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# The German measles case

Andreas Kucher

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Andreas P. Kucher[1]

**Abstract**

High vaccination rates have a social protection function in addition to individual prevention of infections and diseases. To reach herd immunity thresholds and to protect risk groups, the timeliness of immunization is an important goal for vaccination policy. There is currently no causal evidence of age-appropriate immunization for childhood vaccinations. This research investigates how changing the recommended timeliness of vaccination in childhood affects vaccination status, leaving the number of doses during the primary vaccination unchanged. I analyze an adaption in 2001 that shifts the timeliness two and a half years earlier within the second year of life. Using representative German survey data based on vaccination cards, I investigate a timeliness adaption of the measles primary vaccination in 2001, which changed the scheduled age of the second dose among young children aged 2 to 7 years, and use variation of the implementation across states. For adjusted timeliness of the second measles vaccination, the data imply a significant shift into earlier ages after the policy for the treatment group. In the short run, a difference-in-difference strategy implies causal evidence of the up-to-date vaccination probability at the end of the 7th year of life. Additionally, the adaption induced a significant timeliness effect on the up-to-date level of the first measles dose at the end of the second year of life. This effect can be seen as evidence that individuals, in this case parents, respond to nonbinding vaccination recommendation policies and that timing of vaccination is an important factor for reaching vaccination policy aims.

*Keywords:* Childhood immunization, Difference-in-differences, Measles vaccination, Timeliness.

*JEL classification numbers:* H75 · I12 · I18

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[1]University of Augsburg, Department of Economics, Universitätsstraße 16, 86159 Augsburg, Germany, andreas.kucher@wiwi.uni-augsburg.de

# 1 Introduction

"*This century promises to be the century of vaccines, with the potential to eradicate, eliminate or control a number of serious, life-threatening or debilitating infectious diseases, and with immunization at the core of preventive strategies.*" (Global Vaccine Action Plan, World Health Organization WHO (2013, p. 13))

For 14 out of 25[2] vaccine-preventable infections, the German immunization schedule recommended a primary vaccination within the first two years of life in 2018 (see STIKO (2018, p. 338)). Vaccination is a highly effective way that parents can protect their children from more than a dozen major infectious diseases, sequelae, hospitalization and even death[3]: looking at the measles vaccine, the field effectiveness of the first dose is on average 91 % regardless of a child's age or region. Studies for Europe showed an effectiveness between 79 and 99 % for the first dose and between 93 and 99 % for the second dose.[4] From 2000 to 2015, measles incidence rates declined by 75 %.

Although there is an effective vaccine, there were still 36 cases per million population contracted worldwide in 2015, the majority among children under the age of 5.[5] Based on this information, the measles death rate was estimated at 134,200 worldwide (see Patel et al. (2016, p. 1230f)). Additionally, there are risks for secondary diseases such as ear infections, bronchitis, and pneumonia as well as long-run risks such as brain inflammation of the type subacute sclerosing panencephalitis (called SSPE) (see Moss and Polack (2001, p. 298), McLean et al. (2013, p. 3) and Schönberger et al. (2013)). The virus still ranks first in the list of deaths for vaccine-preventable diseases worldwide[6]; therefore, a continuing priority

[2]Number of infections with existing licensed vaccines (see WHO (2013, p. 16)).

[3]For a short historical summary for the United States of America, McLean et al. (2013) described incidence, hospitalization and death rates for measles, rubella, and mumps.

[4]See Uzicanin and Zimmerman (2011) for a review of the field effectiveness for measles.

[5]For Germany, children under 5 years had highest incidence rates in 2001 (30 %) and 2017 (over 35 %) (Hellenbrand et al. (2003, p. S213) and Matysiak-Klose and Wicker (2017, p. 1769)).

[6]In 2000, measles caused 5 % of all child deaths under the age of 5 and were responsible for

of measles eradication has been pursued for decades (see Kabra and Lodha (2013, p. 2)). For both Germany and the European WHO region, this goal[7] should have already been reached in 2010, but it was postponed several times and is currently set for 2020 (see Federal Ministry of Health (2015)).

Why is it so difficult to eradicate the measles despite its high vaccine effectiveness?

The measles virus is highly contagious on contact (*e.g.*, air, droplet, or casual touching). Symptoms initially resemble a cold or flu until a typical skin rash appears. However, individuals are already infectious and transmit the virus before a skin rash outbreak (see Halloran, Longini Jr., and Struchiner (2010, pp. 11, 64, 220)). In addition to the aggressive nature of measles, challenges are driven by a shortened protection period after birth by maternal antibodies within the first year of life and the waning of vaccine-induced immunity[8], as well as vaccine fatigue[9]. Factors for fatigue are seen in the individual perception of incidence and secondary diseases[10], persisting misinformation and beliefs (*e.g.*, fraudulent evidence regarding autism in the late 1990s), or medical, religious and philosophical exemptions (see Salmon et al. (1999)). All these factors increase contagion potential over the lifecycle.

To facilitate a successful implementation of the WHO strategic plan for the eradication of measles, a high overall nationwide vaccination coverage (over 95 %) with two doses of measles vaccine[11] should be achieved. Additionally, susceptible subgroups of people must be identified and targeted by vaccination programs in order to interrupt the transmission of measles (see WHO (2005 and 2013), Halloran, Longini Jr., and Struchiner (2010, p. 59)).

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over 40 % of all deaths of vaccine-preventable infections for children under the age of 15 (see WHO (2002, p. 50)).

[7]Eradication of measles in the European region is defined by an immunization coverage over 95 %, an incidence under 1 per million population per region and year, and no deaths (see Ramsay (1999, pp. 1, 13)).

[8]In the past, the term of protection for newborns was longer because the mothers themselves had experienced measles. For vaccinated mothers, the protective function of the child is shortened (see Waaijenborg et al. (2013)). Similarly, a decrease in vaccine-induced immunity is anticipated, as the mechanism of lifelong immunity has yet not been fully understood (see Halloran, Longini Jr., and Struchiner (2010, p. 59) and Moss and Polack (2001, p. 302).

[9]This can be observed in all vaccine-preventable diseases and is not a specific measles problem (see Larson et al. (2011)).

[10]Local and/or regional success contrarily causes less perception of disease risk and risks of secondary diseases (see (Matysiak-Klose and Wicker (2017, p. 1767)).

[11]With an average vaccine effectiveness of 91 %, even if all received one dose, the necessary threshold would not be reached.

However, which policy should the government implement to achieve its goals?

There is considerable heterogeneity: policy options (*e.g.*, mandates, recommendations, or mixed policies) are combined with vaccination programs, cultural or national features, legal frameworks, ethical justifications, and access to vaccinations. However, evidence is rare, and external validation is difficult.[12]

Empirical evidence for the causal effects of vaccination policies had only been established for certain select vaccinations. The empirical strategy is to use a natural experiment that randomly assigns the vaccination policy to the population. State-level introduction over time represents a suitable exogenous variation using a treatment-control group design to investigate national evidence.

To the best of my knowledge, Abrevaya and Mulligan (2011) and Lawler (2017) investigate U.S. vaccination policies in the last two decades in such a causal manner. Abrevaya and Mulligan (2011) show that vaccination rates for varicella (chicken pox) increased after introducing state-level mandates in 2000. For hepatitis A, Lawler (2017) finds evidence for two policies - recommendations and mandates - enacted in 1999 or later at the state level. Both policies significantly increased vaccination rates and are associated with decreasing incidence. Given the few studies examining the causal effect of the *introduction* of childhood vaccination policies, such as mandates or recommendations, on immunization rates exploiting state-level diversity, there is no causal evidence of the *timeliness* of childhood vaccinations. For European countries and the Commonwealth of Independent States, investigations of measles/measles-mumps-rubella (MMR) timeliness have been limited to cross-sectional and survival analyses without control groups: *e.g.*, for Germany (Fell, David, and Reintjes (2005) and Siedler et al. (2002)), for Sweden (Dannetun et al. (2004)), for the UK (Walton et al. (2017)), and for Armenia, Kazakhstan, Kyrgyzstan and Uzbekistan (Akmatov et al. (2008)). The same applies to Canada (Périnet et al. (2018)).

Despite the importance of timely immunization, there has been extremely limited empirical research focusing on the effects of an age-appropriate implementation of vaccination policies.

On the one hand, to estimate the causal effect of an age-appropriate vaccination policy we have to exploit exogenous variation and random assignment of age-specific recommendations. Since reunification, the German vaccination policy has undergone a number of changes, *e.g.*, nationwide introduction of new

[12]See MacDonald et al. (2018), which described factors that should be mentioned together with an implementation strategy such as mandates but that also apply to other policy strategies.

vaccination (for instance, haemophilus influenzae type b) or a change in timing recommendations by several months. The reform that I seek to exploit is the adaption of the second measles dose from the fifth to second year of life in 2001. In this context, an exogenous source would be diverse responses within the public vaccination guidance of individual federal states because implementation of the vaccination recommendations is the responsibility of the federal states. The recommendation of the second measles dose of the primary immunization and its timeliness adaption by several years is one such *unique* case within the German vaccination system.

On the other hand, the main problem has been the availability of national vaccination records (see Fell, David, and Reintjes (2005, p. 29) for the German case). With the "The German Interview and Examination Survey for Children and Adolescents (KiGGS)" from the Robert Koch Institute (RKI), such data are now available. One limitation of the KIGGS data is that the data allow us to analyze the effect of the 2001 timeliness adaption for measles only in the short term since birth cohorts up to and including 2003 could be considered to end 4 years after the policy. Additionally, information about the vaccination status and timing for both measles doses are not exactly known: the measles status for the first dose at the age of 2 years and for the second dose at the age of 7 years. Since a pure recommendation policy without binding age limits is applied within this analysis, the latter point seems less critical because a certain delay in measurement does not appear problematic.

My paper contributes to the previous literature in several ways. First, I provide evidence for the effect of an age-appropriate recommendation policy, here the recommended timing of the second measles dose. The up-to-date measles status at the interview period between 2003 and 2005 allows me to analyze the age-specific vaccination shift of the recommendation adaption in a control group setting.

Second, using the state-level variation of the adaption of the age-appropriate timing in 2001 and the age-specific information about the up-to-date status at the age of 7 years before and after policy change, I estimate the causal adaption effect of the recommendation on the vaccination probability for the timely second measles dose and fill the lack of timeliness evidence in the vaccination context.

Third, in addition to the direct policy effect on the measles status of the second dose, I investigate the 'side effects' of the adaption on the first measles vaccination demand. Due to the shift into the second year of life temporally following the first vaccination in the context of the primary immunization, it is to be assumed that

the 2001 adaption also affects the first dose status at the age of 2 years.

Fourth, these analyses will be extended with a regional stratification, a dynamic policy regression model for short-term dynamics, and a robustness section in which methodological and content-related aspects are additionally discussed.

Finally, the effect of the adaption on measles incidence rates in Germany is considered with reporting data and will be discussed.

Results at a glance: An up-to-date analysis shows a clear increasing trend from 2003 to 2005 over all ages from 2 to 6 years with constant rates within the control group at the same time. For the difference-in-differences (DD) framework, the common trend assumption holds and individuals who are affected by the adaption already respond in the short run. For both the first and second measles dose, there is a significant positive effect of over 9 percentage points.

The regional stratification differs for the second measles dose but is equal for the first dose. The dynamic policy results give a constant probability effect for the first dose and some increasing effect for the second dose.

The remainder of the paper proceeds as follows. In Section 2, economic theory on vaccination is considered. Section 3 summarizes the historical and institutional background and measles vaccination policy for the German case. Section 4 describes the data source and the variables used. Section 5 presents the empirical strategy. The main results are presented in Section 6. Section 7 gives some robustness analyses. Finally, Section 9 concludes with a discussion of the main findings.

# 2 An economic view on vaccination decisions and policies

From a theoretical point of view, there is no clear statement about the effect or direction of individual vaccination decisions. The commodity 'protected against preventable infections' by vaccinations suffers from free-riding and external effects, decisions under uncertainty and misinformation[13].

At the individual level, there is a decision trade-off between costs (in particular,

[13]There are other predictors that have also been named and recognized in the literature. From a medical point of view, missed appointments or the impossibility of vaccination due to acute illness and social neglect play a major role (see Schmitt (2001, S3)). Poethko-Müller, Kuhnert, and Schlaud (2007) and Poethko-Müller et al. (2009) analyze sociodemographic predictors, such as socioeconomic status (outcome and proxy of preferences) or migration status, and parental factors, such as beliefs, in Germany.

time and suffering from side effects) and benefits (individual protection). Additionally, society gains from decreasing transmission of diseases, which depends on the proportion of people being vaccinated in society (social protection): individual protection reduces the likelihood of infection of all unvaccinated persons and the population prevalence decreases (physical positive externality). Therefore, high vaccination rates give an incentive for non-vaccination because the individual profits from the transmission reduction and could avoid vaccination costs. Due to this externality, socially optimal demand is not reached (see Zweifel, Breyer, and Kifmann (2009, p. 157f)). Both situations lead to an inefficient (too low) vaccination rate, since the individual does not take into account the positive external effect and tends to free-ride.[14]

In addition, Geoffard and Philipson (1997) showed that the demand for vaccines are prevalence dependent - with an increase population vaccination rate and the willingness to pay for immunization decreases. that prohibits the eradication totally of such infections.

Additionally, the vaccination decision is a decision under uncertainty: pay the costs today and receive the benefits (perhaps) tomorrow. Therefore, risk and time preference also play an important role in the health context and for vaccination decisions. The role of economic and other preferences in the individual vaccination context has been analyzed empirically with survey data (see, *e.g.*, Nuscheler and Roeder (2016)) or within laboratory experiments (see, *e.g.*, Binder and Nuscheler (2017)).

Misinformation and misperception relate, for example, to the effectiveness of vaccination and the assessment of the likelihood of infection in the context of vaccination.[15] Research had already shown that people generally and in the health context have problems with misleading beliefs and correct perception (*e.g.*, optimistic bias) (see Weinstein (1982 and 1987), *e.g.*, in the context of smoking behavior see Viscusi and Hakes (2008)). Many investigations have supported these points for individual vaccination decisions: For both patients and doctors, inadequate information and misjudgments about vaccinations and vaccines are important issues (see Favin et al. (2012), Nuscheler and Roeder (2016), and Smith et al. (2017)).

