggest that the P/F Brass method should no longer be used in the low-fertility low-infant-mortality context of contemporary Brazil. The adjustment suggested by the P/F method is significantly larger than plausible estimates of birth under-registration in the national administrative system, and current patterns of rapid fertility decline along the onset of fertility postponement no longer warrant the application of a method that is based on the assumption of constant fertility. Overall, we find that household surveys and the national registration systems present consistent estimates of the Brazilian TFR that differ sharply from the official estimate that uses the P_2/F_2 Brass adjustment, and we believe that registry-based TFR estimates (with adjustment for plausible levels of under-registration) currently provide the best estimates of the national fertility level in Brazil. Based on these estimates, the Brazilian TFR is about 8% lower than is suggested by official estimates, and Brazil may have reached below-replacement fertility (NRR < 1) earlier than suggested by official estimates using P/F Brass. The violation of the constant fertility assumption is likely to be the main reason for the overestimation of the TFR current encountered in Brazil's official TFR estimate. Research should further investigate a solution for state-level estimates analyzing the possible effects of different regional age patterns of migration in states' TFR.

The Effect of the 2010 Bias on Population Projections

When countries attain below replacement fertility levels, a decimal difference in the TFR is likely to have large effects on long-term population growth. By estimating the stable population growth rate in Brazil in 2010, we can observe that a TFR of 1.76 children per women results in a rate of decline of 0.57% per year, while a TFR of 1.90 results in a rate of decline of 0.29% per year[4]. The rate almost doubles with the SINASC adjusted TFR. Another important consequence of having an overestimated TFR is its impact in the UN Population Projection. The UN currently uses Brazil's official TFR, so we re-estimate the UN medium-variant projection using the SINASC adjusted TFR, which provides in our perspective the most reliable data source for estimating live births in Brazil. The UN medium-variant projection consists in estimating a Bayesian hierarchical model (BHM) of fertility and mortality for each country based on the country's historical trend (level 1) and the world's historical trends (level 2). The fertility assumption for countries that have attained below replacement fertility levels, which is the case of Brazil, is projected based on the experience of low-fertility countries that have had a fertility recovery, with an upper limit of 2.1 children per woman and the lower limit of 0.5 child per woman. Given the country's observed international migration data, and the mortality and fertility projections resultant from the BHM, a cohort-component projection is estimated deriving the final probabilistic population projection (United Nations 2014).

[4] The intrinsic growth rate of Brazil is calculated with the equation: $r = ln(TFR \times S \times p(Am))/T$, see Preston et al (2001), p. 153. In this estimation we assume that the probability of surviving until the end of the reproductive cycle [p(Am)] is 1 and that T, the mean length of replacement of a generation in the stable population, corresponds to the mean age of childbearing observed in Brazil in 2010. Based on the 2010 SINASC database, we estimate that the mean age of childbearing is 26.645 years and the proportion of births that are female (S) is 0.487.

Figure 4 shows the estimation of the BHM fertility time-series in Brazil using the official TFR and the adjusted SINASC TFR for the last observed point estimate of the 2005-2010 period. We can observe in Fig. 4 that fertility varies considerably depending on the baseline TFR used. The lowest TFR projected when using official estimates in 2010 is 1.69 children per women in 2030-2035, however when using the SINASC adjusted TFR we already observe a TFR of 1.64 children per women in 2015-2020, which is lower than any projected value when using the official estimate. The lowest TFR using the SINASC adjusted TFR is 1.60 children per women in 2025-2030, very different from the 1.69 found when using official estimates. The convergence of the two fertility trajectories in 2065-2070, as showed in Fig. 4, is resultant of the model's assumptions that, for countries with below replacement fertility levels, relies only in below-replacement fertility countries that have already experienced a TFR recovery.

The total projected population using the UN medium-variant shows a population in 2050 of 230,323,924[5] individuals using the official TFR estimate in 2010, and 223,181,973 with the SINASC adjusted estimate, a 7 million difference in 40 years of projection changing only one data point. Not only is the total projected population different when using different baseline TFRs, but also the projected age structure of the population. Figure 5 shows the differences in the population pyramids in 2050 when using different baseline TFR by type of assumption assumed in the projection, the UN medium-variant using Bayesian projections of fertility and mortality explained

