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Vaccination and fertility: modelling the potential impact of Covid-19 vaccination on total fertility rate in Czechia

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Abstract

As with Northern European countries, Czechia experienced unexpected fertility developments during the Covid-19 pandemic. Fertility in Czechia increased between 2020 and 2021 from 1.76 children per woman to 1.83. However, between 2021 and 2022, fertility fell significantly to just 1.62 children per woman. The main change that occurred between 2020 and 2021, which is thought to have affected fertility one year later, comprised vaccination against Covid-19. This vaccination of the adult population was very specific in terms of both its scope and the timing of vaccination for each age group as organised by the state. The mass scale of the vaccination campaign and its implementation within a very short period of time were unprecedented. However, along with the significant degree of uncertainty concerning the appropriateness of vaccination for pregnant women, vaccination was seen as a factor that potentially acted to significantly change women's reproductive plans in the short term and, as a consequence, potentially exerted a significant short-term impact on both birth rates and fertility indicators. This study models the maximum potential impact of vaccination on fertility levels under the assumption that all the vaccinated women chose to avoid conception in the month in which they were vaccinated. Applying the indirect standardisation principle, we calculated the expected monthly live births after excluding women who were vaccinated nine months earlier. The comparison of hypothetical and observed fertility revealed that the perceived potential impact of vaccination was largely consistent with the observed fertility decline in Czechia between 2021 and 2022.

Keywords: Fertility, Vaccination, Covid-19, Conception, Delay of conception, Indirect standardisation

Introduction

The Czech total fertility rate (TFR) of 1.83 children per woman in 2021 was one of the highest in Europe (VID, 2022) despite the development of the Covid-19 pandemic during 2020. During the spring 2020 wave of the pandemic, however, Czechia had one of the lowest proportions of infected persons in Europe, whereas, conversely, during the autumn wave of 2020, Czechia had one of the highest proportions (Hasell et al., 2020; Hulíková Tesárková & Dzúrová, 2022; Mathieu et al., 2021). The Czech TFR witnessed a sharp drop to 1.62 in 2022 (Štyglerová & Němečková, 2023), with the mean ages of women at birth and at first birth remaining the same as in 2021 (CZSO, 2023a).

While the first year of the pandemic (2020) did not apparently negatively affect fertility in most European countries in 2021, the situation had changed significantly one year later. In addition to the direct impacts of the pandemic on mortality, the indirect impacts on fertility were discussed from the outset of Covid-19 (Aassve et al., 2020; Berrington et al., 2022; Wilde et al., 2020). It was expected that the potential negative factors would outweigh the positive considerations. The positive factors included the reduction of the opportunity costs of having children, more time available to spend with the partner due to the lockdown, and the facilitation of combining family and work life thanks to the expansion of working from home options. The negative factors included an increase in economic uncertainty, stress associated with increased demand for childcare services and health concerns (Berrington et al., 2022). The direct impacts of the Covid-19 pandemic on fertility in the context of the health and economic crises have also been assessed by, e.g. Cozzani et al. (2023), Lappegård et al. (2023), Matsushima et al. (2023) and Sobotka et al. (2021).

The initial expectation concerning fertility trends in high-income countries was that the Covid-19 pandemic would comprise the main cause of fertility decline (Aassve et al., 2020). However, this was confirmed only in certain countries (Aassve et al., 2021; Sobotka et al., 2021). For example, in Northern European countries, no decline in fertility was observed directly following the outbreak of the Covid-19 pandemic (Bujard & Andersson, 2024; Lappegård et al., 2023; Neyer et al., 2022; Nisén et al., 2022). However, at the beginning of 2022, a decline in fertility was observed in e.g. Sweden (Bujard & Andersson, 2024). Bujard and Andersson (2024) evaluated the association between the development of unemployment, infection rates, Covid-19 deaths and vaccination and fertility in Sweden and Germany. The only association they observed concerned that between fertility and the commencement of vaccination. A decrease in fertility levels was observed at the onset of the vaccination campaign in many high-income countries (Jasilioniene et al., 2024). While vaccination was considered by most people as a means for facilitating the lifting of pandemic-related restrictions, in the early days of vaccination, concerns were raised about the safety of vaccination, largely due to the spread of misinformation (Berkowitz & Jacobson Vann, 2023; Sajjadi et al., 2021). Moreover, such concerns were more frequently expressed by women who were breastfeeding, pregnant or planning to become pregnant than the rest of the population (Januszek et al., 2021; Riad et al., 2021). The dominant argument used by disinformers was that vaccination causes infertility in both men and women, even to the extent that vaccinated individuals could spread their infertility to unvaccinated persons (Berkowitz & Jacobson Vann, 2023; Diaz et al., 2021). A study by Wesselink et al. (2022), however, demonstrated that vaccination did not result in a decrease in the fecundity of women in the subsequent 90 days (rather an increase in fecundity, which may have been the consequence of compensation for short-term delayed fertility due to vaccination) rather, the fecundity of women decreased in the 90 days after experiencing Covid-19, which was most likely due to the overall weakening of the human body, which is not the ideal state in which to conceive.

Similar trends to those witnessed in Sweden concerning fertility development in 2021 and 2022 were observed in Czechia. The question therefore arises to what extent the decline in fertility in Czechia between 2021 and 2022 can be attributed to vaccination. Accordingly, the aim of our study was to discuss the potential relationship between a fear of becoming pregnant due to Covid-19 vaccination and the fertility decline in 2022. We attempted to form an understanding of the specific role of a new factor that could have exerted a direct impact on fertility in 2022 rather than to explain the change in the fertility trend in Czechia as a multifactorial and complex process. As in other high-income countries, Czechia implemented an extensive vaccination programme from the end of 2020. Moreover, detailed data on vaccinated persons, including their age and date of vaccination, are available. Therefore, we were able to evaluate the maximum potential impact of vaccination against Covid-19 on fertility in Czechia from the commencement of the vaccination campaign. We attempted to quantify this impact applying the indirect standardisation principle. We proceeded on the assumption that women who decided to be vaccinated against Covid-19 also decided not to become pregnant in the same month as that in which they were vaccinated. The resulting expected numbers of live births were then compared with the actual observed numbers of live births in individual months; this was followed by a discussion on the extent to which vaccination may have contributed to the decrease in the TFR between 2021 and 2022.