[14]There is empirical research that analyzes these points, *e.g.*, Ibuka et al. (2014) observed free-riding under laboratory conditions or the quantity of external effects by Boulier, Datta, and Goldfarb (2007).

[15]Nuscheler and Roeder (2012) found a huge impact of misinformation next to the role of family doctors for the influenza vaccination with German survey data.

This consideration raises the social and political question of which vaccination policy and incentives can be pursued to support the individual vaccination decision and reach the social goals (*e.g.*, herd immunity, disease eradication).

The effectiveness of the measles vaccination is high, but not perfect (see 1). Looking at monetary incentives, Rosian-Schikuta et al. (2007) give an international review of costs and benefits for the MMR vaccination; for Germany, data are not available. Generally, the costs of the disease and estimated indices (such as cost-benefits) vary widely across countries and subgroups, but from a monetary point of view, vaccinations are preferable to the disease infection and treatment costs. The subsidization of costs by public health or health insurance is widespread. In Germany, the vaccine and the medical expenses of recommended vaccinations are covered by health insurance.

One might argue that because of the mentioned market failures, only vaccination mandates can achieve immunity and eradication goals, and they are the preferred choice instead of a recommendation policy. Geoffard and Philipson (1997) showed theoretically that even vaccination mandates could not reach disease eradication because of the nature of vaccination demand.[16] In addition to financial and market arguments, the enforcement of a vaccination policy depends on the country in view of the legal framework and historical conditions.

# 3 Institutional background

Historically, before the German reunification in 1990, the German Democratic Republic (DDR) instituted vaccination mandates for children and adults. In the Federal Republic of Germany (FRG), there was only one general vaccination mandate: the pox vaccination between 1945 to 1983. After abolishment until today, health authorities pursued a simple nonbinding recommendation policy for citizens in contrast to other industrial countries, such the U.S. and other European countries.

## 3.1 Structural organization

In Germany, the Paul-Ehrlich Institute (PEI) is the agency responsible for evaluating the safety and efficacy of new vaccines. The Standing Committee on Vacci-

[16]See Brito, Sheshinski, and Intriligator (1991) for further theoretical investigations about the justification of mandates and comparison to other regimes such as free choice.

nation[17] (STIKO) at the RKI[18] develops annual evidence-based national recommendations for the use of licensed vaccines by the PEI. These recommendations are age- and subgroup-specific, but they are not legally binding at the state level. By law, each federal state has to extend its public vaccination guidance based on the STIKO recommendations. Following the approval of a new vaccination or timeliness recommendations, individual states may conform with it or differ from it.[19] Participation in the program is voluntary, and the STIKO recommended vaccination are nowadays offered free of charge by sickness funds.[20] The majority of all vaccinations in childhood take place in the outpatient sector by pediatricians and family physicians.

## 3.2 Measles recommendations, status and research questions

In Germany, the measles vaccination has been recommended by the STIKO since 1974 (see STIKO (1974, p. 291)). Starting with a monovalent[21] live vaccine for measles, there is a trivalent MMR vaccine that has been licensed and recommended by the STIKO for West Germany since 1988 (see STIKO (1988, p. 412)). During the division of Germany, the measles vaccination was mandated for all children at 9 months in the DDR and was recommended at 12 months in the FRG; after 1980, it was recommended at 14 months (see STIKO (1980, p. 314)). After reunification, the FRG recommendations were adopted. Since that time, there was one adaption of the first measles dose: In 1997, the timing of the first dose was dated between 11 and 14[22] months of life (see STIKO (1997, p. 101)).

In 1991, the STIKO recommendation for a second measles dose[23] was published

[17]The committee is a national immunization technical advisory group appointed by German Federal Ministry of Health. For detailed information on structure, working procedure and publications, see STIKO (2016).

[18]The RKI emerged from the Federal Health Agency ("*Bundesgesundheitsamt*"), which was dissolved in 1994.

[19]The separation of national and federal state levels is based mostly on monitoring, claim for damages of injuries from immunization (see §11 and §60 Infektionsschutzgesetz (IfSG))

[20]After the annual publication by the STIKO within a time span of a few months, the Federal Joint Committee decide to cover the payment for vaccination of the immunization schedule by the service catalog of the statutory health insurance.

[21]One licensed single measles vaccine is still listed in Germany (compared to 21 tri/tetravalent vaccines) (licensed vaccine list available under www.pei.de/impfstoffe)

[22]If admission to a childcare institution is considered, the MMR-series could start at 9 months. Then, a second dose is recommended at 14 months (see STIKO (1995, p. 109)).

[23]In the DDR, a second measles dose was mandated, and after reunification, was recom-

for all children aged 5 years and older and was adopted by all federal states (see STIKO (1991, p. 384)). This recommendation was motivated by evidence from the U.S. and some Scandinavian countries to improve the lack of immunity and to obtain adequate herd immunity on a population level.

For practical reasons, the school entry health exam[24] is mentioned as a good point in time for the second measles dose indication (see STIKO (1995, p. 109f)). Since 1998, the recommended age in the STIKO immunization schedules was cited at age 4 and older (see, *e.g.*, STIKO (1998, p. 104)) without any explanation or text mention. However, the controlling advice within the school entry health exam persisted in all STIKO recommendation publications until the 2001 recommendation adaption.

In 2001, the STIKO timing of the second dose was shifted to within the second year of life (15 to 23 months of age) in connection to the first dose (see STIKO (2001, p. 205)). The dating of the second dose into the second year of life was justified with the importance of an early and timely immunization and initial vaccinations without sufficient immune response (nonresponders) should be compensated as early as possible. Because in the first two years of life additional vaccinations and well-child visits are pending, there are comparatively more doctor contacts. The temporal coincidence supports the vaccination implementation.[25].

Fifteen federal states instituted the new timing of the second measles dose, but only the Free State of Saxony maintained its timing at 5 years and above until 2016.[26] The population living in the Free State of Saxony will be the control group in the data used for the policy evaluation of families that live in the treatment

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mended for one year without the STIKO recommendation.

[24]This screening takes place nationwide and is obligatory for all preschool children. It is organized in the preschool year by the local Department of Health. In general, children are required to attend school if they have their 6th birthday before the deadline (country-specific between June and September) and will be enrolled at the earliest possible date. This data source is still used widely for official publications on the vaccination status of children and adolescents at school enrollment.

[25]In phases of recommended well-child visits within fixed-time windows, vaccination coverage increases (see figure 2 in Rieck et al. (2013, p. 3))

[26]Both the STIKO and the Free State of Saxony rely on evidence from the U.S. and other industrial countries for their timing recommendation. For example, in the U.S. the Center for Disease Control and Prevention and the Advisory Committee on Immunization Practices recommend a 2-dose series at 12–15 months and 4–6 years. The WHO recommended the second measles vaccination at school entry conditional on high vaccination rates for the first dose ($> 90$) and high school enrollment ($> 95$), and otherwise in the second year of life (see WHO (2017, p. 221)). Since 2017, the second measles recommendation in the Free State of Saxony has been at 45 months of age and older (Sächsiche Landesärztekammer (2018)). Nevertheless, the second dose is preferable for indication (*e.g.*, measles exposure; note that the minimum length of time to the first vaccination is 3 months).

states. This STIKO timeliness adaption was the first adaption of more than 2 years of an existing recommendation, which means that the possible time span of a timely immunization is more than halved.

Since 2006, the varicella ('chicken pox') vaccination has been recommended and could be combined with MMR (*e.g.*, with a licensed tetravalent vaccine) (see STIKO (2006).)

An overview of the age-specific recommendations for the measles[27] vaccination since introduction of the second dose until today is listed in Table 2.1.

Table 2.1: STIKO measles recommendation for primary vaccination

| **Measle** | **Recommendations and time span 1991–2019** | | | |
|---|---|---|---|---|
| **dose** | 8/1991[1]–2/1997 | 3/1997[1]–2/1998 | 3/1998[1]–6/2001 | 7/2001[1]–2019 |
| *1st* | 14 | 11–14 | 11–14 | 11–14 |
| *2nd* | 60 | 60 | (48–) 60 | 15–23 |

Notes: The age limit (*in months*) represents the recommended age that a child should be (at a given point in time) and be eligible for the first/ second measles dose. [1] Publication date of the vaccination recommendations. Sources: STIKO (1991, 1997, 1998, 2001, and 2018).

Since 2001, the states have reported infections and vaccination status in school entry health exams.[28]

In 2016, the average German vaccination rates based on vaccination card information[29] are 97.1 % for one measles dose and 92.9 % for two doses at the age before school entry: The first rate reaches on average the critical herd immunity threshold of 95 %, and the second is just below. The regional variation varies for one shot from 95.2 % (Baden-Württemberg) to 98.3 % (Mecklenburg-West Pomerania and Saxony-Anhalt) and for two shots from 89.5 % (Baden-Württemberg) to 95.8 % (Mecklenburg-West Pomerania). This was the first year that all

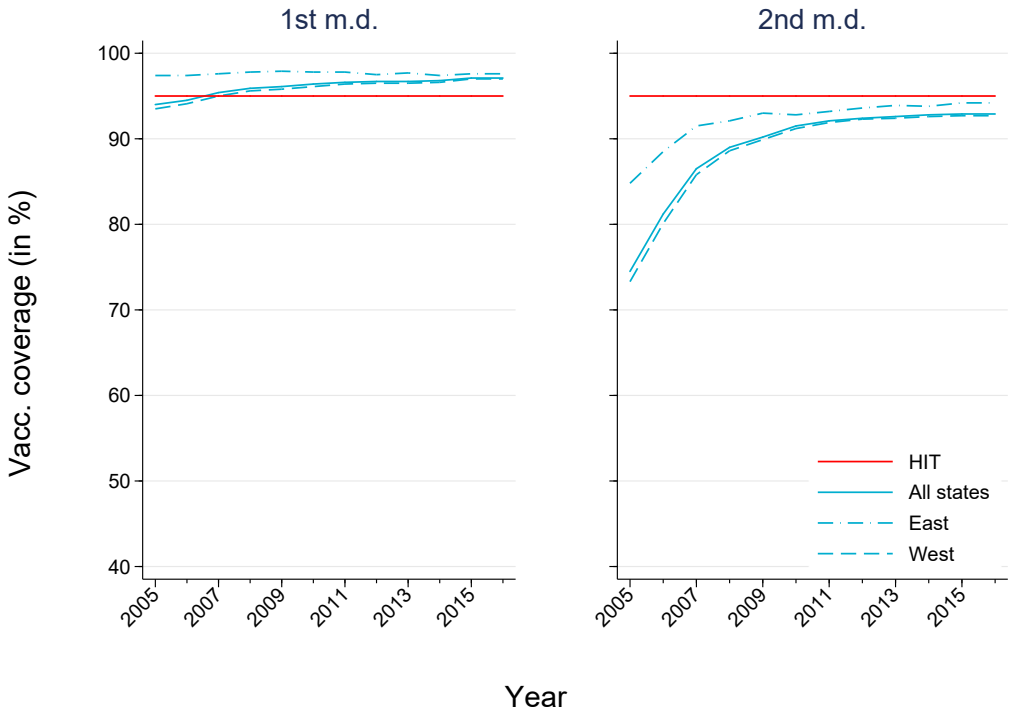
[27]In the time span from 1991 until 2018, the first and second dose recommendations against measles, mumps and rubella are identical. Only for girls, a third rubella dose is recommended at age 11 and older.

[28]The law aimed to build up a nationwide, statutory reporting and central surveillance for all 431 county and 16 state health departments managed by the RKI (see §34 Abs. II IfSG). Before the law, there was voluntary, nonsystematic reporting to the RKI, and rates often were estimations on single survey data.

[29]Rates are based on children with vaccination cards at the health check-up before school entry (on average between 90.9 and 92.6 % for the period 2005 to 2016; in east states, the annual card rates are some higher, between 0.1 and 2.8 percentage points; the east-west population ratio is approximately 1:8.)

states exceeded the herd immunity threshold (HIT) at 95 % vaccination coverage at least for the first dose (see Robert Koch Institute (2018, p. 153)).[30]

Figure 1: Measles status at school entry health exam by *region*




Notes: Data from Robert Koch Institute (2008-2018), own calculations. The red line is the herd immunity threshold at 0.95.

In Figure 1 looking at the data from the school entry health exam in the period from 2005 to 2016, a continuous increase in West Germany can be seen for the first vaccination. As of 2008, the 95% threshold was exceeded in East and West Germany. For the second vaccination, the increase is very clear in the years 2005 to 2009, possibly due to the adjustment in 2001. Since then, the rates show a horizontal course.

To obtain a more accurate picture at the timing of vaccination, the measles quota by birth cohorts totally and by age of vaccination are given in Figure 2. The data are based on the KiGGS data. On the left side, the totally up-to-date status (solid) and the timely status at the age of 2 (dashed) for the first measles dose are shown; shown in the right figure are the corresponding rates for the second dose

[30]It should be remembered, however, that for more than 7 % of the preschool child population, the information was not documented, and the measles field effectiveness is below 100 % (see section **??**).

totally and at the age of 7. At the beginning of the period considered, the gap between the overall rate and the age-recommended rate for both vaccinations was over 20 percentage points, showing a clear rapprochement over time. Interestingly, these data for the first vaccination show a steady decline for the birth cohort in 1997 and younger. This observation shows that some of the overall rates are achieved much later than recommended. Vaccine fatigue could of course also be behind this finding.

Given the recommendation adaption in 2001, there are direct and indirect investigations of interest: Directly, the adaption aims to reach an earlier date of the second measles dose and to increase overall vaccination status at school entry. Indirectly, the new recommended time span for the primary measles immunization ending at the age of 2 could support a timely first immunization.

Whether and how strongly vaccination policies work is ultimately an empirical question. This applies to mandates, recommendations and adjustments of these policies. In summary, I investigate whether the recommendation adaption affects the measles vaccination status

*(i)* for the second dose at age 2 to 6 (*age shift* effect)

*(ii)* for the second dose at age 7 (*direct adaption* effect) and

*(iii)* for the first dose at age 2 (*indirect adaption* effect).

Finally, I take a closer look at reporting data on the incidence of measles, which must be legally recorded and reported by the health authorities in the federal states since 2001.

