Forecasting Australian Births Using a Three-Parameter Model

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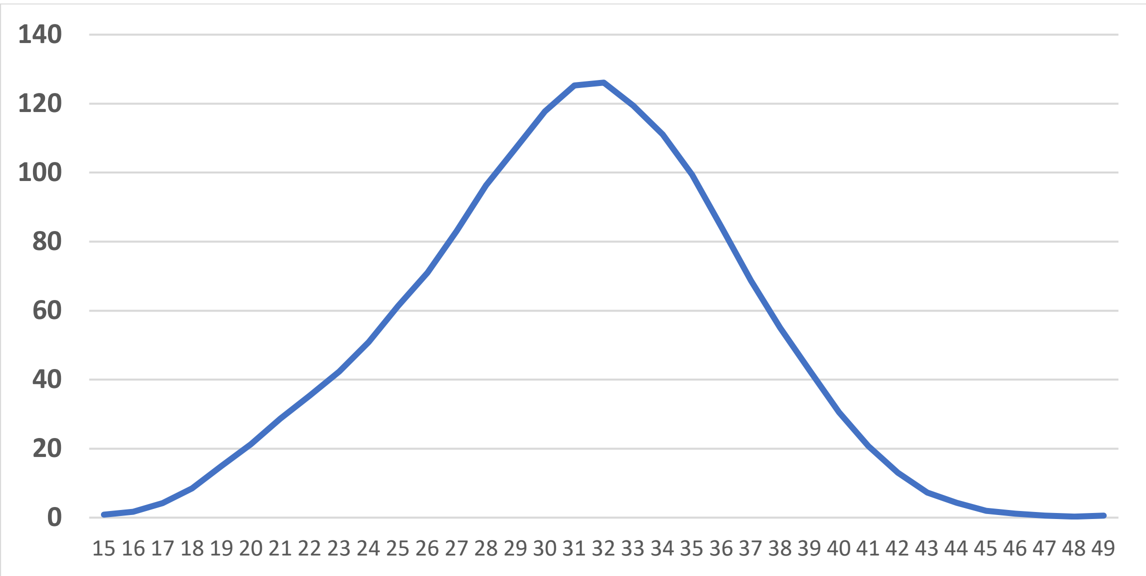
Introduction

As part of an Australian Research Council Linkage Grant with the Department of the Treasury and the Australian Bureau of Statistics (ABS), the authors were asked to forecast births in Australia during the 2020s using a three-parameter model. The three parameters (or characteristics of the woman) that are used are the woman's age, her parity and the time since her previous birth. The term 'forecast' is used in distinction from the usual demographic approach of 'projection'. Projections generally examine the longer-term future pathways of population subject to hypothetical assumptions about future trends in the components of demographic change, births, deaths, and migration. In contrast, a forecast attempts to measure demographic trends accurately rather than hypothetically in the short term. Forecasts of births in the short term have very important planning implications for all forms of children's services but especially for the planning of capital-intensive services such as schools and childcare centres.

In the short term, typically within a decade, forecasting errors related to birth rates are attributed to methodological shortcomings rather than to unexpected social changes (Raftery & Ševčíková, 2023). The Australian Bureau of Statistics has conventionally projected births using only one parameter, the woman's age (ABS 2024). However, a woman's age alone is not a very reliable predictor of whether she will give birth in a particular year. For instance, even though fertility is generally higher at age 30 compared to age 35, a 35-year-old woman who had her first child three years ago is more likely to have another child in the next year than a 30-year-old woman who had her first and only child a decade ago (McDonald and Kippen, 2011). While fertility certainly varies by age (Figure 1), rates of birth are relatively high over a wide range of ages (above 40 per 1000 from age 23 to 39).

Figure 1. Age-Specific Fertility Rates (per 1000 women), Australia, 2020-21



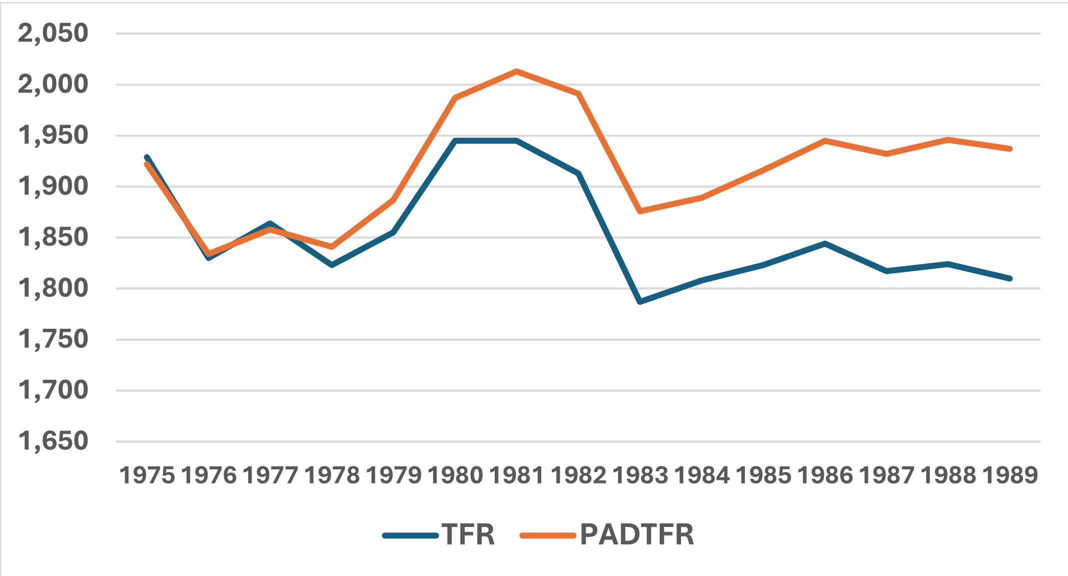
Source. Year of occurrence data provided by Centre for Population, Department of the Treasury.

