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The contagious nature of a vaccine scare: How the introduction of HPV vaccination lifted and eroded MMR vaccination in Denmark

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ABSTRACT

Background: Human papillomavirus (HPV) vaccine coverage was high in Denmark until it plunged following negative media coverage. We examined whether the decline in HPV vaccination undermined uptake of another adolescent vaccine, measles, mumps and rubella (MMR).
Methods: The Danish national health register provided data on uptake of MMR vaccine dose 2 (at age 13) for children born from 1991 to 2003 (n = 827,716). The primary exposure variable comprised three time periods: before HPV vaccine introduction, during high HPV vaccine coverage, and after the drop in HPV vaccine coverage. To examine the effect of HPV vaccination on MMR2 uptake, we estimated MMR2 uptake by age 13 using logistic regression, controlling for gender, birth month, birth year, and maternal education.
Findings: MMR2 vaccination coverage was high for both girls and boys (86% and 85%) in 2009. Following the introduction of HPV vaccine for girls in 2009, MMR2 coverage increased for girls even as it decreased for boys (gender gap 4·6 percentage points, 95% CI 4·3 to 4·8). Coverage with MMR2 for girls continued to be high over the following four years, and almost all girls (91%) who received MMR2 vaccination also received HPV1 vaccination within the same week. When negative media coverage led to a decline in HPV vaccination, MMR2 uptake for girls also declined. By 2015, MMR2 coverage for girls and boys had become similar again (80% and 79%). Families with the highest level of maternal education showed the strongest decline in MMR2 coverage for girls.
Interpretation: Concomitant vaccine provision can increase overall vaccine uptake. However, reduced demand for one vaccine may reduce concomitant vaccination and undermine resiliency of a country's vaccination program.
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1. Introduction

Childhood vaccination programs are among the most cost-effective public health interventions [1]. Coverage is high for many childhood vaccines, yet many countries struggle with upholding satisfactory uptake in order to effectively control or eliminate serious diseases [2]. Indeed, the World Health Organization designated vaccine hesitancy as one of the leading threats to global public health. Several recent studies have related declines in vaccine uptake to media coverage of unsubstantiated safety scares [3–9].

Concomitant delivery of vaccines may magnify a vaccine crisis by undermining uptake of other vaccines [3,10,11]. Such spillover effects may be due to parental time costs in bringing the child for vaccination. Scheduling multiple vaccines at the same time reduces parental time cost, which can increase vaccine uptake [12–14]. Concomitant vaccination may also mitigate missed opportunities arising from forgetfulness. However, if rumors or negative media coverage make parents concerned about and postpone a specific vaccine, it could undermine uptake of other vaccines usually delivered concomitantly. In Denmark, general practitioners provide vaccination free-of-charge through the public health care system, delivering several vaccines concomitantly in vaccine "packages" in the program. Danish vaccination data

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provides an excellent framework for studying aspects of concomitant vaccination. Boys and girls were already scheduled for a vaccine dose at age 12, when HPV vaccination was introduced for girls in Denmark. HPV vaccine initiation was also recommended at age 12, and female HPV vaccine uptake was initially very high, but declined substantially following negative media coverage. Negative media coverage of HPV vaccine began in a large Danish newspaper in 2013 and intensified in 2015 after a TV documentary had aired on a national television network. Danish media conveyed unsubstantiated claims that HPV vaccination was associated with serious side effects, and some people interviewed expressed doubts about the efficacy of the vaccine. Possible side effects mentioned in this coverage were cramps, frequent headaches, dizziness, fainting and tiredness. HPV vaccine uptake fell from about 95% to just over 30% during this period [5,15]. We sought to examine whether the decline in HPV vaccination in Denmark due to negative media coverage undermined uptake of another adolescent vaccine, measles, mumps and rubella (MMR).

2. Methods

2.1. Context and population

Danish children born before April 1, 2004 were scheduled to receive the first dose of MMR vaccine (MMR1) at 15 months and the second dose of the vaccine (MMR2) at age 12. HPV vaccination was introduced in the national vaccination program in 2009, for girls aged 12–15, with 12 being the recommend age of HPV vaccine initiation. HPV vaccination was also offered to older cohorts through a temporary catch-up program. During the study period, HPV vaccination required an initial dose (HPV1) and one to two additional doses given within a year of the first dose. Changes in the Danish vaccination program offer a rich and unique opportunity for analyzing the effect of concomitant vaccines. As HPV vaccine for Danish girls was recommended to be given at the age of 12 (i.e. the same age as recommended for MMR2 vaccination), we are able to relate variation in MMR2 vaccine uptake to the introduction of concomitant HPV vaccine and the decline in HPV vaccine uptake following negative media coverage.