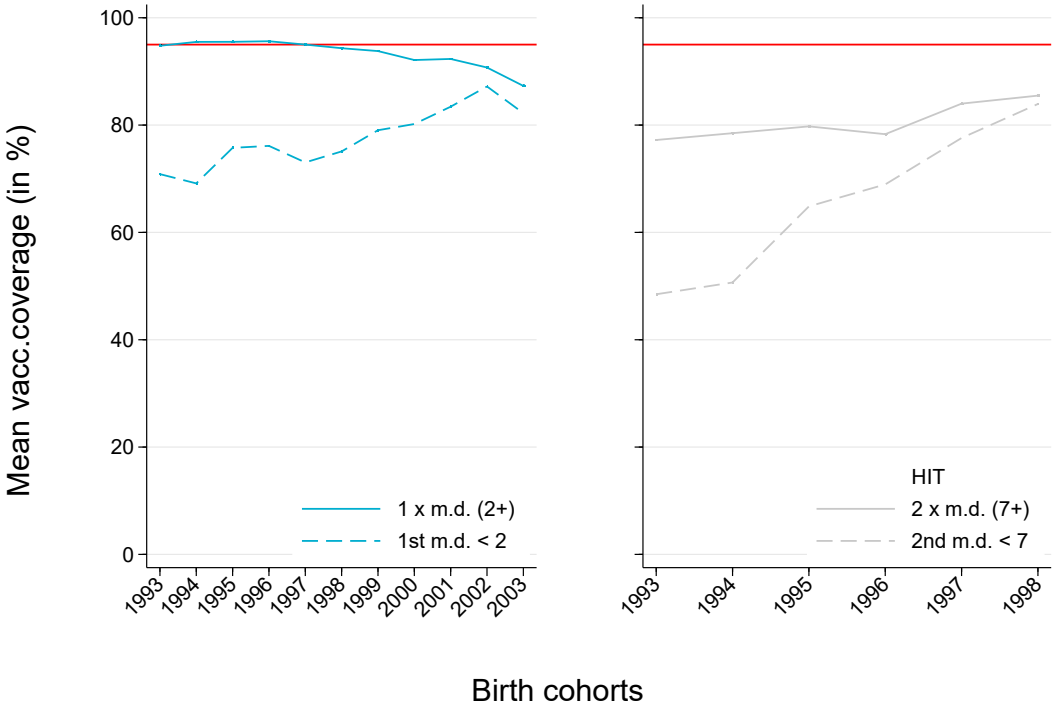
# 4 Data

Initially, I will describe the dataset generally and the sample selection. Next, I will go into more detail about the variables used in the empirical analyses, first and foremost the individual information for the measles vaccination. After sample stratification by birth cohorts, I will describe the covariates.

## 4.1 Survey data and sample selection

The KiGGS data from the RKI are a cross-sectional dataset collected between May 2003 and May 2006. The dataset is representative of the German population aged up to 18 and contains a massive set of sociodemographic individual and

Figure 2: Measles status and timeliness by *birth cohort*




Source: KiGGS data, own calculations.

household variables, health inputs and outcomes and information on vaccinations based on vaccination cards records. The KIGGS data cover birth cohorts from 1985 to 2006. In a first step, 167 sample locations were randomly selected at the community level (primary sample units). Then, age-specific random samples were drawn from population registries (secondary sample units).[31]

For the analyses, the survey years 2003 to 2005 are considered because there are no observations in 2006 for the control group. All children are mentioned that had a vaccination card, were born and have lived since birth in Germany, and reside with at least one biological parent. All child and household information is provided by at least one biological parent, and observations with missing values are dropped. The full sample has 6,272 observations. Table 2.2 shows the sample size after the selection criteria in the upper panel. The size of the samples depends on selected birth cohorts based on the research question and empirical analyses (see Section 4.2).

[31]For more details on the setting and the sampling procedure, see Kurth (2007).

Table 2.2: Sample selection and size

| **Selection criterion** | **Sample size** |
|---|---|
| None (full sample) | 17,640 |
| Survey years 2003 to 2005 | 14,988 |
| birth cohorts 1993 to 2004 | 9,718 |
| Child with vaccination card | 9,265 |
| Child born in Germany | 8,988 |
| Child lived with at least one biological parent | 8,916 |
| Questionnaire responder was biological parent | 8,896 |
| Observations without missing information | 6,272 |

## 4.2 Vaccination status and timeliness

When analyzing the timeliness of vaccination, it is important to know the age of the child at the time of vaccination. The most direct method of assessing the age shift of recommendation on timely up-to-date vaccination status is to compare the the age at vaccination before and after the adaption.[32] The KIGGS data provide such information with limitations. Retrospectively, especially for the pre-policy period, the age-specific timeliness information on a child's vaccination status is not known exactly. For each individual, there is age-specific timeliness information if the child received the first (second) measles dose before the age of 2 (7) years. Additionally, the up-to-date information about the total sum of measles doses at the date of interview is known.

I use two samples to analyze the recommendation adaption: the timely up-to-date sample and the pre-post sample.

The up-to-date sample involves the post-policy period from 2003 to 2005 to investigate the age- and group-specific up-to-date measles status of children aged 2 to 6 years for two measles doses. I also check the difference of children aged 1 to 2 years between treatment and control group for the first measles dose. The corresponding cohorts are listed in Table 2.3.

The pre-post sample contains all children aged 2 and older for the first measles dose or aged 7 years and older for the second measles dose before and after the recommendation adaption. For the pre-policy period, all children were taken into account, so the recommended vaccination age *and* the measured time of vaccination status are not affected by the adaption. This is also the case for the

[32]For the considered time period the registry of reported data by the German health departments are not helpful for Germany because it started nationwide by law in 2001. Administrative data derived from health insurance claims could be an alternative source if the control group is well represented.

post-policy period if both recommendation and measurement of the vaccination come after the policy introduction. For earlier policy decisions or other adaption to have no effect, I start with the previous period in 1998. Children born between in 1999 and 2000 (first dose) and in 1995 (second dose) were excluded because the (age-appropriate) vaccination recommendation or the school entry health exam is before the 2001 adaption, but the measurement of vaccination status falls into the post-period. Therefore, it is unclear whether the decision is driven by the 2001 adaption. In Table 2.3, birth cohorts considered in the analyses are defined by sample, measles doses, age, pre-period, and post-period.

Table 2.3: Sample birth cohorts

| **Sample** | **Measles dose** | **Age** (*in years*) | **Vacc. age** (*in years*) | **Pre-period** *1998 – 2000* | **Post-period** *2003 – 2005* | ***N*** |
|---|---|---|---|---|---|---|
| *Up-to-date* | 1st dose | 1 | | | 2002 – 2004 | 625 |
| | | 2 | | | 2001 – 2003 | |
| | 2nd dose | 2 | | | 2001 – 2003 | 3,114 |
| | | 3 | | | 2000 – 2002 | |
| | | 4 | | | 1999 – 2001 | |
| | | 5 | | | 1998 – 2000 | |
| | | 6 | | | 1997 – 1999 | |
| *Pre-post policy* | 1st dose | | $< 2$ | 1996 – 1998 | 2001 – 2003 | 3,098 |
| | 2nd dose | | $< 7$ | 1993 – 1994 | 1996 – 1998 | 2,473 |

## 4.3 Parental, household and offspring characteristics

The dataset used includes a wide range of individual and household characteristics to account for individually heterogeneity. These include proxies for a parent's socioeconomic status (education, occupation, income), migration background, household size, birth order, and regional structure.

There is also information on child care and school enrollment. Both are criteria that can play a role in the vaccination decision (see Section 3.2 and footnote 22). Furthermore, vaccination-specific and health-specific information is available in the dataset, including well-child visits, medical vaccination advice, parental reasons against vaccinations, chronic illnesses and timeliness of other vaccinations. The vaccination guidelines advise a steady control of the vaccination status of children as part of the well-child visits (so-called U-exams): For analyses of the first

measles dose, the U6 (10 to 12 months old) and U7 (21 to 24 months) groups are included; for the second dose, the U8 (46 to 48 months) and U9 (60 to 64 months) groups are also included. In addition, medical advice and recommendation has an important role for the parental decision, for which, of course, individual reasons also play a role, *e.g.*, the individual opinion of the non-need for immunization. A child's health can also influence the decision. There is information about a set of chronic diseases and their first appearance by age: For the first measles dose, all chronic diseases that occurred in the first two years of life are considered, and for the second dose, the first three years are considered. Last but not least, it is possible to check for the revealed vaccination preferences of the parents. Therefore, a vaccination is considered that had taken place earlier: For the first measles dose, the timely primary immunization for hepatitis B[33] is used; the second dose is the timely first vaccination against measles. Table 2.13 in the Appendix lists all mentioned variables with attributes. The descriptive statistics for the full sample and both the treatment and control groups are provided in Tables 2.14, 2.15 and 2.16 in the Appendix.

# 5 Empirical strategy

My empirical exploration has two parts. First, investigating the age-specific development of timeliness, I compare the treatment and control groups (difference in mean) in an age-period regression framework after 2001 using sample 1. Second, I use a difference-in-differences (DD) regression framework that allows me to take advantage of the variation in the implementation of recommendation adaption between states using multilevel data. I estimate the policy effects of the STIKO recommendation adaption on the parental decision of a child's measles vaccination as an outcome variable using individual data from the KIGGS dataset. Using sample 2, I estimate the causal effect of the recommendation adaption in 2001 for the measles vaccinations level for the first dose at the end of the second year of life and the second dose at the end of the 7th year of life.

To take advantage of the available observed sociodemographic information at the individual and household level, the unit of analysis is an individual $i$ to control for heterogeneity and improve the power of the estimates.

After model descriptions, I will discuss the identification strategy and chal-

[33]I chose hepatitis B because it is still not a standard vaccination in the first year series such as diphtheria, tetanus, or pertussis.

lenges with serial correlation and clustering within policy evaluation.

## 5.1 Age shift regression model

The adaption contains a recommendation age shift into the second year of life. Analyzing this shift effect, I use a 3-way interactions regression model for the group-specific age-period vaccination timing. Formally, the outcome indicator for the parental choice of child $i$ living in state $s$ in period $t$ to be vaccinated against measles is $VAC_{ist}$.

$$Pr(VAC_{ist} = 1|.) = F(age_i \text{ x } treated_s \text{ x } period_t, X_{ist}) \tag{1}$$

where $X_{ist}$ captures individual and household controls and $treated_s$ is the indicator for the treatment, the age-adaption for the second measles vaccination within the second year of life. For flexible model specification I include indicators for age and period. For the distribution function $F$, the identity is assumed to be a linear probability model (LPM). For robustness, I will estimate the regressions with age to be continuous and squared assuming a positive increasing age-effect on vaccination probability within the age span from 2 to 6. Additionally, I assume the normal distribution for the distribution function to estimate a nonlinear probit model accounting for the binary nature of the dependent variable. I will provide graphical analyses of the partial effects because, even in linear models, these effects require computation of the coefficients.[34] In this model, the age-period effects are of interest. I control for birth cohorts without additional restrictions using individual records because there is no exact linear dependency between age, period and cohort in the data (see Robertson and Boyle (1986, p. 530)): *e.g.*, individuals who are 2 years old at the date of interview in the survey year 2003 might be born in the year 2000 or 2001, in the survey year 2004 in 2001 or 2002, and so on.

[34]For comparison with the nonlinear model, it is also easier and more meaningful (Ai and Norton (2003) and Greene (2010)).

## 5.2 Policy evaluation regression model

Now, let $VAC_{is\tau}$ be the outcome indicator for the parental choice of individual $i$ living in state $s$ born in year $\tau$[35] to be vaccinated against measles.

The linear probability model within the DD framework then is

$$Pr(VAC_{is\tau} = 1|.) = \gamma_s + \lambda_\tau + \beta D_{s\tau} + X_{is\tau}\delta + \epsilon_{is\tau} \tag{2}$$

where $\gamma_s$ and $\lambda_\tau$ are state and cohort fixed effects. Individual and household controls are captured by $X_{is\tau}$. $\epsilon^v_{is\tau}$ is the error term. $\gamma_s$ captures group differences between treatment and control group before the policy change (with the assumption to be constant over time in the absence of treatment), and $\lambda_\tau$ implies the cohort effects of vaccination rates for both groups. $D_{s\tau}$ is an indicator whether state $s$ recommended the adaption for birth cohort $\tau$ and the DD estimator for $D_{s\tau}$ is the parameter of interest.[36]

To obtain some dynamic policy insights, the DD model can be extended to birth cohort treatment effects:

$$Pr(VAC_{is\tau} = 1|.) = \gamma_s + \lambda_\tau + \sum_{j \in J} \beta_j \; D^j_{s\tau} + X_{is\tau}\delta + \epsilon_{is\tau} \tag{3}$$

where $\gamma_s$ and $\lambda_\tau$ capture state and year of birth fixed effects. $D^j_{s\tau}$ is an indicator equal to 1 if cohort $j$, with $J = \{-m, .., -1, 1, .., n\}$, was affected by the policy ending with $m$ 'leads' and $n$ 'lags' treatment effects. The reference group will be the last pretreatment birth cohort ($j$=0). The coefficients $\beta_j$ represent the cohort $j$-specific DD estimator. Assumptions and challenges of the DD framework are discussed in detail in the next section.

## 5.3 Identification and inference

I use variation across birth cohorts and state-specific age recommendations for vaccination to identify the effect of the vaccination timeliness adaption at the state level on individual vaccination probability. Next, to control for observed heterogeneity by adding powerful individual controls for the vaccination decisions,

[35] In this model, birth cohorts are the 'time' perspective (see Section 4.2).

[36] For robustness, a nonlinear DD model is estimated (Puhani (2012)).

both the variance of residuals and the standard errors of the estimates are reduced, and the estimates become more precise. This approach is helpful in the DD framework if the covariates are not affected by the timeliness adaption themselves; otherwise, they are *bad controls* in the sense of Angrist and Pischke (2009, 22f, 64). The use of a timely first measles dose as a control variable in the regression of the second dose probability is unproblematic here since the first decision was completed prior to the policy for all birth cohorts used.

