New Cohort Fertility Forecasts for the Developed World: Rises, Falls, and Reversals

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Just when public concern about the "population bomb" has been replaced by fears of "empty cradles" and "demographic winter" (Ehrlich 1971; Longman 2004; Stout 2008; Last 2013), signs indicate that fertility rates are rising in many low-fertility countries. These increases, reported for example by Goldstein, Sobotka, and Jasilioniene (2009), are often attributed to a combination of a slowdown in the postponement of births (Bongaarts and Sobotka 2012) and increasing levels of socioeconomic development (Myrskylä, Kohler, and Billari 2009), per capita income (Luci and Thévenon 2010), and gender equity (Feyrer, Sacerdote, and Stern 2008; McDonald 2000). With period fertility having risen in many countries with low birth rates, an important emerging question is whether cohort fertility trends are also reversing.

Cohort fertility estimates the average number of children women have over their lifetimes. Fluctuations in period fertility are driven both by transitory changes in fertility timing ("tempo") and by changes in the total number of children women have ("quantum"). Cohort fertility, on the other hand, is free of this interpretive difficulty. If cohort fertility falls, it is a pure "quantum" effect: women really are having fewer children over their lifetimes.[1] The challenge of cohort fertility analysis is incomplete observation. The cohorts that have completed childbearing (conventionally taken as having reached age 45) by 2010 were all born before 1965. For more recent cohorts, completed fertility is estimated by what has been seen so far and what is likely to happen in the future. The classic method of doing this (Frejka and Calot 2001a; Frejka and Sardon 2004) is to "freeze" age-specific rates at the levels of the last observed period. This freeze-rates approach can substantially underestimate completed cohort fertility when childbearing is shifting to older ages, making it susceptible to the similar problem faced by period measures.

In this article, we use a new method involving limited extrapolation of recent age-specific trends in fertility. We estimate the trend based on the past five years, extrapolate the trend five years into the future, and then freeze the rates. The five-year approach was our own initial attempt at an appropriate basis for estimating trends and extrapolating them. Subsequent experimentation with alternative lengths failed to improve on this approach. Our method is simple to implement and, in its use of historical data, less prone to error than the freeze-rates approach or than other extrapolation methods that involve a longer or shorter base period for trend estimation, or longer or shorter periods for trend extrapolation. Furthermore, our method allows explicit estimates of uncertainty, indicating how reliable our estimates of completed fertility are, say, for a cohort aged 40 today, as compared to one aged 30. We apply the method to all low- and moderate-fertility countries for which we were able to obtain recent age-specific fertility rates (through 2009). Our forecasts include 37 developed countries covering all world regions with prolonged below-replacement period fertility.

The new forecasts produce two principal findings. The first, expected but informative, is that cohort fertility in low-fertility countries is indeed much higher than period fertility. On average across 37 countries, forecasted cohort fertility averages about 1.8 children for women born in the mid-1970s. This is much higher than the comparable observed period rates, which averaged only about 1.5 across these countries. The common mistake of reporting the period TFR as the "average number of children women have" underestimates the actual experience of populations by some 20 percent.

Our second finding, which is both more surprising and more controversial, is that cohort fertility is leveling off or is even increasing in at least part of every world region that has recorded very low period fertility over the last few decades. In many countries the reversal of cohort fertility trends is clear. These include countries in the English-speaking world and Scandinavia, but also such interesting individual cases such as France and Germany. We also find signs of an increase in Asia (Japan) and in the Mediterranean (Spain), as well as a clear end to declines in cohort fertility in Eastern Europe. The reversal is not without exception: we forecast that Portugal and Taiwan, for example, will continue to show notable declines in lifetime fertility.

Recent research on cohort fertility

We review recent research on cohort fertility.[2] Previous work includes Ryder (1986), who applied the constant-rate (or "freeze-rates") approach to estimate completed fertility for American women born between 1935–39 and 1955–59, and Höpflinger (1984), who documented fertility patterns in 16 European countries for cohorts born between 1940 and 1960 using the freeze-rates method and a relational Gompertz model. The fertility of these cohorts is completed and known, and the focus has shifted to women born in the 1970s and even in the 1980s.

The recent literature documents low lifetime fertility for the 1970s cohorts—women who are now in their 30s and early 40s—in the developed world. The most recent large-scale studies on cohort reproductive patterns were conducted by Frejka and Calot (2001a) and Frejka and Sardon (2004). The former reported cohort fertility patterns and trends for women born between 1930 and the 1960s in 27 populations of Europe, North America, East Asia, and Oceania. The freeze-rates method was used to estimate completed fertility of women who were still in their childbearing ages. The results suggested that completed fertility declined rapidly, averaging 2.48 for the 1931 birth cohort, 2.08 for the 1946 cohort, and 1.89 for the 1962 cohort. For later cohorts, the observed patterns suggested that the decline would continue. In a related paper, Frejka and Calot (2001b) analyzed cohort fertility patterns in the Nordic countries. Without attempting to complete the remaining fertility of the 1970s cohorts, Frejka and Calot found that their "fertility deficit"—completed fertility at a given age when compared to a cohort born ten years earlier—was large. For example, for the 1970–71 and 1975–76 cohorts, the average fertility deficits at ages 26 and 21 were 18 percent and 22 percent, respectively. Without recuperation, such deficits would result in approximately 1.6 lifetime children per woman.

Other research published at about the same time as Frejka and Calot published their 27-country analyses also suggested low fertility for the 1970s cohorts. Kohler and Ortega (2002b) used tempo-adjusted period parity progression ratios (Kohler and Ortega 2002a) and projected completed cohort fertility for the 1970s cohorts in Sweden, the Netherlands, and Spain to be in the range 1.50–1.75. Scherbov and van Vianen (2001) found that completed Russian fertility had declined to 1.7 for the 1960 birth cohort.

Frejka and Calot's analyses were later expanded into a book (Frejka and Sardon 2004) that provides comprehensive assessments of 35 countries that have experienced below-replacement fertility since circa 1970. For women who were still at childbearing ages (i.e., those born after 1960), Frejka and Sardon calculated estimates of their final fertility levels using the freeze-rates method. Consistent with earlier research, the estimates suggested very low lifetime fertility for the 1970s cohorts. Across all Western market economies, average fertility for the 1975 birth cohort was predicted to be 1.6. Several countries (e.g., Italy, Spain, Austria, Germany, Switzerland) were predicted to have fertility as low as 1.2–1.3 for the 1975 cohort.

More recent research finds signs of higher cohort fertility trends, particularly for Europe. Andersson et al. (2009) compared cumulated and completed cohort fertility patterns by education in the Nordic countries (Denmark, Finland, Norway, and Sweden) for women born in 1935 and later. They found a high degree of similarity in the postponement and recuperation patterns across countries and across educational groups. Moreover, their results suggest that completed cohort fertility in the Nordic countries may already have stabilized by the 1960s cohorts, at a level close to 2 children per woman.

Caltabiano (2008) calculated completed cohort fertility rates for various regions of Italy for cohorts born between 1935 and 1968 and examined the first phase of the reproductive lives of cohorts born in the 1970s and early 1980s. The results suggested that while fertility declined in the cohorts born up to the 1960s, in the cohorts born from the 1970s and later the speed of the fertility decline slowed in particular in the northern regions of Italy and may even have halted in several regions. In southern Italy, however, the decline seems to continue.

Sobotka and colleagues (2011) synthesized a benchmark model and Lesthaeghe's relational model based on three postponement indexes—initial fertility level, absolute fertility decline at younger ages, and the relative degree of fertility recuperation at older ages (Lesthaeghe 2001)—and estimated completed fertility levels of post-1965 cohorts in Austria, the Netherlands, Spain, and the Czech Republic. Their projections, based on various scenarios, include the possibility of stabilization of completed fertility in the Netherlands (at 1.8) and Austria (at 1.6), an increase in the Czech Republic (to 1.9), and a decline in Spain (to 1.3).