[5] The projections were estimated using the R scripts 'bayesPop', 'bayesLife', and 'bayesTFR' (Ševčíková et al. 2013). There is a small difference on the values published by the United Nations (2013) with the baseline TFR of 1.90 compared with the estimations using the R scripts and the same TFR. The total population in 2050 using the medium-variant is 231,120,024, almost 800,000 more individuals than using the R scripts. The fertility trajectory after 2040 is also slightly different. These differences, however, do not affect our findings because both of our analyses, with the TFR of 1.90 and the TFR of 1.76 uses the same R scripts and baseline population, the only difference is the TFR in 2010.

above or assuming constant mortality, fertility, and zero international migration. In the medium-variant projection the mean age of the population obtained using the TFR of 1.76 is 44.67 and with the TFR of 1.90 it is 43.94, and so, with the new TFR we can expect a population that is almost one year older than predicted with the official estimate. Thus, assuming a greater TFR can provide different results in terms of old age dependency ratio, and, consequently, may influence differently pensions and taxes prognoses.

The upward bias in the TFR may also have influenced the baseline population used in the UN projection, because the UN adjusts the baseline population for under enumeration in order to maintain consistency between the country's age pyramid and its fertility, mortality, and international migration trends (United Nations 2013, table "WPP2012_F02_METAINFO.xls"). Figure 6 shows the difference between the age pyramids of the 2010 Census and the estimated UN baseline population. It can be observed that the UN estimation has a considerably larger number of individuals in the 0 to 4 and 5 to 9 age groups. And so, we can observe that, if the P/F Brass method is in fact overestimating Brazil's TFR as we defend here, it is biasing not only the Bayesian projection of the TFR, but also the baseline population pyramid used in the projection.

Discussion

The National Institute of Geography and Statistics (IBGE) in Brazil has used the P/F Brass method to adjust the TFR of Population Censuses from 1940 to 2010 (IBGE 2002 and IBGE 2012). The use of P/F Brass method in the context of fertility decline was justified when fertility decline in Brazil was mostly due to stopping behavior at older ages (Carvalho 1985) that did not significantly affect the fertility rates at ages 15 to 24 on which the P/F adjustment is based. In recent years, however, Brazilian fertility has not only attained below-replacement level, but Brazil is also experiencing the onset of a fertility postponement that starts to shift childbearing to older ages. From 2000 to 2010, for instance, there was a significant fertility decline in fertility at ages 15-24, and an increase in childlessness at these ages. In addition to the substantive significance of this onset of the postponement transition (Kohler et al 2002), the resulting change in the age-pattern of early fertility implied a violation of the assumptions underlying the P/F adjustment. In Brazil's contemporary low-fertility context, it is therefore possible that the P/F adjustment "causes more harm than good" and importantly distorts and upward-biases official TFR estimates. Using registry-based information and a correction for birth under-registration, we estimated a 2010 TFR of 1.7629 using the Civil Registry and 1.7632 using SINASC data. Both registry systems provide almost the same TFR after adjusting for under-registration. The similarities in the TFRs obtained from the two sources increased our confidence that the TFR of 1.90 children per women published by IBGE (2012) significantly overestimated the country's TFR. More research is needed in order to estimate the TFR at the regional level, since states with high levels of immigration might not fit well with the mid-year population assumption for person-years in the denominator. Despite these limitations, however, our analyses suggest that the further use of the P/F method for national TFR estimates should be carefully evaluated and possibly discontinued.

The consequences of disseminating a TFR of 1.90 children per women in 2010 by the official statistics bureau (IBGE 2012) produced biased estimates for institutions and researchers using this source. We have shown that for the United Nations (2013), the overestimation of the TFR affected not only the projected TFRs for the 2015-2100 period, but also an adjustment in the age pyramid of the baseline population. When re-estimating the medium-variant UN projection using the SINASC-adjusted TFR of 1.76 children per women, the predicted population in 2050 was 7 million smaller and almost one year older than using the TFR of 1.90 children per women published by IBGE (2012). The total population and age structure predicted from the two estimates were also different, which can result in diverging pensions and taxes prognoses by specialists.

Colombia, Peru, Venezuela, and Ecuador are also using the P/F Brass method to estimate its Census' TFR. Similar to Brazil, these countries have also experienced rapid fertility decline and an increase in the percentage of childless women at younger ages. As a result, we believe that in these Latin American – and possibly other middle-income countries – recent fertility declines may have progressed further than is suggested by official TFR estimates, and fertility in these countries may have dropped to below-replacement levels earlier than has previously been believed to be the case.