The context of the pandemic in Czechia

In the European context, the impact of the first wave of the pandemic in Czechia (spring 2020) was very mild; at this time the smoothed number of persons infected was a maximum of 25 per one million of the population (Fig. 1). Despite this relatively low Covid-19 infection level (from today's perspective), strict measures were imposed from mid-March 2020 that significantly limited the free movement of people, the provision of services and the operation of educational facilities (Slabá, 2022). This affected, inter alia, the functioning of households (Höhne & Žáčková, 2023; Šťastná, 2023) and may have led to households adopting a more family-oriented life approach (Ahmed et al., 2020). Moreover, it exerted a positive impact on fertility, as reflected in an increase in the TFR in Czechia from 1.76 in 2020 to 1.83 in 2021. In addition, the increase in the TFR between 2020 and 2021 was also partially due to the refinement of information on the number of women of reproductive age based on the 2021 census (Koukalová, 2022).

The impact of the second wave of the pandemic in Czechia (autumn 2020) was much more serious than the first (Fig. 1). After a brief improvement at the end of 2020, a further worsening of the situation was observed which culminated in the first half of April 2021. Czechia evinced one of the highest relative increases in infected persons in Europe over the entire first quarter of 2021 (Hulíková Tesárková & Dzúrová, 2022). Nevertheless, surveys conducted in Czechia at the end of 2020 and following the end of the spring wave of 2021 (Kreidl et al., 2021a, 2021b) revealed that the declared short-term reproductive intentions of Czech men and women had not been negatively affected by this development (Paloncyová, 2022; Slabá, 2023).

Starting in January 2021, registration for vaccination against Covid-19 was introduced in Czechia. Older persons and those working in at-risk professions were prioritised (Slabá, 2022). The availability of vaccines was limited in the early days of vaccination; hence, it was unclear when registration would open for women of reproductive age. At the end of January 2021, a lack of vaccines for already-registered

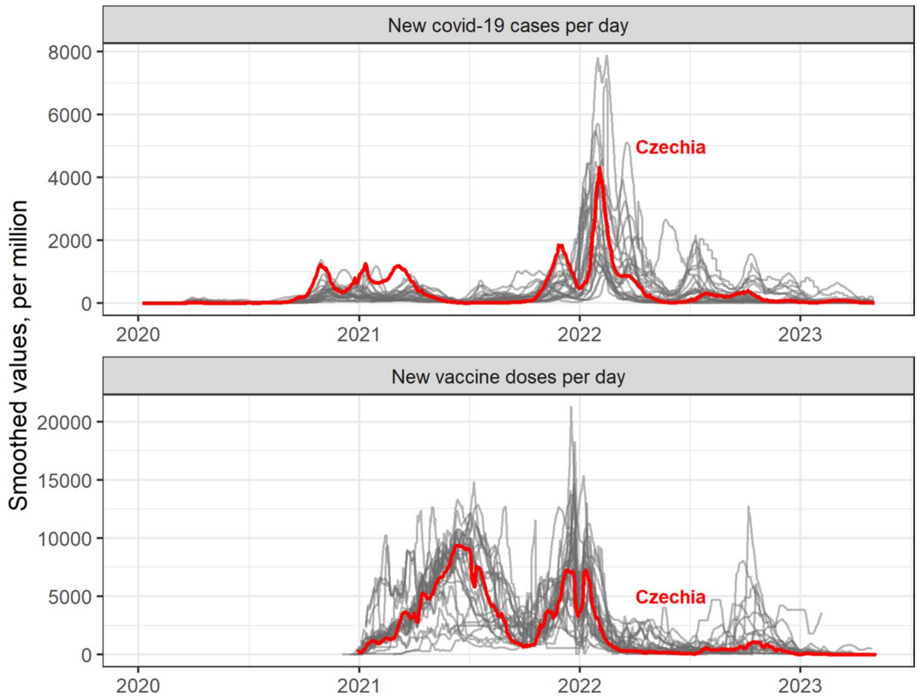

Fig. 1 Development of Covid-19 cases and vaccination doses in selected European countries focusing on Czechia. Data source: Hasell et al. 2020; Mathieu et al., 2021 (data collected on 13 April 2023). Note: The grey lines represent European states with populations of over 5 million inhabitants aimed at eliminating outlying fluctuations in terms of incidence in small populations

seniors, which led to the cancellation of appointments, was reported intensively in the media, and only during February 2021 was a government campaign launched to promote vaccination aimed at reversing the generally negative attitude of Czechs to vaccination. Despite the delays, all those interested were promised that vaccination would be possible by the summer of the same year.

In mid-April 2021, it was announced that those over 40 could register for vaccination at the end of June. Finally, vaccination registration for those over 45 years of age commenced on 10th May and for those over 40 on 17th May. Registration was opened to those aged 35 and over on 24th May and for those over 30 on 26th May. From 4th June, vaccination was possible for all persons over 16 (Slabá, 2022). Aimed at encouraging vaccination, a change was introduced regarding the recognition of non-infectiousness for everyday life; from November 2021, the PCR test was no longer recognised and only completed vaccination was considered in this respect (Slabá, 2022). This contributed to the re-opening of society and a return for many to a less home-centred life, which is thought to have negatively influenced fertility in 2022 (Bujard & Andersson, 2024). However, whereas the direct impact of vaccination programmes on fertility has been discussed (Bujard & Andersson, 2024), this topic has not yet been examined in detail. Despite the positive effects of vaccination against Covid-19, the perceived fear of the potential unintended impacts on the health of pregnant women may well have influenced the planning and timing of childbearing.