Our highly detailed individual level register data allowed us to investigate how possible spillover effects of the reduction in HPV vaccination rates potentially undermined MMR2 vaccine coverage. Our study relies on Danish register data for all children born in Denmark between 1991 and 2003 and observed in the registers every year up until age 13. The cohort comprises 403,073 girls and 424,643 boys.

2.2. Measures

From the register on public health insurance, we obtained individual-level information about MMR (girls and boys) and HPV vaccination (girls only). The database has the record of visits to general practitioner, with information on MMR and HPV vaccinations including the age of the child receiving the vaccine. Danish children have had individual health insurance cards with personal records since 1997. Before 1997, children's health services in the public health care system were recorded under the parents' civil registration number (usually the mother), with a code to indicate that the service was given to a child.

From the national registers, we obtained information on maternal level of education, which we use as a proxy for household education. Information on vaccine status, age of vaccination, and maternal education were linked at the individual level using the unique personal identifiers in the Danish registers. This enabled us to follow vaccination for our study cohort from 1991 to 2017.

The primary outcome variable is MMR2 coverage by age 13. We also present results for HPV vaccine initiation by age 13 and MMR1 vaccine coverage by age 3 (see the appendix for definitions).

2.3. Statistical analysis

To examine the effect of HPV uptake on the MMR2 uptake, we compared the uptake of MMR2 of girls with the uptake of boys. We considered girls as the "treatment group", as they were directly affected by HPV vaccinations and news about the vaccine, and boys as a "control group". First, we characterized the population with respect to education and vaccine coverage (MMR1, MMR2, and HPV1). Second, we estimated a logistic regression for MMR2 uptake. The dependent variable was a binary variable indicating whether the child received MMR2 by age 13. The explanatory variables were a dummy variable for sex; dummy variables for birth year; sex interacted with birth year; and dummy variables for birth month (to account for seasonality). We also estimated a logistic regression for MMR1 coverage by age 3 with the same explanatory variables. Third, we estimated logistic regression models for MMR2 by age 13 for girls. Here we included dummy variables for birth month; dummy variables for birth year; dummy variables for maternal education (in five categories) and maternal education interacted with birth year. Similarly, we estimated a logistic regression for HPV1 by age 13 with the same set of explanatory variables. Fourth, we examined those who decline both MMR2 and HPV1 vaccines. The dependent variable was a binary variable that took the value 1 if the girl has neither received HPV1 nor MMR2 by age 13 and 0 otherwise. The explanatory variables were dummy variables for birth month; dummy variables for birth year; dummy variables for maternal education (in five categories) and maternal education interacted with birth year. Empirical analysis was done using STATA version 14.1, using two-tailed statistical tests with a significance level of 0·05.

3. Results

MMR vaccination coverage was generally high (Table 1). Across all birth cohorts, MMR1 coverage by age 3 was 86·3% and MMR2 coverage by age 13 was 84·0%. In contrast, HPV1 coverage by age 13 was somewhat lower, 76·8%.

3.1. Temporal changes in vaccination

Almost all girls (91%) who received MMR2 and HPV1 vaccination by age 13 received both vaccines the same week, likely during the same visit to their general physician. To understand the temporality of HPV vaccine events relative to changes in girls' uptake of MMR2, we examined gender difference in the monthly number of MMR2 vaccinations given (Fig. 1). The large spike in female MMR2 vaccinations in January 2009 coincided with the introduction of HPV vaccination in Denmark. Similarly, the two months with the lowest number of female-to-male MMR2 vaccinations coincided with dates in 2013 and 2015 with negative media coverage of HPV vaccination, which has been shown to affect HPV coverage significantly [5,7]. Boys received slightly more MMR2 vaccinations than girls in the earlier time period, because boys made up 51% of the population which more than offset their lower coverage with respect to total doses given.

In the time period before HPV vaccination was introduced for girls, MMR2 coverage declined slightly for both girls and boys, from 86% overall for the oldest birth cohort (1991) to 85% overall for the 1995 birth cohort (Fig. 2). The introduction of HPV vaccination for girls born from 1996 and onwards coincided with a sizable increase in MMR2 coverage for girls, while coverage continued to

Table 1
Demographic characteristics of population.