In standard difference-in-differences models, identification relies on the *common trend assumption* that in the absence of the policy, outcomes in the treated states would have evolved as in the control group. More precisely, to achieve identification, I assume linearity, and any unobserved time-varying state characteristics that affect outcomes are uncorrelated with treatment. Checking this trend assumption, I need at least two periods before the recommendation adaption for both groups, *i.e.*, treatment and control groups. With equation 3, the significance of all leads[37] of the DD estimator checks the common trend assumption and should be zero (Granger causality test, see Angrist and Pischke (2009, p. 177)).

Another point is the individual home decision. The federal state where the family lives is a decision variable that is (at least partly) under individual control. In response to the state's policy decisions, parents might move. In my context, it is unlikely that a nonbinding vaccination recommendation and its adaption directly influence parental home decisions; both measles doses were already introduced and are free of charge as they are statutory health insurance benefits. Therefore, it can be assumed that when parents insist on a second vaccination, they could also go to another state to obtain the vaccination. In the case of measles exposure, even in Saxony, an earlier second vaccination was recommended. In addition, I cannot control for German internal migration since the place of residence is known only at the time of the interview and not at the time of vaccination. Public statistics show that the majority of German internal migration takes place within a federal state, which is not a problem in this framework of policy analyses. In addition, migration within the states of the treatment group would not be a problem either.[38].

For valid inference of the t-statistics in my regression frameworks, two pitfalls must be considered: clustering and serial correlation (see Bertrand, Duflo, and

[37]Here, leads are birth cohorts that are not affected by the recommendation adaption.

[38]Since reunification, annual German internal migration has been approximately 5 %, of which $\frac{3}{4}$ takes place within the federal states (Destatis (2016, pp. 14, 20)).

Mullainathan (2004) or Angrist and Pischke (2009, chapter 8)).

One challenge is the calculation of the 'correct' standard errors choosing the 'right' clusters[39]: The level of clustering is the highest level of aggregation determined by the data used[40] or the empirical strategy. Within the DD framework, the timeliness adaption policy affects both states and birth cohorts and must be used as the level of clustering. This consideration accounts for the presence of a common random effect at the state and birth cohort levels (see Bertrand, Duflo, and Mullainathan (2004), Donald and Lang (2007), and Moulton (1986)); the individual age-specific vaccination decision in the same state tends to be correlated because individuals in the same state are exposed to the same policy environment, *e.g.*, federal-state (vaccination) policies and education system.

Within the clustered data, the assumption for the error term is $E[\epsilon^v_{ist}\epsilon^v_{jst}|X] = \rho\sigma^2_\epsilon > 0$ for individual $i$ and $j$ in the same state, $s$, and the same year of birth, $t$, where $\rho$ is the intraclass correlation coefficient (ICC) and $\sigma^2_\epsilon$ is the residual variance (see Angrist and Pischke (2009, 231f)). There is no standard ICC method for binary outcome variables[41], but within regression frameworks, the influence of ICC depends on the level of clustering. Additionally, the regression model 3 with state-fixed effects allows state-specific intercepts that account for within-group error correlation next to cluster robust standard errors (so-called 'cluster-specific effects models' in Cameron and Miller (2016, p. 8)). Thus, clustering and cluster fixed effects are common practice (see Cameron, Gelbach, and Miller (2011, p. 242)).

The other challenge in DD models is policy autocorrelation inducing a serial correlation problem. For example, the persistence of regional structural factors or a regional shock could induce time-series correlation at the state level. A practical solution suggested by Bertrand, Duflo, and Mullainathan (2004, p. 267) is to collapse data into a pre-period and post-period. This is mentioned in the regression equation 2. Additionally, here, another quick fix is to go to the next higher clustering level (*states*) for the calculation of the standard errors and to allow residual correlation over time within states (see Angrist and Pischke (2009, p. 319)). How-

[39]Normally, in ordinary-least-square regressions, standard errors are underestimated (overstates t-statistics) if the data are clustered (see Cameron and Miller (2016)).

[40]The KiGGS study design is a two-stage cluster sampling scheme (nested clusters). The first stage includes 167 study locations over all states; at the second stage, a random sample from the population register is drawn (see Kamtsiuris, Lange, and Rosario (2007)).

[41]Wu, Crespi, and Wong (2012) compared five ICC estimation procedures for binary data and discussed the shortcomings.

ever, this approach has its price[42] in a reduction of clusters: with higher cluster aggregation and smaller group number, a common and simple correction[43] for the inference is to use a $T(G\text{-}1)$ distribution for p-values and critical values instead of the standard normal distribution (see Cameron and Miller (2016, p. 11)). In Section 7.1, I will review the robustness of the results depending on the chosen level of aggregation over the DD regression models.

# 6 Results

## 6.1 Age shift

The linear predictions by measles vaccination, age group and groups are presented in Table 2.4. For the first dose, both treatment and control group reach approximately 90 % for children aged under 3 years. Within treated states, the probability for the second dose is approximately 70 % for both age groups, 2 to 4 years and 5 to 6 years. Within in the younger age group, the probability is over 5 times larger and approximately 15 percentage points higher for the older children compared to those in the control group. The control group had a probability of 10 (49) % for age group 2 to 4 years (5 to 6). In the older age group, there are only significant differences in 2005.

For visualization of the three-way interaction regression results, I plot age- and group-specific marginal effects over periods. The left graph in Figure 3 plots the predicted vaccination probability over the three survey periods: the average rate of all 2- to 6-year-old children increases from below 60 % in 2003 to 70 % in 2004 and 75 % in 2005 in the treatment group and no time effects within the control group. Looking at the age-specific rates by survey periods in the middle and right graphs, this upwards shift holds for both age groups in the treatment group. For the control group, predicted probabilities stay constant over time, with a higher level in the older age group.

[42]With clustering on the highest possible aggregation level, the state level here, the number of clusters is 16, raising the question of whether the standard errors are also calculated incorrectly. For Germany, there is research using similar evaluation frameworks for policy analyses on state-level variation, *e.g.*, to analyze bans (see Anger, Kvasnicka, and Siedler (2011) and Marcus and Siedler (2015)) or schooling duration (Pischke (2007)). An unfinished discussion exists about the minimum number of clusters and some 'solution' procedures (see Angrist and Pischke (2009, 231f), Hansen (2007a,b)). One example is a bias correction with the bias-reduced linearization procedure by Bell and McCaffrey, but it does not work in a DD model (Angrist and Pischke (2009, p. 239)).

[43]Stata takes into account the number of clusters and chooses the distribution for critical values.

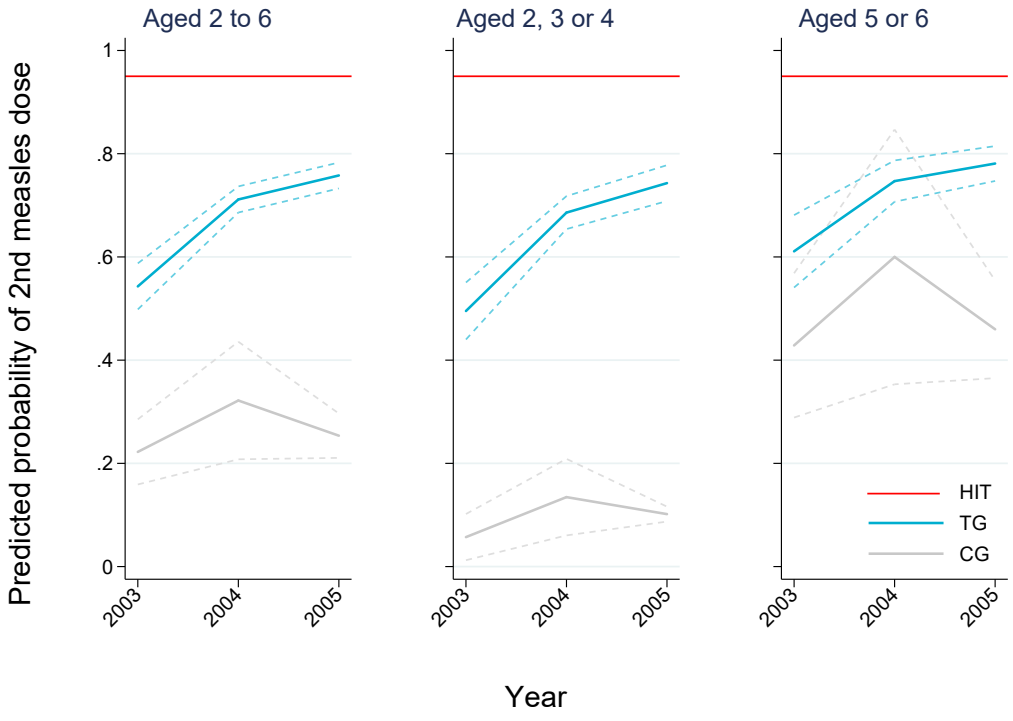
Table 2.4: Predicted vaccination probability by *dose*, *group* and *age*

| **Measles dose** | **Age-group** | **TG** *Margin* | [95% *CI*] | | **CG** *Margin* | [95% *CI*] | |
|---|---|---|---|---|---|---|---|
| **Pr**(*1 x m.d.* = 1) | 1 – 2 | 0.898 | 0.866 | 0.930 | 0.890 | 0.847 | 0.934 |
| **Pr**(*2 x m.d.* = 1) | 2 – 4 | 0.676 | 0.647 | 0.704 | 0.102 | 0.077 | 0.128 |
| | 5 – 6 | 0.735 | 0.703 | 0.768 | 0.487 | 0.400 | 0.573 |

Notes: Average predicted probabilities calculated as the average of the probability among individuals in the LPM with *state* x *year of birth* clustered S.E. using *Stata*'s .margins.

Aside from the positive significant development within the treated states, one should note that the necessary herd immunity threshold of 95 % is still missed by 20 percentage points within this age group.

Figure 3: 2nd measles vaccination by *agegroups* and *period*




Source: KiGGS data, own calculations.

Assuming age squared and supplementary estimating a probit model, the results remain similar, and Figure 7 and 8 in the Appendix show the same pattern: the predicted probabilities are constant in the treatment group and increase in the

control group with age (on the left). Over time, the probabilities increase for the treatment group for age 3 to approximately 5 but remain constant for the control group (on the right).

Additionally, the results raise the question as to whether this development directly causes the 2001 adaption, and if so, how strongly. For an age-specific causal interpretation of the policy effects, information on the second measles dose is required for the same age groups for the policy, but is not available. Therefore, a causal analysis for the direct policy effect is possible for children aged 7 years and older before and after the adaption. Fortunately, the indirect policy effect could be explored in this manner as well.

## 6.2 Policy evaluation

Figure 4 shows the means of vaccination rates by birth cohorts and groups for both measles vaccinations based on children with vaccination cards. The vertical black line is the 2001 recommendation adaption at the first affected birth cohorts and separates pre-period and post-period; the 2000 birth cohort was the first for which the primary vaccination should be finished at age 2, the 1996 birth cohort was the first for which school entry health exam and 7th birthday were after the 2001 adaption.

The DD regression results with one collapsed pre-cohorts and post-cohorts[44] (indicator variable $POST$ for post-cohorts) for both the first measles dose at age 2 and the second at age 7 are presented in Table 2.5. Column $M1$ is the DD model without additional explanatory variables. In specification $M2$ the parental, household and child controls are included. In $M3$ state fixed effects allow state-specific intercepts to account for differences in levels and for intracluster correlations.

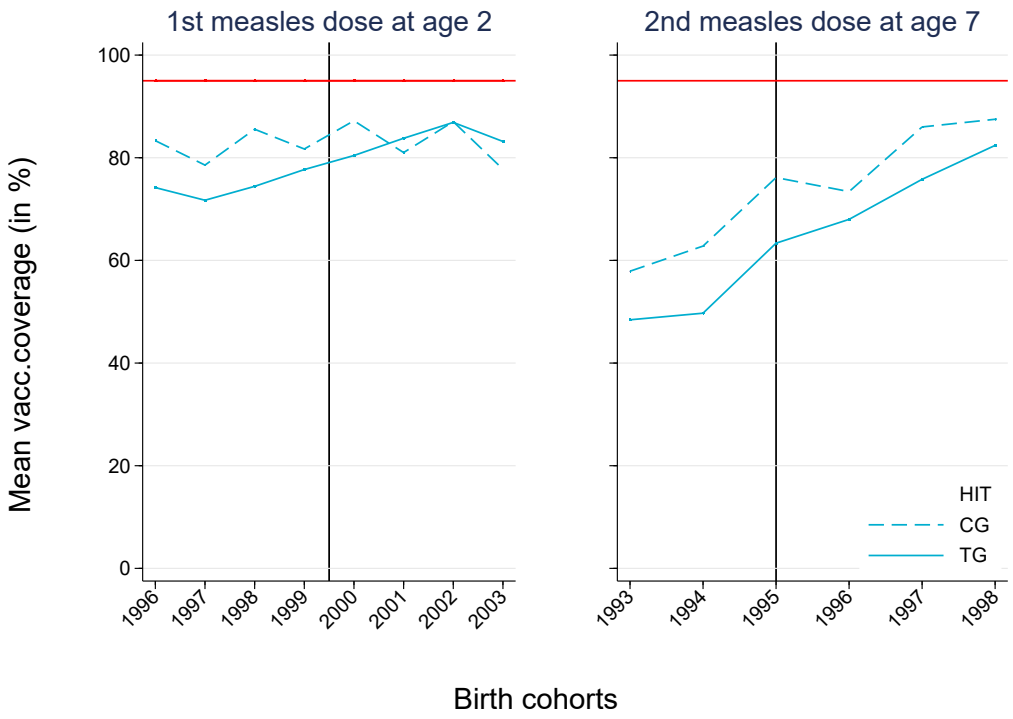
The temporal development in the vaccination probability (coefficient for $POST$ in $M3$) shows no change over time for the first measles dose and an increase of over 13 percentage points for the second dose, which implies a rather large secular trend.

The same for the average outcome levels in both groups in the pre-period that is estimated by the TG indicator: After including controls, there is no difference between control and treatment group for the first dose but a significant level difference of 7.5 percentage points in favor of the control group ($M2$). Specification

[44]See Section 4.2 for period classification.

$M3$ allows state-specific intercepts to account for possible within-group correlation, but they are not suitable for interpretation at the state level, as there are, for example, a number of small states.