Figure 1 shows that the relative vaccination coverage of the Czech population during the years 2021 and 2022 was slightly below the average of other European countries. The number of new vaccinations increased steadily up to June 2021. The beginning of autumn 2021 saw a decline in vaccinations, which was followed at the turn of 2021/2022 by an increase related to the administration of booster doses (mainly the third dose). The overall vaccination rate of the Czech population reached 66% at the end of 2022 (Mathieu et al., 2021). Vaccination rates as at 11 April 2023 for men and women according to age were as follows: 18–29 years 65%, 30–34 years 62%, 35–39 years 64%, 40–44 years 67% and 45–49 years 76% (Ministry of Health of the Czech Republic, 2023a). Thus, a high rate of vaccination coverage was ensured for women of reproductive age in a relatively short time, which provided ideal conditions for the analysis of the potential impact of the large-scale vaccination campaign on fertility over a very short time period. The availability of detailed monthly data on both the numbers and age structure of vaccinated women and the monthly numbers of live births allowed for the detailed analysis of the topic.

Attitudes to vaccination in Czechia were initially far from positive, especially among younger age groups (STEM, 2021; Život během pandemie, 2023), despite vaccination being strongly recommended by experts (Markert et al., 2021; Pratama et al., 2022) even for pregnant and breastfeeding women. However, the official expert opinion that supported vaccination for pregnant and breastfeeding women was not published until 3 June 2021 (Česká vaccinologická společnost, 2021). Nevertheless, it was recommended that pregnant women be vaccinated only after the 12th week of pregnancy. It is noteworthy that even one year following the initiation of vaccination, some doctors expressed the opposite opinion and recommended that pregnant women should not be vaccinated (Hamplová, 2022). Moreover, the Czech media drew attention to the fact that some hospitals insisted that those who wished to be vaccinated provided their signed informed consent, the form for which included the statement that Covid-19 vaccination was not suitable for pregnant and breastfeeding women (Novinky.cz, 2021). In addition, research revealed that pregnant women were less willing to be vaccinated than the general population since additional factors had to be considered in the decision-making process (Januszek et al., 2021).

The two studied scenarios

Vaccination against Covid-19 was unprecedented in modern times in terms of its scope and the short period of time in which it was introduced. Aimed at contributing to the understanding of the fertility decrease in Czechia between 2021 and 2022, two scenarios were constructed so as to reflect the maximum possible impact of vaccination on the number of live births.

Both scenarios were based on the assumption that women of reproductive age made the rational decision not to conceive a child in the month in which they were vaccinated. We assumed that women avoided becoming pregnant in one month only (specifically one menstrual cycle) at the time of vaccination due to potential side effects. Most women who reported a change in their period following vaccination found that it returned to normal for the following cycle (Male, 2021). If women did not experience any consequences of vaccination after a few days following the event, their concerns about becoming pregnant due to vaccination were no longer sufficient to warrant a further delay in their fertility. In addition to this main assumption, we modelled estimates of the potential impact of vaccination on the monthly number of live births based on a series of assumptions: 1) since the aim was to quantify the potential impact of vaccination on fertility changes between 2021 and 2022, provided no other factor influenced fertility, we expected the same chance of conception in a given month in 2021 as that in the same month of the previous year (2020); 2) we did not expect Covid-19 vaccination to reduce the chance of becoming pregnant in subsequent months (Wesselik et al. 2022; Zace et al. 2022); 3) the reproductive behaviour of women in other months (except for the month of Covid-19 vaccination) was the same as that of women in the same months in 2020; 4) the pregnancy lasted the full nine months; and 5) the probability that women planned a pregnancy was equal for those women who opted for vaccination as for those who decided not to be vaccinated.

Thus, for calculation purposes, all the women in a given age group who were vaccinated in a given month were subtracted from the total studied female population for the given month only and were subsequently re-added to the total female population in the following month. The age-specific fertility rates in 2021 were taken as the standard since they a) were constructed applying the updated age structure of women of reproductive age based on the latest 2021 data and b) reflected the stable fertility pattern in Czechia that pertained at the outset of the pandemic. The total fertility rate in Czechia experienced a gradual increase from 1.43 in 2011 to 1.83 in 2021 (CZSO, 2023b). An increase in fertility rates was observed over almost the entire reproductive age range of women, with the marked retardation of fertility postponement and the stabilisation of the age distribution of fertility rates at the modal age of 30 (Koukalová, 2022; CZSO, 2023a). Since we did not know whether and to what extent women avoided conception due to vaccination, the following scenarios assessed the maximum possible hypothetical impact in the case that all the women avoided pregnancy only in the month in which they were vaccinated.

Scenario 1: Avoiding conception in the month of the first dose of Covid-19 vaccination. It was assumed that women were concerned about vaccination and decided not to attempt to conceive a child in the month in which they were vaccinated with the first dose. Hence, women vaccinated in a given month were excluded from the female mid-year population in the first-dose vaccination month and re-added to the population one month later.

Scenario 2: Avoiding conception in both months of Covid-19 vaccination (first and second doses). It was assumed that women decided not to attempt to conceive a child in the months in which they were vaccinated. As with Scenario 1, vaccinated women were excluded from the female mid-year population in the months in which they were vaccinated and re-added to exposure in the following months.