	Born 1991–1995		Born 1996–2000		Born 2001–2003		All
	Boys %	Girls %	Boys %	Girls %	Boys %	Girls %n	%
Child's vaccination							
MMR1 before 3y	82.9	82.9	87.8	88.0	89.6	89.9	86.3
MMR2 before 13y	85.1	86.4	82.9	87.5	78.5	79.8	84.0
HPV1 before 13y	–	–	–	82.9	–	66.4	76.8*
Mother's education							
Elementary	21.3	21.4	17.1	17.1	14.3	13.9	18.1
Vocational	45.2	45.3	44.6	44.8	41.0	41.7	44.2
Short	3.8	3.8	4.4	4.4	5.3	5.1	4.4
College	22.3	22.0	24.2	24.0	26.9	26.6	23.9
University	5.5	5.5	8.1	8.0	10.9	11.0	7.7
Unknown	1.9	1.8	1.7	1.7	1.7	1.7	1.8
N	166,648	158,314	163,244	154,727	94,751	90,032	827,716

Note. Children born in Denmark in the period 1991–2003, who lived continuously in Denmark until age 13. MMR1 is defined as the 1st MMR dose. MMR2 is the 2nd MMR dose. If only one dose is received, the age of the child determines if it is the MMR1 or MMR2 (see definition in appendix). HPV1 is defined as HPV vaccine initiation (first dose). Short education is short-cycle higher education and is about 14 years of education. HPV not part of the public vaccination program for children between 12 and 13. * This number is only based on girls born 1996–2003.

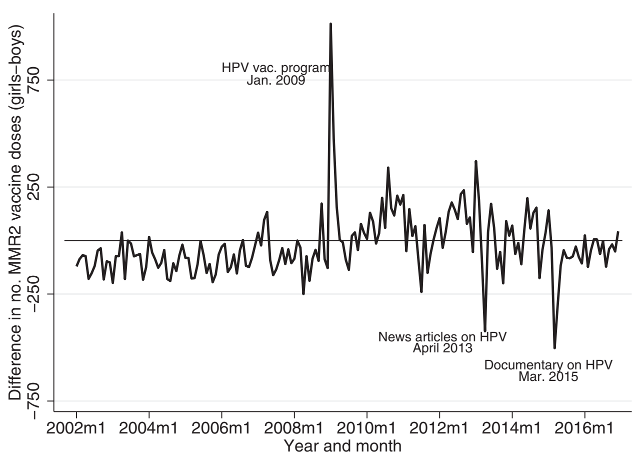

Fig. 1. Monthly difference in number of MMR vaccine doses given to girls and boys ages 12–15. *N = 823,709.* The number of MMR vaccines is defined as the number of MMR vaccines given in Denmark to girls, less the number given to boys, ages 12–15. On average, 1802 girls and 1826 boys, ages 12–15, received MMR2 each month for the period 2002–2015. The notes at the spikes inside the graph refer to three key events: 1) introduction of the HPV vaccination program in January 2009, 2) first negative media coverage of HPV vaccination in a Danish newspaper in April 2013, 3) national TV documentary on negative side effects of HPV vaccine in March 2015.

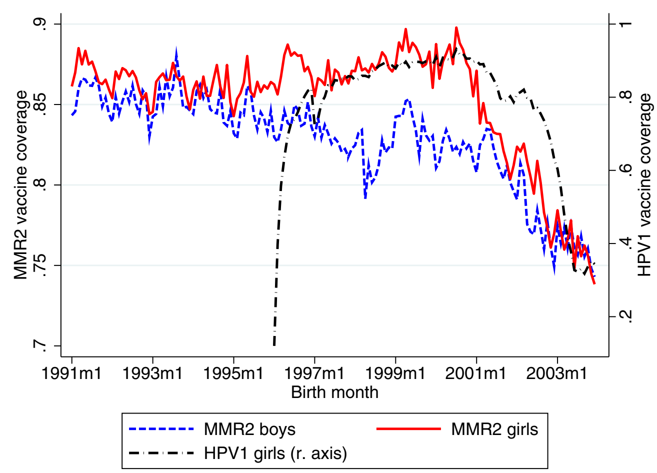

Fig. 2. MMR2 and HPV1 vaccine coverage for girls and boys by birth month by age 13. *N* = 827,716. Children born in 1991–2003 in Denmark, who have lived in Denmark in all years from birth until age 13. MMR2 is the 2nd MMR dose. If only one dose is received, the age of the child determines if it is the MMR1 or MMR2 (see definition in appendix). This figure shows the MMR2 vaccine coverage by age 13. HPV1 is defined as the first HPV vaccine dose by age 13.

decline slightly for boys. As HPV vaccine uptake began to fall in 2013, HPV1 coverage plunged for girls born in 2001 or later, and we observed a concomitant, sharp decline in MMR2 coverage for these same age cohorts. For the 2003 cohort, MMR2 coverage for girls declined to the level of boys. MMR2 coverage then rapidly declined for both boys and girls, and it fell below 77% for the youngest birth cohort (2003).

The difference between girls and boys in MMR2 coverage increased from 1·6 percentage points (95% CI 1·1–2·2%) for the 1995 cohort to 4·3 percentage points (95% CI 3·8–4·8%) for the 1999 cohort (Fig. 3, right panel). The gender gap narrowed rapidly for cohort 2001, and it was no longer noticeable for the youngest cohort born in 2003. The findings for MMR2 stand in contrast to MMR1 vaccination coverage for boys and girls, which was almost identical and largely unchanged over time (Fig. 3, left panel). Only one of the thirteen confidence intervals for MMR1 sex differences (birth cohort 2002) did not contain zero, a finding that we attributed to chance.