In general, this paper draws attention to the use of the P/F Brass adjustment at the country level and the risks incurred by the researcher when applying it to populations with rapid fertility declines and an onset of delayed childbearing. It is important to increase the awareness of the use of this method by statistical offices. We consider important that international compilations of the TFR, as in United Nations (2013), state explicitly the use of this indirect method in the estimation of TFRs. To date, the institution does not publish a list of countries currently using the method.

Conflict of Interest Statement

I hereby confirm that the authors of this paper have NO financial interests or connections, direct or indirect, or other situations that might raise the question of bias in the work reported or the conclusions, implications, or opinions stated - including pertinent commercial or other sources of funding for the individual author(s) or for the associated department(s) or organization(s), personal relationships, or direct academic competition.

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Tables

Table 1: Type of Birth Registry for Children Aged Zero in August 1st 2010 in Brazil

Type of Birth Registry	Frequency	Percent	Cum.
Notary	2,545,713	93.83	93.83
Health facility	89,760	3.31	97.14
Indigenous birth certificate	4,693	0.17	97.31
Don't have	69,886	2.58	99.89
Don't know	3,069	0.11	100.00
Total	2,713,121	100	

Source: Census Universe 2010.

Note: 0.005% (n=123) individuals had missing information and were removed from the sample.

Table 2: Birth Registry, SINASC, and Proactive Search Adjustments in 2010

State	Civil Registry Adjustment	SINASC Adjustment	Proactive Search Adjustment
Brazil	*1.07*	*1.03*	*1.05*
Acre	1.20	1.10	1.05
Alagoas	1.08	1.04	1.06
Amapá	1.15	1.08	1.07
Amazonas	1.27	1.14	1.11
Bahia	1.07	1.03	1.08
Ceará	1.09	1.04	1.07
Distrito Federal	1.05	1.01	1.00
Espírito Santo	1.02	1.01	1.00
Goiás	1.04	1.01	1.08
Maranhão	1.20	1.09	1.11
Mato Grosso	1.07	1.04	1.07
Mato Grosso do Sul	1.08	1.06	1.01
Minas Gerais	1.02	1.01	1.06
Pará	1.24	1.12	1.11
Paraíba	1.09	1.02	1.06
Paraná	1.02	1.01	1.02
Pernambuco	1.07	1.03	1.06
Piauí	1.17	1.07	1.06
Rio de Janeiro	1.04	1.01	1.01
Rio Grande do Norte	1.06	1.03	1.08
Rio Grande do Sul	1.02	1.01	1.03
Rondônia	1.07	1.03	1.09
Roraima	1.25	1.17	1.07
Santa Catarina	1.02	1.00	1.00
São Paulo	1.02	1.00	1.00
Sergipe	1.08	1.04	1.05
Tocantins	1.11	1.05	1.07

Source: Census Universe 2010 and RIPSA (2012).

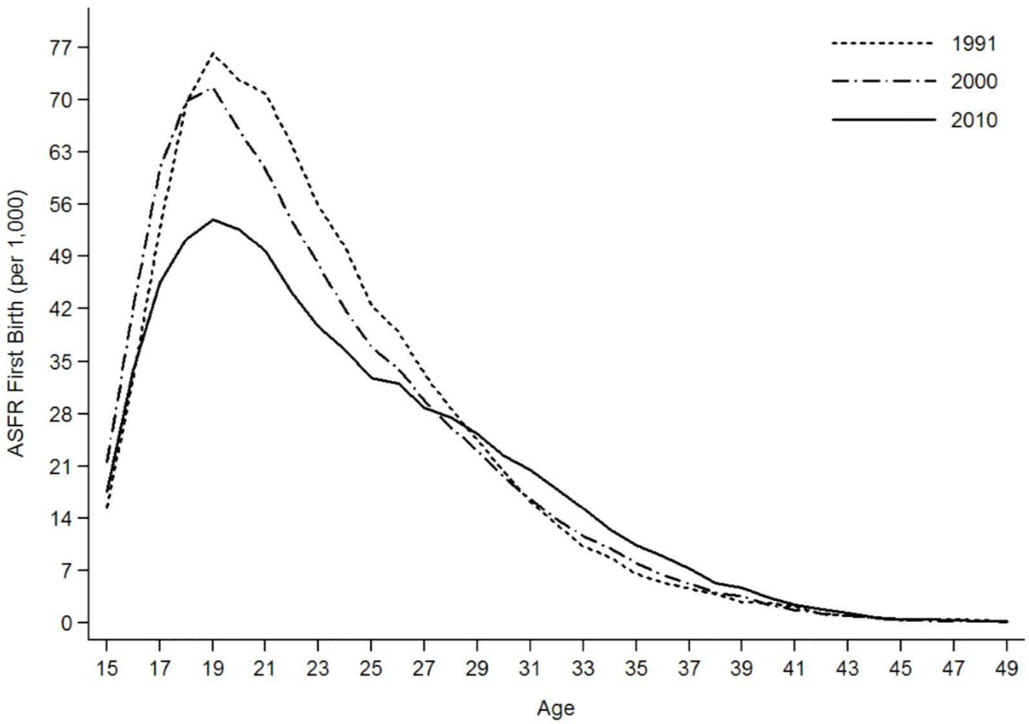
Table 3: Estimated TFR of Brazilian States in 2010 by Data Source and Adjustment

