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Fertility Response to the COVID-19 Pandemic in Developed Countries – On Pre-pandemic Fertility Forecasts

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Abstract: The COVID-19 pandemic has affected all areas of our lives. Among other outcomes, the academic literature and popular media both discuss the potential effects of the pandemic on fertility. As fertility is an important determinant of population development and population forecasts are important for policy decisions and planning, we need to address to which extent fertility forecasts performed before the pandemic still apply.

Using Monte Carlo forecasting based on principal components of fertility rates, we quantify the effects of the pandemic on fertility for 22 countries and discuss whether forecasts made prior to the pandemic need adjustment based on more recent data.

Among the studied countries, 14 countries show no significant effect of the pandemic at all, while six countries have significantly lowered numbers of births in comparison to counterfactual trajectories that assume that past trends will hold. These countries are primarily in the Mediterranean and East Asia. For Finland and South Korea, there is statistical evidence for increased fertility in the early phases of the pandemic. In all cases with statistically significant fertility differentials caused by the pandemic, reproductive behavior normalized quickly. Therefore, we find no evidence for long-term effects of the pandemic on fertility, leading to the conclusion that pre-pandemic fertility forecasts still apply.

Keywords: COVID-19 · Fertility · International Trends · Causality · Stochastic Forecasting · Principal Component Analysis · SARIMA Models · Monte Carlo Simulation

1 Background

The COVID-19 pandemic has affected many areas of life, both via direct effects on morbidity (*Fernández Villalobos et al.* 2021) and on mortality (*Vanella et al.* 2021) as well as via indirect effects, by increasing the demand for healthcare services (*Khailaie et al.* 2021). Moreover, national and regional governments have introduced

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a variety of non-pharmaceutical interventions (NPIs) aimed at limiting the spread of the virus (*ECDC* 2021). While the impacts of the pandemic on mortality and morbidity have been well-investigated, our understanding of other factors, such as long-term effects of the NPIs on mental health or behavior, has not advanced as far. This is because data on those issues are still very limited, and effects will only show up in the long term. We do not know whether we will observe significant long-term changes in behavior, whether pre-pandemic behavior will re-establish itself immediately (potentially after short-term catch-up effects) after all restrictions have been lifted and all individuals have been sufficiently immunized, or whether it will take some time to return to the pre-pandemic state (*Berrington et al.* 2022; *Goldstein* 2020).

In this contribution, we are specifically interested in the impact of the pandemic and associated NPIs on fertility. With regard to fertility, future trends will likely be influenced by socioeconomic characteristics of the affected countries and their previous fertility levels and trends (*Aassve et al.* 2020). From a demographic perspective, the long-term effects of the pandemic on fertility are of interest for family policy and for planning in fields associated with the future development of the population and especially numbers of births, for example the labor market (*Fuchs et al.* 2018; *Berrington et al.* 2022) or social insurance (*Vanella/Deschermeier* 2019). Our study investigates the overall effects of the pandemic on reproductive behavior for a variety of countries and outlines potential future developments based on our empirical findings.

In particular, our focus is on pre-pandemic fertility forecasts and whether and how those should be adjusted in response to the pandemic. Our paper aims at presenting an advanced approach to quantifying effects of extraordinary events on fertility in different countries. Our case study addresses the first one and a half years of the COVID-19 pandemic. We apply a fully stochastic approach that considers long-term trends in fertility, monthly seasonality, autocorrelations, and cross-correlations of fertility rates across countries. We thereby adapt a model previously suggested by *Vanella, Basellini,* and *Lange* (2021) in a study on excess mortality to monthly fertility patterns. Based on the first results, we compare the lessons learned from the most recent data with theoretical considerations on the long-term effect of the pandemic on fertility to draw conclusions about whether fertility forecasts should be modified in light of the pandemic.

In the next section, we present a threefold literature review. We first address effects on fertility observed in past crises. Second, we discuss the potential future impact of the COVID-19 pandemic on fertility according to previous studies on the matter. Third, we will give a short overview of forecast approaches in demography relevant to our present paper. In the next section of the paper, we discuss the data used and our methodological approach. We then present results generated from our simulations and a suggestion on the need to adjust pre-pandemic fertility forecasts for those countries identified as being significantly affected in terms of their reproductive behavior during the pandemic situation, matching our results to theoretical considerations stated earlier in studies on fertility forecasting in the light of the pandemic. We then close our paper with a discussion of the results and our approach.

2 State of Knowledge

2.1 Effects of past crises on fertility

The COVID-19 pandemic can be seen as a health crisis as well as an economic crisis (*Dorn et al.* 2020, 2022). It is quite possible that both the pandemic itself (including associated increases in mortality rates and associated contact reduction measures) as well as the economic downturn associated with it could influence current and future fertility. A large body of research has addressed the effects of crises, or other shocks on fertility.

The majority of scholarly work on the effects of crises on fertility has focused on economic downturns (*Comolli* 2017; *Comolli et al.* 2021; *Goldstein et al.* 2013; *Lee* 1990, 1997; *Matysiak et al.* 2021; *Neels et al.* 2013; *Sobotka et al.* 2011). It is generally agreed that fertility is pro-cyclical; fertility tends to increase in times of economic prosperity and decline in times of economic weakness (*Lee* 1997; *Sobotka et al.* 2011; *Matysiak et al.* 2021). Historically, the effects of economic downturns have often been short-lived (*Neels et al.* 2013; *Sobotka et al.* 2011). The work of *Lee* (1990, 1997) on shocks to the population equilibrium is well-known. Other scholars, too, have discussed the effects of economic downturns, epidemics and pandemics as well as natural disasters on fertility. These studies may provide some guidance on possible effects of the pandemic on future fertility.

Whereas Lee’s methods appear to present a comprehensive and rather mathematical approach to tackling fertility change in times of uncertainty, they tend to oversimplify the complex phenomenon of fertility, as not all cases fit this model. Many countries in Eastern and Central Europe have witnessed significant declines in their total fertility rates (TFRs) during their transition from socialist to capitalist societies and associated economic shocks since the late 1980s. This process dragged on until the turn of the millennium, followed by geographically heterogeneous recoveries in fertility until the onset of the *Great Recession* after 2007 (*Frejka/Gietel-Basten* 2016). The Great Recession of 2007-2009 offers – for some countries at least – a striking exception to the general pattern of fertility decline followed by a relatively rapid recovery (*Comolli et al.* 2021; *Comolli* 2017; *Goldstein et al*. 2013; *Matysiak et al.* 2021; *Seltzer* 2019). *Buckles et al.* (2022) described the aftermath of the Great Recession in the United States (US) as a *baby-less recovery*. In many developed countries, a fertility rebound did not occur, and in many countries, the birth rate has continued to decline. In other countries, fertility recovered relatively quickly after the Great Recession, even in the absence of rapid economic recovery (*Comolli* 2017; *Sobotka et al.* 2011).

Fertility is affected by a number of secular trends, including changing fertility intentions, and would likely not be stable even in the absence of economic fluctuations (*Sobotka et al.* 2011). *Lee* (1979) famously described fertility as a *moving* *target*, meaning that the desired number of children reacts to exogenous factors. The fact that fertility is affected by many different, often countervailing, forces means that it is often difficult to ascertain causal connections. A likely mechanism linking economic condition to fertility is changes in fertility timing due to perceived uncertainty about the future (*Comolli* 2017; *Sobotka et al.* 2011).