To establish that changes in HPV1 and MMR2 were coincident at the level of patients, we examined coincident vaccination for girls at age 13 (Fig. 4). The majority of girls born before 2001 followed the recommended schedule (receiving both vaccines at age 12) with the percentage peaking at about 80%. Coverage with both vaccines began to decline for girls born in 2001, and then fell rapidly for girls born in the latter half of 2002 or later. About 7% of girls born from 1997 to 2001 received neither MMR2 nor HPV1 vaccines by age 13. The percentage of girls receiving neither vaccine increased substantially for cohorts born 2002 and 2003, and about 20% of girls born in 2003 received neither MMR2 nor HPV1 according to the vaccine schedule.

3.2. Parental education and vaccination

The percentage declining both vaccines was lowest for the cohorts born 1997–2001. Within these cohorts, young girls whose mothers had the lowest level of education stand out with about 10% declining both vaccines (Fig. 5). When looking across cohorts born from 1997 to 2003, young girls whose mothers had the high-

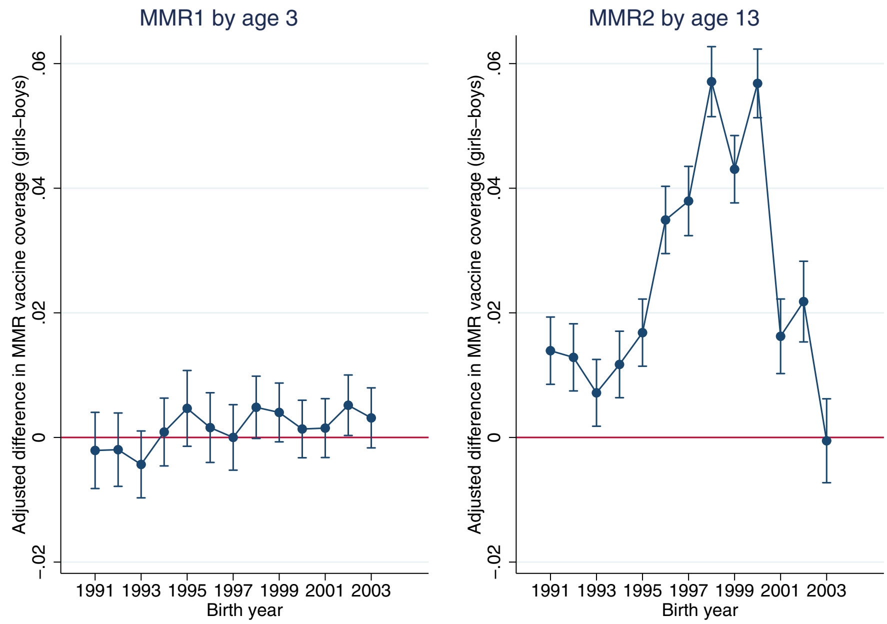

Fig. 3. Adjusted differences between girls and boys in MMR1 and MMR2 coverage by birth year. N = 827,716. Children born in 1991–2003 in Denmark, who have lived in Denmark in all years from birth until age 13. Positive values show higher vaccination coverage for girls. MMR1 is defined as the 1st MMR dose. MMR2 is the 2nd MMR dose. If only one dose is received, the age of the child determines if it is the MMR1 or MMR2 (see definition in appendix). The left panel displays the estimated differences between girls and boys in MMR1 coverage. The right panel displays the estimated differences in MMR2. The gender differences are estimated as marginal effects in a logit model (STATA version 14.1) for the interaction term of birth cohort and gender. Estimates adjusted for birth year, gender, interaction of gender and birth year and birth month. Error bars show 95% confidence intervals.

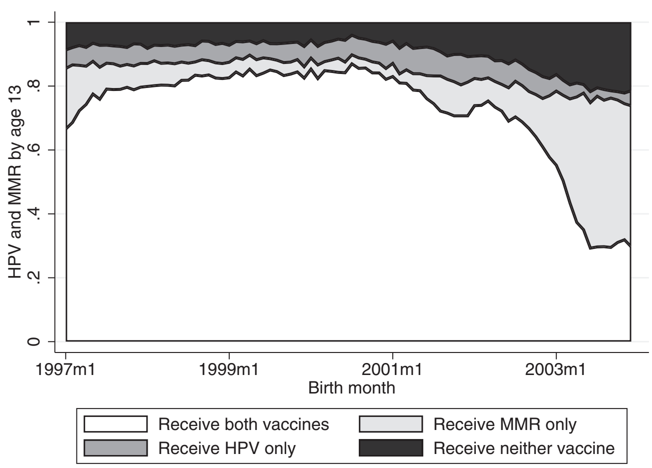

Fig. 4. Combination of MMR2 and HPV1 coverage for girls by birth month. N = 213,485. Girls born in 1997–2003 in Denmark, who have lived in Denmark in all years from birth until age 13. MMR2 is the 2nd MMR dose. If only one dose is received, the age of the child determines if it is the MMR1 or MMR2 (see definition in appendix). The figure shows MMR2 vaccine coverage by age 13. HPV1 is defined as the first HPV vaccine dose by age 13.