State Code	State Name	Census	Census Confidence Interval	Oficial Estimates (P/F Brass)	Civil Registry	Civil Registry Adjusted	SINASC	SINASC Adjusted	SINASC Adjusted Active Search	Rank Census TFR	Rank SINASC Adjusted	Total Population
1	*Brazil*	*1.60*	*1.53 - 1.66*	*1.90*	*1.65*	*1.76*	*1.71*	*1.76*	*1.79*	*10*	*13*	*190,755,799*
11	Rondônia	1.73	1.38 - 2.08	2.15	1.70	1.82	1.77	1.83	1.94	18	16	1,562,409
12	Acre	2.14	1.37 - 2.90	2.82	1.97	2.37	2.44	2.68	2.68	26	27	733,559
13	Amazonas	2.22	1.70 - 2.73	2.66	1.91	2.41	2.29	2.61	2.55	28	26	3,483,985
14	Roraima	2.08	1.37 - 2.79	2.52	2.00	2.49	2.31	2.70	2.58	25	28	450,479
15	Pará	1.96	1.66 - 2.27	2.43	1.66	2.06	1.96	2.20	2.17	24	24	7,581,051
16	Amapá	2.14	1.65 - 2.63	2.60	2.14	2.46	2.31	2.49	2.54	27	25	669,526
17	Tocantins	1.86	1.47 - 2.24	2.33	1.81	2.01	1.93	2.02	2.10	21	22	1,383,445
21	Maranhão	1.95	1.63 - 2.27	2.50	1.71	2.06	1.94	2.11	2.18	23	23	6,574,789
22	Piauí	1.72	1.43 - 2.02	1.97	1.57	1.84	1.74	1.86	1.86	17	19	3,118,360
23	Ceará	1.62	1.37 - 1.87	2.00	1.62	1.77	1.69	1.76	1.81	12	12	8,452,381
24	Rio Grande do Norte	1.60	1.32 - 1.89	1.99	1.61	1.71	1.67	1.71	1.78	11	8	3,168,027
25	Paraíba	1.75	1.49 - 2.01	1.97	1.67	1.82	1.77	1.81	1.88	19	15	3,766,528
26	Pernambuco	1.64	1.43 - 1.85	1.90	1.66	1.77	1.72	1.77	1.81	14	14	8,796,448
27	Alagoas	1.87	1.54 - 2.20	2.22	1.84	1.99	1.89	1.97	2.04	22	20	3,120,494
28	Sergipe	1.70	1.35 - 2.05	2.00	1.69	1.82	1.78	1.84	1.86	16	18	2,068,017
29	Bahia	1.63	1.42 - 1.84	2.03	1.63	1.74	1.67	1.72	1.80	13	9	14,016,906
31	Minas Gerais	1.47	1.32 - 1.61	1.77	1.54	1.56	1.53	1.55	1.59	3	1	19,597,330
32	Espírito Santo	1.52	1.26 - 1.78	1.80	1.66	1.69	1.67	1.69	1.69	7	6	3,514,952
33	Rio de Janeiro	1.42	1.27 - 1.57	1.68	1.50	1.55	1.61	1.63	1.62	1	5	15,989,929
35	São Paulo	1.43	1.31 - 1.56	1.67	1.67	1.71	1.68	1.69	1.69	2	7	41,262,199
41	Paraná	1.59	1.39 - 1.79	1.85	1.69	1.73	1.72	1.73	1.74	9	10	10,444,526
42	Santa Catarina	1.51	1.32 - 1.69	1.72	1.56	1.59	1.58	1.58	1.59	6	3	6,248,436
43	Rio Grande do Sul	1.47	1.31 - 1.63	1.75	1.53	1.56	1.56	1.57	1.58	4	2	10,693,929
50	Mato Grosso do Sul	1.78	1.47 - 2.10	2.06	1.80	1.94	1.86	1.97	1.91	20	21	2,449,024
51	Mato Grosso	1.67	1.38 - 1.95	2.11	1.71	1.83	1.77	1.84	1.87	15	17	3,035,122
52	Goiás	1.59	1.37 - 1.81	1.86	1.60	1.66	1.61	1.63	1.72	8	4	6,003,788
53	Distrito Federal	1.49		1.74	1.70	1.78	1.74	1.75	1.74	5	11	2,570,160