The explanation for the lack of a rapid rebound in fertility in response to the Great Recession in some countries may be related to wide-spread and long-lasting uncertainty about the future, caused both by the Great Recession itself and by structural changes to the global economy, which have led to unprecedented global interdependence, increased economic insecurity, and the intensification of neoliberal social policies (*Comolli* 2017; *Comolli et al.* 2021; *Comolli/Vignoli* 2021; *Matysiak et al.* 2021; *Seltzer* 2019; *Vignoli et al.* 2020). Concern about climate change and political instability in many parts of the world may have also contributed to what may be described as a state of *chronic uncertainty*. *Vignoli et al.* (2020) have developed a new theoretical approach – the *narrative framework for the analysis of the fertility decision-making process* – that makes coping with uncertainty about the future the centerpiece of understanding fertility trends. According to the authors, people make fertility decisions in the face of uncertainty based on imaginative scenarios of *what to expect* in one's life course, which they call *narratives of the future*. In a globally inter-connected world, public and social media play a large role in shaping narratives of the future. Therefore, it may be that a narrative of chronic uncertainty has become the basis of fertility decision-making for many people.

Other scholars have investigated the effects of diseases, such as the well-studied influenza pandemic of 1918 (*Boberg-Fazlic et al*. 2021; *Chandra/Yu* 2015), which led to an immediate and striking decrease in fertility followed by a long *baby boom* (*Beach et al.* 2022). The Zika epidemic of 2015 (*Marteleto et al.* 2020) has also been studied with regard to its impact on fertility in Brazil. The authors compared the annual changes in monthly live births and age-specific fertility rates from 2015 to 2016 relative to the corresponding changes from 2014 to 2015. They showed that, in summer 2016, approximately nine months after the major media reports on the Zika outbreak, fertility declined significantly relative to the year 2015. However, it is hard to compare one disease to another. For example, mortality in the 1918-2020 influenza pandemic was significantly increased for people of childbearing age (*Çilek et al.* 2018), while this is not the case for the recent COVID-19 pandemic (*Vanella et al.* 2021; *Vanella et al.* 2022). To add an example of a natural disaster and its consequences for fertility, *Nobles et al.* (2015) studied the Indonesian Tsunami of 2004 by comparing the differences in age-specific fertility rates in the years before the Tsunami against the years 2006-2009. For this, the authors stratified regions with and regions without mortality caused by the Tsunami, finding decreased fertility for the regions not directly affected by the Tsunami, while regions with Tsunami mortality had increased fertility. The authors concluded that the death of multiple own children triggered an increase in reproductive behaviors by many females. However, we see again that the idiosyncratic characteristics of each natural disaster make it hard to compare their consequences for fertility.

This overview of the literature shows that fertility is a complex phenomenon that may be influenced by institutional and economic opportunities, as illustrated by the large body of literature on the connection between fertility and the institutional economic or political setting, and individuals' preferences for children, which are also subject to the economic situation and perceived uncertainty (*Lee* 1979; *Vignoli et al.* 2020). In low-fertility countries, pro-natalist social policies may affect reproductive behaviors as well (*Vanella/Deschermeier* 2019). A holistic projection approach after a shock such as the pandemic should factor in the driving forces of the fertility phenomenon.

2.2 Research on the impact of the COVID-19 pandemic on future fertility

The COVID-19 pandemic may have impacted fertility either on a biological level or on a behavioral level. Possible scenarios and mechanisms have been outlined by *Berrington et al.* (2022). At the biological level, those include increased maternal mortality, different timing of births (premature, for instance, see *Sentilhes et al.* 2020), a higher proportion of stillbirths (*DeSisto et al.* 2021), or higher infertility among the infected (*Li et al.* 2021). There might also have been decreases in births due to pandemic restrictions lowering access to assisted reproductive technology, which could have led to smaller numbers of births among females aged over 35 (*Berrington et al.* 2022; *Gromski et al.* 2021). However, so far, there is little evidence one way or the other concerning biological effects of COVID-19 on fertility, although the existence of such effects is plausible (*Li et al.* 2021; *Madjunkov et al.* 2020). *Li et al*. (2021) have outlined a research protocol to explore these issues.

As noted in the previous paragraph, the pandemic might have also affected fertility through behavioral mechanisms. The fear of the virus and its effects on the child or a general increase in subjective future insecurity might have given rise to smaller fertility rates (*Guetto et al.* 2022). Furthermore, younger couples not living together, and in some cases, being forced to move back to their parents could have meant less privacy and restricted opportunities to engage in sexual activity, leading to fewer unplanned children (*Berrington et al.* 2022). *Carballo* and *Corina* (2020) suggested that the most important effect of COVID-19 on fertility would be behavioral changes caused by uncertainty about the future. A study of Google searches during the pandemic (*Wilde et al.* 2020) suggested that people might have changed their fertility-related behavior as a response to the pandemic. The authors predicted large declines in fertility in the US, with the greatest declines among racially and economically marginalized women. In a study of five countries (Italy, Germany, France, Spain, UK), *Luppi et al.* (2020) showed that effects of COVID-19 on fertility plans varied by country. *Aassve et al.* (2020), *Carballo* and *Corina* (2020), and *Ullah et al.* (2020) posited that consequences might differ for low-income countries vs. high- and middle-income countries.

On the other hand, measures aimed at contact reductions could have led to intensified contacts between couples living together and, therefore, increased sexual and reproductive activity. This was the subject of much speculation in the popular press (see, e.g., *Puffett/Hall* 2021; *Deutsche Welle* 2021). Also, reduced access to contraceptives or abortion clinics as a consequence of increased social distancing measures and other precautions could have led to increases in unplanned births (*Berrington et al.* 2022).

In addition to effects on the quantum of fertility, the pandemic situation might have had consequences for the tempo of births (see *Bongaarts/Feeney* 1998), as couples might have either decided to postpone intended births because of the reasons mentioned above or to have births earlier than previously planned in response to better opportunities to work from home and greater labor flexibility (*Berrington et al.* 2022).

There is already some evidence suggesting that fertility rates were declining in high-income countries (*Kearney/Levine* 2021; *Sobotka et al.* 2021). A few scholars have made projections about the impact of the pandemic on fertility but have used different approaches as opposed to ours. Based on his earlier studies on historical effects of crises on fertility, *Lee* (2021) advised demographers to ignore the COVID-19 crisis when formulating longer-run fertility projections. *Carballo* and *Corina* (2020) took the Great Recession as the basis of a historical simulation model for their projections and predicted an acceleration of downward fertility trends in some high- and middle-income countries but less of an effect in low-income countries. *Sobotka et al.* (2021) compared fertility in 2021 with that of the previous year. They found substantial declines in fertility in many countries and do not expect a return to pre-pandemic levels in the near future. However, in an international study, *Sobotka et al.* (2022), found evidence that the pandemic appeared to have affected the volatility of fertility, rather than the mean. Thus, their results suggested that the tempo rather than the quantum of fertility had been affected. *Bujard* and *Andersson* (2022) supported this conclusion for the cases of Germany and Sweden, mentioning that females of reproductive age, who did not belong to the groups that were prioritized in the enrollment of vaccinations, might have delayed their wishes to reproduce to a point in time after which broad and secure vaccinations for pregnant women would be available. This would support an effect of the pandemic on the tempo rather than the quantum of fertility.

Goldstein (2020), adapting *Lee's* (1979) *Moving Target Theory*, identified four major scenarios for the future course of fertility after the end of the pandemic: the *boom, bounce, whimper,* and *thud scenarios.*

- The boom scenario assumes a significant and abrupt increase in fertility immediately post-pandemic, after which the level of fertility will slowly converge to the pre-pandemic level.
- The bounce scenario assumes an immediate re-installment of the pre-pandemic fertility level.
- The whimper scenario assumes a slower convergence of the fertility level to a target level below the pre-pandemic level.
- The thud scenario assumes a further decrease post-pandemic, after which it slowly converges to a level below the pre-pandemic level.