In contrast, it is argued that fertility is relatively more predictable if, in addition to the woman's age, it is based on a three-parameter model: her age, the number of children she has already (parity) and the time since the most recent birth.

Three-parameter model of fertility: Theory

The three-parameter model was described in detail in a paper by Rallu and Toulemon (1994). In that paper, the authors compare the results for France of a range of cross-sectional or period measures of fertility. Demographers are very attuned to the use of the Total Fertility Rate (TFR, the sum of the age specific rates in a year) as the leading index of fertility while not appreciating that the annual fertility rate can be obtained using age and parity specific rates of birth (PATFR in Rallu and Toulemon, a two-parameter approach) or age, parity and time since the previous birth (PADTFR in Rallu and Toulemon, a three-parameter approach). Rallu and Toulemon conclude that the PADTFR is a more satisfactory measure of the underlying fertility trend than is TFR because TFR is much more likely to be distorted by 'demographic upheaval'. Their results for France for the years 1975 to 1989 show quite different levels for PADTFR than for TFR (Figure 2) although purporting to measure the same thing: the cross-sectional incidence of births.

Figure 2. Total Fertility Rate and Total Fertility Based on a Three-Parameter Model (PADTFR), France, 1975-1989



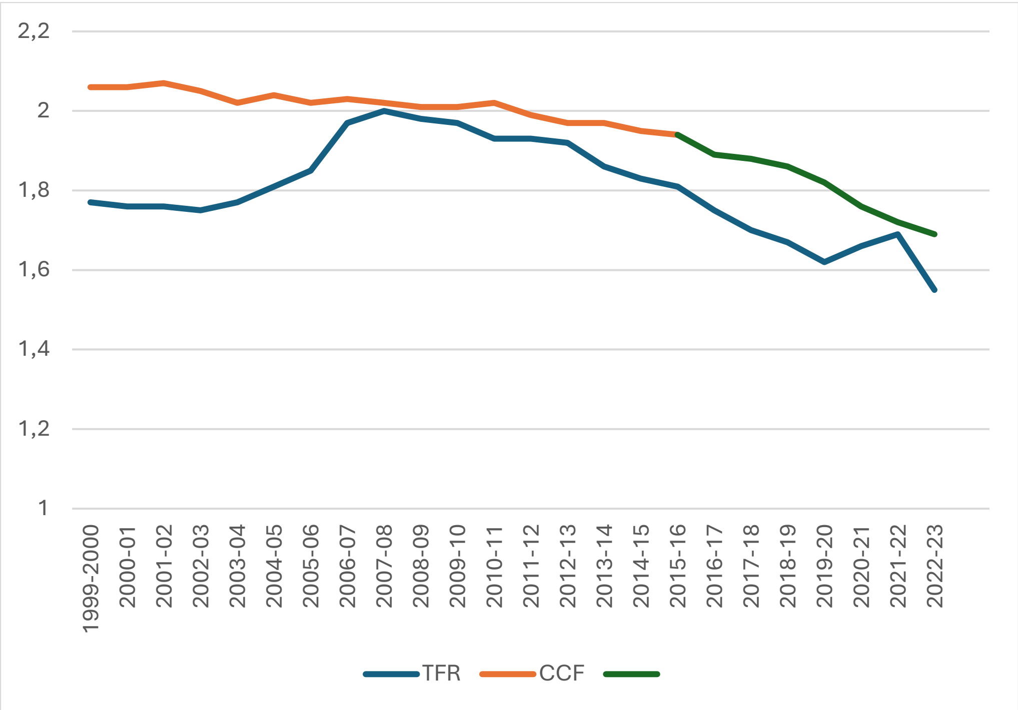
Source. Graphed from data in Rallu and Toulemon, 1994, p. 93.