est level of parental education showed the highest increase in receiving neither of the vaccines. Thus, for cohorts 2002 and 2003, vaccine uptake was lowest for parents with low and high education, showing a distinctive U-shape (Fig. 5).

For the individual vaccines, coverage declined for both MMR2 and HPV1, albeit the drop in HPV1 is substantially higher than the drop in MMR2 (Fig. 6, right panel). While coverage dropped for all levels of education, the girls born to mothers with the lowest level of education experienced the smallest decline, while girls born to mothers with the highest level of education had the largest decline, in particular for HPV1 coverage. Thus, HPV1 coverage was declining in the level of education for girls born in 2003.

4. Discussion

Introduction of HPV vaccination in Denmark appeared to support a small increase in female MMR2 coverage. However, when HPV vaccine uptake declined, so did MMR2 coverage. This conclusion is supported by the coincident timing of the drops in the two vaccines and the concomitant delivery of almost all of the doses for two vaccines. Two specific findings support our interpretation that the spillover effects were from HPV to MMR2. First, the introduction of female HPV vaccination was followed by an increase in female MMR2 uptake while male MMR2 uptake continued a slight decline. Second, the decline in HPV vaccine uptake coincides with a sudden sharp decline in female MMR2 uptake that eliminates the gender gap in MMR2 uptake. Our study is one of the first to document how instability in one vaccine's coverage is a contagion that can spread to other vaccines on the same platform.

It is perhaps understandable that HPV vaccine uptake fell in Denmark during a period with negative media coverage of serious (but unsubstantiated) side effects. The negative impact of Danish media coverage on HPV vaccine uptake is well documented [5,7]. However, we document a distinct pattern of spillover from the drop in HPV vaccination onto MMR2 vaccination, especially girls. We attribute the initial gender gap to adolescent girls having more contact with general physicians than adolescent boys [16] and therefore being more likely to be vaccinated by age 13. Interestingly, negative media coverage of MMR vaccination at a different time did not appear to have undermined MMR uptake in Denmark, perhaps due to the brief period of coverage or the perception that the problem was specific to the UK [4]. The decline in MMR2 coverage at the end of our sample may, in part, have been due to a

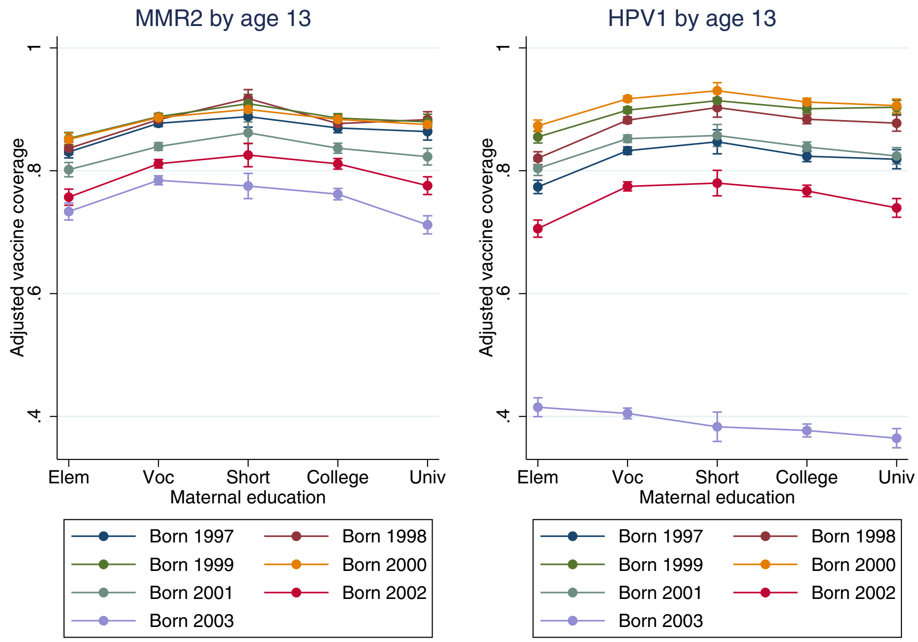

Fig. 5. The adjusted probability of receiving neither MMR nor HPV by age 13 by maternal education and birth year. N = 209,950. Girls born in 1997–2003 who lived in Denmark from birth until age 13. MMR2 is the 2nd MMR dose. If only one dose is received, the age of the child determines if it is the MMR1 or MMR2 (see definition in appendix). The figure shows MMR2 vaccine coverage by age 13. HPV1 is defined as the first HPV vaccine dose by age 13. Data for girls for whom the mother's education is unknown is not included. Maternal education: Elementary Schooling, Vocational training, Short further education, College education, University education. Estimates adjusted for birth year, maternal education, interaction of maternal education and birth year and birth month. Error bars show 95% confidence intervals.