Figure 4: 2nd measles vaccination by *age* and *period*




Notes: KiGGS data, own calculations. The 2001 adaption is indicated by the vertical line (black).

The parameters of interest, the DD coefficients (TG x POST), indicate the adaption policy effects: for both the first and second measles dose, the adaption increases the likelihood of a timely vaccination status by over 9 percentage points significantly at the 1% and 5% significance levels.[45] The average vaccination rate in the pre-period was 83.9 % (74.5 %) for the first measles dose and 60.4 % (48.4 %) for the second dose in the treatment (control) group. If one then sets the DD coefficients in relation to the counterfactual conditional in order to calculate the effect size, the result for the first vaccination is an increase of 12.2 % and for the second vaccination of 12.6 %.[46]

[45]The results of nonlinear probit estimations for $M2$ are similar, calculating margins and the effect of interest as differences of cross differences (see Table 2.17 in the Appendix).

[46]first m.d.: $\frac{9.8}{83.9-3.6}$; second m.d.: $\frac{9.3}{60.4-13.3}$.

Taking into account the level difference in the previous period, this means a higher timely vaccination probability for the first vaccination in the treatment group after adaption and a resolution to the level of the control group, which itself experienced a significant increase in this time.

Table 2.5: Pre-post estimates - *1st and 2nd measles dose*

| | **Dep. var.: child's vaccination status** | | |
|---|---|---|---|
| | **Pr**(*1st measles dose at age 2* = 1) | | |
| | $M1$ | $M2$ | $M3$ |
| POST | -0.019 (0.023) | -0.038 (0.025) | -0.036 (0.025) |
| TG | -0.098*** (0.021) | -0.027 (0.022) | |
| TG x POST | 0.119*** (0.028) | 0.097*** (0.029) | 0.098*** (0.027) |
| $N(df)$ | 3,075 (3,072) | 3,075 (3,018) | 3,075 (3,004) |
| adj. $R^2$ | 0.013 | 0.237 | 0.237 |
| | **Pr**(*2nd measles dose at age 7* = 1) | | |
| | $M1$ | $M2$ | $M3$ |
| POST | 0.176*** (0.031) | 0.127*** (0.035) | 0.133*** (0.038) |
| TG | -0.119*** (0.023) | -0.075*** (0.025) | |
| TG x POST | 0.073 (0.045) | 0.098** (0.044) | 0.093** (0.044) |
| $N(df)$ | 2,459 (2,456) | 2,459 (2,397) | 2,459 (2,383) |
| adj. $R^2$ | 0.064 | 0.196 | 0.202 |
| **Controls** | | √ | √ |
| **State FE** | | | √ |

Notes: LPM with clustered standard errors (in parentheses) at the *state* x *year of birth* level. Significance: *p<0.1, **p<0.05, ***p<0.01. Controls are control variables child (gender, medical vaccination advice, reasons against vaccination, chronic diseases, well-child visits, child care and/or school entry, timely vaccination record of hepatitis B/first measles), and control variables household (income, ISCED-97, parental occupation, migration background, no. of children in household, firstborn indicator, local living area).

Next, the DD framework is stratified with two treatment regions: to consider the different immunization policies until reunification all 'old' (*West* Germany) and all 'new' federal states except the control group (*East* Germany) are grouped

together. Despite the policy history, both groups respond similarly to the adaptation: For both measles doses, the point estimate is greater in the old states. For the second dose, the DD point estimate of the East states is 6 percentage points, but not significantly different from the massive and significant time effect of the control group (0.133). The results are shown in Table 2.6 column *East* and *West*.

Table 2.6: Pre-post estimates - *east/west*

| | **Dep. var.: child's vaccination status** | | |
|---|---|---|---|
| | **Pr**(*1st measles dose at age 2* = 1) | | |
| | *All* | *East* | *West* |
| POST | -0.036 (0.025) | -0.036 (0.025) | |
| TG x POST | 0.098*** (0.027) | 0.085*** (0.030) | 0.103*** (0.028) |
| *adj.* $R^2$ | 0.234 | 0.237 | |
| | **Pr**(*2nd measles dose at age 7* = 1) | | |
| | *All* | *East* | *West* |
| POST | 0.133*** (0.038) | 0.133*** (0.038) | |
| TG x POST | 0.093** (0.044) | 0.060 (0.054) | 0.104** (0.046) |
| *adj.* $R^2$ | 0.157 | 0.202 | |

Notes: LPM with clustered standard errors (in parentheses) at the *state* x *year of birth* level. Significance: *p<0.1, **p<0.05, ***p<0.01. All specifications include state FE and control variables child (gender, medical vaccination advice, reasons against vaccination, chronic diseases, well-child visits, child care and/or school entry, timely vaccination record of hepatitis B/first measles), and control variables household (income, ISCED-97, parental occupation, migration background, no. of children in household, firstborn indicator, local living area).

As the adaption is shown to have positive significant effects on both vaccination decisions, possible short-term dynamic effects within the post-period are considered below.

In Table 2.7, the last column are the results of the dynamic DD regression with several cohorts before and after policy adaption to analyse (short-term) dynamic policy patterns. The middle column contains the previous results for comparison.

Table 2.7: Pre-post estimates - *policy dynamics*

| | **Dep. var.: child's vaccination status** | |
|---|---|---|
| | **Pr**(*1st measles dose at age 2* = 1) | |
| TG x POST | 0.098*** (0.027) | |
| TG x 1996 (pre) | | 0.017 (0.019) |
| TG x 1997 (pre) | | 0.034 (0.023) |
| TG x 1998 (pre) | | reference group |
| TG x 2001 (post) | | 0.120*** (0.016) |
| TG x 2002 (post) | | 0.103*** (0.023) |
| TG x 2003 (post) | | 0.114*** (0.025) |
| *adj.* $R^2$ | 0.237 | 0.238 |
| **Common trend** | | $F(2, 93)$ = |
| $F(n, m)(Prob > chi2)$ | | 1.21 (0.3031) |
| | **Pr**(*2nd measles dose at age 7* = 1) | |
| TG x POST | 0.093** (0.044) | |
| TG x 1993 (pre) | | 0.022 (0.027) |
| TG x 1994 (pre) | | reference group |
| TG x 1996 (post) | | 0.098*** (0.027) |
| TG x 1997 (post) | | 0.084*** (0.028) |
| TG x 1998 (post) | | 0.147*** (0.037) |
| *adj.* $R^2$ | 0.207 | 0.252 |
| **Common trend** | | $F(1, 78)$ = |
| $F(n, m)(Prob > chi2)$ | | 0.72 (0.3992) |

Notes: LPM with clustered standard errors (in parentheses) at the *state* x *year of birth* level. Significance: *p<0.1, **p<0.05, ***p<0.01. All specifications include state FE and control variables child (gender, medical vaccination advice, reasons against vaccination, chronic diseases, well-child visits, child care and/or school entry, timely vaccination record of hepatitis B/first measles), and control variables household (income, ISCED-97, parental occupation, migration background, no. of children in household, firstborn indicator, local living area).

First, looking at the significance of the pre-policy interaction terms, the *common trend assumption* for the first measles dose (the years 1996 and 1997 (TG x 1996 and TG x 1997) compared to 1998, the last-pretreatment period (reference group)) and the second (TG x 1993 compared to reference group 1994) holds: the null hypothesis that the temporal development between the control and treatment groups is equal before the policy introduction could not be rejected.

Looking at the dynamics of policy, for all post-cohorts affected by the adaption, the vaccination probability increases significantly: the first dose point estimates of the post-policy period appear to be constant for the birth cohorts 2001 to 2003 (TG x 2001=.12 to TG x 2003=.114) and increasing, but are not statistically different, for the cohorts 1996 to 1998 (TG x 1996=.098 to TG x 1998=.147).

Comparing these results for the second dose with the group differences of the age shift in Section 6.1 the effects here are clearly smaller, but causal. As previously described within the DD analyses, older cohorts had to be included, and for that, the recommendation adaptation replaces the upcoming previous vaccination recommendation: when the adaption came into force in 2001, the post-period cohorts (1996 to 1998) were already 3 years and older, and for them, the vaccination for the second dose was immediately due. Additionally, the pre-policy practice in both groups is fully considered to control the vaccination status in the context of the School Medical Entry and, if necessary, to initiate vaccination.

# 7 Robustness

In this section, I address concerns regarding my empirical strategy as mentioned before. First, the clustering level will be changed, allowing different error relationships within the chosen units and calculating the corresponding standard errors. Second, instead of birth cohorts, I use school cohorts for the second measles dose, because the school entry health exam is appointed in the preschool year for the forthcoming school beginners. Third, the parental vaccination decision for measles might be influenced by other contemporaneous vaccination decisions (here rubella and mumps). Therefore, I estimate a three-equation model as seemingly unrelated. Fourth, I check for parallel events that possibly influence vaccination demand. Finally, I perform a placebo test on a preventive health examination.

## 7.1 Clustering within DD

Avoiding potential biases in the estimation of the standard errors (see the discussion in Section 5.3), it is important to account for the possible correlation of the errors $\epsilon_{ist}$ across time and/or space.

Checking the robustness of the main results, I apply different clustering levels. I allow for any covariance structure within regional areas over time by computing the standard errors clustered at the federal state (policy aggregation level) and the sample points (sampling structure) level. Additionally, I compute standard errors clustered at the state-time level with only two cohort periods (pre-post) and compare these standard errors with the chosen level in the main specification, the state and year of birth level. Finally, robust and OLS standard errors are calculated. Shown in Table 2.8 are the standard errors at the different clustering levels.

In the upper panel in Table 2.8, the policy effect for the first measles dose appears robust over all specifications. For the second dose, the standard errors are increasing with lower aggregation assumption for the clustering.

Table 2.8: Pre-post estimates - *clustering*

| | | **Dep. var.: child's vaccination status** | | | | |
|---|---|---|---|---|---|---|
| | *Coef.* | **Pr**(*1st measles dose at age 2* = 1) | | | | |
| TG x POST | 0.098 | ***(0.014) | ***(0.010) | ***(0.027) | ***(0.038) | **(0.042) |
| *No. of clusters* | | 16 | 32 | 94 | | |
| | | **Pr**(*2nd measles dose at age 7* = 1) | | | | |
| TG x POST | 0.093 | ***(0.019) | ***(0.014) | ** (0.044) | * (0.056) | * (0.056) |
| *No. of clusters* | | 16 | 32 | 79 | | |
| **Cluster-standard errors at level** | | *state* | *state x pre-post* | *state x year of birth* | *robust*[1] | *OLS* |

Notes: LPM with level-clustered standard errors are in parentheses. [1] White heteroskedastic. Significance: *p<0.1, **p<0.05, ***p<0.01. All specifications include state FE and control variables child (gender, medical vaccination advice, reasons against vaccination, chronic diseases, well-child visits, child care and/or school entry, timely vaccination record of hepatitis B/ first measles), and control variables household (income, ISCED-97, parental occupation, migration background, no. of children in household, firstborn indicator, local living area).

## 7.2 School cohorts

The STIKO recommendations for the second measles dose suggested School Medical Entry in the preschool year as the practical point in time to control the up-to-date vaccination status. One might consider school cohorts as the affected policy cohort. Next to public health policy, education and school policy is administered by the federal states. Therefore, school cohorts differ slightly between states because the school age cut-off[47] is different within a three month span: There are eight states with a cut-off at June 30, two states with an August 30 cut-off and six with a September 30 cut-off. These dates were considered in the analysis.

Table 2.9: Pre-post estimates - *cohorts*

| **Dep. var.: child's vaccination status** **Pr**(*2nd measles dose at age 7* = 1) | | | |
|---|---|---|---|
| *Birth cohorts* ($N$=2,459) | | *School cohorts*($N$=2,669) | |
| TG x POST | 0.093** (0.044) | TG x POST | 0.113** (0.051) |
| *adj.* $R^2$ | 0.212 | *adj.* $R^2$ | 0.183 |
| TG x 1993 (pre) | 0.022 (0.027) | TG x 1993/94 (pre) | -0.032 (0.020) |
| TG x 1994 (pre) | reference group | TG x 1994/95 (pre) | reference group |
| TG x 1996 (post) | 0.098***(0.027) | TG x 1995/96 (post) | 0.068** (0.028) |
| TG x 1997 (post) | 0.084***(0.028) | TG x 1996/97 (post) | 0.085***(0.026) |
| TG x 1998 (post) | 0.147***(0.037) | TG x 1997/98 (post) | 0.228***(0.026) |
| *adj.* $R^2$ | 0.252 | *adj.* $R^2$ | 0.199 |
| | | *Common trend* $F(n,m)(Prob > chi2)$ | $F(1,78)$ = 2.51 (0.1175) |

Notes: LPM with clustered standard errors (in parentheses) at the *state* x *year of birth* and at *state* x *school cohort* level. Significance: *p<0.1, **p<0.05, ***p<0.01. All specifications include state FE and control variables child (gender, medical vaccination advice, reasons against vaccination, chronic diseases, well-child visits, child care and/or school entry, timely vaccination record of hepatitis B/first measles), and control variables household (income, ISCED-97, parental occupation, migration background, no. of children in household, firstborn indicator, local living area).

The policy adaption in 2001 was released in July next to the start of school, so the 2002/2003 school cohort, born in the second half of 1995 and the first half of 1996, was the first cohort that was affected by the adaption.

[47]The child starts school in the year in which his or her 6th birthday is before the cut-off.

The results for the school cohorts are robust with the standard and the dynamic policy model; with school cohorts, the increasing dynamics are slightly steeper.

## 7.3 MMR - seemingly unrelated

Since the mid-1980s, the trivalent combination vaccine measles-mumps-rubella has been initially recommended for simultaneous vaccinations in addition to the existing monovalent vaccines. Therefore, the measles vaccination can also be viewed as a conditional, non-independent decision with the other two vaccinations.