Since the paper by Rallu and Toulemon was written, demographers have paid much more attention to the distortion of the annual TFR that results from increases in age at first birth, the 'postponement transition'. It is this 'postponement transition' which primarily constitutes Rallu and Toulemon's 'demographic upheaval'. When first births are delayed, births are pushed out into the future and TFR falls. Furthermore, when first births are delayed, there is a shift to later ages of childbearing at which fertility rates tend to be lower. (Kohler and Ortega 2002). This process (referred to as a 'tempo effect') can continue for a very long time meaning that the TFR understates the underlying (or completed cohort) level of fertility for many years:

> The ‘postponement transition’ results in a prolonged stage of depressed, and often very low, period fertility levels. This stage typically lasts several decades, followed by at least a partial ‘recuperation’ of period fertility rates, linked with the diminishing pace of fertility postponement (Sobotka 2017, p. S37).

This impact of changing age at first birth on the Total Fertility Rate in Australia is indicated in Figure 3 which shows the TFR for Australian financial years (1 July to 30 June) compared with the Cohort Completed Fertility (CCF) of cohorts born 31 years before the year for which TFR is shown. A 31-year lag is chosen to approximate the average age at birth of mothers over this period of time. The green part of the CCF line is projected CCF but the projections will be very accurate as only the very low fertility rates for ages 41 to 49 are required for the projection. This figure shows that Completed Cohort Fertility has been subject to lower fluctuations than has the age-based Total Fertility Rate. TFR has fallen below CCF in all these years.

Figure 3. Annual Total Fertility Rate (TFR) compared with the Completed Cohort Fertility (CCF) of Cohorts Born 31 Years Earlier, Australia, 1999-2000 to 2021-22



Source. Authors’ database constructed from various sources.

There was a temporary rise in TFR starting after 2004-05 so that TFR and CCF became equal by 2007-08. The temporary rise in TFR was due partly to the ending of the delay of births for many women in their thirties (McDonald and Kippen 2011) but also family-friendly policies introduced after the 2004 election and the economic boom in these years. In the early part of this rise, fertility rates rose at all ages including young ages bringing a temporary halt to the long-term rise in average age at first birth. From about 2013-14 onwards, however, TFR has fallen again below CCF as age at first birth has continued to fall. the long-run relative stability of TFR combined with the slow decline of CCF suggests that the two measures are coming closer together which can only occur if the long-term increase in age at first birth slows to a halt.

CCF has been declining each year following a regular trend, but the decline has accelerated in recent years. This observation supports the use of a completed cohort fertility approach to the projection of fertility as used for the Department of the Treasury projections (McDonald 2020). Interpretation of this trend has been enhanced through the inclusion of a question on the number of children ever born to women in successive censuses since 2006[1]. These data show that CCF falls a little each year as the small increase in age at first birth leads to slightly lower percentages of women having three or more children. This is the continuation of a very long-term trend from the 1970s. It provides a basis for an assumption about fertility in the short-term future: that change will continue to be gradual and not radical. If radical change were to occur, it would be the result of increasingly higher percentages of women opting to have no children as is already evident in countries in East Asia.

Forecasting of births with the three-parameter model: experience

McDonald and Kippen (2011) applied the three-parameter model to the forecasting of births in Australia from 2001 to 2011 assuming constant three-parameter rates of birth. The model proved to be accurate even to the point of predicting the turning point in the Total Fertility Rate from 2004 shown in Figure 3. This accuracy was the result of two circumstances:

. The long-term increase in age at first birth slowed down during the projection period meaning that first births were less likely to be further delayed, and

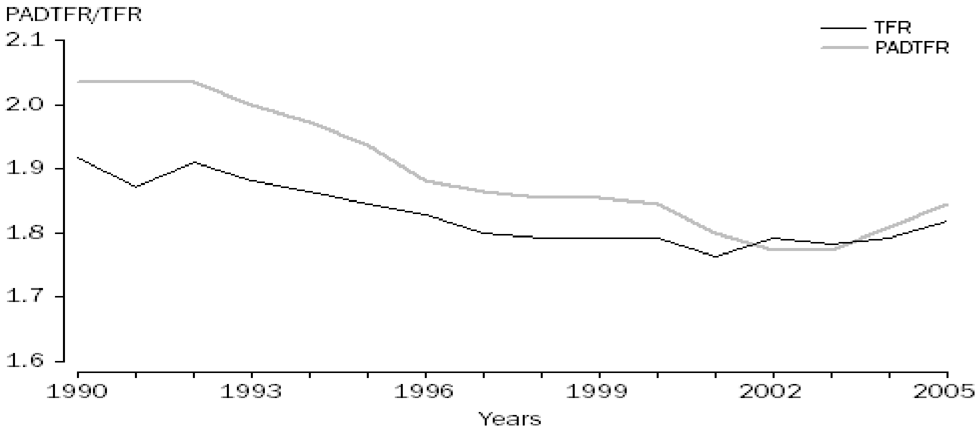
. for second and higher order births, the age-parity-duration specific birth rates had remained almost constant for over 20 years prior to the projection and, also, based on the results, appear to have done so during the projection period.