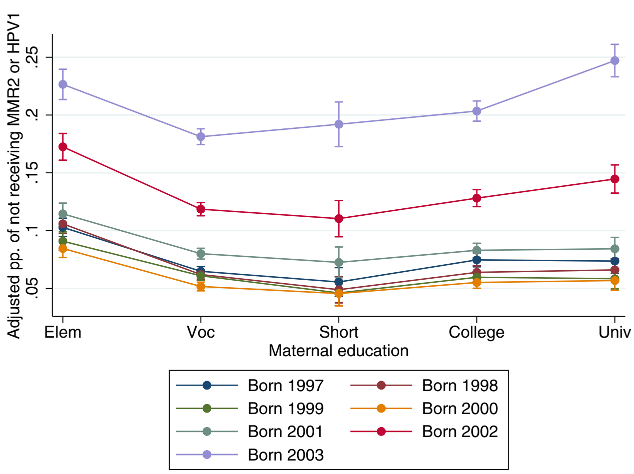

Fig. 6. Relation between maternal education and MMR2 and HPV1 vaccine coverage for the 1999, 2001 and 2003 birth cohort of girls. N = 209,950. Girls born between 1997 and 2003 who lived in Denmark from birth until age 13. MMR2 is the 2nd MMR dose. If only one dose is received, the age of the child determines if it is the MMR1 or MMR2 (see definition in appendix). HPV1 is defined as the first shot of HPV before the age of 13. The figure shows MMR2 and HPV1 coverage before the age of 13. Maternal education is measured when the girls were 12. Data for girls for whom the mother's education is unknown is not included. Maternal education: Elementary Schooling, Vocational training, Short further education, College education, University education. Estimates adjusted for birth year, maternal education, interaction of maternal education and birth year and birth month. Error bars show 95% confidence intervals.

change in the Danish vaccine schedule. Children born after April 1, 2004 were scheduled to receive MMR2 vaccination at age 4, instead of age 12. Thus cohort 2003 is among the last to be scheduled for MMR2 at age 12, and some children may have had younger siblings who received MMR2 at age 4. The change in schedule may have resulted in some parents and physicians forgetting that the older siblings were still scheduled for MMR2 vaccination at age 12. This speculation seems unlikely to account for a drop of the magnitude we documented and does not explain the elimination of the gender gap in MMR2 coverage seen for cohort 2001 and later.

Parental education shaped the effects we saw on MMR2 and HPV1 coverage. We documented an inverted U-shape in MMR2 vaccine coverage as a function of maternal education. Mothers with the least or the most education had daughters with the lowest MMR2 coverage. The inverted U-shape was also present for HPV1 coverage, for the first six cohorts. Most importantly, the last cohort, 2003, experienced a sharp decline in HPV1 coverage, and the decline was far more pronounced for those with high levels of education, resulting in HPV1 coverage being downwards sloping as a function of parental education for cohort 2003. Previous studies have shown conflicting results for the significance of parental education and income in HPV vaccination [10,17–20]. UK uptake of the MMR, following the 1998 publication of serious negative side effects of MMR vaccine (a publication later deemed to be fraudulent), declined faster in areas with a larger fraction of parents with more education. Similarly, a US study found that it was the high-educated who reduced vaccination rates of their children the most [3,10]. A Danish study found that HPV uptake was lower for girls born to parents with lower education [21]. Our results are similar. We also found that more highly educated parents (with college or university education) were slightly more likely to decline vaccinations for the older cohorts (born 1997–2001), as suggested by Fig. 5. However, the findings for people with the least education are remarkable, yielding the U-shape of the graphs shown in Fig. 5 for the younger cohorts (born 2002–03). The non-linear and moderated findings in our study underline the complexity of the role of education in vaccine uptake.

Countries facing vaccine scares may need to be prepared for drops in coverage. Researchers have suggested strategies to address such scares includes having a strong crisis communication plan, being proactive, and relying on coordinated communication efforts. Our data suggest that the countries should also be alert for drops in vaccines on the same platform [22] (i.e., among children receiving other vaccines at the same age). While the drops may be less pronounced, they may still be problematic.