The seemingly unrelated regression (SUR) model[48]:

$$Pr(VAC^{v}_{is\tau} = 1|.) = \gamma_s + \lambda_\tau + \beta D_{s\tau} + X_{is\tau}\delta + \epsilon^{v}_{ist}$$

with $VAC^{v}_{is\tau}$ is an indicator for whether individual $i$ living in state $s$ in cohort $\tau$ has been vaccinated against $v = 1, .., V$ with $V = 3$ for set (measles, mumps, rubella)

Table 2.10: Pre-post estimates - *seemingly unrelated*

| | **Dep. var.: child's vaccination status** | | |
|---|---|---|---|
| | **Pr**(*2nd ... dose at age 7* = 1) | | |
| | *measles* | *mumps* | *rubella* |
| POST | 0.122***(0.037) | 0.120***(0.037) | 0.114***(0.035) |
| TG | -0.073***(0.025) | -0.075***(0.025) | -0.081***(0.025) |
| TG x POST | 0.101** (0.044) | 0.101** (0.044) | 0.101** (0.044) |
| *N* | 2,459 | | |

Notes: LPM with clustered standard errors (in parentheses) at the *state* x *year of birth* level. Significance: *p<0.1, **p<0.05, ***p<0.01. Controls are control variables child (gender, medical vaccination advice, reasons against vaccination, chronic diseases, well-child visits, child care and/or school entry, timely vaccination record of corresponding first dose), and control variables household (income, ISCED-97, parental occupation, migration background, no. of children in household, firstborn indicator, local living area).

[48]I used Roodman's Stata .cmp that allows for clustering (see Roodman (2009)).

The results highlight a similar pattern for all three vaccinations: starting from a higher level in the control group, an increase over time for both the control and treatment groups could be observed with an additional policy effect of approximately 12 to 13 percentage points for all vaccinations.

## 7.4 Outbreak or policy?

The causal inference within DD regression frameworks persists on the common trend assumption and that there are no other secular trends or events influencing the vaccination decision. Regional outbreaks could be such events. Therefore, I divide the treatment states into two groups, one with a documented measles outbreak in the post-policy period and the other with no such event. Database are publications of the European Centre for Disease Control and Prevention (ECDC) describing regional outbreaks (see Hellenbrand et al. (2003), Siedler (2005), Siedler, Hellenbrand, and Rasch (2002), and Siedler et al. (2006)): For the period 2001 to 2005, there were outbreaks in regions of Bavaria (November 2001 and March-July 2005), Lower Saxony (November 2001-March 2002), North Rhine Westphalia (January-March 2002), Hesse (January-May 2005), and Schleswig-Holstein (January-April 2001). Measles outbreaks and their reports are usually restricted on local areas, *e.g.*, counties. However, there is no local information in the KiGGS data within the states. Therefore, the separation can be made only very roughly at the level of the federal states.

Table 2.11 shows the results for both measles vaccinations: For the first and the second measles dose, there is no difference between the two groups.

Outbreaks may affect demand, but the question is whether this occurrence is only regional. The reporting of measles epidemics is often very medial, so it is not limited to local print media in Germany, especially in the considered time period. Furthermore, measles outbreaks are not uncommon, since due to their infection potential at low vaccination rates, outbreaks occur regularly and reoccur partly regionally.

In Section 8, I will take a closer look at incidences in the period after policy adaption.

Table 2.11: Pre-post estimates - *outbreaks*

| | **Dep. var.: child's vaccination status** | | |
|---|---|---|---|
| | **Pr**(*1st measles dose at age 2* = 1) | | |
| | *All* | *Outbreaks*[1] | *No outbreaks* |
| TG x 2001 (post) | 0.120***(0.016) | 0.156***(0.017) | 0.092***(0.024) |
| TG x 2002 (post) | 0.103***(0.023) | 0.094***(0.032) | 0.108***(0.030) |
| TG x 2003 (post) | 0.114***(0.025) | 0.101***(0.022) | 0.125***(0.038) |
| *adj.* $R^2$ | 0.235 | 0.238 | |
| $N$ | 3,075 | 3,075 | |
| | *Common trend* | $F(2, 93) =$ | $F(2, 93) =$ |
| | $F(n, m)(Prob > chi2)$ | 2.16 (0.1216) | 0.10 (0.9070) |
| | **Pr**(*2nd measles dose at age 7* = 1) | | |
| | *All* | *Outbreaks*[1] | *No outbreaks* |
| TG x 1996 (post) | 0.098***(0.027) | 0.133***(0.057) | 0.056* (0.032) |
| TG x 1997 (post) | 0.084***(0.028) | 0.070* (0.054) | 0.100***(0.034) |
| TG x 1998 (post) | 0.147***(0.037) | 0.157***(0.056) | 0.131***(0.036) |
| *adj.* $R^2$ | 0.167 | 0.208 | |
| $N$ | 2,459 | 2,459 | |
| | *Common trend* | $F(1, 78) =$ | $F(1, 78) =$ |
| | $F(n, m)(Prob > chi2)$ | 0.01 (0.9052) | 2.30 (0.1335) |

Notes: LPM with clustered standard errors (in parentheses) at the *state* x *year of birth* level. Significance: *p<0.1, **p<0.05, ***p<0.01. [1] Bavaria, Hesse, Lower Saxony, North Rhine Westphalia and Schleswig-Holstein. All specifications include state FE and control variables child (gender, medical vaccination advice, reasons against vaccination, chronic diseases, well-child visits, child care and/or school entry, timely vaccination record of Hepatitis B/first Measles), and control variables household (income, ISCED-97, parental occupation, migration background, no. of children in household, firstborn indicator, local living area).

## 7.5 Placebo test

As a final robustness analysis and to assess whether my results might be driven by a secular trend, I look at the adaption effects of a placebo health outcome. The outcome variable of the policy adaption, the measles status of the child, is replaced by another prevention measure that was not the content of the adaption but is done in parallel. One possibility for this would be a child health screening such as well-child visits. The $U9$ scheduled for the age of 5 years (between the 60th and 64th month of life) or $U10$ after the 7th birthday would be suitable. After the U10, which has been offered in Germany since 2006, no information is available on the birth cohorts used. In contrast to age-recommended vaccinations, the execution of these examinations must take place within a certain time interval and cannot be made up after being exceeded (see Gemeinsamer Bundesausschuss (2017, p. 7)).

Table 2.12 presents the results of the placebo outcome regression. For this child screening, there are no trend differences between the both groups in the considered period of time either before timeliness adaptation in 2001 or in the years thereafter. This and the previous outbreak analysis give no indication of a parallel policy trend and support the previous causal analysis.

# 8 A look at incidence rates in the long-run

The long-term expectations of a vaccination policy are high immunization rates and associated declining disease rates in the population. One goal of the timeliness adaption for the second measles vaccination in the context of primary immunization is to increase the protection of children under the age of 5 years.

Since 2001, it has been a legal obligation to report all notifiable disease cases and pathogens to the RKI. In Figure 5, the incidence cases per million population in Germany are plotted from 2001 to 2016.[49] In addition, the proportion of incidence cases that occurred in the age groups 0 to less than 5 years and 0 to less than 15 years are calculated. In line with the policy change, the two groups from the previous analyzes are again compared; the left figure shows the average over all federal states without Saxony, and the right contains the Saxon measles cases.

First, it can be seen that there were still regular outbreaks during this period, which occurred at a distance of 2 to 4 years (gray bars). It can also be stated that in 7 of the 16 years, Saxony had an incidence rate of less than 1 case per million

[49]Data for measles incidences are available until 2018, but population statistics end in 2016.

Table 2.12: Pre-post estimates - *placebo*

| | **Dep. var.: child's vaccination status** | **Dep. var.: child's screening status** |
|---|---|---|
| | **Pr**(*2nd m.d. at age 7* = 1) | **Pr**(*U9 screening* = 1) |
| TG x 1993 (pre) | 0.022 (0.027) | -0.022 (0.023) |
| TG x 1994 (pre) | reference group | reference group |
| TG x 1996 (post) | 0.098*** (0.027) | 0.026 (0.016) |
| TG x 1997 (post) | 0.084*** (0.028) | 0.010 (0.017) |
| TG x 1998 (post) | 0.147*** (0.037) | -0.001 (0.023) |
| *adj.* $R^2$ | 0.167 | 0.065 |
| *N* | 2,459 | 2,459 |
| *Common trend* $F(n,m)(Prob > chi2)$ | | $F(1,78)$ = 0.95 (0.3321) |

Notes: LPM with clustered standard errors (in parentheses) at the *state* x *year of birth* level. Significance: *p<0.1, **p<0.05, ***p<0.01. [1] Bavaria, Hesse, Lower Saxony, North Rhine Westphalia and Schleswig-Holstein. All specifications include state FE and control variables child (gender, medical vaccination advice, reasons against vaccination, chronic diseases, well-child visits, child care and/or school entry, timely vaccination record of Hepatitis B/first Measles), and control variables household (income, ISCED-97, parental occupation, migration background, no. of children in household, firstborn indicator, local living area).

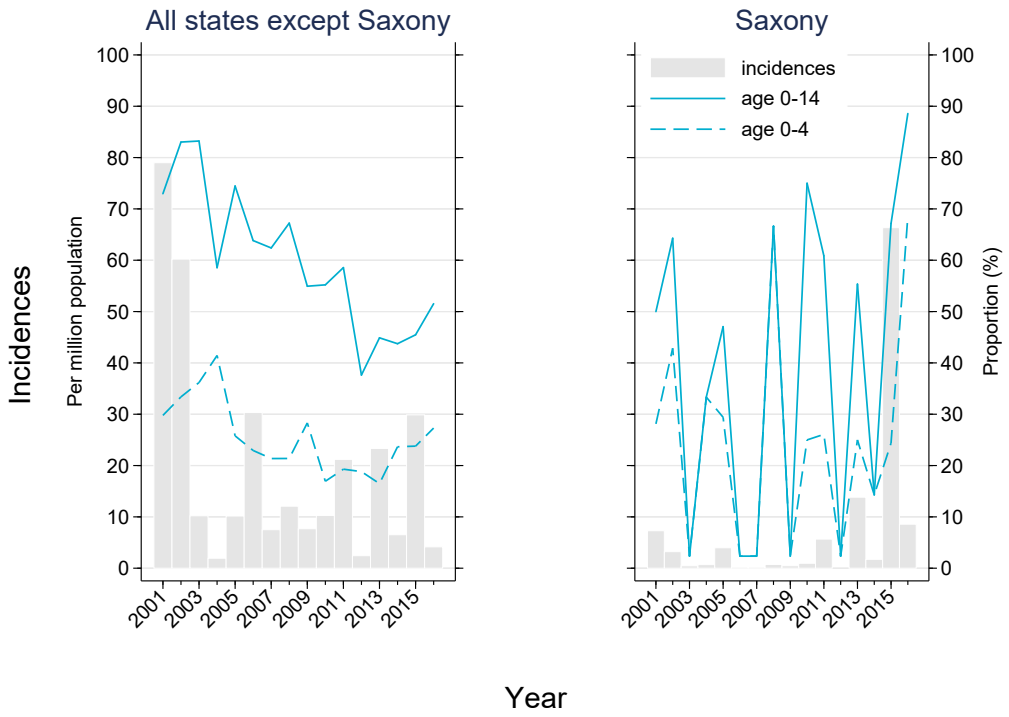
population and generally below-average incidence rates. In recent years, however, the local rates in Saxony are increasing with an above-average high in 2016.

Second, in the states where the measles timeliness adaption was implemented in 2001, there is a steady decline in the proportion of disease cases in both age groups. For Saxony, in the years in which the incidence rate was over 5 cases per million population, the proportion of cases among children under 15 years was 50 % or even higher.

The average German incidence rates, however, are regionally very different: for instance, in Germany, the absolute incidences were over 1,500 cases[50] in 2001, 2002, 2006, 2011, 2013, 2015, and 2017. For example, in North-Rhine Westphalia, in 2 of these 7 years, the regional quota was over 50 % (53 in 2017; 74 in 2006), and in 2 of these 7 years, the quota was over 25 % (26 in 2001; 34 in 2002).

[50]Relative to the German population, with approximately 82 million inhabitants, the cases are over 18 per million population, which is half of the worldwide average in the year 2015 and over 18 times above the measles eradication definition (see Section 1).

Figure 5: Measles cases *per million* and *proportions of age groups*




Source: Data from the Robert Koch Institute *SurvStat@RKI* 2.0, and from *Destatis*, own calculations.

# 9 Conclusion

According to current recommendations, timely primary vaccination should be completed for all children in the first two years of life. Almost all recommended immunizations require a certain number of vaccinations to ensure the necessary immune response.

The results here, representing further analyses of health department's reporting data and claims data of health insurance, show a positive development of vaccination status for Germany in the last 15 years. The introduction of the adaption already shows initial success in the short and long run. Rieck et al. (2013) analyzed claims data for the birth cohorts 2004 to 2006 regarding age and vaccination status: their results show high first measles dose status and an increasing second measles dose status for 2- and 3-year-old children, which are in line with my findings. Compared to the rates at the school entry health exam, the level of the first dose is reached already at a young age (see Figure 1). For the second dose, the difference between the rates at 3 years and before school entry differs between 10 and 15 percentage points when including the Free State

of Saxony in the data.

It can be assumed that the opportunity costs for measles vaccinations decreased by the 2001 adaption because the vaccinations take place next to the well-child visits in the first years of life. Due to higher parental screening compliance in the first years, doctor visits are increased, time costs are reduced, and the probability of having already experienced an infection is lower under otherwise identical conditions. These results give reason to certify a nonbinding vaccination policy; however, the incentives should be used as best as possible, especially with a recommendation policy framework.