They concluded that the movement in the age-based TFR during the projection period was due not to changes in fertility rates but mainly to the structure of the population at risk according to the three parameters. This showed the importance of using this structure in making forecasts of births. McDonald and Kippen's results in terms of TFR and PADTFR are shown in Figure 4. By using the structure of the population based on the three parameters, the distorting effect of increasing age at first birth tends to be eliminated for higher order births – but not the first birth.

In another example, Hosseini-Chavoshi, McDonald and Abbasi-Shavazi (2024) have recently used the three-parameter model to forecast births in Iran for the second decade of the 21st century. In making the forecast, they assumed constant rates of birth according to the three parameters. The results are shown in Figure 5. In this example, the forecast births do not match the actual number of births that occurred. Actual births exceeded the forecast until 2018, and the authors conclude that this was due to a fall in age at first marriage for women and a consequent fall in age at first birth. From 2018, however the reverse situation applied, and the authors showed that this was due to a new pattern of behaviour with the first birth being delayed within marriage. This study shows how the three-parameter model can be used to interpret past trends in fertility and the significance of the timing of the first birth.

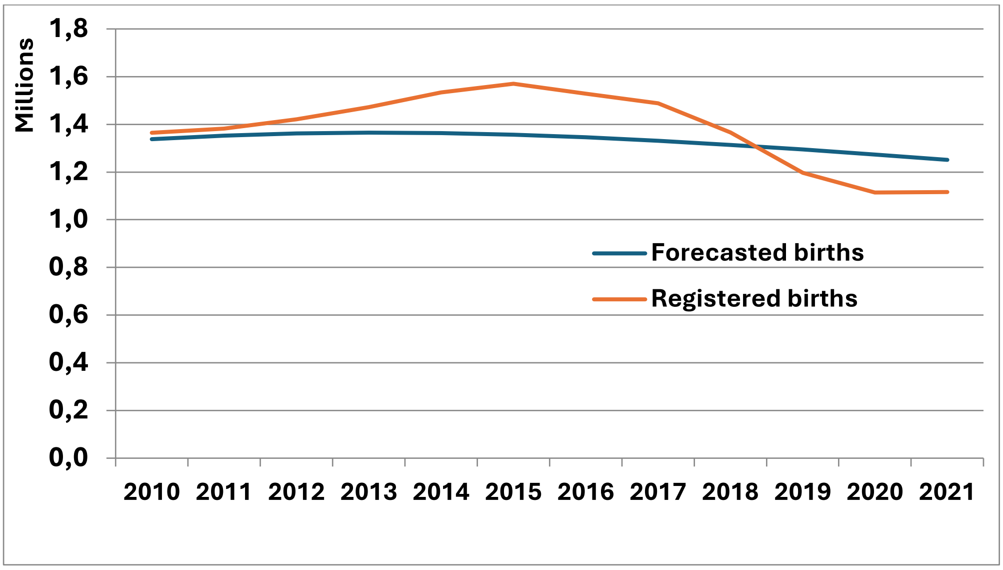
[1] ABS has decided not to include the children ever born question at the 2026 Census. This will mean that it will be much more difficult to monitor and explain any new directions in Australian fertility, for example, an increased tendency for women to have no children.

Figure 4. The Age-Based Total Fertility Rate (TFR) and the Parity-Age-Duration TFR (PADTFR), Australia **-** 1990 to 2005



Source: McDonald and Kippen, 2011.

Figure 5. Iran: Registered births 2010-2021 compared with births expected using fertility rates from a constant, three-parameter model



Source: Calculated by the authors using the 2016 Census and 2010 Iran Demographic and Health Survey.

The present paper

In this paper, the authors apply the three-parameter model to the forecasting of births in Australia in the 2020s based on estimates of three-parameter birth rates for the years, 2016 to 2021. The base population is taken from the 2021 Population Census. The rates for the five years from 2016 to 2021 are used to examine the trends in the three parameter rates and, crucially, the trend in first birth rates to inform the assumptions for the forecasts from 2021.

Data and methods

The aim of the research is to construct rates of birth simultaneously by three parameters, the age of the mother at the time of the birth, the birth order or parity of the birth and the time since the previous birth (for second and higher order births). This is done for each of the financial years, 2016-17 to 2020-21 to indicate the directions of recent trends.

In Australia, births are registered separately by the Registrars of the eight states and territories. Once registered, reports are sent by each of the jurisdictions to the Australian Bureau of Statistics for publication. In its annual publication, *Births Australia*, the ABS publishes analyses of births that are **registered** in the particular year. It is very important to note that the number of births registered each year differs from the number of births occurring in that year, often by several thousand. For analysis of fertility trends, it is imperative to use births by year of occurrence. ABS maintains a database on births occurring each year but does not publish the results in any comprehensive way. For the purposes of this research, the ABS provided the authors with the numbers of births occurring in each of the financial years, 2016-17 to 2020-21 by age of mother at the time of the birth.