Cohort fertility may also be relatively high in China, although the lack of data makes cohort analysis difficult. Analysis of China's fertility trends by Morgan, Guo, and Hayford (2009) suggested a relatively high level of approximately 1.6–1.7 children per woman for the 1970s birth cohorts. While this is well below replacement level, it is significantly higher than their estimate of 1.5 for period fertility rates at the turn of the twenty-first century. In wealthier East Asian countries, however, fertility rates for the 1970s birth cohorts are very low. Forecasts by Frejka and colleagues for cohorts in rich East Asian countries born around 1970 indicate that fertility is declining on average to less than 1.5 children (Frejka, Jones, and Sardon 2010). Iwasawa and Kaneko (2007) estimated that completed fertility in Japan fell rapidly from 1.81 in the 1960 cohort to 1.39 and 1.23 in the 1970 and 1980 birth cohorts. Chuan (2010) found that cohort fertility levels are low and declining in Singapore.

Taken together, the analyses by Frejka and colleagues indicate that two thirds of the European population in 2008 lived in countries whose cohort fertility was considerably below replacement. Yet, with recent rises in period fertility levels in many developed countries (Bongaarts and Sobotka 2012; Goldstein, Sobotka, and Jasilioniene 2009; Myrskylä, Kohler, and Billari 2009; Trovato 2010), projections based on freeze-rates procedures run the risk of underestimating fertility recuperation and completed cohort fertility. Extrapolation of age-specific trends has been implemented (independently of our work) by Prioux, Mazuy, and Barbieri (2010) and Mazuy et al. (2011) for the cohorts born in 1974 and 1975 in Europe. Our approach differs from their method in several respects. First, those analysts used a much longer basis for extrapolation, 15 years rather than 5, producing much larger forecast errors (as we show in the section on forecast accuracy.) Second, we freeze extrapolation after 5 years, allowing us to estimate fertility of cohorts born more recently (up to 1979) without risking large errors. Third, we produce estimates of historical performance and statistical uncertainty, which tell us explicitly the uncertainty attached to cohort forecasts. All of these improvements allow us to apply our method globally and to more recent cohorts.

Data and methods

Data

Our analysis is based on data on period fertility rates by single year of age for 37 countries. We use fertility rates for ages 15–49, starting from 1965. Thus our first cohorts were born in 1950. For the majority of countries, the last observation year is 2009, implying that, for cohorts born up to 1965, cohort fertility is almost completely observed (up to age 44), while forecasting is needed for later cohorts. We present forecasts for cohorts born until 1979, for whom we predict future fertility after age 30. Our data sources are the Human Fertility Database (2012), Eurostat (2012), national statistical agencies, and individual researchers through personal communication. Table 1 lists the countries and data sources.

As specified in the table, for some countries the data start later than 1965. In such cases we have completed the past fertility history by "backcasting" fertility rates to 1965 by scaling the earliest period fertility schedule up or down to reproduce the known period total fertility rate.[3]

Methods

We believe that our new forecasting method, which is inspired by the Lee–Carter model for period mortality (Lee and Carter 1992) and Lee's model for period fertility (Lee 1993), is an improvement over existing methods for three reasons: greater forecast accuracy, ability to estimate forecast uncertainty, and simplicity. More sophisticated Bayesian forecasting methods are in development (e.g., Schmertmann et al. 2012) that can incorporate autocorrelated fertility change over age and time into the estimation of uncertainty.

Our method allows the forecasting to be conducted using only a spreadsheet. If embedded into a more general forecasting framework, the method allows derivation of confidence bounds for the forecast, as detailed in the Appendix. Regarding forecast accuracy, prior research includes several alternatives for forecasting cohort fertility. Some of these involve parametric models, while a few others combine parametric methods with extrapolation (Chandola, Coleman, and Hiorns 1999; Evans 1986; Frejka and Sardon 2004; Li and Wu 2003; Peristera and Kostaki 2007; Schmertmann 2003).

TABLE 1 Countries used in the analysis and data sources

Country	Years	Source[a]	Backcasted[b]
Australia	1965–2009	Statistics Australia	1965–1974
Austria	1965–2009	HFD	
Belgium	1965–2009	Eurostat	
Bulgaria	1965–2009	HFD	
Canada	1965–2007	HFD	
Czech Republic	1965–2009	HFD	
Denmark	1965–2009	Eurostat	
Estonia	1965–2009	HFD	
Finland	1965–2009	HFD	
France	1965–2009	HFD	
Germany, East	1965–2009	HFD	
Germany, West	1965–2009	HFD	
Greece	1965–2009	Eurostat	
Hungary	1965–2009	HFD	
Iceland	1965–2009	Eurostat	
Ireland	1965–2009	HFD	
Italy	1965–2009	Eurostat	
Japan	1965–2009	Personal communication[c]	
Korea, South	1965–2009	Personal communication[d]	1965–1969
Lithuania	1965–2009	HFD	
Luxembourg	1965–2009	Eurostat	1965–1981
Netherlands	1965–2009	HFD	
New Zealand	1965–2009	Statistics New Zealand	
Norway	1965–2009	HFD up to 2006; 2007–2009 Eurostat	
Poland	1965–2009	Eurostat	1965–1989
Portugal	1965–2009	HFD	
Romania	1965–2009	Eurostat	1965–1974
Russia	1965–2009	HFD	
Singapore	1965–2009	Population Trends 2010, Statistics Singapore[e]	
Slovakia	1965–2009	HFD	
Slovenia	1965–2009	HFD	1965–1982
Spain	1965–2009	HFD up to 2006; 2007–2009 Eurostat	
Sweden	1965–2009	HFD	
Switzerland	1965–2009	HFD	
Taiwan	1965–2009	Statistical Yearbook of the Republic of China, 1976–2009	1965–1975
United Kingdom	1965–2009	HFD	1965–1973
United States	1965–2007	HFD	

[a]Human Fertility Database (HFD) data are obtained from http://www.humanfertility.org/.
Eurostat data obtained from http://epp.eurostat.ec.europa.eu/portal/page/portal/eurostat/home/
[b]For some countries, the data start later than 1965. In such cases we have completed the past fertility history by backcasting the fertility rates to 1965.
[c]Ryuichi Kaneko, National Institute of Population and Social Security Research; and Rikiya Matsukura, Nihon University Population Research Institute.
[d]Kwang-Hee Jun, Professor of Demography and Sociology, Chungnam National University.
[e]Data refer to five-year intervals.

Although the performance of these methods varies, it is commonly agreed that for short-term forecasts (i.e., forecasts made for the next decade, such as ours), more complex parametric models have not produced greater accuracy than simple geometric ones (Lee, Carter, and Tuljapurkar 1995; Rogers 1995; Smith 1997).