The boom scenario corresponds to what some in the popular press have predicted based on the fact that couples may be spending more time together than before the pandemic due to working at home and the closure of many social activities. The bounce scenario describes a quick re-installment of the pre-crisis fertility level. The whimper and thud scenarios are what one might expect in situations of chronic uncertainty. The thud scenario assumes that fertility trends initiated during the crisis would continue afterward, while the whimper scenario assumes that extremely low rates of fertility were unsustainable in the long term. *Goldstein's* approach provided good qualitative descriptions of possible post-pandemic trends in fertility, but it did not make any specific predictions.

Guetto et al. (2022) conducted surveys on fertility intentions among Italians during the first COVID-19 wave based on *Vignoli et al.'s* (2020) earlier mentioned narrative framework. Controlling for socio-economic characteristics and personal preferences for children, the authors showed in a regression analysis that a worse personal perception of the political and economic situation and high exposure to daily news had a negative effect on the intentions to procreate after the pandemic. Moreover, the study participants were randomly exposed to pseudo-press releases on the length of the pandemic expected by a panel of Italian experts. The authors showed that personal expectations about the duration of the pandemic significantly affected participants' intentions in regard to having another child after the pandemic. Those with more pessimistic expectations about the duration of the pandemic had – ceteris paribus – decreased intentions to procreate. We will check the results from our forecast approach against the theoretical considerations by *Goldstein* (2020) and draw conclusions about necessary adjustments to fertility forecasting during and after the pandemic based on the connection of both. The findings from the two studies presented suggest that, at least for economically weakened countries such as Italy, a boom is unlikely and that the two realistic extreme scenarios are the bounce or the thud scenario, i.e., a quick re-installment of the pre-pandemic fertility trend against a long-lasting decreased fertility in comparison to what could have been expected in the counterfactual scenario of no pandemic.

The literature review suggests that the effects of the pandemic on fertility are expected to be heterogeneous internationally, depending on cultural and economic background, among other factors. The pandemic could, based on these early empirical studies and theoretical considerations, cause fertility declines, increases, or no effects. However, the most probable outcomes appear to be that fertility declines rather than increases.

Our review shows that studies on the projection of post-pandemic fertility have primarily been based on theoretical considerations that were not connected to empirical evidence and described future scenarios qualitatively, which gives an idea of future paths but cannot be directly translated into concrete fertility projections. Even the quantitative approaches are somewhat restrictive, as they deterministically suggest a limited number of future scenarios. The latter, however, fail to quantify the probabilities of certain scenarios to occur (*Lee* 1998) and always have an individual probability close to zero. Moreover, such deterministic approaches cannot cover future risk and uncertainty sufficiently, as the quantified scenarios only represent a small subset of all realistically possible developments (*Vanella et al.* 2020). This appears especially problematic in situations such as the pandemic, which is an event not witnessed before and therefore, not represented in past data. Given that historical data is at best only partially representative of the future, uncertainty about the future development of fertility is naturally higher. This points to the importance of a stochastic approach for the current case study.

2.3 Approaches to demographic forecasting

A variety of approaches to fertility forecasting can be found in the literature. Whereas statistical offices tend to rely on deterministic scenario approaches that state assumptions for the future course of age-specific fertility rates (ASFRs) (see, e.g., *Eurostat* 2020), the scientific literature suggests a variety of forecast approaches based on time series analysis. Among those are approaches that predict births by birth order (*De Beer* 1985), autoregressive integrated moving average (ARIMA) models based on principal component analysis (PCA) (*Bozik/Bell* 1987) – well-known as *Lee-Carter models* (*Lee* 1998)*,* or age-period-cohort models (*De Beer* 1989). There is also a variety of extensions for the Lee-Carter model. For instance, *Vanella* and *Deschermeier* (2019) suggest including family and social policy variables as predictors for low-fertility countries.

A limitation of time series approaches is that they are purely quantitative and rely only on available data. Therefore, they only include observed trends in forecasts of future developments. Thus, yet-unobserved developments, such as the pandemic, are not considered in the forecasts. Alternative approaches to the frequentist models mentioned above include qualitative expert opinions in the simulations. For instance, Lutz and colleagues suggested simulating the TFR based on sampling out of a range of judgments of an expert panel, who were asked to give their prediction with lower and upper bounds of realistic scenarios for the TFR (*Lutz et al.* 1998; *Lutz* 1995). Those approaches have been extended and refined, applying more sophisticated mathematical models in the TFR projections for the United Nations (*Alkema et al.* 2011). Alternatively, *Schmertmann et al.* (2014) suggested Bayesian forecasting of the cohort fertility rate instead of the TFR. Bayesian approaches are, in principle, capable of integrating qualitative information, such as subjective assessments and guesses, into forecasts. They are, however, sensitive to biases by subjective misjudgments and personal opinions and should, therefore, be applied with caution (*Lee* 1998; *Vanella et al.* 2020). Keeping that in mind, it is important to include a reasonable number of realistic future scenarios in Bayesian projections. *Bijak* (2011) suggested Bayesian averaging among a selection of possible models for the case of international migration, assigning likelihood-based probabilities to those models, such that there is a likelihood for each model family so that they can be assigned further probabilities to cover a sufficiently large number of scenarios and quantify them with likelihoods. That approach, however, requires that representative past data are available which can be used to apply likelihoods via backtesting; these are not available in our case.

It is not immediately obvious when (and if) fertility forecasts (or demographic forecasts in general) should be adjusted in response to a changing environment. For instance, *Destatis* (2017) presented a new projection of international migration to Germany as a response to the refugee shock that started in 2014, especially from Syria, Iraq, and Afghanistan, stating that a valid estimation of the long-term effects of the crisis on migration and the structure of the population in Germany could not be performed at that time, but that an adjustment of the previous assumptions would be necessary for projections that build on the population projection. This seems conceivable since *Lee's* (2021) suggestion of ignoring shocks (here: the pandemic) might lead to systematic biases in fertility projections for countries that show significantly altered reproductive behaviors. Nevertheless, his assumption is in the realm of realistic scenarios and should therefore be considered a possibility in each projection. Even in the event of a significant fertility response to the pandemic in the early stages, it is not straightforward to determine how long the process of recovery to a pre-pandemic level might take. Section 2.1 has illustrated that, for past crises, the duration of fertility change, if it has occurred at all, has been very heterogeneous with quick re-installments of fertility to the levels before the crises in some cases and long periods of recovery for others. Again, the issues mentioned above call for a stochastic approach that includes the variety of different possible outcomes and the increased uncertainty involved in estimating future fertility.

First, we need to assess counterfactual scenarios of fertility to estimate the effect of the pandemic on fertility as observed so far. These ideas derive from estimation rooted in epidemiology on excess mortality due to extraordinary causes. *Vanella et al.* (2021) suggested extending the Lee-Carter forecast approach to weekly mortality data for several countries to evaluate age- and sex-specific excess mortality during the pandemic, taking long-term mortality trends, international correlations caused by the spread of the virus across country borders, interannual seasonality, and stochasticity into account. We adjust their approach to construct counterfactual fertility trends under the assumption of no pandemic and associated NPIs and quantify distributions of the yet observed pandemic effect on fertility.