The Registrars in each state and territory collect information on the parity (birth order) of the birth being registered but, unfortunately, the data are useless because different definitions of birth order are used across the jurisdictions (Corr and Kippen 2006). A consistent and correct definition of birth order is used in the alternative birth collection, the National Perinatal Data Collection, coordinated by the Australian Institute of Health and Welfare, with data provided from all public and private maternity services across Australia. This latter data source should be used to analyse trends in Australian fertility by parity, but the relevant data were not available for the research in this paper. Accordingly, the authors have used data from the 2021 Population Census to estimate the parity of births in each of the five years before the census.

Neither of the two official data sources of births gathers information on the third parameter, time since most recent birth. We estimate the time since the most recent birth from the age of the youngest child of the woman as recorded in the 2021 Census. This requires matching of children to their mothers. This is not always possible if for some reason the mother and child are not enumerated in the same household of if, within the same household, there is a confusion as to which of more than one woman is the mother of the designated child. However, in this exercise we make use only of children aged less than five years and as shown in Table 1, almost all of these children can be matched to their mother.

Table 1. Percentage of children matched to their mother by age of child, 2021 Census

Age of Child	Percentage matched to their mother
0	99.0
1	98.8
2	98.5
3	98.3
4	97.9

Source. Derived from supplied ABS tables

Input data and adjustments to the numbers

The required data were provided by the Australian Bureau of Statistics based on the following requests from the researchers.

Births data (numerators for rates)

Source: 2021 Census Families file

1. Obtain a file of all children aged less than 5 by their age at the census in single years
2. To each child record, attach the age of the child's mother when the child was born (Mothers age at birth = Mothers age at census – child's age at census)
3. To each child record, attach the mother's parity at the time of birth of the designated child (mother's parity at census -1 for youngest child; mother's parity at census – 2 if second youngest child, etc.)
4. To each child record, attach the difference in age between the designated child and its next older sibling (age of next older sibling – age of designated child)

The result is a file of children by four characteristics. Obtain a table that cross-tabulates all four characteristics simultaneously. Codes required:

Age of child in single years, 0-4 (born in each of the five years preceding the census).

Age of mother at child's birth in single years: 15-49

Mother's parity at birth of the child in single numbers of children: 0-10

Number of years that child is younger than next older sibling in single years: 0-10

In this table, parity not stated was distributed pro rata across the known parities for each age of the mother. A similar adjustment was not made for non-statement of the years since the previous birth. Most non-statement of this type related to cases where children were not living with their mothers. This occurs primarily as children get older and is not common for children under the age of five (Table 1).

The ABS also provided a table showing the number of births occurring in each of the five financial years preceding the 2021 Census by single years of age of mother. To obtain the three parameter births to be used as the numerators for the rates, the values obtained in the initial census table are blown up to the number of births occurring in each of the five years preceding the census for each single year of age of mother. This procedure corrects for children not matched to mothers, census undercount, deaths of children, and the small difference in dates between the 12 months preceding the census and the financial year. The sizes of the adjustments made are shown in Table 2. Surprisingly, the adjustments were very similar at each age (year of birth). The assumption here is that the 14 per cent of births missing from the census count have the same pattern of characteristics as the 86 per cent recorded in the census.

Table 2. Comparison of estimated births in census three -parameter table and births in the corresponding financial year

Age	Three Parameter Table	Births in Financial Year	Column 2 as % of Column 3
0	261620	305054	85.8
1	257998	299314	86.1
2	260907	304732	85.6
3	262738	304564	86.3
4	267955	307799	87.1

Population data (denominators of rates)

At both the 2016 and 2021 Censuses, the number of women by their age, their parity and the age of their youngest child were tabulated in the same detail as the births table. These two tables were then blown up first to match the census table of age by parity (to account for time since previous birth not stated) and then blown up again to match the Estimated Resident Population by age for 30 June 2016 and 2021.

Calculation of Birth Probabilities

Once the adjustments to the numerators and denominators were complete, birth rates were calculated for each of the many three parameter cells. These rates were then applied to obtain the forecasts of births as described below.

Step 1: Birth probability for women with parity zero

For women with **parity zero** (childless), the birth probability is the probability of having the first child by the age. For women with **parity one or more** (those who have already had at least one child), the probability of having the next child depends on the time since their last birth at each parity level and their age.

Pa,b1= Ba,p0 / Wa,p0

Where

Pa,b1 is the probability of having first birth by age a

Ba,p0 is the number of first births (parity zero at birth) to mothers of age a

Wa,p0 is the number of women of parity zero

Step 2: Birth probability for women with parity one or more

<u>Pa,bn= Ba,pn-1,i / Wa,pn-1,j</u>

Where

Pa,bn is the probability of having second birth or higher to mother of age a and parity n and age j of the youngest child

Ba,pn,i is the number of second birth or higher (parity n-1 at birth) to mothers of age a with birth interval of i. This involves using the **number of births** for each parity group and the time since the previous birth.