Data

For modelling purposes, we employed data sources that included information on vaccination, live births and the age structure of women of reproductive age:

a) Data on Covid-19 vaccinated persons, which are available on the Czech Ministry of Health website, was used to calculate the monthly age-specific vaccination rates. The information on vaccinations included gender, age group, date of vaccination, order of the vaccination dose and the type of vaccine (Ministry of Health of the Czech Republic, 2023b). We considered the age groups 18–24, 25–29, 30–34, 35–39, 40–44 and 45–49 years so as to cover the reproductive age range.
b) Data on live births—we employed both monthly and yearly data on live births in 2012–2022 as obtained from the Human Fertility Database (HFD) (Jdanov et al., 2022) so as to determine the seasonality of fertility. We also used age-specific data on live births in 2021 published by the Czech Statistical Office (CZSO, 2022), which was entered into the analysis as the standard. Data from the Czech Statistical Office comprise the primary resource for the HFD (adjusted according to the HFD methodology). Since no data for 2022 was yet available in the HFD, we decided to employ data on live births from the same source as the data on the age structure of the women, which were also entered into the analysis (see the following point).
c) Data on the age structure of women of reproductive age (the mid-year population). We employed data on the population of women as of 1 July 2021 and 1 July 2022 for the age units, as published on the Czech Statistical Office website (CZSO, 2023c). This data was then aggregated into the same age groups as those for which vaccination data were available.

Methods

The study proceeded via three analytical steps: 1) the calculation of the monthly age-specific vaccination rates of women in Czechia in the period from the introduction of vaccination against Covid-19 from December 2020 to April 2023; 2) the calculation of the expected number of live births per month for the period October 2021 to December 2022 based on the two scenarios defined above and applying the indirect standardisation principle; 3) the calculation of the hypothetical total fertility rate in 2022 based on the expected number of live births.

Add 1) The monthly age-specific vaccination rates for women of reproductive age were defined as:

$$_{t}vaccinationrate_{x}^{f} = \frac{_{t}Vaccinated_{,x}^{f}}{_{1.7.2021}P_{x}^{f}}, \quad (1)$$

where *Vaccinated* is the number of women vaccinated in age group x in given month t, and P_x comprises the mid-year population of women in given age group x in 2021.

We used the results to identify the months in which the vaccination rates were highest for a given age group and to interpret the differing impacts of vaccination for individual months and age groups.

Add 2) We employed the indirect standardisation principle in the second step to calculate the expected number of live births. The indirect standardisation method is routinely applied if no age-specific data are available (Sigel & Swanson, 2008). In this case, we had no age-specific data on monthly live births at our disposal. The indirect standardisation principle involves the calculation of the number of expected events (live births for the purposes of this study), which is then compared to the number of observed events. According to the indirect standardisation method, the set of rates from the standard population is applied to the population that is being subjected to comparison so as to calculate the expected number of live births. Since the decrease between 2021 and 2022 was the subject of interest, the fertility intensity in 2021 was used as the standard for the modelling of the fertility trend in 2022. The fertility rates in 2021 represented the highest fertility levels in the latest observed decade with an unchanged age pattern (CZSO, 2023b).

The essential inputs for the indirect standardisation method comprise: 1) a set of age-specific fertility rates (ASFR) as the standard, which was represented in our model by the ASFR 2021 for given age groups as calculated from vital statistics (Table 1), and 2) the population that is being compared, which was represented in our model by the female population of reproductive age as reduced by those vaccinated in the given months under the two studied scenarios of the impact of vaccination on fertility (the non-reproduction in the month of the first vaccination dose model and that concerning non-reproduction in the months of the first and second doses). We had information for each observed calendar month on the number of women in a given age group (x) who were vaccinated (first/any dose). The numbers of vaccinated women in a given age group in a specific calendar month were subtracted from the age group of women on 1 July 2021.

The expected number of live births for age group x and month t (${}_tB_x^{exp}$) was calculated as follows (Formula 2):

$$ {}_tB_x^{exp} = \left({}_{1.7.2021}P_x^f - {}_{t-9}Vaccinated_x^f \right) * {}_{2021}ASFR_x * {}_tRelative\ share. \quad (2) $$

The ASFR in 2021 were applied to the compared population, i.e. to the female mid-population as reduced by those vaccinated in months t-9 (conception months). This number was subsequently multiplied by the relative share of the number of live births in month t (delivery month) (see Table 2). The relation between delivery and conception is presented in Table 2.

The total expected number of live births in delivery month *(t)* (Formula 3) was determined as the sum of the expected live births of all the age groups of women:

Table 1 Live births, the mid-year female population and age-specific fertility rates in Czechia in 2021 in the vaccination-defined age groups

Age group	Live births 2021	Women, 1 July 2021	Fertility rates (ASFR) 2021	Relative contribution to TFR 2021
18–24	12,357	323,529	0.0382	15%
25–29	33,325	283,481	0.1176	32%
30–34	40,478	330,333	0.1225	34%
35–39	20,268	345,370	0.0587	16%
40–44	4,469	409,949	0.0109	3%
45–49	348	429,232	0.0008	0%

Source: Czech Statistical Office 2022: Tables D.04 and I.01

Table 2 Average relative distribution of live births per calendar year from 2012 to 2021, monthly distribution

Delivery month (t)	Conception month (t-9)	Relative share (t)	Delivery month (t)	Conception month (t-9)	Relative share (t)
January	April	0.0828	July	October	0.0921
February	May	0.0759	August	November	0.0888
March	June	0.0830	September	December	0.0862
April	July	0.0813	October	January	0.0832
May	August	0.0847	November	February	0.0771
June	September	0.0867	December	March	0.0782

Source: Human Fertility Database

$$ {}_tB^{exp} = \sum_{18-24}^{45-49} {}_tB_x^{exp}. \quad (3) $$

The calculation worked with the assumption that pregnancy lasted for 40 weeks; hence, the result was interpreted as the expected number of live births nine months following conception (i.e. the delivery month).