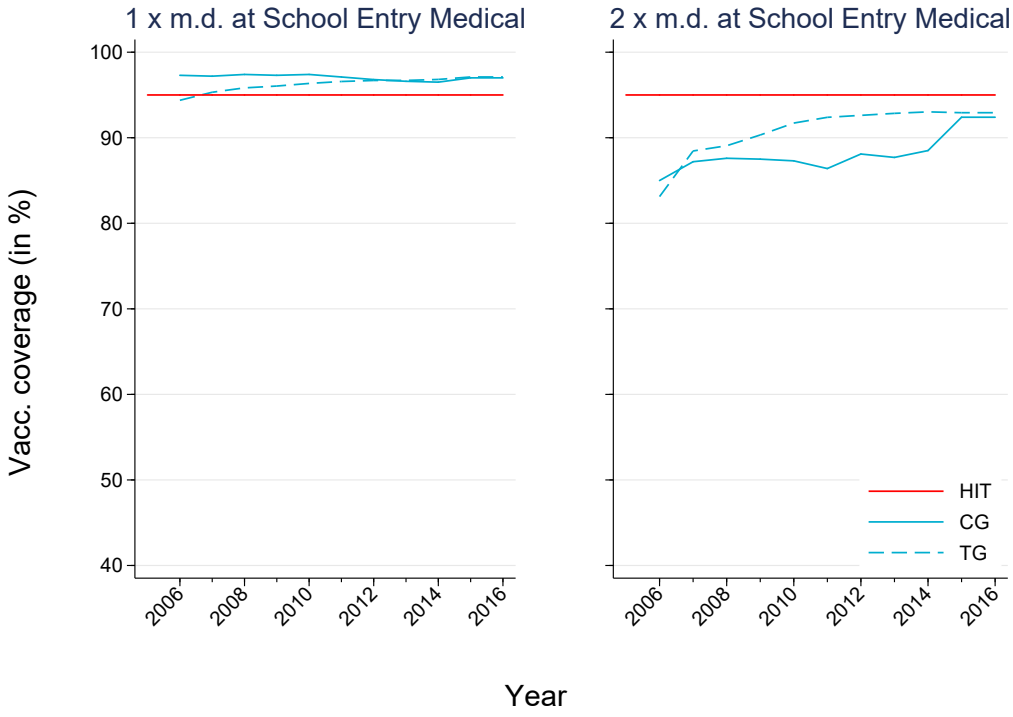
From an economic point of view, it is of great benefit to know how the distribution of those policy effects is accomplished on both market sides, *i.e.*, vaccination demand by parents and doctoral supply efforts. This consideration is important to transfer and implement policy adaption efficiently. Limited by the data, this remains here an open question.

Despite these positive findings, the coverage rates are still not sufficient to prevent outbreaks, and in 2019, we are still far from having the nationwide coverage required to build adequate protection and advance the elimination of the measles virus.

The main problem is that a relatively high immunization rate is needed in the population and a pure recommendation vaccination policy reaches its limits. Whether in the case of measles, such as France and Italy, Germany should finally achieve a vaccination mandate or intervene in other ways remains an exciting political discussion.

# 10 Appendix

Figure 6: Measles status by *year of school entry health exam*




Source: Data from Robert Koch Institute (2008-2018), own calculations.

Table 2.13: Explanation of variables

| | |
|---|---|
| **Dependent variables** | |
| 1st m.d.[b] | measles vaccination status: 1 = child got 1st measles vaccination timely; 0 = else |
| 2nd m.d.[b] | measles vaccination status: 1 = child got 2nd measles vaccination timely; 0 = else |
| $U9$[b] | screening status: 1 = child got $U9$ well-child visit; 0 = else |
| **Control variables** | |
| *Child characteristics* | |
| Gender[b] | 1 = child is female; 0 = else |
| Child care under age 2[b] | 1 = child care in the first/second year of life; 0 = else |
| School enrollment (4 cat.) | regular; delayed; earlier; not yet |
| Well-child visit[b] (U6 to U9) | 1 = child visited the screening; 0 = else |
| Medical advice against vaccination (4 cat.) | MMR or one single component; all; single vaccination; non |
| Chronic illness under 2[b] (N=14) | 1 = child has illness within the first second years of life; 0 = else |
| Chronic illness under 3[b] (N=14) | 1 = child has illness within the first three years of life; 0 = else |
| Reasons against vaccination (3 cat.) | yes; no; don't know |
| Vaccination side effects (3 cat.) | yes; no; don't know |
| Timely hepatitis B vaccination[b] | 1 = child got vaccination at age of 2; 0 = else |
| *Parental and household characteristics* | |
| Professional qualification (8 cat., mother and father) | apprenticeship; professional training school, vocational college; specialist college; technical college, engineering college; university, polytechnic; other training qualification; No professional qualification; still in professional training. |
| Education (3 cat.) | max. household ISCED (1997): low, middle, high |
| Income (4 cat.) | 0 < 1,500; 1,500 < 2,250; 2,250 < 3,000; 3,000 and more |
| Migration background (3 cat.) | both sides; one-sided; non |
| Children in household (4 cat.) | single child; two; three; four and more |
| Birth order[b] | 1 = child is firstborn, 0 = else |
| Region (4 cat.) | rural (<5' inhabitants), small town (5' < 20'), middle town (20' < 100'), urban (> 100') |

[b] binary

Table 2.14: Descriptive statistics - *part* 1

| | **full sample** | **Treatment group (TG)** | **Control group (CG)** |
|---|---|---|---|
| *N* | 6,272 | 5,571 | 701 |
| **Dependent variables** | | | |
| 1st measles dose[1] | 0.94 | 0.93 | 0.95 |
| 2nd measles dose[1] | 0.72 | 0.70 | 0.26 |
| 1st measles dose ($< 2$)[2] | 0.77 | 0.76 | 0.82 |
| 2nd measles dose ($< 7$)[2] | 0.62 | 0.61 | 0.69 |
| $U9$[2] | 0.64 | 0.64 | 0.65 |
| **Control variables** | | | |
| Female | 0.49 | 0.49 | 0.52 |
| Age | 12.9 | 12.9 | 12.6 |
| Child care under age 2 | 0.19 | 0.18 | 0.32 |
| Timely hepatitis B vaccination[2] | 0.59 | 0.57 | 0.74 |
| *School enrollment* | | | |
| Regular | 0.44 | 0.44 | 0.43 |
| Delayed | 0.03 | 0.03 | 0.04 |
| Earlier | 0.03 | 0.03 | 0.01 |
| Not yet | 0.50 | 0.50 | 0.51 |
| *Well-child visit* | | | |
| U6 | 0.96 | 0.96 | 0.98 |
| U7 | 0.94 | 0.94 | 0.95 |
| U8 | 0.73 | 0.73 | 0.73 |
| *Medical advice against vaccination* | | | |
| MMR or one component | 0.01 | 0.01 | 0.00 |
| All | 0.00 | 0.00 | 0.00 |
| Single vaccinations | 0.03 | 0.04 | 0.00 |
| Non | 0.95 | 0.95 | 0.98 |
| *Parental reasons against vaccination* | | | |
| Yes | 0.09 | 0.09 | 0.05 |
| No | 0.91 | 0.91 | 0.95 |
| Don't know | 0.00 | 0.00 | 0.00 |
| *Vaccination side effects* | | | |
| Yes | 0.02 | 0.02 | 0.02 |
| No | 0.98 | 0.98 | 0.98 |
| Don't know | 0.00 | 0.00 | 0.00 |

Notes: [1] Mean values refer to cohorts of the up-to-date sample, [2] Mean values refer to cohorts of the pre-post sample.

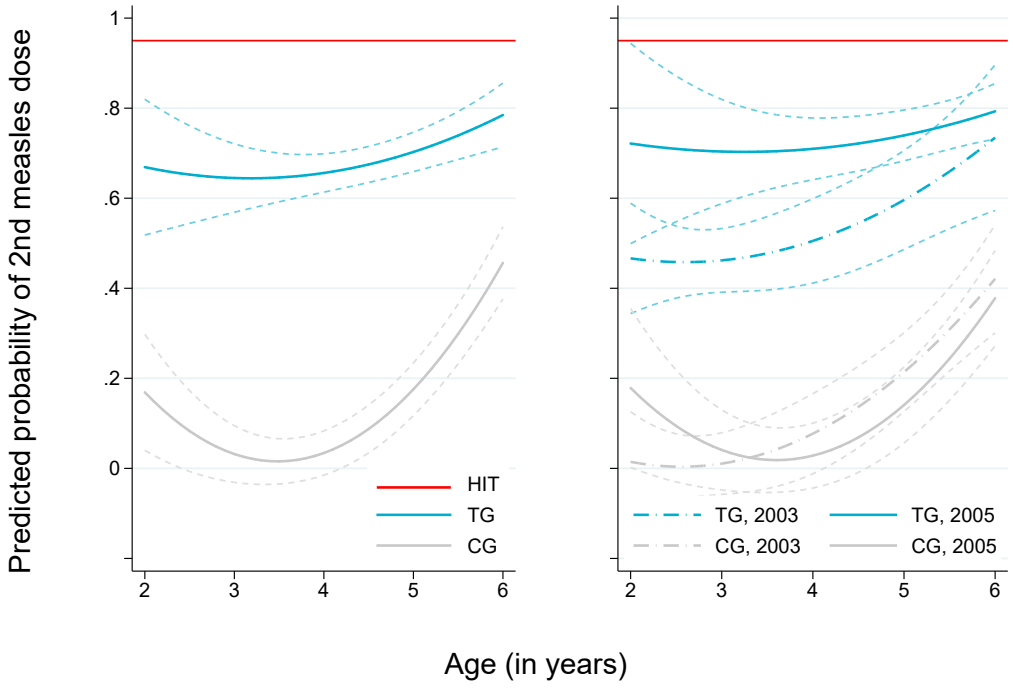
Table 2.15: Descriptive statistics - *part* 2

| | **full sample** | **Treatment group (TG)** | **Control group (CG)** |
|---|---|---|---|
| *N* | 6,272 | 5,571 | 701 |
| *Professional qualification* (mother/ father) | | | |
| Apprenticeship | 0.43/0.42 | 0.44/0.41 | 0.40/0.47 |
| Professional training school | 0.16/0.11 | 0.16/0.11 | 0.17/0.17 |
| Vocational college | 0.12/0.15 | 0.12/0.15 | 0.16/0.11 |
| Engineering college/ applied university | 0.06/0.09 | 0.06/0.09 | 0.09/0.08 |
| University | 0.11/0.15 | 0.11/0.16 | 0.14/0.14 |
| Other training qualification | 0.03/0.02 | 0.03/0.03 | 0.01/0.01 |
| No professional training | 0.08/0.05 | 0.08/0.05 | 0.01/0.01 |
| Still in professional training | 0.01/0.00 | 0.01/0.00 | 0.01/0.00 |
| *Household ISCED education* | | | |
| low | 0.03 | 0.03 | 0.01 |
| middle | 0.48 | 0.48 | 0.50 |
| high | 0.49 | 0.49 | 0.49 |
| *Household income* | | | |
| 0 < 1,500 | 0.17 | 0.16 | 0.21 |
| 1,500 < 2,250 | 0.27 | 0.26 | 0.36 |
| 2,250 < 3,000 | 0.30 | 0.30 | 0.25 |
| 3,000 and more | 0.27 | 0.28 | 0.18 |
| *Migration background* | | | |
| both sides | 0.09 | 0.10 | 0.01 |
| one-sided | 0.08 | 0.08 | 0.02 |
| non | 0.83 | 0.81 | 0.97 |
| *Children in household* | | | |
| Single child | 0.18 | 0.17 | 0.22 |
| Two | 0.52 | 0.53 | 0.47 |
| Three | 0.20 | 0.20 | 0.20 |
| Four and more | 0.10 | 0.09 | 0.11 |
| Firstborn | 0.47 | 0.47 | 0.47 |
| *Region* | | | |
| Rural | 0.26 | 0.25 | 0.38 |
| Small town | 0.27 | 0.26 | 0.31 |
| Middle town | 0.25 | 0.26 | 0.15 |
| Urban | 0.22 | 0.23 | 0.17 |

Table 2.16: Descriptive statistics - *part* 3

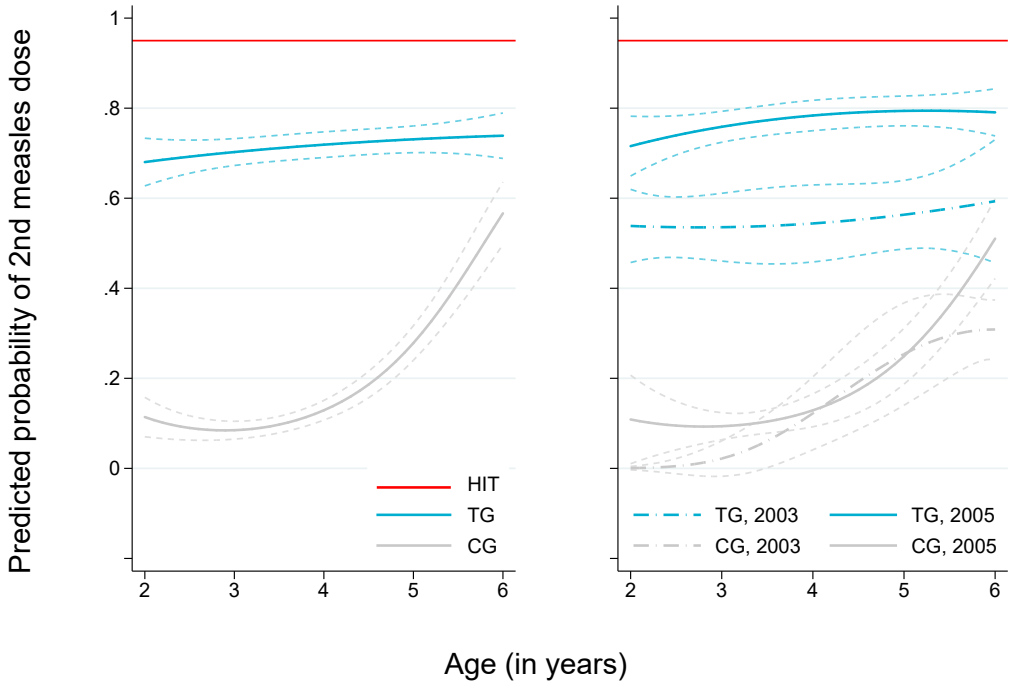
| | **full sample** | **Treatment group (TG)** | **Control group (CG)** |
|---|---|---|---|
| *N* | 6,272 | 5,571 | 701 |
| *Chronic disease under* 3 *years* | | | |
| Allergic rhinitis/ conjunctivitis | 0.01 | 0.01 | 0.01 |
| Atopic dermatitis/ eczema | 0.12 | 0.12 | 0.12 |
| Asthma | 0.01 | 0.01 | 0.01 |
| Chronic obstructive pulmonary disease | 0.10 | 0.11 | 0.07 |
| Pneumonia | 0.06 | 0.06 | 0.04 |
| Otitis media | 0.33 | 0.33 | 0.32 |
| Heart disease | 0.02 | 0.02 | 0.02 |
| Anemia | 0.01 | 0.01 | 0.01 |
| Epileptic seizure | 0.03 | 0.03 | 0.03 |
| Thyroid | 0.00 | 0.00 | 0.00 |
| Diabetes mellitus | 0.00 | 0.00 | 0.00 |
| Scoliosis | 0.00 | 0.00 | 0.00 |
| Migraine | 0.00 | 0.00 | 0.00 |
| Other diseases | 0.13 | 0.13 | 0.16 |
| *Chronic disease under* 2 *years* | | | |
| Allergic rhinitis/ conjunctivitis | 0.01 | 0.01 | 0.00 |
| Atopic dermatitis/ eczema | 0.10 | 0.10 | 0.09 |
| Asthma | 0.01 | 0.01 | 0.01 |
| Chronic obstructive pulmonary disease | 0.08 | 0.08 | 0.06 |
| Pneumonia | 0.04 | 0.05 | 0.04 |
| Otitis media | 0.22 | 0.22 | 0.21 |
| Heart disease | 0.02 | 0.02 | 0.01 |
| Anemia | 0.01 | 0.01 | 0.01 |
| Epileptic seizure | 0.02 | 0.02 | 0.02 |
| Thyroid | 0.00 | 0.00 | 0.00 |
| Diabetes mellitus | 0.00 | 0.00 | 0.00 |
| Scoliosis | 0.00 | 0.00 | 0.00 |
| Migraine | 0.00 | 0.00 | 0.00 |
| Other diseases | 0.09 | 0.09 | 0.11 |

Figure 7: 2nd measles vaccination by *age* and *period*




Source: KiGGS data, own calculations.