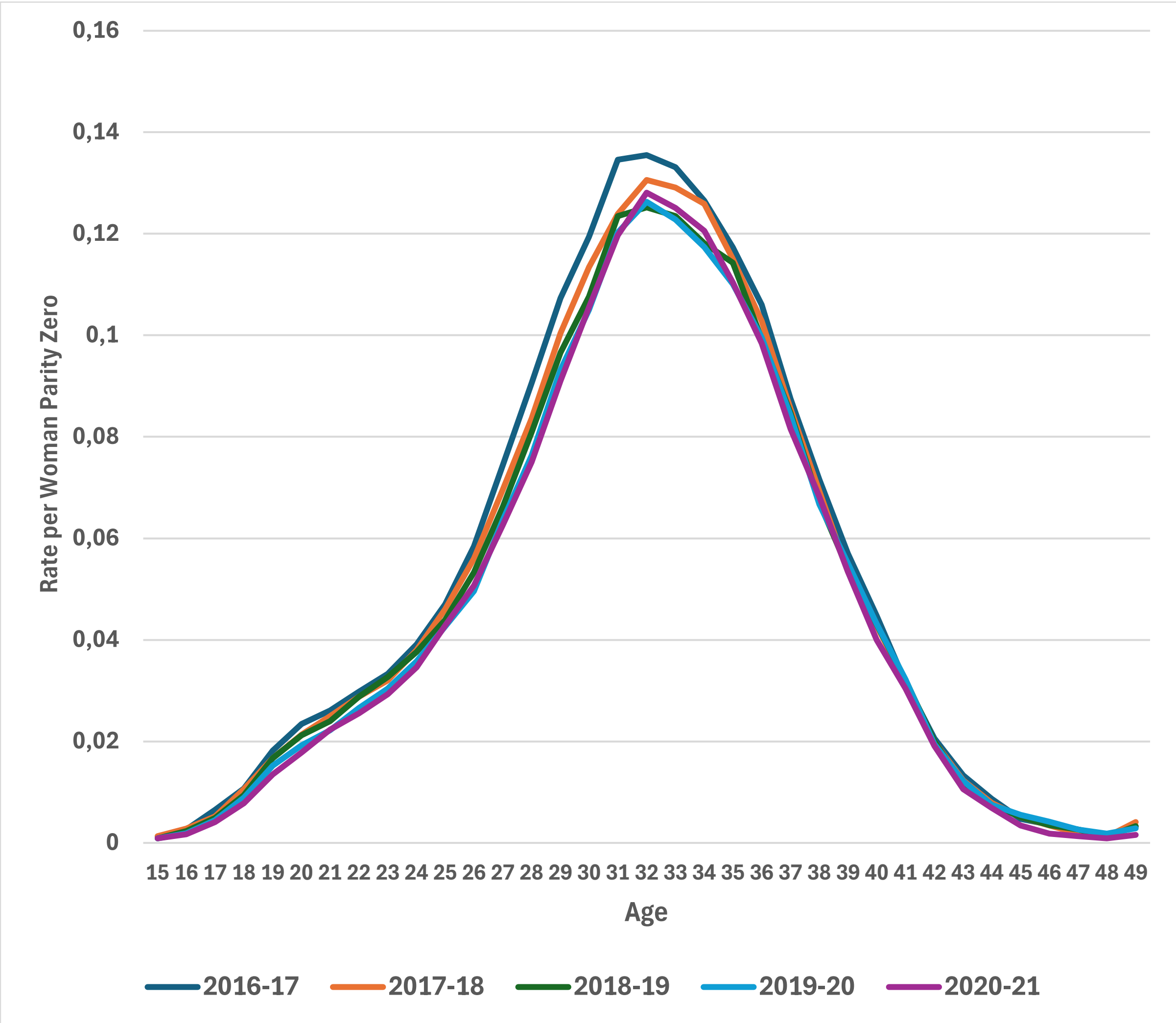
Wa,pn,j is the number of women of age a and parity n-1 with age j of youngest child

Step 3. Forecasting the Number of Births

After calculating the birth probabilities for each group of age a, parity n, age j of youngest child the number of births is forecasted.

Analysis of trends in the intercensal period showed that age-specific first birth rates were close to constant in the three years preceding the 2021 Census (Figure 6). Accordingly, we assumed that these rates would continue across the forecasting period. The other three parameter rates were also assumed to remain constant.

Figure 6. Age-Specific First Birth Rates, 2016-17 to 2020-21, Australia



Source. Derived by the authors from data supplied

The future births to women present at the time of the 2021 Census are then forecast as follows.