To conclude, we document spillover effects in vaccination rates across concomitant vaccines. The introduction of HPV vaccine in Denmark supported higher MMR2 vaccination rates for girls. However, following negative media attention on HPV vaccination, MMR2 coverage fell considerably for girls. Moreover, highly-educated mothers were apparently more sensitive to negative information about HPV vaccine leading to a higher drop in vaccination rates for their daughters. Our results point to potential benefits of concomitant vaccine delivery if the public considers vaccines to be safe. However, in a period of a vaccine scare, there may be negative spillover effects across concomitant vaccines.

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Disclosures

Dr. Brewer has received research grants or served as a paid consultant for Merck, the US Centers for Disease Control and Prevention, and the US Food and Drug Administration.

Role of funding source

The funders of the study had no role in study design, data collection, data analysis, data interpretation, or writing of the report. The corresponding author had full access to all the data in the study and had final responsibility for the decision to submit for publication.

CRediT authorship contribution statement

Mette Gørtz: Conceptualization, Formal analysis, Funding acquisition, Investigation, Project administration, Writing - original draft, Writing - review & editing. **Noel T. Brewer:** Conceptualization, Investigation, Validation, Writing - original draft, Writing - review & editing. **Peter Reinhard Hansen:** Conceptualization, Investigation, Validation, Writing - original draft, Writing - review & editing. **Mette Ejrnæs:** Conceptualization, Formal analysis, Funding acquisition, Investigation, Methodology, Writing - original draft, Writing - review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A

See Fig. A1 and Table A1.

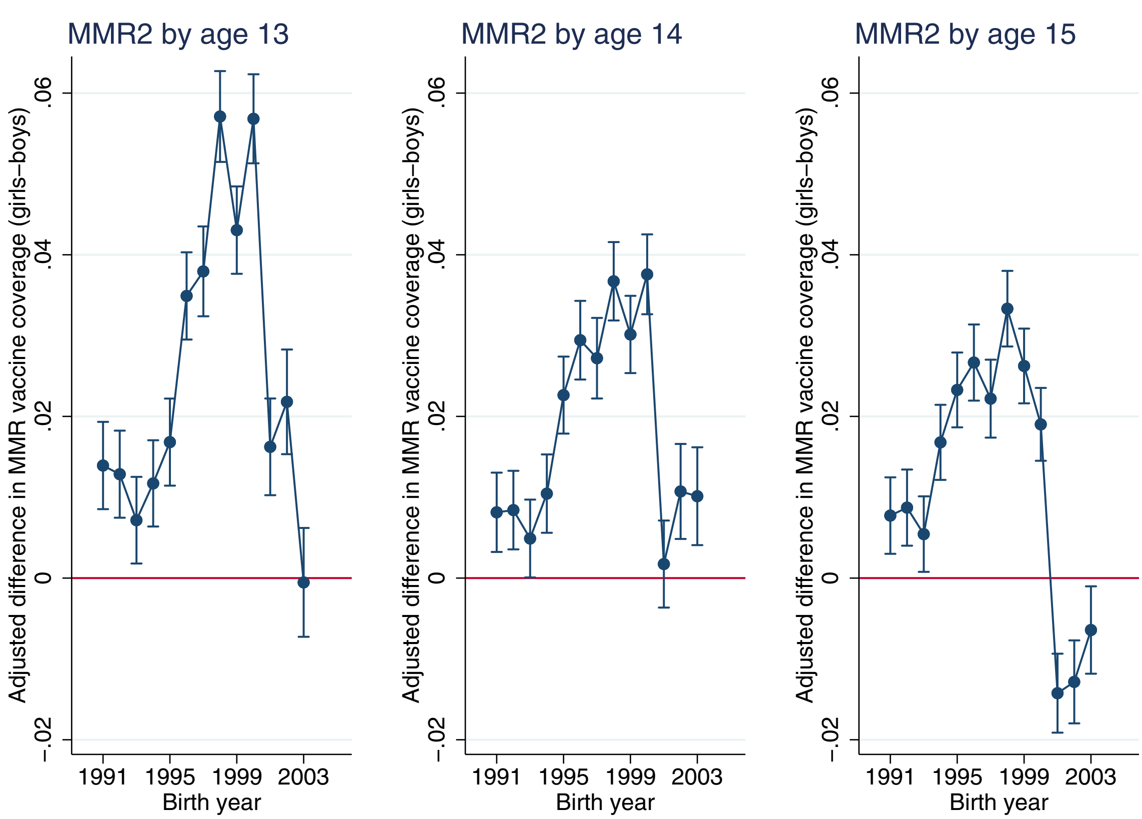

Fig. A1. Adjusted differences between girls and boys in MMR2 coverage at age 13, 14 and 15 by birth year. N = 827,716. Children born in 1991–2003 in Denmark, who lived in Denmark in all years from birth until age 13. MMR2 is the 2nd MMR dose. If only one dose is received, the age of the child determines if it is the MMR1 or MMR2 (see definition in appendix). Positive values show higher vaccination coverage for girls. The left panel displays the estimated differences between girls and boys in MMR2 coverage by age 13. The middle panel displays estimated differences between girls and boys in MMR2 coverage by age 14. The right panel displays the estimated differences in MMR2 by age 15. The gender differences are estimated as marginal effects in a logit model (STATA version 14.1) for the interaction term of birth cohort and gender. Estimates adjusted for birth year, gender, interaction of gender and birth year and birth month. Error bars show 95% confidence intervals.