Source: Official TFR estimates: obtained from the National Institute of Geography and Statistics (IBGE), table 3727 available at www.sidra.ibge.gov.br, last accessed on May 11th, 2015. Census estimates: obtained from the Census microdata. Census TFRs refer to the twelve months prior to the survey's reference date. SINASC: Live Births Information System with data available online at http://tabnet.datasus.gov.br/cgi/deftohtm.exe?sinasc/cnv/nvuf.def, last accessed on May 11th 2015. The reference period is January 1st to December 31st. Civil registry: obtained from the National Institute of Geography and Statistics (IBGE), tables 343 and 2680 available at www.sidra.ibge.gov.br. The reference period is from January 1st to December 31st. Adjustments: SINASC and Civil Registry adjusted TFR are based on the 2010 Census question asking whether children younger than one year old had a birth certificate or a live birth declaration (DNV). The active search adjustment of SINASC is based on the information on RIPSA (2012) for the 2010 calendar year.

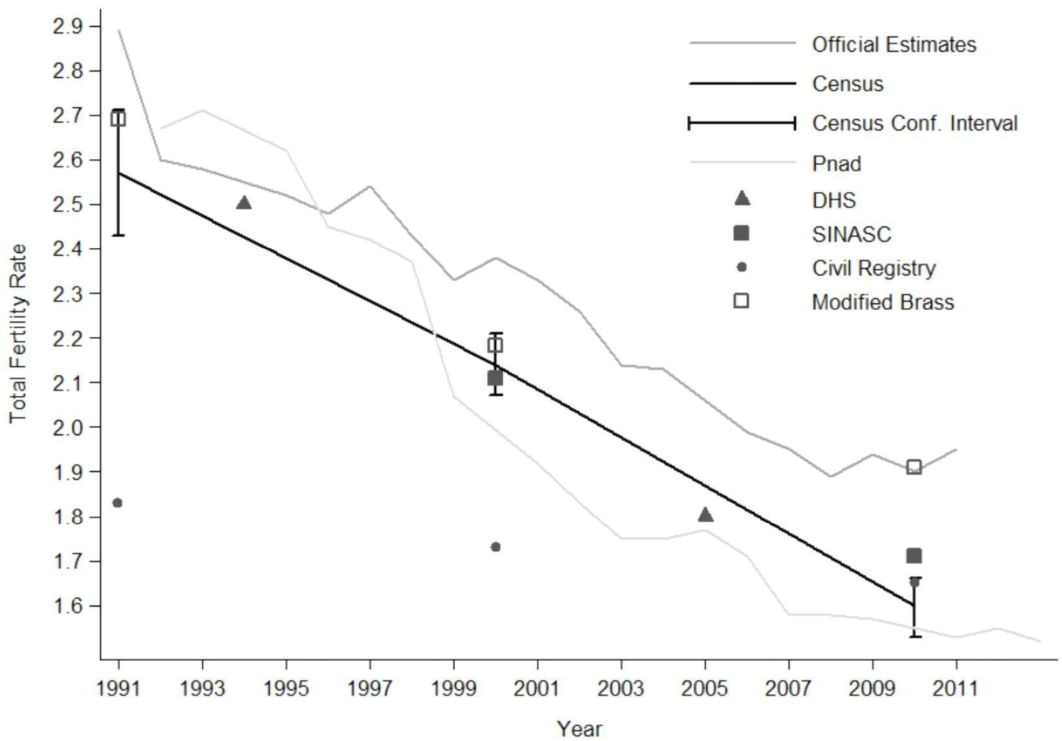
Figures

Figure 1. Age Specific Fertility Rates for First Births per 1,000 women



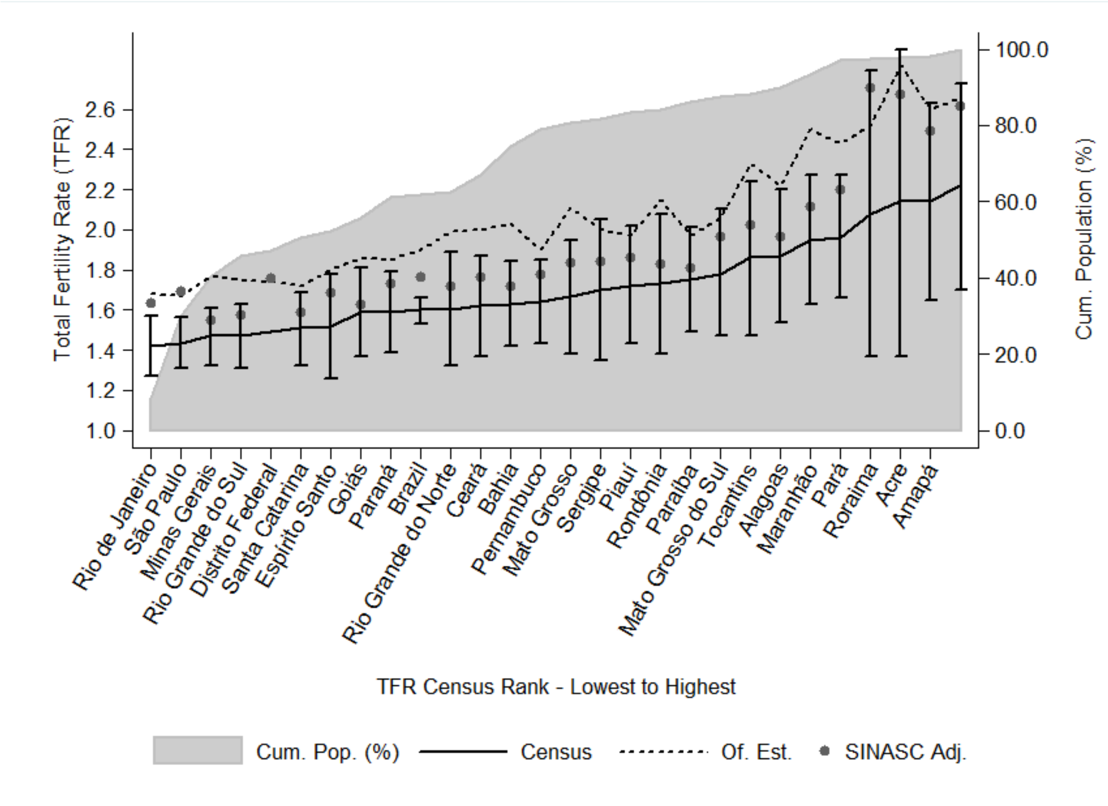
Source: IBGE. Brazilian Demographic Censuses of 1991, 2000, and 2010.

Figure 2: Estimated Total Fertility Rate in Brazil in Different Data Sources from 1991 to 2013