Forecasted births in year t=(Pa,b1 x Wa,p0) + $\sum_{p1\text{-}10}$ (Pa,bn,i x Wa,pn-1,J)

The number of women at risk will change each year becoming the women at risk of having birth for the next year. Accordingly, the calculated probabilities are applied to the generated number of women at risk year by year to calculate a set of births born in each year. This means that for each forecasting year a new set of denominators are produced. For example:

- Women with age a, parity n and youngest child age j in 2021 will be women with age a+1, parity n and youngest child age j+1 in 2022 in the absence of progression to the next birth. While they will be women with age a+1, parity n+1 and youngest child age 0 in 2022 in the case of progression to the next birth

A further very small adjustment was made to the number of forecasted births to take account of mortality of women of reproductive age alive at the 2021 Census who had died by each successive projection year. This made use of population survival ratios from the 2019-21 life table for Australian females. The adjustment was very small as even 10 years after the 2021 Census, 99.75 per cent of the women would still have been alive.

Migration effects

The steps described above forecast births only for residents present in 2021. This does not take account of births to migrants who are added to the resident population after the census. It is not appropriate to apply the three parameter rates to migrants arriving after the 2021 Census because they did not have the Australian experience underlying the three-parameter rates.

A further problem is that most migrants after 2021 will at least initially be temporary migrants such as international students and working holiday makers whose fertility is very low. McDonald (2025) has estimated that the inclusion of temporary residents in the population reduces the Australian TFR by about 0.2 births per woman, that is, from 1.5 to 1.7. Consistent with this, the TFR for Australian-born women was 1.7 births per woman for the most recently published data.

This problem is offset to some extent because temporary migrants are included in the denominators of estimated fertility rates for Australia, including the three parameter rates calculated here. However, due to COVID border closures, the temporary population was relatively low at the time of the 2021 Census which provides the denominators for the three-parameter model. Also, after the borders were re-opened, there has been an unprecedented flood of temporary migrants. As it is not possible to estimate the fertility rates of temporary migrants, we have not made estimates of births to migrants in these projections.

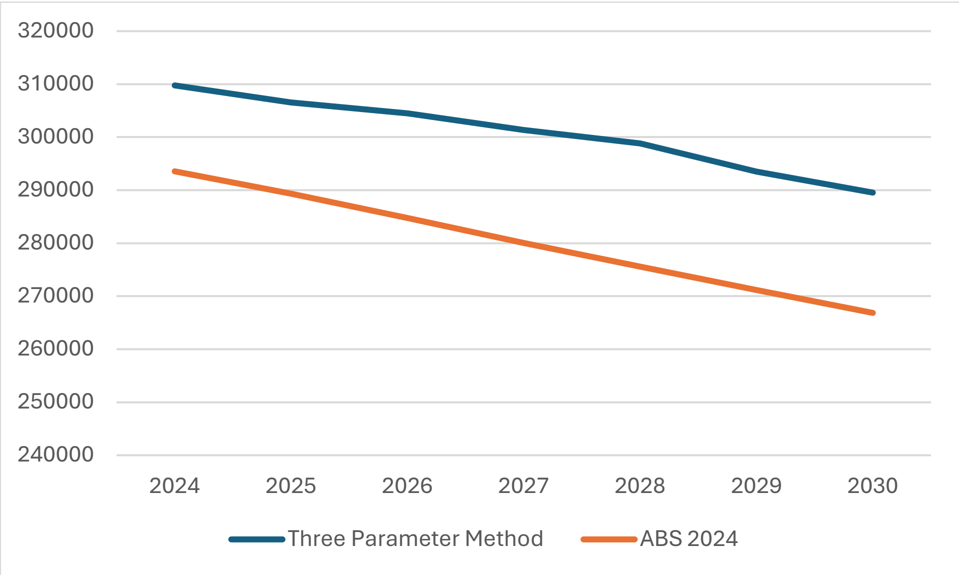
Results: Forecast births using the three-parameter model

The three parameter forecasts from 2024 to 2030 are presented in Figure 6 in comparison with the ABS medium variant projection made in 2024 (numbers supplied by ABS upon request). Both projections exclude births to persons who migrated to Australia from 1 July 2021 onwards. The three-parameter projection is 16,000 more than the ABS projection in 2024, rising to 23,000 by 2030.

Inclusion of births to recent migrants would reverse the apparent downward trend for both projections. However, the recent massive surge of temporary migrants and the unknown but very low level of fertility for temporary migrants complicates the inclusion of recent migrants in the projection.

Because the children ever born question will not be asked in the 2026 Census, it will not be possible to apply the three-parameter model again for the next decade. Other methods of forecasting/projecting births will have to be used. The data demand is the principal limitation of the three-parameter method. However, the authors recommend the use of a two-parameter model for countries that have birth data by age and parity.

Figure 6. Annual number of births, 2024-2030, based on the three-parameter method forecasts in comparison with the ABS one-parameter (age) projection (Note: both projections exclude births to migrants arriving from 1 July 2021 onwards)



Other outcome measures

An advantage of the multi-parameter method is that other useful measures are generated. Results for age-specific first birth rates have already been described but it is possible to measure all age/parity specific rates. It is also possible to measure TFR based on two or three parameters and lifetime parity progression ratios.