An illustration is provided below of the calculation of the expected number of live births in May 2022 to women aged 30 to 34 years in the case that the exposed population was reduced by the number of vaccinated women in August 2021, i.e. in the supposed month of conception (Formula 4):

$$ \begin{aligned} {}_{V/22}B_{30-34}^{exp} &= \left({}_{1.7.2021}P_{30-34}^{f} - {}_{VIII/21}Vaccinated_{30-34}^{f}\right) \\ &* {}_{2021}ASFR_{30-34} * {}_{V}Relative\ share \\ &= (330333 - 12250) * 0.1225 * 0.0847 = 3300. \end{aligned} \quad (4) $$

Of the 330,333 women in the 30–34 age group, 12,250 were vaccinated in August 2021. The annual fertility rate of the women in the 30–34 age group was assumed to be 0.1225 in 2021 (Table 1), with the proportion of children born in May accounting for 8.47% of annual live births (Table 2). Thus, as a result of the reduction in the female population by those women who were vaccinated in August 2021, it could be expected that 3,300 children would be born to women in the 30–34 age group in May 2022.

The expected monthly number of live births was compared with the observed monthly live births in 2021 and 2022.

Add 3) Subsequently, the hypothetical total fertility rate (TFR) in 2022 (Formula 6) was calculated as the expected number of live births in 2022 related to the female population in a given age group on 1 July 2022. The expected number of live births for given age group x in 2022 was calculated by summating the expected number of live births for each month of 2022 (Formula 5). The hypothetical TFR thus took into account the shorter reproductive interval of 18–49 years:

$$ {}_{2022}B_x^{exp} = \sum_{I/2022}^{XII/2022} {}_tB_x^{exp}, \quad (5) $$

$$_{2022}TFR_x^{hypoth.} = \sum_{18-24}^{45-49} \frac{_{2022}B_x^{exp}}{_{1.7.2022}P_x^f}. \quad (6)$$

Results

Development of the intensity of Covid-19 vaccination in the various age groups

Figure 2 shows the development of the monthly vaccination rates of women in the fertility-related age groups. Figure 2 shows that the highest interest in vaccination occurred immediately following the commencement of registration, i.e. in May 2021 for the 40–44 and 45–49 age groups and in June 2021 for the 18–24, 25–29, 30–34 and 35–39 age groups. Comirnaty was the dominant vaccine in Czechia, concerning which the interval between the first and second doses was initially 42 days, and from mid-July 2021 just 21 days. Doses of all orders were thus administered most intensively during June, July and August 2021.

In autumn 2021, a slight increase in first vaccination rates was evident following changes introduced concerning the definition of being infection-free, as was an increase

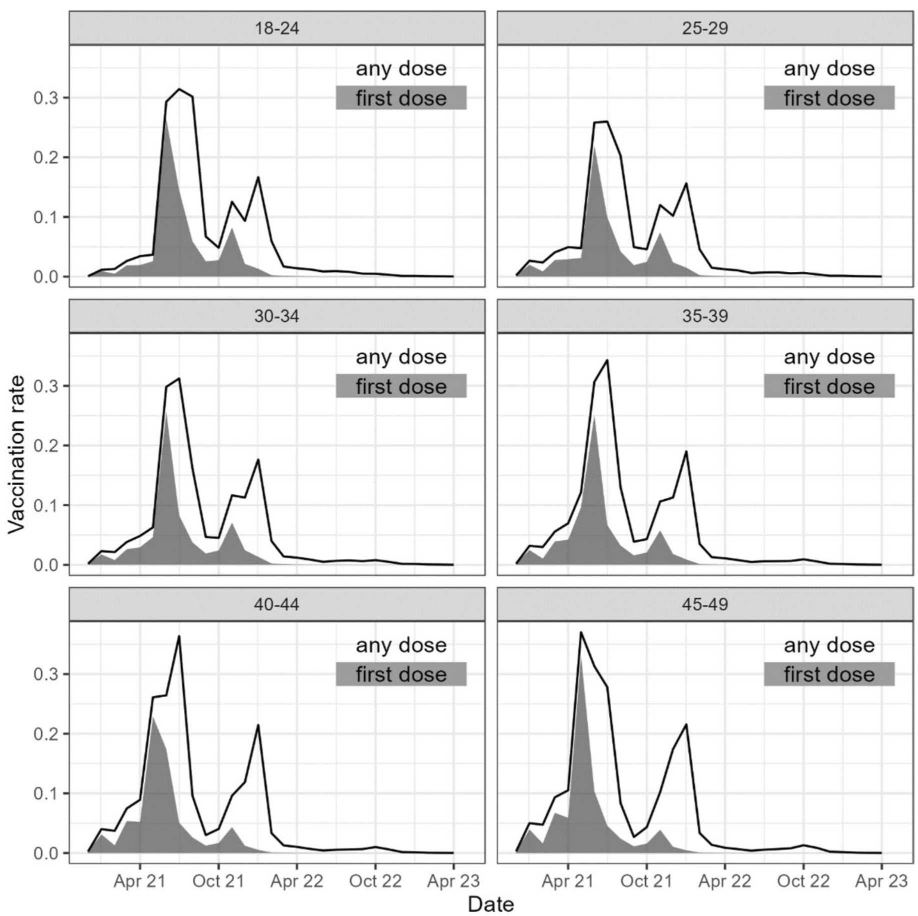

Fig. 2 Trends in monthly vaccination rates by selected age groups, women, Czechia, 12/2020 to 04/2023
Source: Ministry of Health of the Czech Republic, 2023b (vaccination doses); CZSO, 2022 (population)