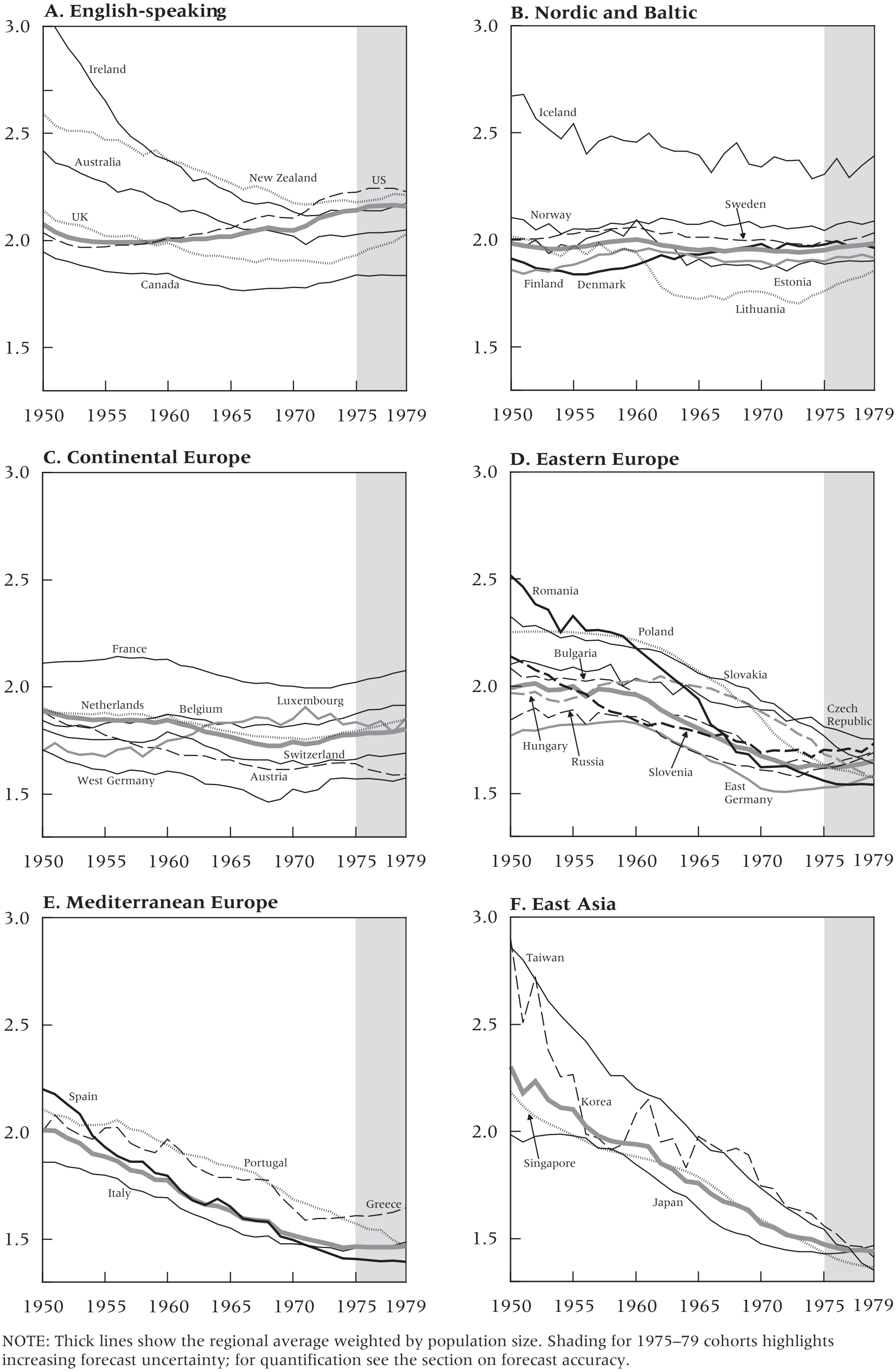
Because complex forecasting methods may not provide improved accuracy over simpler ones, we tested our 5-year extrapolation method against other simple geometric alternatives using historical data. The most conservative approach is to set the trend to zero immediately: none of the past trends continue into the next year. Other alternatives include our preferred 5-year extrapolation based on the last 5 years' trend, fixing the trend permanently based on the last 5 years' trend, or using a fixed trend based on the past 15 years, as in Prioux, Mazuy, and Barbieri (2010).[4] We studied forecast accuracy with these alternatives (see the section on forecast accuracy) and found that the 5-year extrapolation, which strikes a balance between immediate freezing of rates and unlimited extrapolation with a fixed trend, had lower bias, variance, and root mean squared error than the alternative methods. One may also vary the method for estimating the past trend that is used to forecast the trend for the next 5 years before freezing the rates. We considered estimating the trend from the last 3 or the last 10 observations. This did not change the results when compared to using the last 5 observations.

In addition to being accurate in comparison to alternative extrapolation methods, our 5-year method was reasonably accurate in absolute terms. For example, when forecasting cohort fertility with data observed only up to age 34 (which corresponds to the 1975 birth cohort if data are available up to 2009), the average forecast error across the 1950–65 cohorts in 25 countries is less than .02 children, or approximately 1 percent of completed fertility. At age 30—the youngest cohorts we present here—the average forecast error in historical data was approximately .06 children, or 3 percent of completed fertility.

Results

Figure 1 shows the new cohort fertility forecasts by country and region[5] for the 1950–79 birth cohorts for our sample of 37 developed countries. The regions are arranged by their most recent cohort fertility level. While there is variation across regions, we use the regional averages to support the claim that the long-term trend in lifetime fertility decline is flattening or has reversed in all world regions previously characterized by low fertility. Taking into account the forecasted recent trend, cohort fertility appears to be steadily increasing in the English-speaking world (Panel A), is remarkably stable in the Nordic and Baltic countries (Panel B), and shows signs of reversed direction from decline to rise in Continental Europe (Panel C). In Eastern Europe (Panel D) and the Mediterranean (Panel E), decades of decline appear to be

FIGURE 1 Completed fertility, 1950–79 cohorts



NOTE: Thick lines show the regional average weighted by population size. Shading for 1975–79 cohorts highlights increasing forecast uncertainty; for quantification see the section on forecast accuracy.

coming to an end. Only in East Asia (Panel F) is cohort fertility continuing to fall, but even here the decline is slowing.

Each region shows variation. Notable in the English-speaking countries are the increases in the United States and the United Kingdom, both with cohort fertility exceeding 2. Within the Nordic and Baltic states, Sweden is remarkable for decades of nearly constant cohort fertility despite swings in period fertility. Denmark is notable for an early rise in cohort fertility, attributed in part by some to generous subsidies for assisted reproductive technology (Andersson et al. 2009).[6] Only in Lithuania is cohort fertility considerably below replacement; but lifetime fertility is increasing, and the rate of 1.75 for the 1975 cohort far exceeds the period rates, which were below 1.3 for much of the 1990s and 2000.

In Continental Europe, fertility fell for the generations born in the 1960s but appears to be rising for the 1970s cohorts; Austria is an exception, with a declining trend up to the cohorts of the late 1970s. The countries with the region's highest and lowest fertility—France (fertility for the 1975 cohort 2.0) and Germany (1.6)—have parallel paths occurring for the same generations, albeit at different levels. Lifetime fertility for Continental Europe averages 0.1–0.3 children per woman above the period rates that prevailed in the 1990s, reaching 1.8 for the most recent generations.

Eastern Europe shows a distinct pattern. For the 1950s cohorts, completed fertility was on average nearly 2. Cohorts born in 1960s were in their prime childbearing years when the Soviet Union collapsed. In response to the resulting societal transformation, men and women reduced childbearing at the young ages that characterized Eastern European family formation. Fertility was universally postponed and to some extent forgone, but cohorts coming of age after the mid-1990s show no sign of continued decrease. Instead, cohort fertility has stabilized at 1.6 children per woman, again a level much higher than the period rates, which fell below 1.3 in all countries of the region in the post-Soviet era.

Among the Mediterranean countries, only Portugal continues to experience declining cohort fertility, whereas Greece, Italy, and Spain show a leveling off or a slight increase. These forecasted increases take account of the first year or two of the recent economic recession.[7]

The lowest observed cohort fertility rates are in East Asia, where completed family size declined to nearly 1.4 for the cohorts of the mid to late 1970s. Cohort fertility continues to fall in Taiwan, Singapore, and South Korea, but has increased slightly for recent cohorts in Japan, which has historically been a demographic trendsetter for the region.[8]

Table 2 summarizes the cohort fertility trends. In our sample of 37 countries, average lifetime fertility for the 1975 cohorts is 1.77. The mean change over the 1975–79 cohorts is zero.[9]

The statistics on change in Table 2 show that over the cohorts 1950–60 and 1960–70 most countries recorded declining fertility. For example, only

TABLE 2 Actual and forecasted cohort fertility (CTFR) and change in cohort fertility in 37 developed countries