Table A1
Logit estimation.

	MMR1 by age3	MMR2 by age 13
Birth year = 1991	0.000	0.000
	(.)	(.)
Birth year = 1992	0.042*	−0.055*
	(0.020)	(0.022)
Birth year = 1993	0.335***	−0.008
	(0.022)	(0.022)
Birth year = 1994	0.226***	−0.059**
	(0.021)	(0.022)
Birth year = 1995	−0.132***	−0.111***
	(0.020)	(0.022)
Birth year = 1996	0.195***	−0.137***
	(0.021)	(0.022)
Birth year = 1997	0.381***	−0.220***
	(0.022)	(0.022)
Birth year = 1998	0.518***	−0.294***
	(0.023)	(0.022)
Birth year = 1999	0.665***	−0.146***
	(0.023)	(0.022)
Birth year = 2000	0.721***	−0.257***
	(0.024)	(0.022)
Birth year = 2001	0.692***	−0.300***
	(0.024)	(0.022)
Birth year = 2002	0.628***	−0.539***
	(0.023)	(0.021)
Birth year = 2003	0.645***	−0.629***
	(0.023)	(0.021)
Girl	−0.014	0.119***
	(0.021)	(0.024)
Girl * Birth year = 1991	0.000	0.000
	(.)	(.)
Girl * Birth year = 1992	0.000	−0.014
	(0.029)	(0.032)
Girl * Birth year = 1993	−0.022	−0.059
	(0.031)	(0.033)
Girl * Birth year = 1994	0.021	−0.024
	(0.030)	(0.032)
Girl * Birth year = 1995	0.043	0.014
	(0.028)	(0.032)
Girl * Birth year = 1996	0.026	0.167***
	(0.030)	(0.033)
Girl * Birth year = 1997	0.014	0.176***
	(0.031)	(0.032)
Girl * Birth year = 1998	0.061	0.323***
	(0.032)	(0.033)
Girl * Birth year = 1999	0.058	0.241***
	(0.034)	(0.033)
Girl * Birth year = 2000	0.029	0.334***
	(0.034)	(0.033)
Girl * Birth year = 2001	0.030	−0.006
	(0.034)	(0.032)
Girl * Birth year = 2002	0.069*	0.012
	(0.034)	(0.031)
Girl * Birth year = 2003	0.048	−0.122***
	(0.034)	(0.030)
Birth month = 1	0.000	0.000
	(.)	(.)
Birth month = 2	0.004	0.028
	(0.016)	(0.015)
Birth month = 3	0.030	0.050***
	(0.016)	(0.015)
Birth month = 4	0.068***	0.045**
	(0.016)	(0.015)
Birth month = 5	0.093***	0.070***
	(0.016)	(0.015)
Birth month = 6	0.060***	0.010
	(0.016)	(0.015)
Birth month = 7	0.059***	0.039**
	(0.015)	(0.015)
Birth month = 8	0.035*	0.022
	(0.015)	(0.015)
Birth month = 9	0.014	0.002
	(0.016)	(0.015)
Birth month = 10	0.088***	−0.018
	(0.016)	(0.015)
Birth month = 11	0.101***	−0.035*
	(0.016)	(0.015)
Birth month = 12	0.066***	−0.071***
	(0.016)	(0.015)
Constant	1.443***	1.778***
	(0.018)	(0.019)
N	827,716	827,716

Note. Numbers are unstandardized regression coefficients and standard errors in parentheses. Children born in 1991–2003 in Denmark, who lived in Denmark in all years from birth until age 13. MMR1 is defined as the 1st MMR dose. MMR2 is the 2nd MMR dose. If only one dose is received, the age of the child determines if it is the MMR1 or MMR2 (see definition in the appendix). Positive values show higher vaccination coverage for girls. The left panel displays the estimated differences between girls and boys in MMR1 coverage by age 3. The right panel displays the estimated differences in MMR2 by age 13. The gender differences are estimated as marginal effects in a logit model (STATA version 14.1) for the interaction term of birth cohort and gender. The marginal interaction effects are shown in Fig. 3.

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