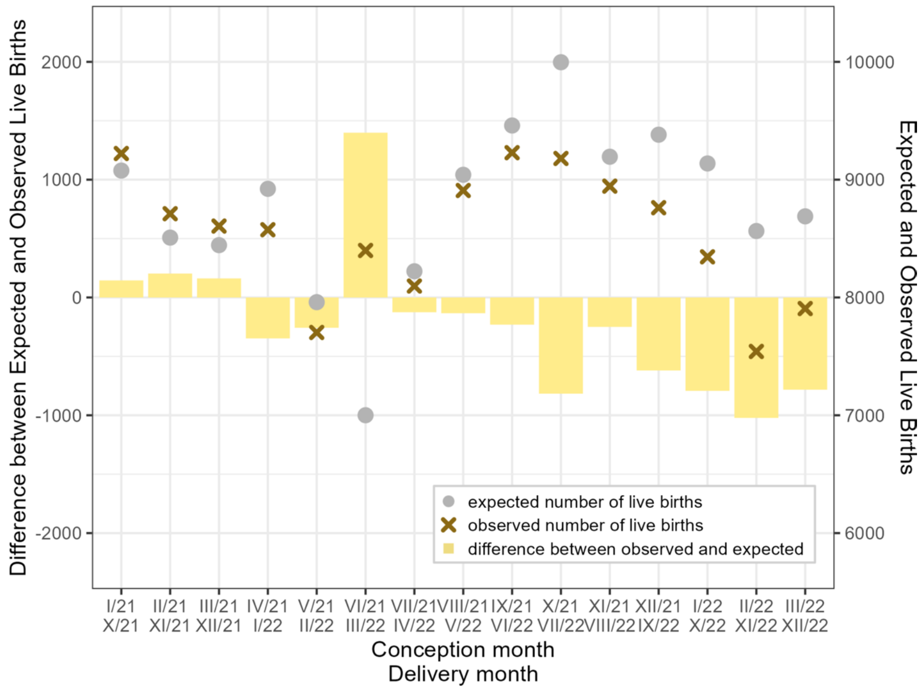

Fig. 3 Observed and expected monthly live births after excluding women who received the first dose of vaccine from the exposed population

in any-dose vaccination rates at the turn of 2021/2022 due to the introduction of the booster dose.

Scenario 1: avoiding conception in the month of the first dose of Covid-19 vaccination

Figure 3 reveals the remarkable similarity between the expected and observed numbers of live births over the period October 2021 to June 2022 (which corresponded to conception from January to September 2021) with the exception of births in March 2022 (conception in June 2021). Thus, the hypothesis of the avoidance of conception in the month of the first dose of vaccination appears to provide a valid mechanism for the explanation of the decline in the number of births in this period.

The observed number of births in March 2022 (conception in June 2021) significantly exceeded the estimate based on *Scenario 1*, i.e. by more than 1,000 live births (Fig. 3). The explanation may lie in the fact that first-dose vaccination was most intense in June 2021 (Fig. 2), especially for women in those age categories that most contribute to fertility (Table 1). Thus, according to *Scenario 1,* it was expected that the highest numbers of women would avoid conception in this month, which was reflected in the lowest number of expected births. However, this represented the maximum possible estimate of the decline in births, which took all vaccinated women into account. It can be expected that some women did not consider the timing of conception according to vaccination, or conception may have occurred after vaccination within the given month.

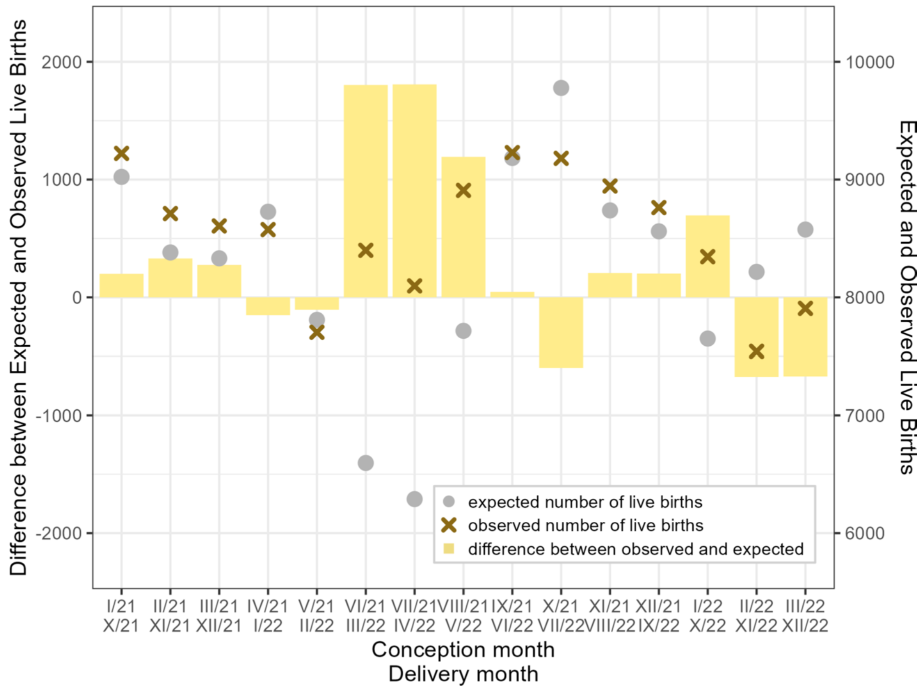

Fig. 4 Observed and expected monthly live births after excluding women who received the first and second doses of vaccine from the exposed population

Concerning the following period, a lower number of observed live births than expected was evident in the period July to December 2022 (conception in the period October 2021 to March 2022), together with increasing differences between the observed and expected numbers of births. Thus, the impact of the first dose of vaccination according to *Scenario 1* gradually waned, and it became more relevant to take into account the impact of subsequent vaccinations (Scenario 2) (see Fig. 4).

Scenario 2: avoiding conception in both months of Covid-19 vaccination (first and second doses)

Figure 4 illustrates that when more than one vaccination is considered as a potential reason for the short-term avoidance of conception, the results concerning the expected number of live births in the period October 2021 to February 2022 (conception in the period January to May 2021) were similar to those determined in *Scenario 1* (Fig. 3), i.e. the period in which the effects of the first vaccination dose dominated (Fig. 2). The observed numbers of births significantly exceeded the expected numbers in the subsequent period from March to May 2022 (conception in the period June to August 2021), during which the first and second vaccinations were administered with the greatest intensity (Fig. 2) for women in the age categories that most contribute to fertility (Table 1). Thus, this represented the maximum possible estimate of the decline in births, which took all vaccinated women into account in a similar way as for *Scenario 1*. Moreover, this is the period in which the Covid-19 restrictions were significantly relaxed both in Czechia (Slabá, 2022) and internationally, and thanks to vaccination, the prospects for the end of the pandemic seemed realistic. Therefore, it is possible that the impacts of the other negative factors that could potentially have led to the prevention of conception during the pandemic had been mitigated.