	Fertility by birth cohort (CTFR)					Change in CTFR (shading indicates decrease)				CTFR reversal significant (*)[a]	1979 cohort, proportion of completed fertility observed
	1950	1960	1970	1975	1979	1950–60	1960–70	1970–75	1979–75		
United States	2.04	2.01	2.10	2.22	2.23	–0.03	0.09	0.12	0.01	*	0.56
United Kingdom	2.14	1.99	1.91	1.93	2.03	–0.15	–0.08	0.02	0.10	*	0.55
Lithuania	2.02	1.94	1.76	1.76	1.86	–0.08	–0.18	0.00	0.10	*	0.66
Belgium	1.84	1.87	1.82	1.88	1.91	0.03	–0.05	0.06	0.04	*	0.59
Netherlands	1.90	1.87	1.76	1.79	1.85	–0.03	–0.11	0.03	0.06	*	0.50
Russia	1.84	1.86	1.61	1.62	1.69	0.02	–0.25	0.01	0.07	*	0.70
Germany, East	1.77	1.81	1.51	1.55	1.58	0.04	–0.30	0.05	0.03	*	0.59
France	2.11	2.13	2.00	2.02	2.08	0.02	–0.12	0.02	0.06	*	0.57
Canada	1.95	1.85	1.78	1.84	1.84	–0.10	–0.07	0.06	0.00		0.42
Germany, West	1.71	1.61	1.52	1.57	1.57	–0.10	–0.09	0.05	0.01	*	0.56
Iceland	2.67	2.46	2.34	2.31	2.39	–0.21	–0.12	–0.03	0.09	*	0.57
Slovenia	2.14	1.84	1.69	1.70	1.73	–0.30	–0.15	0.01	0.03		0.56
Estonia	1.99	2.09	1.86	1.89	1.90	0.10	–0.23	0.02	0.02		0.62
Ireland	3.08	2.37	2.13	2.14	2.17	–0.71	–0.24	0.01	0.03		0.41
New Zealand	2.59	2.37	2.17	2.18	2.21	–0.22	–0.20	0.00	0.03		0.55
Switzerland	1.80	1.79	1.66	1.66	1.69	–0.01	–0.13	0.00	0.03		0.46
Norway	2.10	2.09	2.06	2.04	2.09	–0.02	–0.03	–0.01	0.05		0.55
Sweden	2.00	2.06	2.00	2.00	2.03	0.05	–0.06	–0.01	0.04		0.49
Australia	2.42	2.17	2.02	2.03	2.05	–0.25	–0.15	0.01	0.02		0.51
Bulgaria	2.09	1.97	1.68	1.63	1.70	–0.12	–0.29	–0.05	0.07		0.71
Finland	1.86	1.95	1.90	1.90	1.92	0.09	–0.05	0.00	0.02	*	0.55

Italy	1.86	1.69	1.48	1.46	1.49	–0.17	–0.21	–0.02	0.03		0.45
Greece	2.00	1.97	1.64	1.61	1.65	–0.04	–0.32	–0.03	0.04		0.50
Luxembourg	1.70	1.75	1.85	1.84	1.85	0.05	0.10	–0.01	0.02	*	0.55
Japan	1.99	1.85	1.48	1.43	1.47	–0.14	–0.37	–0.05	0.04		0.52
Denmark	1.91	1.88	1.98	1.98	1.96	–0.03	0.10	0.00	–0.02		0.54
Austria	1.89	1.70	1.61	1.64	1.59	–0.18	–0.09	0.03	–0.05		0.60
Romania	2.52	2.16	1.62	1.56	1.54	–0.36	–0.54	–0.06	–0.02		0.73
Spain	2.20	1.80	1.50	1.41	1.40	–0.40	–0.30	–0.09	–0.01		0.41
Czech Republic	2.10	2.04	1.89	1.81	1.75	–0.06	–0.15	–0.08	–0.06		0.59
Singapore	2.19	1.88	1.59	1.43	1.36	–0.30	–0.29	–0.15	–0.07		0.52
Portugal	2.11	1.94	1.69	1.57	1.46	–0.17	–0.25	–0.11	–0.11		0.59
Poland	2.25	2.22	1.85	1.64	1.57	–0.04	–0.36	–0.22	–0.06		0.66
Slovakia	2.33	2.18	1.93	1.77	1.64	–0.15	–0.24	–0.16	–0.13		0.64
Hungary	1.97	2.03	1.88	1.68	1.57	0.06	–0.15	–0.20	–0.11		0.62
Korea	2.90	2.08	1.75	1.56	1.41	–0.82	–0.34	–0.19	–0.15		0.55
Taiwan	2.86	2.20	1.74	1.55	1.35	–0.66	–0.47	–0.19	–0.19		0.63
Average	2.13	1.99	1.80	1.77	1.77	–0.14	–0.19	–0.03	0.00		0.56
Median						–0.10	–0.15	0.00	0.02		0.56
No. of countries stable or increasing						9	3	19	25		
No. of countries with significant increase										12	

NOTE: Countries ranked according to the change in CTFR over the 1970–1979 birth cohorts.
[a]Reversal is significant if the lower bound of the 95 percent confidence interval for the 1979 cohort is above the lowest observed CTFR among the 1960–75 cohorts.

three countries—the US, Luxembourg, and Denmark—had higher fertility for the 1970 cohort than for the 1960 cohort. For the 1970s cohorts the trajectories started to change, and we forecasted that in 19 of the 37 countries fertility for the 1975 birth cohort will be at least as high as for the 1970 cohort. As we show in the section on forecast accuracy, uncertainty for these cohorts is very small. Our forecasts suggest that the positive trend in cohort fertility intensified in the latter half of the 1970s, so that in a majority of the countries, 25 out of 37, fertility for the 1979 birth cohort will be at least as high as for the 1975 cohort. These results suggest that the long-term fertility decline in the developed world has come to an end or at least stalled.[10]

The proportion of eventual completed fertility observed for the most recent birth cohort (1979) is on average 56 percent, and 44 percent of the fertility is forecasted. This is a larger fraction than is often forecasted; for example, Frejka and Sardon (2004) restricted their forecasts to situations in which only 15 percent of completed fertility remained unknown. The larger fraction of forecasted fertility influences the forecast uncertainty. We show below that while uncertainty up to the 1975 birth cohort is very small, for the 1979 cohort the standard errors of the forecasts increase but remain on average only 2 percent of the completed cohort fertility.

Comparing the new country-specific cohort fertility forecasts to the period fertility rates that dominate policy discussion results in remarkable differences. By 2009, 19 of the 37 countries had experienced period fertility below 1.3, a threshold often termed "lowest-low" fertility, and 25 had period fertility below 1.5. In the cohort perspective, and including cohorts born up to 1979, only seven countries are characterized by fertility below 1.5, and no country is forecasted to go below 1.3. These differences suggest that much of the observed very low fertility has been attributable to later, not less, childbearing. Sobotka (2004) and Goldstein, Sobotka, and Jasilioniene (2009) reached similar conclusions.

Forecast accuracy

How certain are our forecasts? For cohorts that have already reached age 40, there is little uncertainty. For younger cohorts, there is obviously more. In order to quantify uncertainty, we used three approaches. First, we used historical data to estimate the magnitude of error that our approach would have produced in the past. Second, we used a statistical model, much like the Lee–Carter model of mortality, to generate forecast intervals based on recent fluctuations in fertility trends. Finally, we present scenarios to illustrate how completed fertility might eventually differ from the main forecasts we give here.

For the historical approach, we applied the 5-year extrapolation method to 26 countries with historical data[11] and to the 1950–65 cohorts whose fertility is now completed.[12] For each completed cohort, 16 observed schedules were generated by truncating the data between ages 30 and 45. We forecasted completed cohort fertility for each truncation age and calculated the average forecast error (bias) and root mean squared error (RMSE) by truncation age. We compared the accuracy of the 5-year extrapolation to the freeze-rates method and to unlimited extrapolation with a fixed trend estimated over the past 5 years or over the past 15 years, the latter as in Prioux, Mazuy, and Barbieri (2010) and Mazuy et al. (2011).