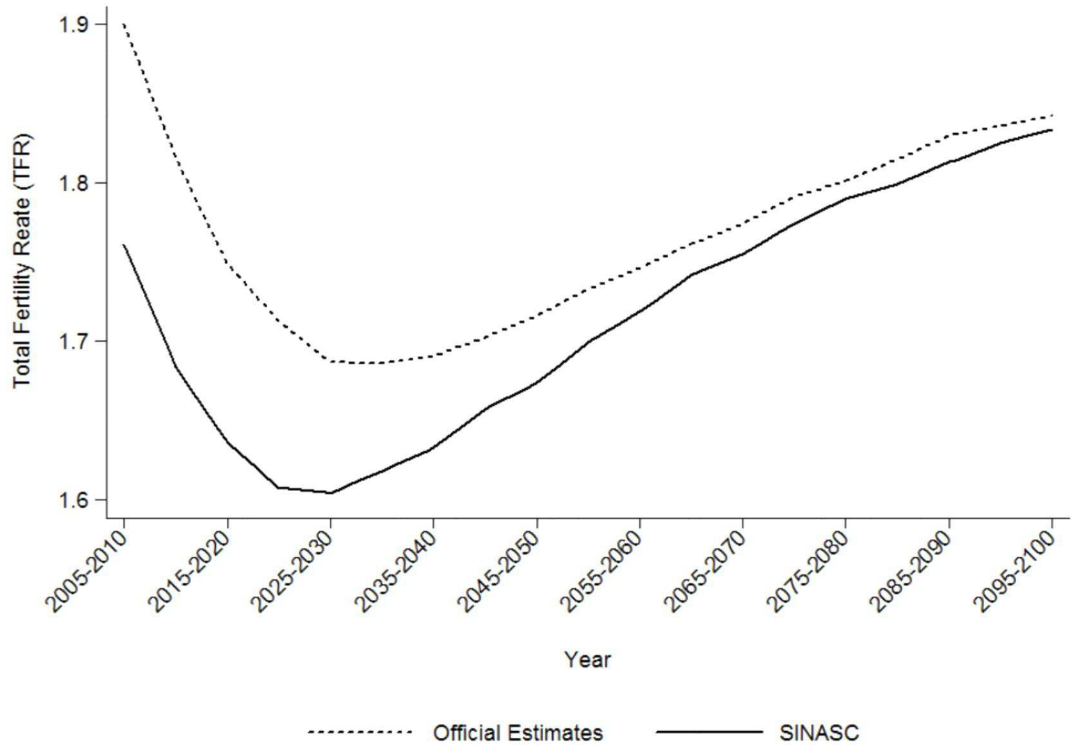
Source: Official TFR estimates: obtained from the National Institute of Geography and Statistics (IBGE), table 3727 available at www.sidra.ibge.gov.br, last accessed on May 11th, 2015. These TFRs are estimated based on the Annual Household Survey (Pnad) during non-census years and in the Demographic Census Surveys of the years 1991, 2000 and 2010. The P/F Brass adjustment is applied in all years. Census and Pnad estimates: obtained from the Census microdata. Census and Pnad TFRs refer to the twelve months prior to the survey's reference date. SINASC: Live Births Information System with data available online at http://tabnet.datasus.gov.br/cgi/deftohtm.exe?sinasc/cnv/nvuf.def, last accessed on May 11th 2015. The reference period is from January 1st to December 31st. DHS: The estimated TFR of the Demographic and Health Surveys (DHS) are available at http://www.statcompiler.com/, for the 1996 DHS, and at http://bvsms.saude.gov.br/bvs/publicacoes/pnds_crianca_mulher.pdf, for its 2006 Brazilian equivalent, the PNDS. The reference period of the TFR is three years before the survey's reference date. In the graph, the data point is located in the mid-period of the three years reference period for both surveys. Civil registry: obtained from the National Institute of Geography and Statistics (IBGE), tables 343 and 2680 available at www.sidra.ibge.gov.br. The reference period is from January 1st to December 31st. Modified Brass: Uses the Demographic Census and the modified P/F Brass method elaborated in Schmertmann et al. (2013).

Figure 3: Estimated Total Fertility Rates by Brazilian States in 2010



Source: Official TFR estimates: obtained from the National Institute of Geography and Statistics (IBGE), table 3727 available at www.sidra.ibge.gov.br, last accessed on May 11th, 2015. Census estimates: obtained from the Census microdata. Census TFRs refer to the twelve months prior to the survey's reference date. SINASC adjusted: Live Births Information System with data available online at http://tabnet.datasus.gov.br/cgi/deftohtm.exe?sinasc/cnv/nvuf.def, last accessed on May 11th 2015. The reference period is from January 1st to December 31st. The adjustment is calculated from a question of the Census universe asking whether the children younger than one year old had a birth certificate or a live birth declaration (DNV).