3 Data and methods: estimating the past effect of the pandemic on fertility

Our methodology follows a hierarchical approach that consists of several steps. In the first step, we use monthly total fertility rate (mTFR) estimates (see *Jdanov et al*. 2022) for 22 countries,[1] as provided by the Human Fertility Database (HFD) in the Short-Term Fertility Fluctuations dataset (*HFD* 2022). The first cases of COVID-19 were reported on 31 December 2019 in China (*Yang et al.* 2020). As the median time

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[1] Austria, Belgium, Czechia, Denmark, England &Wales, Finland, France, Germany, Hungary, Israel, Italy, Japan, Latvia, the Netherlands, Norway, Portugal, Scotland, Slovenia, South Korea, Spain, Sweden, and the US.

of human pregnancy is between 38 and 39 weeks (*Jukić et al.* 2013), any behavioral effects of the pandemic situation would not have become apparent before October 2020 – the exception might be abortions caused by the pandemic. Therefore, we use the mTFRs for the period January 2008 – September 2020 as a baseline period. We combine our data into a matrix with 153 rows (months) and 22 columns (country-specific mTFRs).

Our approach is rooted in principles from classical studies on excess mortality during extraordinary periods. Checking whether some event has affected some target variable is not straightforward, as this is a question of counterfactuals. For instance, we do not know how exactly mortality *would have developed* if we *had not* observed a specific event, in our case the COVID-19 pandemic. Instead, we observed the mortality development *under* the pandemic situation (*Vanella et al.* 2021), including fatality risk after infection with the virus (*Vanella et al.* 2022) or contemporaneous contact reduction measures (*Khailaie et al.* 2021). Therefore, we can only estimate a hypothetical development that we *would have expected* under normal circumstances.

Translating the idea to fertility during extraordinary phases, such as the pandemic, we could only observe fertility under those circumstances, not the counterfactual development which would have been observed under normal circumstances. The latter can be predicted based on some forecast approach. For the case of mortality, *Vanella et al.* (2021) suggest a Lee-Carter-based forecast approach that considers long-term trends, seasonality, and stochasticity to forecast counterfactual distributions of weekly age- and sex-specific mortality rates. Here, we apply the approach to the mTFR time series. Specifically, we perform PCA to log-mTFRs over the period January 2008 – September 2020 for all study countries to cover cross-correlations between their fertility trends over the baseline period.

PCA performs singular value decomposition on the log-mTFR time series, transforming them into new variables that are uncorrelated (so-called principal components or PCs) (*Vanella* 2018). The value of the i^{th} PC for month m is:

$$p_{i,m} \coloneqq \sum_{c=1}^{22} \lambda_{i,c} \cdot lf_{c,m}, \tag{1}$$

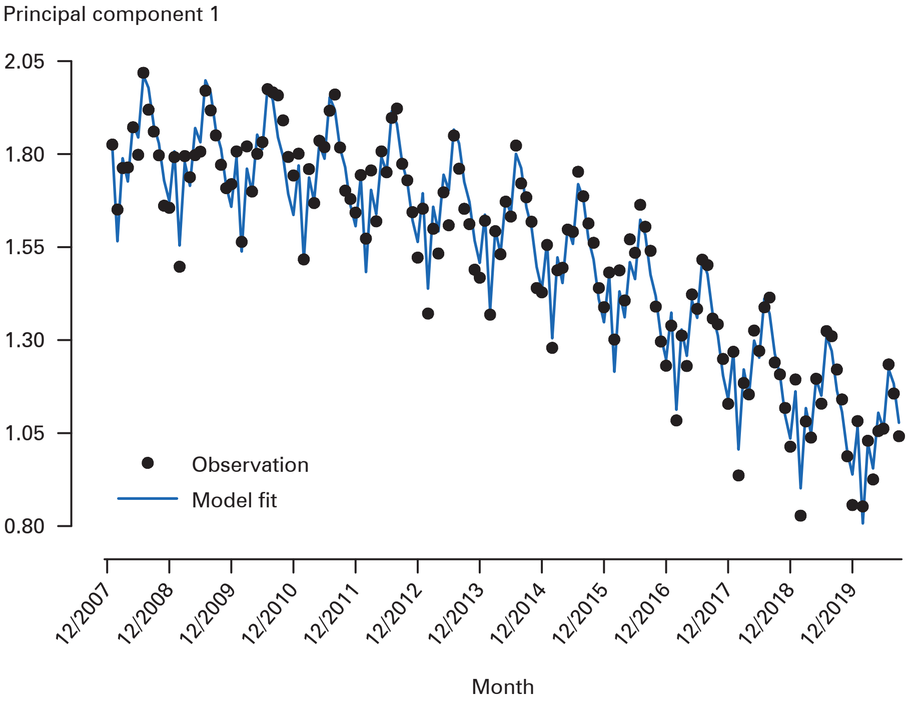
where $\lambda_{i,c}$ is called the *loading* of the log-mTFR of country c on PC i. The loading can be understood as a "correlation" between the original variable (here: the log-mTFR of some country) and the corresponding PC. In matrix notation, the singular value decomposition can be written as

$$P \coloneqq F \times \Lambda, \tag{2}$$

with F being the 153 × 22 matrix of the log-mTFRs over the baseline period; Λ (22 × 22) is called the loadings matrix, and P is the matrix of hypothetical observations for the principal components for the baseline period (153 × 22). Each column in Λ represents the loadings (coefficients) of one PC with respect to all original variables (e.g., the element in the first row and third column of Λ is the coefficient of the third PC with the log-mTFR of the first country, in this case: Austria) and is computed such that the first PC explains a maximum of the variance in F. Then, the second column of Λ is computed such that the second PC explains as much of the variance in F as possible, given the first column of Λ. This process continues until all 22 PCs have been identified. The advantage of PCA is that a high number of correlated variables can be analyzed quite efficiently with a reduced number of variables while also taking the correlations between the variables into account (*Vanella* 2018). Since we take an internationally comparative perspective that analyzes contemporaneous fertility trends, PCA offers an efficient way to both reduce the high complexity of our research question as well as take common international trends into consideration. In a special case like a pandemic, we can expect fertility trends in, e.g., Germany, to be affected by outbreaks in France. Therefore, correlations between countries should be considered as well.

Figure 1 shows PC 1's course for the baseline period (dots).

Fig. 1: Time series of principal component 1 for baseline period with model fit



Source: Authors' computation and illustration

Figure 1 reveals both a negative long-term trend and distinct seasonality. PC 1 represents the pattern of fertility for all study countries since the onset of the Great Recession. The blue line is a trend function fit to the time series that is a combination of a long-term trend function and a seasonality function. The long-term trend is estimated by an inverse logistic trend function, as suggested by *Vanella* and *Deschermeier* (2019) for the case of the German quantum of fertility that has an inflection point in the autumn of 2017. Previous studies do not sufficiently take long-term fertility trends into consideration but rather compare fertility during the pandemic to means of short time periods before the pandemic (e.g., *Sobotka et al.* 2022). Figure 1, however, suggests a clear trend in fertility since the Great Recession. Not accounting for this trend in studies on differential fertility can lead to systematic biases in the formulation of counterfactual scenarios (*Vanella et al.* 2021). To avoid this bias, our model fits the long-term trend to the data.