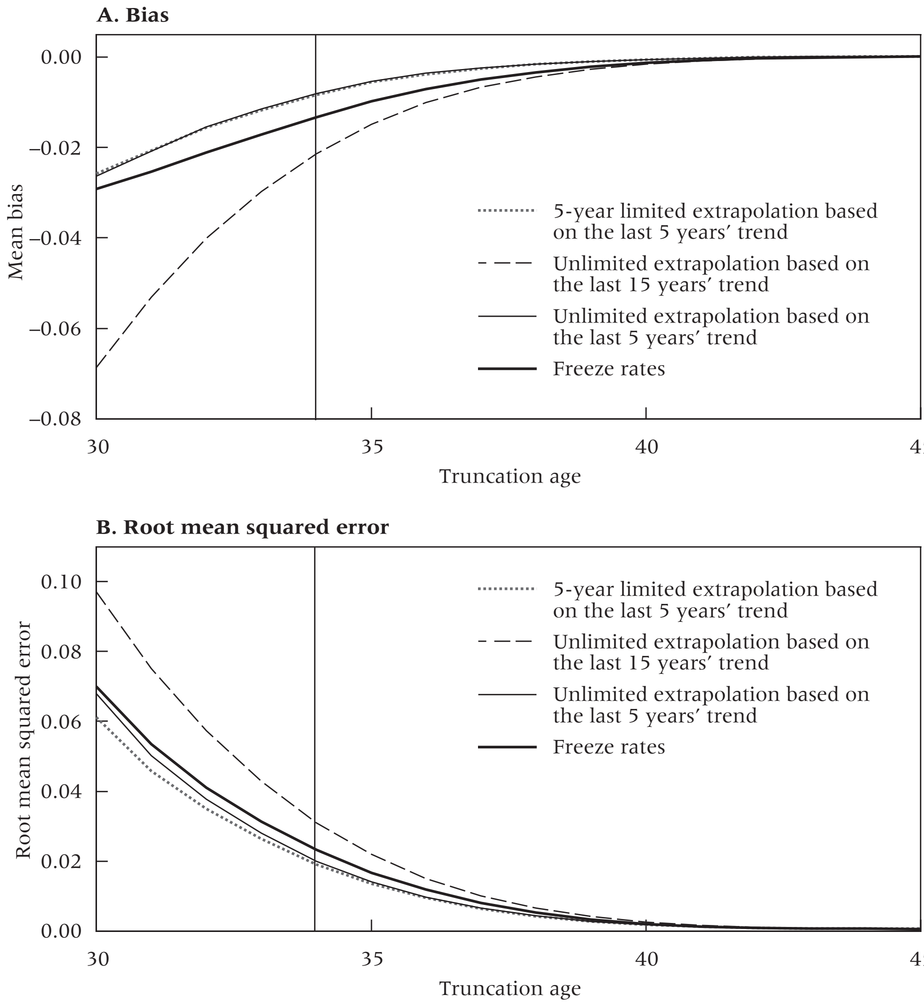
Figure 2 shows the bias and root mean squared error by truncation age for the 5-year limited extrapolation based on the past 5 years' trend, freeze-rates method, and the two unlimited fixed-trend extrapolation methods. The 5-year extrapolation has smaller bias and RMSE than the alternatives for each truncation age. The 5-year extrapolation proves accurate also in absolute terms. The average bias was small but downward, suggesting that our forecasts were conservative, at least for this period. For example, for truncation at age 30 (corresponding to the 1979 cohort when data are available up to 2009), the bias was –.02 and decreased rapidly with truncation age; at ages 34 or above (corresponding to the 1975 or earlier birth cohorts) it was on the order of .01 children or less. The total forecast error measured by the RMSE is about .02 children for truncation at age 34, which corresponds to the 1975 cohort. In relation to completed fertility, this is approximately 1 percentage point. For truncation at age 30 (1979 cohort), the RMSE is still small, approximately 3 percent of completed fertility.

These results show that the 5-year extrapolation markedly improves the forecast accuracy and reduces the underestimation found in previous research, which predicted lifetime fertility for the 1975 cohorts to be as low as 1.2–1.3 children per woman in several European countries (Frejka and Calot 2001a; Frejka and Sardon 2004). According to the forecast error evaluation, we suggest that the forecasted cohort TFR values obtained from the freeze-rates method are consistently inaccurate, since the method systematically underestimates completed cohort fertility levels. Extrapolation of age-specific fertility rates based on a long-term 15-year trend appears to further increase forecast uncertainty. In particular, the long-term extrapolation consistently underestimated cohort fertility.[13]

Linear extrapolation of a recent trend measured over the past 5 years consistently outperforms the freeze-rates method and the extrapolation based on a long-term trend. Of the two extrapolation methods based on the past 5-years' trend, the limited extrapolation of 5 years forward performs better than the unlimited fixed-trend extrapolation, and is our preferred method. We also considered extrapolation based on the last 3 or last 10 years of data, with trend extrapolation 3, 5, or 10 years into the future. The results (not shown) differed from our preferred method only marginally.

Second, we estimated analytically (using methods described in the Appendix) the 95 percent confidence bounds for the real forecasts that are made

FIGURE 2 Mean bias and root mean squared error of forecasts by forecasting method and truncation age



NOTE: Accuracy of each forecasting method is evaluated using out-of-sample forecast errors for 25 countries and 1950–65 cohorts.

for the cohorts up to and including the 1979 birth cohort. Table 3 summarizes the average uncertainty across the 37 countries. Appendix Figure 1 displays the forecasts with 95 percent confidence intervals for all 37 countries.

Table 3 shows that the average width of the 95 percent confidence intervals is narrow until and including the 1975 birth cohort, at only 0.06 (+/–0.03) children per woman. For later cohorts, the confidence interval widens rapidly, to 0.14 (+/–0.07) children per woman for the 1979 birth cohort. Compared to the total forecasted fertility, however, this is only 8 percent

TABLE 3 Forecast uncertainty summarized in terms of the width of the 95 percent confidence interval (CI)

	Birth cohort							
	1950	**1960**	**1970**	**1975**	**1976**	**1977**	**1978**	**1979**
Average CI width	0	0	0.01	0.06	0.08	0.10	0.12	0.14
Ratio of CI width to total forecasted CTFR	—	—	0.01	0.04	0.05	0.06	0.07	0.08
Ratio of CI width to forecasted part of CTFR	—	—	0.19	0.20	0.20	0.20	0.20	0.20

(+/–4 percent). This is slightly less than suggested by the average root mean squared errors in historical analysis, potentially because the formal modeling approach assumes unbiasedness, whereas the historical simulation does not. The ratio of the width of the confidence interval to the amount of the forecasted fraction of fertility is virtually constant at 0.2 across the cohorts, implying that the proportional uncertainty for the *remaining* fertility depends very little on the truncation age.

Deriving aggregated uncertainty for all 37 countries would require information about cross-country dependencies in fertility. An upper bound, however, can be obtained by assuming that the forecast errors are perfectly correlated. Under this assumption, the 95 percent confidence interval for the average cohort fertility across the 37 countries for the 1979 cohort is [1.70, 1.84].

Finally, we considered a scenario-type bounding of our estimates by assuming two extreme scenarios: one using the freeze-rates method, and one in which past trends in age-specific rates continue uninterrupted into the future. The freeze-rates method tends to underestimate fertility, providing a lower bound. The long-term extrapolation assumes that recent fertility increases will continue indefinitely, providing an upper bound.

Our finding of a reversal in the trend toward low fertility is robust across these extreme scenarios. The 5-year extrapolation results in an average fertility for the 1975 cohort of 1.77. The freeze-rates forecast is marginally lower at 1.73, and the long-term extrapolation is 1.79. The freeze-rates, the 5-year extrapolation, and the long-term extrapolation predict, respectively, that in 19, 27, or 28 countries fertility is flat or increasing over the 1975–79 cohorts, or averages above 1.7 (e.g., under freeze-rates, countries such as Australia, the US, Sweden, and Denmark are forecasted to have decreasing cohort fertility, though at a relatively high level). For countries with cohort TFR below 1.7 over the 1975–79 cohorts, the 5-year and long-term extrapolations predict that only eight have declining fertility. The freeze-rates method indicates that 18 countries have fertility below 1.7 and declining. Even for this pessimistic scenario, however, in the majority of countries (19/37) cohort fertility has stopped declining or exceeds 1.7.

Impact of the late 2000s recession

Several reviewers were concerned with how the late 2000s recession influences cohort fertility. In response, we studied the impact of the late 2000s recession on our cohort fertility forecasts by conducting a sensitivity analysis in which we compare forecasts using data that are not affected by the recession to forecasts using data that are influenced by it.

We first used the 5-year extrapolation with fertility data only up to 2008, which are very little if at all affected by the late 2000s recession, to produce new cohort fertility estimates. We then compared these estimates to our main estimates that use data up to 2009 and are thus influenced by the recession. However, the impact of the recession on fertility may be markedly stronger than the difference observed between our two sets of forecast, because the recession started in many countries in 2008 and is likely to have influenced fertility for a period longer than just the following year. To some extent, our forecasting method takes this into account: the method is based on trends, and the observations for 2009 influence the estimated trend, hence have an impact several years into the future. Nevertheless, to err on the conservative side, we conducted a simulation in which we assume that the *decline* in forecasted cohort fertility rates obtained using data up to 2009 versus using data only up to 2008 accounts for only (i) half, (ii) one third, or (iii) one quarter of the total impact of the recession. That is, we magnify the fertility decline by a factor of two, three, or four and assess the implications of these extreme scenarios that assume a prolonged impact of the recession on fertility.