Here we show results based on two parameters: parity and duration since most recent birth. That is, the parameter, age, is not considered. The measures are denoted as 'PD' measures.

Figure 7 shows that PDTFR lies above TFR consistently by about 0.15 births per woman across the five years shown in the figure. That is, the annual incidence of births is higher when these two parameters are used to measure it, but the trends across time are similar.

Figure 8 shows period lifetime parity progression ratios based on the two parameters, parity and duration since most recent birth. The figure shows, as expected, that over the short period, there was a slight downward movement for most transitions. The progressions from zero parity to parity one and from parity one to parity two are quite similar at around 0.8 indicating the relative unpopularity of stopping at one. However, there is a large drop in the rate moving from parity two to parity three indicating the strong two-child preference. Interestingly, the progression ratios rise for the highest parities (5-6 and 6-7) indicating a selection effect.

Figure 7. TFR compared with the two-parameter TFR (PDTFR), Australia, 2016-17 to 2020-21

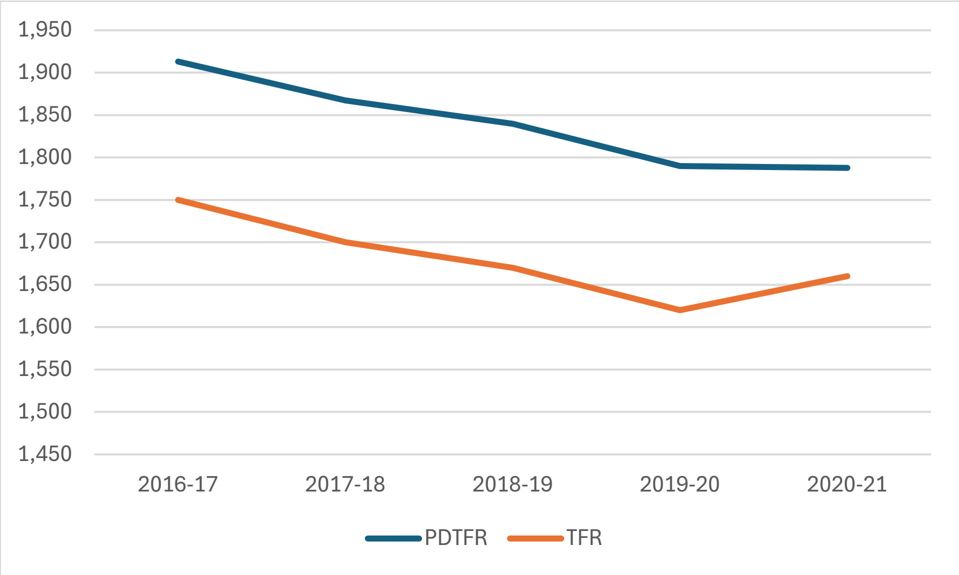
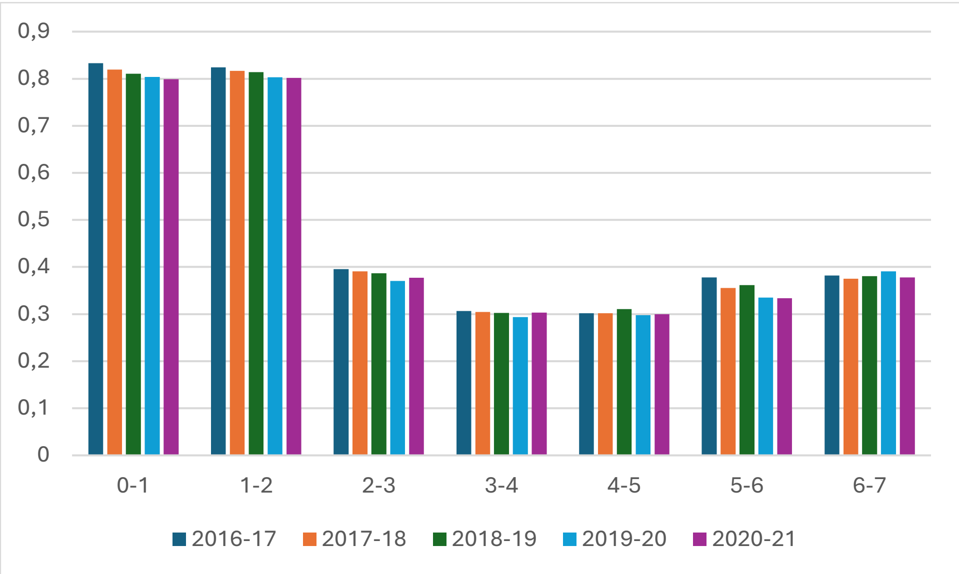


Figure 8. Period lifetime parity progression ratios based on two parameters: parity and duration since last birth, Australia, 2016-17 to 2020-21



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