Concerning the conception period September 2021 to December 2021, at the end of which booster doses dominated, the numbers of observed births (in June, August and September 2022) corresponded well to those expected according to *Scenario 2*. Only in January 2022 did we observe approximately 500 live births more than expected. However, concerning conceptions in February and March 2022, an increasing overestimation of expected live births compared to observed births is evident, which suggests that explanations other than a direct connection with vaccination, which had already ended due to the weakening of the pandemic (Fig. 2), should be taken into account.

Assessment of the 2022 total fertility rate

The calculation of the 2022 hypothetical total fertility rate was based on the expected numbers of live births as estimated by means of the application of the indirect standardisation principle. Both Scenarios 1 and 2 concerning the possible impact of Covid-19 vaccination on the avoidance of conception were applied. The official CZSO estimate indicated a TFR of 1.62 in 2022 based on the 15–49 age group (Štyglerová & Němečková, 2023). The consideration of the reduced numbers of live births due to a fear of becoming pregnant due to Covid-19 vaccination and, therefore, the avoidance of conception in the month of first vaccination indicated a hypothetical TFR for the 18 to 49 age group of 1.69 children per woman. However, the consideration of the reduced numbers of live births due to the avoidance of conception in the months of the first and second doses of vaccination indicated a hypothetical TFR for the 18 to 49 age group of 1.56 children per woman (Table 3).

Discussion

The aim of this study was to model the potential impact of Covid-19 vaccination on fertility in the context of uncertainty concerning vaccination and pregnancy, which during the early days of the vaccination campaign in Czechia was covered extensively in both the professional and lay press. Since Czechia introduced an extensive vaccination programme that was comparable to those of other developed countries, our study serves as a model example for the discussion and understanding of fertility declines in non-standard years. The question concerned the extent to which the decrease in the TFR from 1.83 to 1.62 between 2021 and 2022 in Czechia could have been influenced by the avoidance of conception due to the Covid-19 vaccination campaign. We proceeded from the assumption that vaccination led some women to temporarily avoid pregnancy (Bujard & Andersson, 2024). The state-organised mass vaccination of the adult population over

Table 3 Observed and expected total fertility rates under the considered conditions

Age	Details	TFR
18–49	Hypothetical TFR Scenario 1 = Expected Live Births 2022 assuming the avoidance of conception by those who received the 1st dose of vaccine	1.686
18–49	Hypothetical TFR Scenario 2 = Expected Live Births 2022 assuming the avoidance of conception by those who received the 1st and 2nd doses of vaccine	1.563
15–49	Observed TFR 2022 according to the Czech Statistical Office (Štyglerová & Němečková, 2023)	1.62

a short period of time (2021–2022) was unprecedented; thus, it was deemed relevant to investigate the potential consequences of such intervention and its impact on realised fertility in 2022.

The results suggested that the consideration of the short-term (one-off) avoidance of pregnancy in the vaccination month resulted in a TFR for 2022 of 1.69 in the case of first-dose vaccination, which approximated to the value actually recorded (1.62). In the case of any-dose vaccination, the calculated TFR for 2022 of 1.56 was slightly lower than the value actually observed (1.62). It can, therefore, be assumed that the modelled impacts of Covid-19 vaccination on conception can be considered as a contributary factor with concern to the explanation of the decline in the TFR in Czechia.

Findings based on both Scenarios 1 and 2 revealed remarkable similarities in the expected and observed numbers of live births in the period October 2021 to June 2022 (conception from January to September 2021). Therefore, it is reasonable to assume that the hypothesis concerning the avoidance of conception in the month of the first or second doses of vaccination provides a valid mechanism for the explanation of the decline in the number of births in this period.

Two significant discrepancies between the observed and the expected number of live births were identified in the monitored period. The number of observed live births was significantly higher than the number of expected live births in the period March to May 2022. These births corresponded to conception during the most intensive vaccination period (June to August 2021), which may explain the lower hypothetical TFR (1.56) than the observed TFR (1.62). We are aware of the fact that not all women shared the same concerns about vaccination and behaved according to our assumptions; thus, we emphasise that the results represent the maximum estimate of the decrease in the number of conceptions assuming that all women who were vaccinated avoided conception.

In contrast, the opposite findings were determined for November and December 2022. The increasingly lower numbers of observed live births in these months originated from conceptions in February and March 2022, at which time it was assumed that the negative impacts of other factors prevailed. Firstly, from the beginning of 2022, the worsening economic situation of Czech households was becoming increasingly apparent as a result of rapidly increasing inflation, which commenced in Czechia as early as in autumn 2021 (CZSO, 2023d). Secondly, the Russian–Ukrainian conflict, which broke out at the end of February 2022, posed a serious security threat and exacerbated the worsening economic situation in Czechia. It is likely that both of these factors contributed to the decline in fertility in 2022 following the decrease in conceptions in early 2022. Thus, it is unlikely that vaccination concerns contributed significantly to the drop in the number of observed live births at this time.

Finally, it is important to mention the potential limitations of our approach. The analysis assumed that women may have been concerned about conception in the month of vaccination. However, some women may have decided to avoid conception both in the month of vaccination and in the preceding period, i.e. from when it became clear that vaccination would be available for women in the relevant age groups in the near future. It is also possible that women wished to avoid pregnancy several months after vaccination; however, this is less probable since the reported changes to the menstrual cycle following vaccination were short lived (Male, 2021). In both cases, the prolonged period of the avoidance of pregnancy would have led to a lower expected number of children, thus amplifying the impact of vaccination on the decline in fertility. Furthermore, when considering multiple doses, it is necessary to point out that following the shortening of the interval between the first and second doses to 21 days, some women could have been vaccinated twice within one calendar month and were, therefore, subtracted twice from the exposed population. This potentially applied primarily to conceptions in the summer of 2022, which resulted in the observed numbers of subsequently born children significantly exceeding the expected numbers.