Table 4 shows the average cohort fertility rates in our sample of 37 countries, the forecasted number of countries with cohort fertility of at least 1.75 fertility for the 1979 birth cohort, and the number of countries experiencing the specified fertility change over the 1975–79 and 1970–79 birth cohorts across the simulated recession scenarios. The baseline forecast is the same as we reported in Table 2. The alternative scenarios show what the forecasted fertility rates would be if the impact of the recession is assumed to be 2, 3, or 4 times larger than the difference in forecasted cohort fertility rates using data up to 2009 or 2008. The results in Table 4 show that the forecasts are relatively robust to these scenarios. The average cohort TFR decreases when we increase the magnitude of the simulated recession effect. However, even in the scenario that multiplies the difference in forecasted cohort fertility obtained with data up to 2009 versus 2008 by a factor of four, the average cohort TFR remains above 1.7 at 1.73. In the same scenario, we observe that 19 of the 37 countries have either flat or increasing cohort fertility over the 1975–79 birth cohorts, while 18 have decreasing fertility. For the change over the 1970–79 birth cohorts, this extreme scenario predicts that 14 countries have flat or increasing fertility. The difference with respect to the 1975–79 change is explained by the fact that the 1970 cohort was virtually immune to the recession effect, whereas the 1975 cohort's fertility is forecasted to

TABLE 4 Simulated impact of the late 2000s recession on cohort total fertility rates (CTFR) for the 1970s birth cohorts

	Average CTFR, 1979 cohort	No. of countries with 1979 CTFR > 1.75	Number of countries experiencing specified CTFR change over the 1975–79 cohorts: Change ≥ 0	1975–79 cohorts: Change < 0	1970–79 cohorts: Change ≥ 0	1970–79 cohorts: Change < 0
Baseline forecast using data up to 2009	1.77	18	22	15	24	13
2008–09 change multiplied						
by factor of 2	1.76	18	25	12	21	16
by factor of 3	1.75	17	22	15	18	19
by factor of 4	1.73	16	19	18	14	23
2008–10 change multiplied						
by factor of 2	1.75	18	24	13	20	17
by factor of 3	1.74	17	21	16	16	21
by factor of 4	1.72	16	20	17	15	22

NOTE: Based on a total of 37 countries.

drop on average from 1.77 to 1.74 under this scenario (data not shown). In the other scenarios in which the simulated recession effect is multiplied by a factor of 2 or 3, the slope of cohort fertility trajectories is even more positive. In particular, across all scenarios more than half of the countries have either flat or increasing fertility over the 1975–79 birth cohorts.

As an additional robustness check, we conduct a similar analysis using the change in forecasted fertility with data up to 2010 versus 2008 as a proxy for the effect of the recession on fertility. This change can be calculated for 23 countries for which 2010 data are available; for the other countries we use the 2009 vs. 2008 change. The lower panel of Table 4 shows the results. Across all scenarios, the average cohort TFR stays above 1.70. Moreover, in all scenarios the majority of countries have either flat or increasing fertility over the 1975–79 birth cohorts. For example, in the most extreme scenario in which the fertility decline observed using data up to 2010 versus 2008 is multiplied by 4, average fertility for the 1979 birth cohort is 1.72, and 20 countries have either flat or increasing fertility for the late 1970s cohorts.

Overall, our analysis shows that a continuing or worsening recession is unlikely to produce large changes in completed fertility for cohorts born through the late 1970s, although it could influence later cohorts and alter the prospects of a long-term trend-reversal.

Discussion

Our forecasts of cohort fertility use a large set of countries and a new method for estimating the completed fertility of women who are still in their 30s or

40s. Our results counter concerns about the continued decline of birth rates in the developed world (Lutz, Skirbekk, and Testa 2006). In our sample of 37 countries from all world regions with prolonged below-replacement period fertility, forecasted cohort fertility is often not much different from 2 children per woman, even in many countries where period fertility rates fell below 1.3. Forecasted average lifetime fertility for the 1979 cohorts is 1.77, and 25 countries recorded either increasing or stable fertility for the late 1970s cohorts, while 12 had a negative fertility trajectory. Our results suggest that the long-term fertility decline in the developed world is flattening or reversing in many countries previously characterized by low fertility.

The observed differences between lifetime fertility and the period fertility rates that dominate policy discussion are remarkable. By 2009, 19 of the 37 countries had experienced period fertility below 1.3, a threshold that has been termed lowest-low fertility. In the cohort perspective, and including cohorts born up to 1979, only seven countries experienced fertility below 1.5, and no country is expected to fall below the threshold of lowest-low fertility. These differences confirm that much of the very low fertility is the result of later, not less, childbearing.

The documented gap between cohort and period fertility rates is consistent with the literature on tempo-adjusted period fertility rates. The tempo adjustments aim to estimate what the period total fertility rate would have been in the absence of changes in the timing, or tempo, of fertility. Prior research (Bongaarts and Sobotka 2012; Goldstein, Sobotka, and Jasilioniene 2009; Sobotka 2004) has already argued that a substantial part of the fertility decline in the developed world to low- and lowest-low levels is attributable to fertility postponement, and that the recent increases in period TFR have been driven at least in part by a decrease in the fertility-suppressing tempo effect. The tempo adjustments, however, do not describe the fertility of real cohorts but refer to synthetic cohorts. Our analysis provides a direct approach to the question "how many children are women of real birth cohorts having" by estimating the cohort fertility rate. We find that women in many countries will have more children than the non-adjusted period TFR suggests.

Our forecasts are based on a method in which past age-specific fertility trends are allowed to continue 5 years into the future. Evaluated against historical data, this approach appears quite accurate; in particular it performed much better than the freeze-rates approach. It also outperformed alternative extrapolation lengths. Our evaluation of forecast uncertainty suggested that it is relatively small, with an average expected forecast error of less than +/–.03 children per woman for the 1975 cohort, and less than +/–.06 children (approximately 3 percent of completed fertility) for the 1979 cohort. Thus, while the forecast interval widens rapidly when moving to later cohorts, our results up to and including the 1979 cohort are not critically sensitive to the forecast uncertainty.

The new cohort fertility forecasts showing recent rises in cohort fertility, though numerically small, imply remarkable differences for population size, replacement migration, and aging, all of which depend on the extent to which fertility differs from the replacement level of about 2 children per woman. Taking Europe (EU-27) as an example, we projected the consequences of a difference of 0.25 child per woman for long-term fertility rates, the approximate difference between cohort fertility for the late 1970s birth cohorts and the average period fertility at the beginning of the twenty-first century.[14] In 200 years, the population would shrink from 483 million to 94 million with a fertility rate of 1.5, and to 221 million with a fertility rate of 1.75. The migration levels needed to maintain population size would also differ, with a ratio of 1 migrant for every 3 births required if fertility were 1.5, and 1 migrant for every 7 births if fertility were 1.75. Population aging would also be affected. Even with continued increases in longevity, the population in 200 years would be on average 4 years older (mean age 56) with a fertility rate of 1.5 as compared to 1.75.

While cohort fertility has stopped declining in most developed countries, there is still a wide range of lifetime fertility levels across the industrialized world. For the 1975 cohort, forecasted completed fertility ranges from above replacement (Iceland 2.31, United States 2.22, New Zealand 2.18, Ireland 2.14) to well below 1.5 (Italy 1.46, Singapore 1.43, Japan 1.43, Spain 1.41). The driving forces behind these differences in levels and trends of lifetime fertility are not clearly understood. For increases in period fertility, gender equality, family and labor policies, and economic and human development have all been suggested as important determinants (Feyrer, Sacerdote, and Stern 2008; McDonald 2000; Luci and Thévenon 2010; Myrskylä, Kohler, and Billari 2009). Much less is known about the determinants of cohort fertility, although all of these theories would apply equally well if not better to cohorts than to periods. Indeed, in a related paper Myrskylä, Goldstein, and Cheng (2012) find that both gender equality and socioeconomic development are strong correlates of cohort fertility.

Most recent debates about the long-term decline in fertility or the potential reversal of such a trend have drawn information from the period TFR. While the period measure is substantially distorted during times of fertility postponement, the longer time horizon required for calculating cohort TFR often makes the latter an impractical alternative. Our cohort fertility forecasting method offers a new tool for examining continuity and change in fertility patterns, without having to take the tempo effect into account. It will also facilitate future research into the socioeconomic determinants of actual lifetime fertility, rather than period fertility, in the developed world.