Fertility exhibits strong annual seasonalities such as those observed in Figure 1. These should be considered in counterfactual scenarios (see, e.g., *Sobotka et al*. 2022). We include those seasonalities by a combination of a cosine function and monthly dummies. While a cosine function covers interannual seasonality relatively well, it tends to significantly underestimate the peaks and troughs. Therefore, *Vanella et al.* (2021) suggest adding seasonal dummies to attain a better fit of the trend function to the local extremes. The deterministic model illustrated by the blue line in Figure 1 as derived by ordinary least squares (OLS) for PC 1 is:[2]

$$t_1(m) = 1.83 - 1.1\frac{\exp\left[\frac{(m-117)}{30.56}\right]}{1+\exp\left[\frac{(m-117)}{30.56}\right]} - 0.15\cos\left(\frac{m\pi}{6}\right) + 0.15jan - \tag{3}$$

$$0.12feb + 0.05mar - 0.08apr - 0.09jun + 0.06jul + 0.04aug + 0.03oct$$

with m being a month parameter that is 0 for January 2008.[3] The combination of monthly dummies and a cosine function gives the best model fit based on both Akaike's (AIC) and the Bayesian Information Criterion (BIC). The counterfactual trend is associated with an amount of stochasticity. Equation (3) provides our expectation for the trend. However, a realistic account of a causal connection between the pandemic and fertility developments must factor in random fluctuations as well (*Sobotka et al.* 2022): otherwise, the fertility developments might in many instances be misinterpreted as caused by the pandemic, although they may not be connected to it (*Vanella et al.* 2021). To account for stochasticity and autocorrelations in PC 1, we derive the residuals from (3), i.e., the differences between the observations (black dots) and the blue trend function specified by our model:

$$u_1(m) \coloneqq p_1(m) - t_1(m). \tag{4}$$

Considering the time series of u_1, its autocorrelation function (ACF), and its partial autocorrelation function (PACF),[4] we concluded that the residuals follow an

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[2] We tested seasonal dummies as in *Vanella et al.* (2021) as well but found monthly dummies to perform better according to the AIC and the BIC.

[3] Derived such that the model's R^2 is maximized.

[4] See, for instance, *Shumway/Stoffer* (2016), for more details on the ACF and the PACF.

autoregressive moving average process of orders one and one ($ARMA(1,1)$). In lag notation, this can be written in our case as:

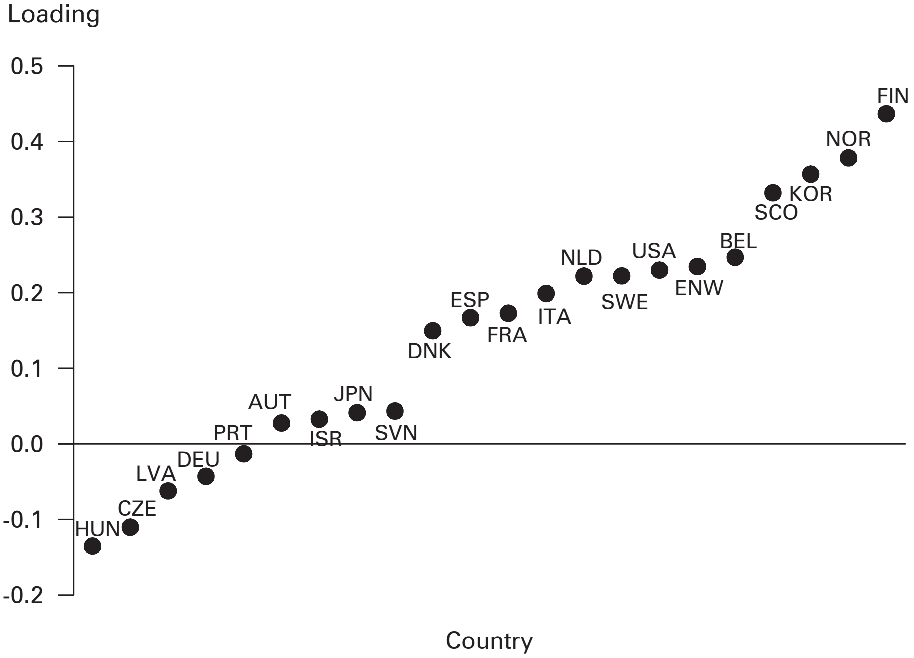
$$(1 - 0.81L)u_1(m) = (1 - 0.48L)\varepsilon_1(m),\ \varepsilon_1(m) \sim NID(0, 0.04^2), \tag{5}$$

that is equivalent to

$$u_1(m) = 0.81u_1\,(m - 1) + \varepsilon_1(m) - 0.48\varepsilon_1\,(m - 1),\ \varepsilon_1(m) \sim NID(0, 0.04^2). \tag{6}$$

Figure 2 illustrates the loadings of PC 1, which present the coefficient for each country-specific log-mTFR.

Fig. 2: Loadings of principal component 1 by country (alpha-3 code)



Source: Authors' computation and illustration

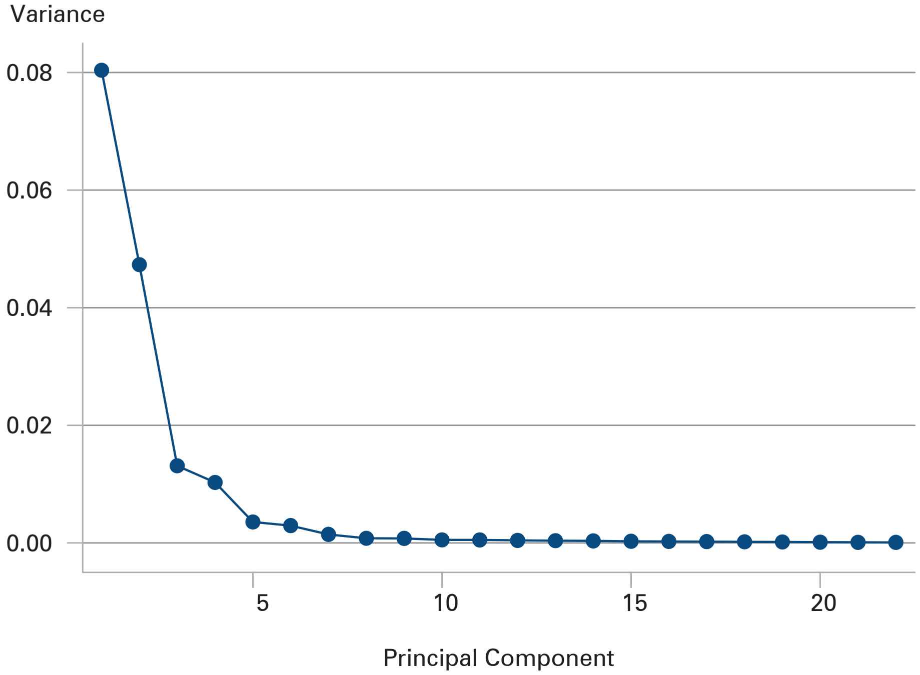
Countries below the horizontal line have a generally positive tendency from the perspective of the mTFR since the onset of the financial crisis and vice versa.

For the case of Germany, *Vanella* and *Deschermeier* (2019) have shown that a combination of demography-related social policy measures introduced since the late 1970s have had positive effects on the quantum of fertility and that the tempo of fertility has stabilized such that delays in births, although still present, have decelerated. This trend appeared to be unaffected by the Great Recession, as Germany's economy coped quite well with the crisis. Portugal, Latvia, Czechia, and

Hungary, after an initial fertility shock, have been showing positive fertility trends in recent years that, for these countries, appear to provide evidence for a baby boom after the financial crisis. The reproductive behavior in the majority of countries, however, appears to be negatively affected by the Great Recession, as the literature overview in Section 2.1 suggests.