This study presented scenarios relating to the maximum hypothetical direct impacts of vaccination on the decrease in fertility in Czechia. However, it should be added that the decline in the fertility level between 2021 and 2022 in Czechia was undoubtedly due to more than one factor. The aim of this study was not to provide an exhaustive explanation of the change in the fertility trend in 2022 in Czechia; indeed, at the time of our research it was too early to assess this development. Rather, we concentrated on a specific new factor that may have exerted a direct impact on fertility and attempted to quantify this impact applying standard demographic procedures. Therefore, the setting of the assumptions corresponded to this objective.

We were aware of the fact that the ASFR reached its highest level in 2021 in the context of recent fertility developments in Czechia. However, given that we were examining the fertility decline between 2021 and 2022, the 2021 rates were used as the standard. As regards the first assumption of no change to conception rates between 2020 and 2021, both years were considered to be pandemic years despite some conceptions in 2020 having occurred before the outbreak of the pandemic. Expert findings have indicated that Covid-19 infection does not increase the risk of foetal losses (Van Baar, 2024) and may be associated with a short-term decline in male fertility only (Wesselink, 2022). Nevertheless, if there had been an impact on the conception rate, it would have been the same in 2020 and 2021. As regards the second assumption, we took into account current knowledge that there is no scientific proof of any association between Covid-19 vaccines and fertility impairment in men or women (Zace et al., 2022).

The third assumption concerning no changes in fertility behaviour between 2021 and 2022 appears to be somewhat optimistic, since we know that the inflation rate had begun to rise significantly by the end of 2021. The increase in economic uncertainty due to the negative impacts of the pandemic on economic development accompanied by the European security crisis were increasingly reflected in a decline in fertility. A recent study on factors that influenced the fertility level following the introduction of the vaccination campaign confirmed the negative impact of increasing inflation on fertility (Winkler-Dworak et al., 2024). However, a further study revealed that with the introduction of the vaccination campaign, fertility levels were returning to the trend observed before the onset of the Covid-19 pandemic (Jasilioniene et al., 2024), which was related to the fact that the mass vaccination programme resulted in the gradual easing of pandemic-related restrictions, a return to work and the resumption of social activities, which led to people returning to their pre-pandemic non-family lives (Sobotka et al., 2023). If the hypothetical fertility were modelled based on pre-pandemic fertility levels, the results would reveal the even more intense impact of vaccination on the decrease in the number of live births in 2022.

The fourth assumption that pregnancy lasted the full nine months was based on current knowledge that the pandemic did not act to increase the occurrence of pre-term births (Charuta et al., 2023; Ozbasli et al., 2023). Moreover, official data from the Institute of Health Information and Statistics of the Czech Republic indicated the unchanged proportions of pre-term, in-term and post-term births in the period 2016–2021 (IHIS, 2023).

Finally, we are aware of the limits regarding the fifth assumption concerning the equal probability of a planned pregnancy for vaccinated and unvaccinated women. It is known that fertility intentions and attitudes towards vaccination are influenced by the individual characteristics of women. The short-term reproductive intentions of Czech women differ by age, number of biological children, partnership status and education (Slabá et al., 2023). Similar characteristics influence attitudes towards vaccination; women, younger persons, persons without a partner, and those with lower education levels evinced higher odds of refusing to be vaccinated against Covid-19 (Zidkova et al., 2023). The probability of fertility intentions in relation to attitudes towards vaccination is unknown with respect to Czech women and, since we had no information on the characteristics (education, partnership status, and number of children) of the vaccinated women, it is impossible to make a more precise assumption. From the above, we can only conclude that women without a partner are less likely to plan a child and have a less positive attitude towards vaccination. Thus, it is logical to assume that vaccinated persons are more likely to be in a partnership and have stronger fertility intentions than the unvaccinated population. Therefore, the expected decline in live births could have been even more intense.

A further factor concerned the change in the age composition of the female population in Czechia as a result of the significant inflow of Ukrainian female refugees who claimed long-term protection status. The comparison of the data provided by the CZSO revealed that the change in the female population due to Ukrainian war refugees led to a difference of 0.05 in the TFR (Štyglerová & Němečková, 2023). Finally, the decrease in fertility in 2022 can be seen as compensating for the increase in fertility one year earlier, i.e. between 2020 and 2021 (from 1.76 to 1.83). This increase may have been the result of the acceleration of childbearing by part of the population, for whom the pandemic strengthened the priority of the family over other aspects of life. These women already planned to have children, but decided to take advantage of the pandemic situation to have their children earlier, thus potentially reducing the number of people who planned a child in the following or subsequent years and, thus, reducing the fertility level in 2022.

In conclusion, apart from the beginning of 2022, the number of vaccinated women had fallen to such low numbers (see Fig. 1) that it was deemed unnecessary to extend the analysis further; it can be expected that in the future there will be no negative impact of vaccination as studied herein on the development of fertility.

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Author contributions

JS: conception, literature review, methodology, data management and analysis, interpretation, drafting of initial text, revision. JK: methodology, interpretation, revision. AŠ: methodology, interpretation, revision. DD: supervision. All authors approved the final version.

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Availability of data and materials

The datasets supporting the conclusions of this article are available online on the websites of Ministry of Health of the Czech Republic (https://onemocneni-aktualne.mzcr.cz/api/v2/covid-19/ockovani-demografie.csv), Czech Statistical Office (https://www.czso.cz) and Human Fertility database (www.humanfertility.org).

Declarations

Competing interests

None declared.

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