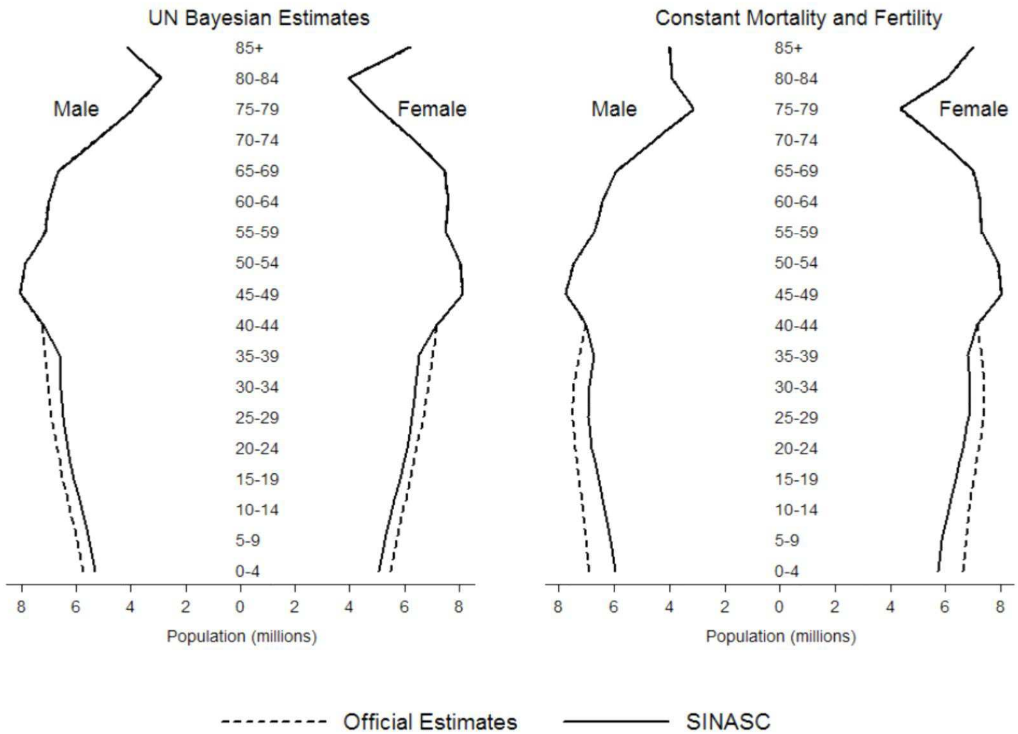
Figure 4: TFR Projections with different baseline estimates in 2010



Source: United Nations (2013) and SINASC, data available online at http://tabnet.datasus.gov.br/cgi/deftohtm.exe?sinasc/cnv/nvuf.def , last accessed on May 11th 2015.

Note: Estimations using the 'bayesTFR' R program (Ševcıková et al. 2011).

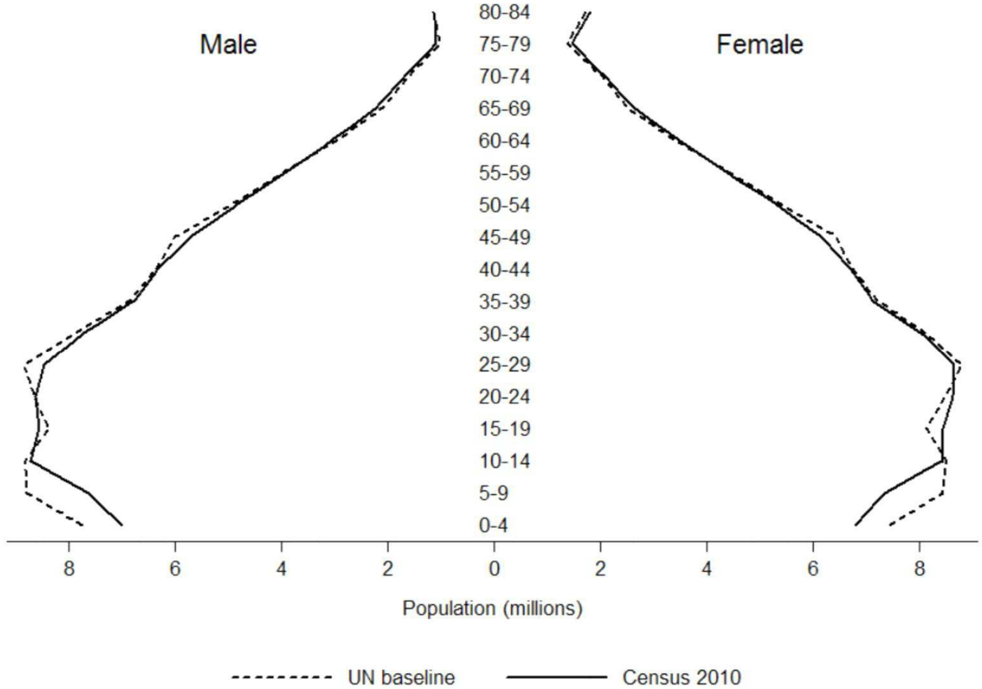
Figure 5: Projected Brazilian's Total Population in 2050 using the Official TFR and the SINASC TFR in 2010, by projection estimates



Source: United Nations (2013) and SINASC, data available online at http://tabnet.datasus.gov.br/cgi/deftohtm.exe?sinasc/cnv/nvuf.def , last accessed on May 11th 2015.

Note: Estimations of the UN Bayesian estimate used the 'bayesPop', 'bayesLife', and 'bayesTFR' programs (Ševčíková et al. 2013).

Figure 6: Differences between the UN Baseline Population and the 2010 Census



Source: United Nations (2013) and IBGE (2010).