The remaining 21 PCs exhibit no long-term trend, but they do show strong seasonalities. To get a good trade-off between accuracy and model complexity, we model several PCs by fitting seasonal autoregressive moving average (SARIMA) models and the remaining PCs as simple random walks (i.e., in expectation held constant at their last observed levels). To decide on the number of PCs to model explicitly, we consider the screeplot that illustrates the variance explained by each PC in descending order (Fig. 3):

Fig. 3: Variance explained by each principal component



Source: Authors' computation and illustration

The graphical criterion for the number of PCs in the analysis is to include all PCs before the "elbow" (*Vanella* 2018). Here, we have an elbow at PC 3 and another one at PC 5. Therefore, we also consider the cumulative shares of explained variance. The first two PCs explain 77.8 percent (48.9 and 28.8 percent, respectively) of the overall variance in the 22 mTFR time series over the baseline period. After adding PC 3 (8 percent) and PC 4 (6.3 percent), the first four PCs explain 92 percent of the variance. Therefore, we model the 2nd, 3rd, and 4th PCs explicitly as SARIMA models.

The remaining 18 PCs are assumed to be random walks, which makes them easy to simulate. As they only explain 8 percent of the variance in the log-mTFRs, the error arising from this simplification is negligible.

The ACFs and PACFs of PCs 2-4 suggest a good fit using the following processes:

$$(1 - L)(1 - L^{12})p_i(m) = \varepsilon_i(m),\ \varepsilon_i(m) \sim NID(0, \sigma_i^2),\ i = 2,3,4. \tag{7}$$

The remaining 18 PCs are modeled by

$$p_i(m) = p_i(m - 1) + \varepsilon_i(m),\ \varepsilon_i(m) \sim NID(0, \sigma_i^2),\ i = 5, \ldots,22. \tag{8}$$

The counterfactual development of the PCs and, therefore, the development of the mTFRs is obviously connected with a lot of risk. To avoid misinterpretation of random deviations of fertility from the predicted course as pandemic-induced differential fertility, we need to forecast counterfactual *distributions* instead of *expectations*. We accomplish this by Monte Carlo simulation, following *Vanella et al.* (2021). We simulate the stochastic parameters (the $\varepsilon_i(m)$) as in (5)-(8) for all PCs 10,000 times for each forecast month (October 2020 – September 2021). This results in 10,000 trajectories for each of the 22 PCs. Let $\widetilde{P}_m$ be the 10,000 × 22 matrix of simulations of all PCs for month m. Then, the corresponding simulation matrix of all log-mTFRs for month m ($\widetilde{F}_m$) is computed by

$$\widetilde{F}_m = \widetilde{P}_m \times \Lambda^{-1}, \tag{9}$$

with Λ^{-1} being the inverse of the loadings matrix derived earlier by singular value decomposition. Here, each column of $\widetilde{F}_m$ corresponds to 10,000 simulations of the log-mTFR for month m. Exponentiation of $\widetilde{F}_m$ then leads to simulations of the mTFRs.

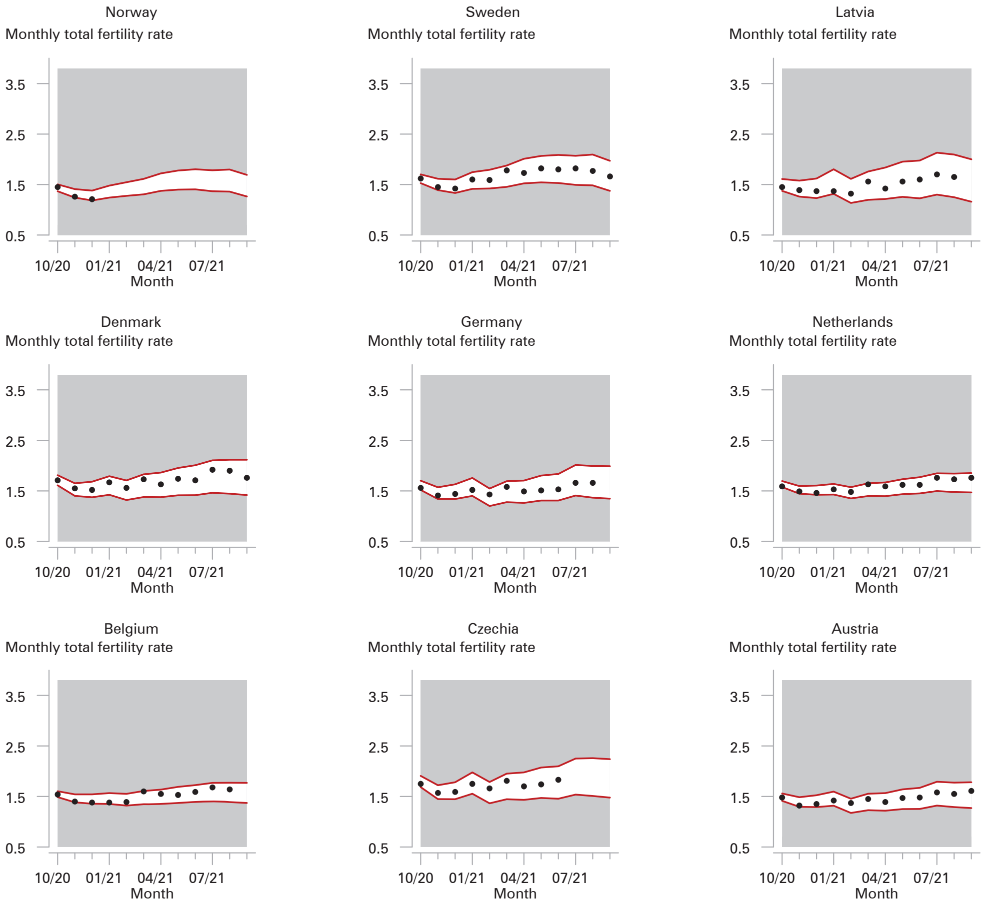
In the next step, we compare the observed mTFRs against prediction intervals (PIs) derived as empirical quantiles from our forecast model for each month of the forecast horizon and each country. Following the principal of classical hypothesis testing, we could, based on a chosen significance level, check how many of the observations exceed the limits of the confidence intervals, which are in our case the monthly PIs derived from the simulations. For instance, under a null hypothesis stating that *there has not been an effect of the pandemic on fertility* over the period October 2020 – September 2021 using a 5 percent significance level, we would expect not more than 5 percent of the observations over that period to exceed the limits of the PIs. We will illustrate this in the next section, employing the data presented earlier.

4 Results concerning the effects of the pandemic on fertility

The analysis is carried out based on the null hypothesis stated in Section 3. If our null is correct, we would, e.g., at a 10 percent significance level expect no more than 10 percent of our observations to lie beyond the bounds of the PIs. In our case, the latter depend on the country and the month and are derived from the mTFR distributions forecast using our model described in the previous section. The limits of the PIs are derived by Monte Carlo simulations as the 5th and 95th percentiles of the trajectories for each country and month, which are illustrated with red lines in Figures 4-7 for the months of October 2020 – September 2021. The gray areas show the rejection areas of the stated hypothesis test against the observed mTFRs as black dots.