Appendix

Forecasting methodology and stochastic forecast errors

The extrapolation model we use for our new cohort forecasts can be written as a special case of the more general model,

$$f(x,t) = a(x) + b(x)K(t)$$

where $f(x,t)$ is the age-specific fertility rate observed for age x at time t, $a(x)$ is the baseline fertility schedule by age, and fertility change is decomposed into a time component $K(t)$ and age component $b(x)$. This is same formulation used by Lee and Carter (1992) for modeling log-mortality rates over time and by Lee (1994) and Lee and Tuljapurkar (1994) for modeling period fertility.[15]

Within this framework, our extrapolative forecasts can be implemented as follows: (i) estimate $\hat{a}(x)$ as the schedule of the most recently observed period t (e.g., 2009); (ii) estimate $\hat{b}(x)$ as the average annual change in fertility rates over the last five years, from $t-4$ to t; (iii) estimate $\hat{K}(t)$ for each year from $t-4$ to t by regressing for each year t, $f(x,t)-\hat{a}(x)$ on $K(t)\hat{b}(x)$, where $\hat{a}(x)$ and $\hat{b}(x)$ are known.

The model reduces the problem of forecasting age-specific fertility rates to the problem of forecasting the univariate time series $K(t)$. Extrapolation for five years can be implemented by assuming that the annual rate of change observed for $K(t)$ over the past five years, which we denote δ, will continue for the next five years. After this δ will be zero.

In order to obtain probabilistic forecasts with uncertainty estimates, we model $K(t)$ as a stochastic time series. Letting

$$K(t) = K(t-1) + \delta + \varepsilon(t) \tag{1}$$

where $\varepsilon(t)$ are random zero-mean innovations that can be modeled for example as normal, makes the time series a random walk with drift. Uncertainty intervals for cohort total fertility rate CTFR can be generated using the analytical forecast variance

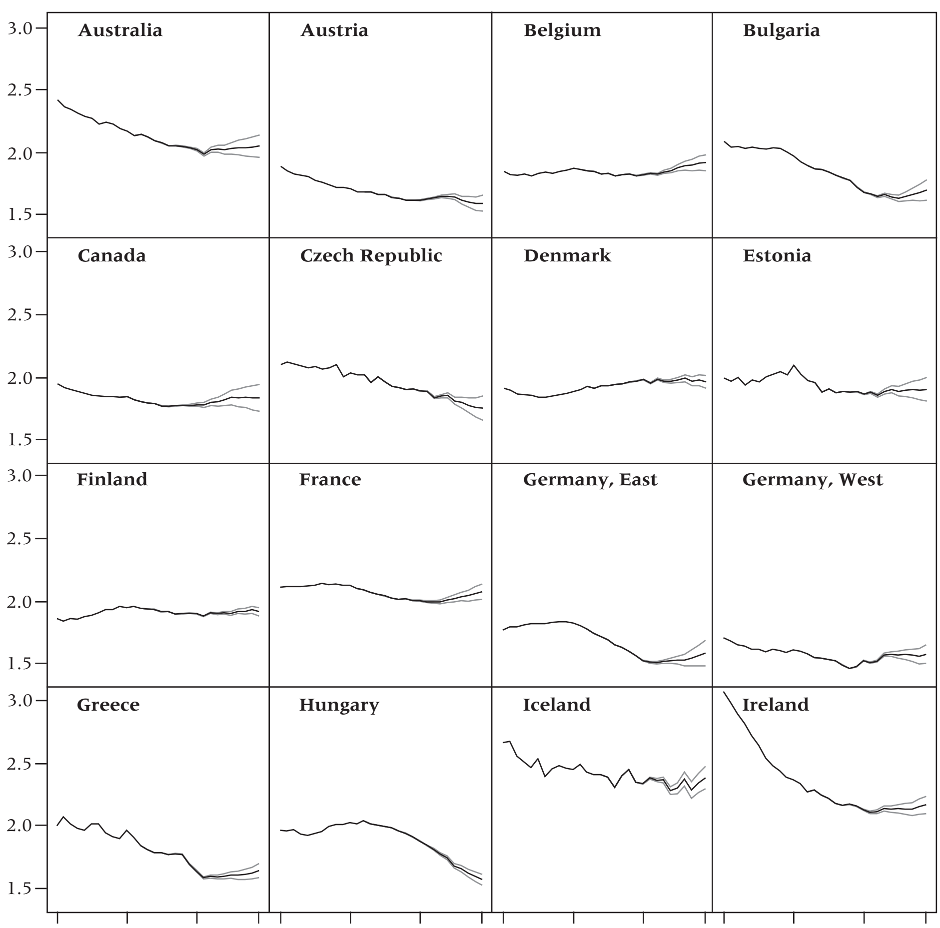
$$Var[CTFR(c)] = \sum_{i=1}^{t-c+i<50} \sum_{j=1}^{t-c+j<50} [\min(i \cdot j, r^2) \cdot \sigma_\delta^2 + \min(i,j) \cdot \sigma_\varepsilon^2]\, b(t-c+i) b(t-c+j)$$

where c is the cohort, t is the last observation period, σ_δ^2 and σ_ε^2 are variances of the trend δ and innovations ε, and r is the number of years the trend is extrapolated before setting it to zero. To obtain a robust estimate of the variance of ε we pool together all 37 countries. The variance σ_δ^2 is estimated by $\sigma_\varepsilon^2/(5-1)$. Uncertainty intervals for cohort forecasts can be obtained assuming normality of errors; then the 95 percent forecast interval covers the region $\pm 1.96\sqrt{Var[CTFR]}$ from the central forecast. Equivalently, one can estimate the intervals by simulating future paths of $K(t)$ by drawing realizations of δ and ε from their normal distributions and calculate the resulting cohort fertility rates for each path.

Our choice of a random walk with drift as the stochastic process used to model $K(t)$ is conservative in that it produces relatively large forecast errors, since the effects of errors compound over time. In contrast, Lee (1993) and Lee and Tuljapurkar (1994) used an ARMA(1,1) model. Their model, however, is close to a random walk specification as the AR parameter is 0.97 (as compared to 1.0 implied by the random walk model). Lee and Tuljapurkar opt for the ARMA model since a random walk with drift would "generate forecast intervals which widen rapidly and without limit" (Lee 1993:189). This is a problem for long-run forecasts, on the order of decades, but not for our purposes, where we need only (relatively) few forecasted years to complete cohort fertility. An additional reason to use the random walk specification is that it is difficult to estimate the ARMA parameters with the short observed time series that we are using, although a method could probably be devised to take into account the variability over longer periods of time or by pooling the sample.

Alternative estimation methods and time-series specifications could be substituted into (1). For example, the freeze-rates method could be implemented by letting δ be zero immediately. Alternatively, the periods upon which the extrapolation is based and assumed to continue could be varied. Our investigation of forecast accuracy suggests that a five-year basis, continuing for five-years into the future, is a good choice obtaining the most accurate forecasts, at least in the historical data.

APPENDIX FIGURE 1 Forecasted cohort fertility rates and simulated 95 percent confidence interval for 37 countries



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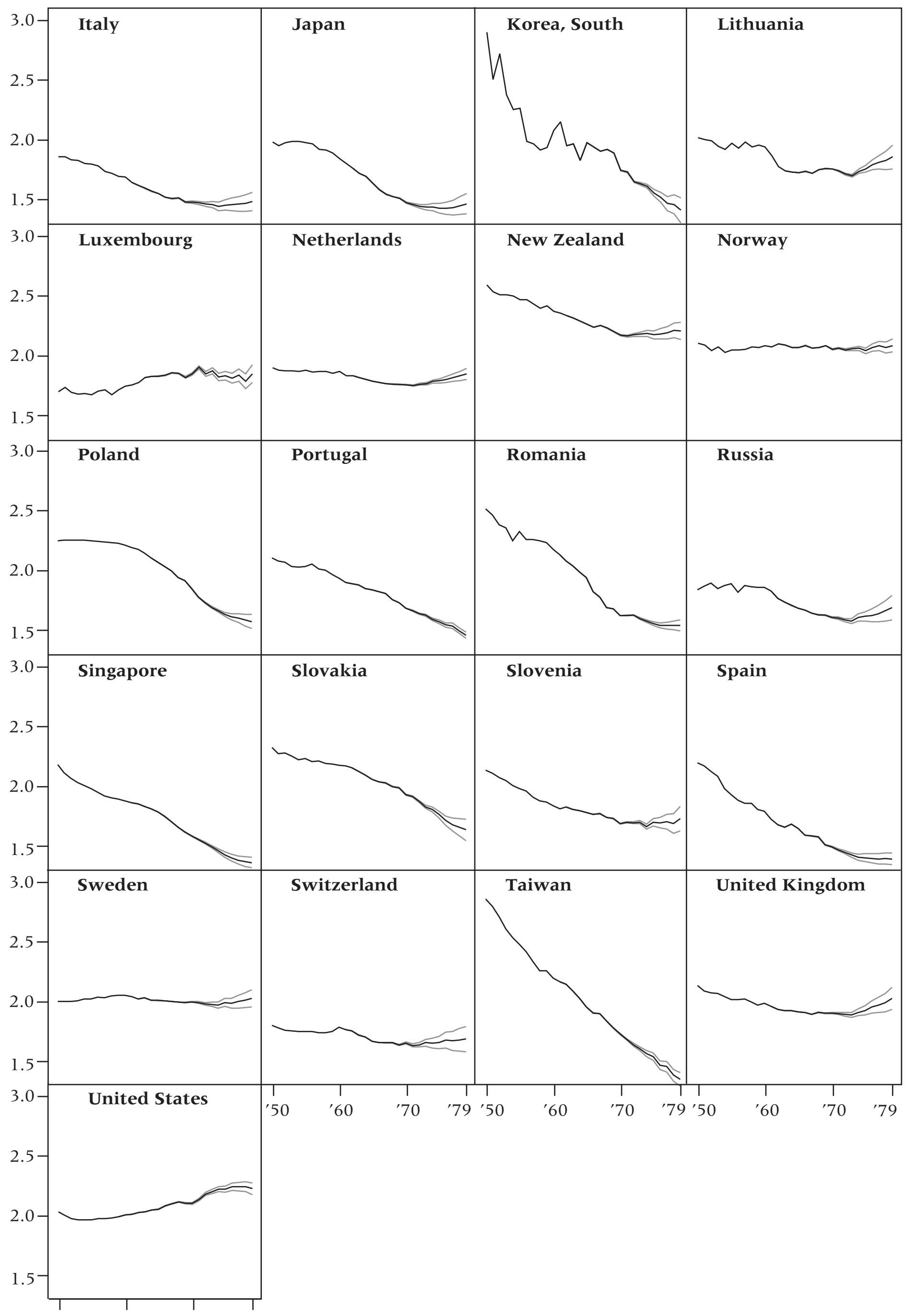
APPENDIX FIGURE 1 (continued)



NOTE: See methods section of text for details of the simulation.

Notes

The forecasted cohort fertility rates and their 95 percent confidence bounds are available for download from «http://www.demogr.mpg.de/go/cohort_fertility/».

1 Strictly speaking, cohort fertility can differ from lifetime fertility in populations open to migration and when mortality is not negligible.

2 Because the focus of our review is on empirical studies, we exclude theoretical work focusing on the differences in cohort versus period fertility patterns, such as van Imhoff (2001).

3 All data obtained are organized in a format of age-by-period fertility matrixes. There are 35 ages (from ages 15/16 to 49/50) for every year of observation. Cohort fertility schedules were obtained by taking the diagonal values of these period matrixes. For the cases where both age-period squares and age-cohort parallelograms were available, we estimated the differences in CTFR obtained from age-period squares. The differences were minimal, in the range of 0.01 births or smaller.

4 In the linear extrapolation with fixed trend, we force the rates to zero on the rare occasions when they drop below zero. In the new 5-year extrapolation method, we did not observe negative rates.

5 The regional averages have been calculated using population weights so that the results represent what is happening to the average person, not the average country. In the English-speaking countries, for example, the US receives more weight than Canada.

6 A substantial increase has been reported in the projected proportion of Danish children born as a result of assisted reproductive technology (ART), from 2.1 percent among mothers in the 1965 cohort to 4–5 percent among mothers in the 1978 cohort. Up to 7 percent of children of native Danish women born in 1975 and later will be conceived by infertility treatment, if intrauterine inseminations are taken into account. An estimated net effect of ART (as compared to the hypothetical situation where no ART treatment is used) is about 3–4 percent (Sobotka et al. 2008).

7 See the section on the impact of the late 2000s recession for further discussion.

8 The weights used in the calculation of the regional averages have little impact on the overall trend in all regions except East Asia. In East Asia the cohort TFR pattern of the largest country, Japan, differs from that of the other countries. While the weighted East Asia average TFR shows signs of the fertility decline leveling off, the non-weighted East Asia average suggests a continued decline for the late 1970s birth cohorts, though with a lower rate than for the cohorts of the 1960s and early 1970s. For example, from 1960 to 1975 the average cohort TFR declined from 2.00 to 1.48 (0.035 per cohort), and from 1975 to 1979 the forecasts suggest a decline from 1.48 to 1.38 (0.024 per cohort).

9 However, the mean is heavily influenced by a handful of countries with very rapid fertility decline, such as South Korea (change over the 1975–79 cohorts –.15) and Taiwan (change over the 1975–79 cohorts –.19). A more robust measure of the average change, the median, is more positive at +.02 children per woman over the birth cohorts 1975–79.

10 The use of alternative measures of change and increase does not alter the overall conclusions. When change is classified by magnitude of change to "likely increase" (1975–79 change +.05 or more), "relatively stable trend" (1975–79 change –.04…+.04), and "likely decrease" (1975–79 change –.05 or more), ten countries are categorized as having a likely increase in cohort fertility, 19 have a relatively stable trend, and eight have a likely decrease in cohort fertility. Model-based estimates of the number of countries with a statistically significant reversal are in line with the change being a very likely increase. When a significant reversal is defined as the lower bound of the 95 percent confidence interval for the 1979 cohort being above the lowest observed cohort TFR among the 1960–75 cohorts, 12 countries are categorized as having a statistically significant increase.

11 Austria (data from the years 1950–2009), Belgium (1961–2009), Bulgaria (1950–2009), Canada (1950–2007), Czech Republic (1950–2009), Denmark (1961–2009), East Germany (1961–2009), Estonia (1961–2009), Finland (1950–2009), France (1950–2009), Greece (1961–2009), Hungary (1950–2009), Italy (1961–2009), Japan (1950–2009), South Korea (1961–2009), Lithuania (1961–2009), Netherlands (1950–2009), Norway (1961–2009), Portugal (1950–2009), Russia (1961–2009), Slovakia (1950–2009), Spain (1961–2009), Sweden (1950–2009), Switzerland (1950–2009), United States (1950–2007), and West Germany (1961–2009).

12 For cohorts that are close to the end of their reproductive years (e.g., women born between 1958 and 1965, assuming age 50 as the "end" of reproduction), we used the forecasted cohort TFR obtained by linear extrapolation with fixed trend as the "completed" fertility level. The difference between completed fertility at age 43 (for the 1965 cohort) and the forecast that uses forecasted fertility at age 44 and above is small for all countries.

13 Comparisons of the estimates for the 1974–75 cohorts between our results and those of Mazuy et al. (2011) are consistent with the historical underestimation: the Mazuy et al. forecasts are on average 3 percent lower than ours. The differences between the two forecasts are largest in Eastern European and Mediterranean countries. This may be because the estimation of the 15-year trend starts in 1993 when fertility may have still been comparatively high in those countries.

14 In both scenarios we used a no-migration and a replacement-migration variant. Life expectancy was assumed to continue to increase according to the United Nations long-term projections (United Nations 2011). Replacement-fertility scenarios were constructed by calculating the rate of immigration at age 20 that would be required to keep the population size constant. For simplicity, migrants were assumed to have the same fertility as the native population.

15 We thank an anonymous referee for pointing out that the model could also be written as $f(x,t) = a(x,2009) + c(x)[TFR(t) - TFR(2009)]$, with $TFR(t) = TFR(t-1) + \beta \cdot \delta + \beta \cdot \varepsilon(t)$ and $\beta = \sum b(x)$. This alternative formulation may be more transparent to some readers.

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