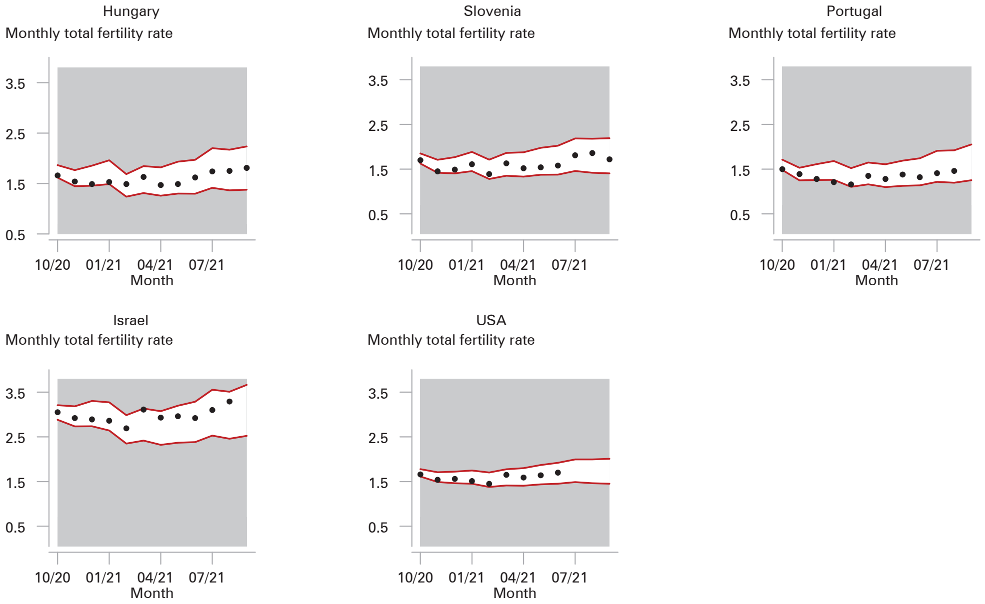
Figures 4 and 5 give the PIs derived from our model with the observed mTFRs for the study countries without statistically significant differential fertility since October 2020.

Fig. 4: mTFRs (dots) against rejection area of two-sided null hypothesis with $\alpha = 0.1$ of no differential fertility (gray area) – Countries in Northern and Central Europe with no significant fertility response



Source: HFD 2022; authors' computation and illustration

Fig. 5: Observed mTFRs (dots) against rejection area of two-sided null hypothesis with $\alpha = 0.1$ of no differential fertility (gray area) – Other Countries with no significant fertility response



Source: HFD 2022; authors' computation and illustration

We have to take into account that only the observations available at the date of data extraction (04 October 2022) could be considered. However, updating the analysis when additional data are available is relatively simple. Our results for countries with very limited time series data available for the pandemic period are to be considered with caution; this is particularly the case for Norway (Fig. 4), England & Wales (Fig. 6) and South Korea (Fig. 7).

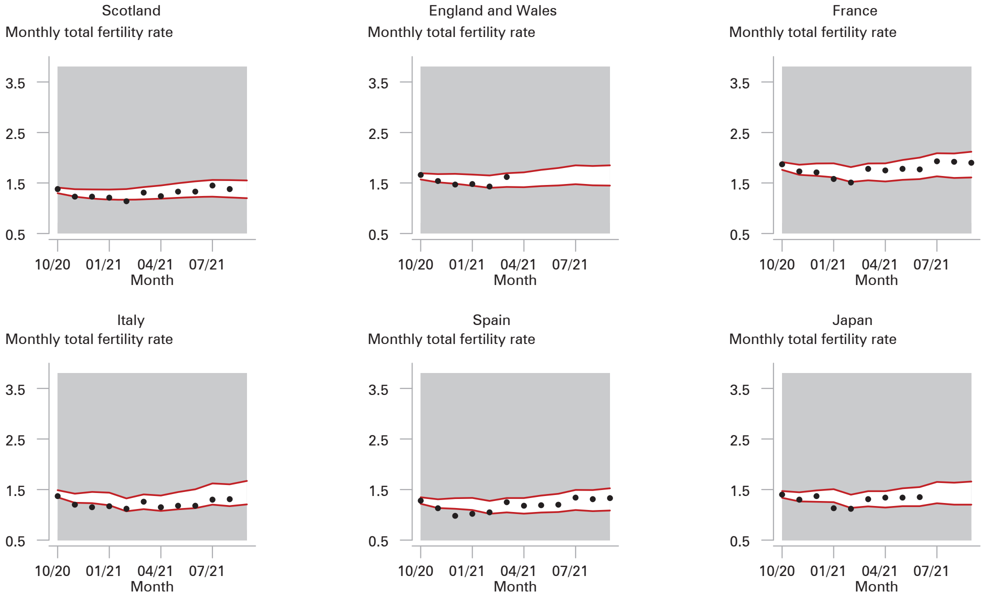
Keeping all this in mind, the figures can be understood as follows: The black dots show the observed mTFRs since October 2020, whereas the grey areas are the rejection areas ($\alpha = 0.1$) for the hypothesis test with H_o "There is no fertility differential caused by the pandemic circumstances." This corresponds with simultaneous testing for both increased and decreased fertility at the 5 percent significance level each. The rejection areas are derived from empirical quantiles generated by our Monte Carlo simulation, as described in Section 3. Here, again, we would expect around 90 percent of the observations to lie in the 90 percent PIs (i.e., the white areas), even if we had not witnessed a pandemic and the associated restrictions in freedom.

In Figures 4 and 5, we see that the majority of countries (14 out of 22) show no statistically significant fertility differential during the pandemic. We understand this to mean that either all observations are within the limits of the 90 percent PIs or, as in the case of Portugal, one out of 11 (9.1 percent) observations exceeds the

PIs, which could be expected even under non-pandemic circumstances given the chosen significance level.

Figure 6 shows the six countries for which we identify statistically significant decreases in fertility since the onset of the pandemic. Those include Japan, the Mediterranean countries, which are economically weakened and were low-fertility countries even before the pandemic (*Vignoli et al.* 2020), and Great Britain. The latter, however, must be interpreted cautiously, since the number of observations is very limited thus far.

Fig. 6: Observed mTFRs (dots) against rejection area of two-sided null hypothesis with $\alpha = 0.1$ of no differential fertility (gray area) – Countries with significantly lowered fertility

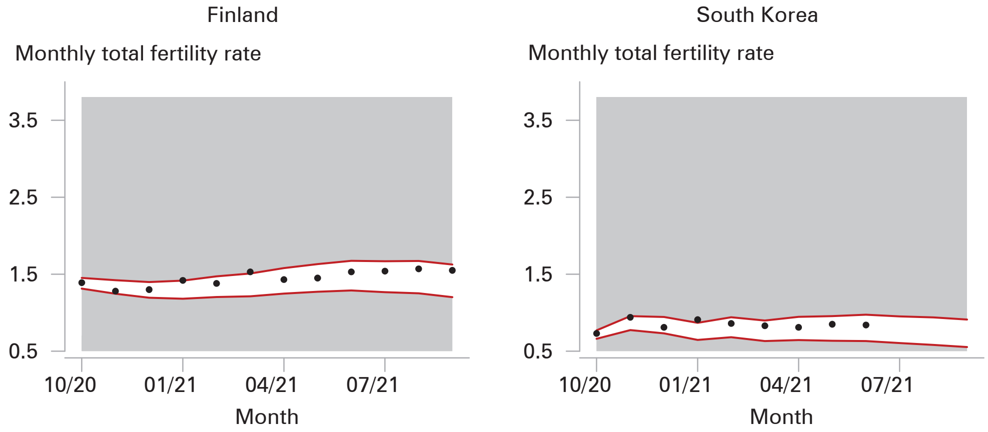


Source: HFD 2022; authors' computation and illustration

The countries in Figure 6 share a similar pattern, as their fertility appears to be affected only in the early phase of the pandemic and returned quickly afterward to an expected level. We will discuss this further in the next section.

Figure 7 presents data for the two countries with increased fertility during the pandemic, namely, Finland and South Korea. The latter, again, should be interpreted with caution, as the available data thus far spans only the period until June 2021 and only one observation exceeds the upper limit of the PI. Similar to the countries with decreased fertility, Finland and South Korea appear to re-establish in the expected fertility range very quickly. We will also discuss these results further in Section 5.

Fig. 7: Observed monthly births (dots) against rejection area of two-sided null hypothesis with $\alpha = 0.1$ of no differential fertility (gray area) – Countries with significantly increased fertility



Source: HFD 2022; authors' computation and illustration

5 Conclusion: fertility response to the pandemic and consequences for forecasting

Our analysis reveals very heterogeneous fertility responses to the pandemic among the study countries. The majority (14) of the 22 study countries showed no statistically significant change in reproductive behavior, as measured via the mTFRs. Six countries showed statistically significant decreases in fertility; however, these decreases have been limited to the early phase of the pandemic from November 2020 to February 2021, i.e., the period of conception from February to May 2020. During this phase, excess mortality due to COVID-19 was observable (*Vanella et al.* 2021), especially in some of the six countries with decreased fertility, such as Scotland, France, Spain (*Vanella et al.* 2021), Italy (*Michelozzi et al*. 2020), and England & Wales (*Basellini et al.* 2021). This indicates more passive reproductive behavior during the highly uncertain early period of the pandemic in these countries, as suggested by *Guetto et al.* (2022). Only two countries show evidence for increased fertility during that period. The latter results, however, must be interpreted with caution, as the increases in Finland could also be associated with bounce-back effects after a period of lowered fertility (*YLE* 2022), while the increase in South Korea is inconclusive, since there is only one observation above the upper critical value of the PI.

In any case, after an initial shock, fertility quickly reached the previously expected ranges, as indicated by the fact that the observations quickly jumped back within the PIs for all countries that showed a statistically significant fertility response to the pandemic. Therefore, our study provides evidence for the bounce scenario formulated by *Goldstein* (2020). Based on the recent evidence, we conclude that fertility forecasts conducted before the pandemic do not need adjustments, as predicted by *Lee* (2021).

6 Discussion

In this contribution, we have discussed theoretical fertility outcomes arising from the COVID-19 pandemic and the associated contact reduction measures as found in academic discourse. Using monthly fertility data since January 2008 provided in the Human Fertility Database, we investigated effects of the pandemic on fertility, adapting a stochastic approach for assessing cross-country excess mortality suggested by *Vanella et al.* (2021). The model draws on a combination of principal component analysis, seasonal time series models, and Monte Carlo simulation. We simulated the first of the 22 principal components with a detailed time series model, thereby including the major long-term trends and seasonality in international fertility. The next three PCs were approximated using seasonal ARIMA models. The remaining PCs varied based on the assumption of random walk processes, which offers a relatively simple model that still takes the stochasticity of all other PCs into account. Failure to take stochasticity into account is a common limitation of most PC-based fertility models, as they only model a small number of PCs and ignore the others, leading to systematic underestimation of future risk (*Vanella/Deschermeier* 2019) because this implicitly assumes zero variance in the omitted PCs, which is not the case. Using this approach, we compared the observed mTFRs to distributions of counterfactual scenarios, taking, not only stochasticity, but also correlations between fertility trends among different countries into account. In this way, changing fertility due to developments in other countries – which is probable in a highly connected and digital world – are taken into account. Our model includes long-term trends in fertility and seasonality of births, both of which are observable, as we have seen. In this way, we adjust for potential biases in the estimation of differential fertility during the pandemic crisis.

Among the study countries, a potential "positive" side effect on fertility of contact reductions and associated lowered mobility, as suggested by the popular press, does not come to fruition on a large scale. The fertility response to the pandemic situation, however, varies very much between the countries. Among the 22 study countries, 14 do not show significant changes in fertility during the pandemic, and six witness significantly decreased fertility. Among those, there is an apparent focus on low-fertility regions of the Mediterranean and East Asia. This holds even after controlling for fertility trends, irrespective of the changed conditions during the pandemic. For the Mediterranean, previous studies have shown the connection between economic downturn and fertility decreases, which could explain our observation as well. Moreover, the Mediterranean, especially Italy, was the European region first affected by the virus, resulting in a severe health crisis with significant excess mortality (*Ghislandi et al.* 2022; *Egidi/Manfredi* 2021; *Vanella et al.* 2021; *Vanella et al.* 2022), which may have led to a more negative subjective outlook on the future, and associated with that, decreased fertility intentions, as contemporary research suggests (*Guetto et al.* 2022). The same could hold true for the other low-fertility region in East Asia, as the virus started in China at the end of 2019 (*Egidi/Manfredi* 2021) and quickly reached neighboring countries (*Johns Hopkins University* 2022).

Our results have strong implications for forecasting. Fertility forecasts are of high importance for population forecasts and further infrastructure and economic planning that relies on future population development. However, these were conducted before the pandemic or cannot include effects of the pandemic on fertility, as historical data does not yet include the effects of the pandemic. We see that for a large number of countries – among those Germany and other central European countries – fertility does not show high sensitivity to the pandemic. For the eight countries that exhibited changing fertility patterns during the pandemic, we have seen that the effect was short-lived. Fertility significantly decreased in the early stages of the pandemic, i.e., in the contraceptive period of February – May 2020. This corresponds to the first "wave" in most countries that was associated with a shock situation and a maximum of future uncertainty. Afterwards, fertility has returned to within the range expected before the pandemic, as identified by our forecast of counterfactual developments. This implies the scenario labeled by *Goldstein* (2020) as a "bounce", i.e., a quick re-installment to previous fertility levels, is the one holding for the case of COVID-19. Therefore, our results imply that pre-pandemic fertility forecasts still hold and do not need specific adjustment to the pandemic.

Obviously, our model has several limitations. It is limited to the available data, which is restricted to overall monthly TFR estimates. Therefore, age-specific effects, such as a change in the tempo of fertility, which we discussed earlier, cannot be identified with the available data, and we can only give a rough estimate of the effect on the quantum. More detailed data (i.e., monthly age-specific fertility rates) could shed even more light on the fertility response to crises, such as the COVID-19 pandemic. *Vanella* and *Deschermeier* (2019) have shown that a principal component approach such as ours can identify trends in the quantum and tempo of fertility quite well and efficiently. Moreover, forecasters need to keep in mind that long-term forecasts need to also account for echo effects, which we have ignored here. Typical fertility and population forecasts, which cover ranges of 30-50 years, need to account for the fact that lower births now will result in lower births in about 30 years as well, since the cohort bearing children then will be today's smaller birth cohort (*Vanella/Deschermeier* 2020). Overall, our data cover only the first year of the pandemic (from the perspective of fertility). Not all the study countries provide data for one full year. Therefore, our concrete results cannot reliably predict long-term effects yet. However, the methodological approach could be easily updated as soon as more data become available. We presented an international study here. This provides some advantages, as we not only cover international correlations in fertility trends (which are often observable and, as explained earlier, might influence one another), but also provide a relatively efficient, comparative perspective for monitoring contemporaneous fertility trends. Instead, one could think of applying national studies that could lead to more accurate estimates for the individual country.

List of Abbreviations

AIC	Akaike's information criterion
ASFR	age-specific fertility rate
BIC	Bayesian information criterion
HFD	Human Fertility Database
i.e.	id est
(m)TFR	(monthly) total fertility rate
NPI	nonpharmaceutical intervention
OLS	ordinary least squares
(P)ACF	(partial) autocorrelation function
PC(A)	principal component (analysis)
(S)ARIMA	(seasonal) autoregressive integrated moving average

Author's Contributions

ALG: investigation, original draft; PD: validation; PV: conceptualization, methodology, software, formal analysis, investigation, resources, data curation, original draft, revisions, visualization, supervision, project administration, funding acquisition. All authors have read and agreed to the final version of the manuscript.

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Availability of data and materials

The data used or generated in this study are provided by the first author upon reasonable request.

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