Figure 8: 2nd measles vaccination by *age* and *period* - *probit*




Source: KiGGS data, own calculations.

Table 2.17: Predicted vaccination probability by *group* and *time* - *probit*

| | $\mathbf{Pr}(1\ x\ m.d.=1)$ | | | $\mathbf{Pr}(2\ x\ m.d.=1)$ | | |
|---|---|---|---|---|---|---|
| | *Margin* | [95% | *CI*] | *Margin* | [95% | *CI*] |
| Pre # CG | 0.798 | 0.762 | 0.834 | 0.559 | 0.532 | 0.586 |
| Pre # TG | 0.769 | 0.750 | 0.789 | 0.491 | 0.457 | 0.525 |
| Post # CG | 0.754 | 0.710 | 0.798 | 0.720 | 0.653 | 0.787 |
| Post # TG | 0.832 | 0.812 | 0.851 | 0.742 | 0.703 | 0.781 |
| $H_0$ : Pre # CG=Pre # TG | | 0.1850 | | | 0.0002 | |
| $H_0$ : Pre # CG=Post # CG | | 0.1131 | | | 0.0002 | |
| $H_0$ : Pre # TG=Post # TG | | 0.0000 | | | 0.0000 | |
| $H_0$ : Post # CG=Post # TG | | 0.0009 | | | 0.5853 | |
| | *Contrast* | [95% | *CI*] | *Contrast* | [95% | *CI*] |
| TIME#TG | 0.107*** | 0.048 | 0.167 | 0.091** | 0.0017 | 0.179 |

Notes: Average predicted margins calculated among group and time using *Stata*'s .margins with contrast option for the difference of cross-differences.

# References


Abrevaya, Jason and Karen Mulligan (2011): "Effectiveness of state-level vaccination mandates: evidence from the varicella vaccine". In: *Journal of health economics* 30 (5), pp. 966–976. DOI: 10.1016/j.jhealeco.2011.06.003.

Ai, Chunrong and Edward C. Norton (2003): "Interaction terms in logit and probit models". In: *Economics letters* 80 (1), pp. 123–129. DOI: 10.1016/S0165-1765(03)00032-6.

Akmatov, Manas K.; Mirjam Kretzschmar; Alexander Krämer and Rafael Mikolajczyk (2008): "Timeliness of vaccination and its effects on fraction of vaccinated population". In: *Vaccine* 26 (31), pp. 3805–3811. DOI: 10.1016/j.vaccine.2008.05.031.

Anger, Silke; Michael Kvasnicka and Thomas Siedler (2011): "One last puff? Public smoking bans and smoking behavior". In: *Journal of Health Economics* 30 (3), pp. 591–601. DOI: 10.1016/j.jhealeco.2011.03.003.

Angrist, Joshua D. and Jörn-Steffen Pischke (2009): *Mostly harmless econometrics: An empiricist's companion*. Princeton university press.

Bertrand, Marianne; Esther Duflo and Sendhil Mullainathan (2004): "How much should we trust differences-in-differences estimates?" In: *The Quarterly journal of economics* 119 (1), pp. 249–275. DOI: 10.1162/003355304772839588.

Binder, Simon and Robert Nuscheler (2017): "Risk-taking in vaccination, surgery, and gambling environments: Evidence from a framed laboratory experiment". In: *Health Economics* 26, pp. 76–96. DOI: 10.1002/hec.3620.

Boulier, Bryan L.; Tejwant S. Datta and Robert S. Goldfarb (2007): "Vaccination Externalities". In: *The B.E. Journal of Economic Analysis & Policy* 7 (1). DOI: 10.2202/1935-1682.1487.

Brito, Dagobert L.; Eytan Sheshinski and Michael D. Intriligator (1991): "Externalities and compulsary vaccinations". In: *Journal of Public Economics* 45 (1), pp. 69–90. DOI: 10.1016/0047-2727(91)90048-7.

Cameron, A. Colin; Jonah B. Gelbach and Douglas L. Miller (2011): "Robust Inference With Multiway Clustering". In: *Journal of Business & Economic Statistics* 29 (2), pp. 238–249. DOI: 10.1198/jbes.2010.07136.

Cameron, A. Colin and Douglas L. Miller (2016): "Robust Inference with Clustered Data". In: *Handbook of Empirical Economics and Finance*. Ed. by A. Ullah and David E. A. Giles. Chapman and Hall/CRC, pp. 16–43.

Dannetun, Eva; Anders Tegnell; Göran Hermansson; Anna Törner and Johan Giesecke (2004): "Timeliness of MMR vaccination—influence on vaccination

coverage". In: *Vaccine* 22 (31-32), pp. 4228–4232. DOI: 10.1016/j.vaccine.2004.04.018.

Destatis (2016): *Datenreport 2016. Ein Sozialbericht für die Bundesrepublik Deutschland*. Statistisches Bundesamt and Wissenschaftszentrum Berlin für Sozialforschung.

Donald, Stephen G. and Kevin Lang (2007): "Inference with Difference-in-Differences and Other Panel Data". In: *Review of Economics and Statistics* 89 (2), pp. 221–233. DOI: 10.1162/rest.89.2.221.

Favin, Michael; Robert Steinglass; Rebecca Fields; Kaushik Banerjee and Monika Sawhney (2012): "Why children are not vaccinated: a review of the grey literature". In: *International Health* 4 (4), pp. 229–238. DOI: 10.1016/j.inhe.2012.07.004.

Federal Ministry of Health (2015): *Nationaler Aktionsplan 20 15–2020 zur Elimination der Masern und Röteln in Deutschland - Hintergründe, Ziele und Strategien*.

Fell, Gerhard; Carola David and Ralf Reintjes (2005): "Impfungen im frühen Kindesalter-Ergebnisse einer epidemiologischen Querschnittstudie in Hamburg". In: *Das Gesundheitswesen* 1 (01), pp. 27–32. DOI: 10.1055/s-2004-813922.

Gemeinsamer Bundesausschuss (2017): *Richtlinie des Gemeinsamen Bundesausschusses über die Früherkennung von Krankheiten bei Kindern (Kinder-Richtlinie) [Stand: 19. Oktober 2017]*. Published in Bundesanzeiger AT 15.03.2018 B2, pp. 1–126.

Geoffard, Pierre-Yves and Tomas Philipson (1997): "Disease Eradication: Private versus Public Vaccination". In: *The American Economic Review* 87 (1), pp. 222–230.

Greene, William (2010): "Testing hypotheses about interaction terms in nonlinear models". In: *Economics Letters* 107 (2), pp. 291–296. DOI: 10.1016/j.econlet.2010.02.014.

Halloran, M. Elizabeth; Ira M. Longini Jr. and Claudio J. Struchiner (2010): *Design and analysis of vaccine studies*. Springer.

Hansen, Christian B. (2007a): "Asymptotic properties of a robust variance matrix estimator for panel data when T is large". In: *Journal of Econometrics* 141 (2), pp. 597–620. DOI: 10.1016/j.jeconom.2006.10.009.

— (2007b): "Generalized least squares inference in panel and multilevel models with serial correlation and fixed effects". In: *Journal of Econometrics* 140 (2), pp. 670–694. DOI: 10.1016/j.jeconom.2006.07.011.

Hellenbrand, Wiebke; Anette Siedler; Annedore Tischer; Christiane Meyer; Sabine Reiter; Gernot Rasch; Dieter Teichmann; Sabine Santibanez; Doris Altmann; Hermann Claus and Michael Kramer (2003): "Progress toward Measles Elimination in Germany". In: *The Journal of Infectious Diseases* 187 (s1), S208–S216. DOI: 10.1086/368046.

Ibuka, Yoko; Meng Li; Jeffrey Vietri; Gretchen B. Chapman and Alison P. Galvani (2014): "Free-Riding Behavior in Vaccination Decisions: An Experimental Study". In: *PLoS ONE* 9 (1). Ed. by Maciej F. Boni, e87164. DOI: 10.1371/journal.pone.0087164.

Kabra, Sushil K. and Rakesh Lodha (2013): "Antibiotics for preventing complications in children with measles". In: *Cochrane Database of Systematic Reviews*. DOI: 10.1002/14651858.cd001477.pub4.

Kamtsiuris, P.; M. Lange and A. Schaffrath Rosario (2007): "Der Kinder- und Jugendgesundheitssurvey (KiGGS): Stichprobendesign, Response und Nonresponse-Analyse". In: *Bundesgesundheitsblatt - Gesundheitsforschung - Gesundheitsschutz* 50 (5-6), pp. 547–556. DOI: 10.1007/s00103-007-0215-9.

Kurth, Bärbel-Maria (2007): "Der Kinder-und Jugendgesundheitssurvey (KiGGS): Ein Überblick über Planung, Durchführung und Ergebnisse unter Berücksichtigung von Aspekten eines Qualitätsmanagements". In: *Bundesgesundheitsblatt-Gesundheitsforschung-Gesundheitsschutz* 50 (5-6), pp. 533–546. DOI: 10.1007/s00103-007-0214-x.

Larson, Heidi J.; Louis Z. Cooper; Juhani Eskola; Samuel L. Katz and Scott Ratzan (2011): "Addressing the vaccine confidence gap". In: *The Lancet* 378 (9790), pp. 526–535. DOI: 10.1016/s0140-6736(11)60678-8.

Lawler, Emily C. (2017): "Effectiveness of vaccination recommendations versus mandates: evidence from the hepatitis A vaccine". In: *Journal of health economics* 52. Ed. by Elsevier, pp. 45–62. DOI: 10.1016/j.jhealeco.2017.01.002.

MacDonald, Noni E.; Shawn Harmon; Eve Dube; Audrey Steenbeek; Natasha Crowcroft; Douglas J. Opel; David Faour; Julie Leask and Robb Butler (2018): "Mandatory infant & childhood immunization: Rationales, issues and knowledge gaps". In: *Vaccine*. DOI: 10.1016/j.vaccine.2018.08.042.

Marcus, Jan and Thomas Siedler (2015): "Reducing binge drinking? The effect of a ban on late-night off-premise alcohol sales on alcohol-related hospital stays in Germany". In: *Journal of Public Economics* 123, pp. 55–77. DOI: 10.1016/j.jpubeco.2014.12.010.

Matysiak-Klose, Dorothea and Sabine Wicker (2017): "Masern in Deutschland – Epidemiologie und Management". In: *DMW - Deutsche Medizinische Wochenschrift* 142 (23). Für die Nationale Verifizierungskommission Masern Röteln (NAVKO) in Deutschland, pp. 1767–1772. DOI: 10.1055/s-0043-117973.

McLean, Huong Q.; Amy Parker Fiebelkorn; Jonathan L. Temte and Greogory S. Wallace (2013): "Prevention of measles, rubella, congenital rubella syndrome, and mumps, 2013: summary recommendations of the Advisory Committee on Immunization Practices (ACIP)". In: *MMWR. Morbidity and Mortality Weekly Report: Recommendations and Reports* 62 (4). Ed. by Centers for Disease Control & Prevention (CDC), pp. 1–34.

Moss, William J. and Fernando P. Polack (2001): "Immune responses to measles and measles vaccine: challenges for measles control". In: *Viral immunology* 14 (4), pp. 297–309. DOI: 10.1089/08828240152716556.

Moulton, Brent R. (1986): "Random group effects and the precision of regression estimates". In: *Journal of Econometrics* 32 (3), pp. 385–397. DOI: 10.1016/0304-4076(86)90021-7.

Nuscheler, Robert and Kerstin Roeder (2012): "Impfbereitschaft in Deutschland am Beispiel der Grippe". In: Böcken, Jan; Bernard Braun and Uwe Repschläger. *Gesundheitsmonitor 2011: Bürgerorientierung im Gesundheitswesen - Kooperationsprojekt der Bertelsmann Stiftung und der BARMER GEK (German Edition)*. Verlag Bertelsmann Stiftung, pp. 77–92. ISBN: 978-3867933469.

— (2016): "To Vaccinate or to Procrastinate? That is the Prevention Question". In: *Health Economics* 25 (12), pp. 1560–1581. DOI: 10.1002/hec.3268.

Patel, Minal K.; Marta Gacic-Dobo; Peter M. Strebel; Alya Dabbagh; Mick N. Mulders; Jean-Marie Okwo-Bele; Laure Dumolard; Paul A. Rota; Katrina Kretsinger and James L. Goodson (2016): "Progress Toward Regional Measles Elimination — Worldwide, 2000–2015". In: *MMWR. Morbidity and Mortality Weekly Report* 65 (44). Ed. by Centers for Disease Control & Prevention (CDC), pp. 1228–1233. DOI: 10.15585/mmwr.mm6544a6.

Périnet, Simone; Marilou Kiely; Gaston De Serres and Nicolas L. Gilbert (2018): "Delayed measles vaccination of toddlers in Canada: Associated socio-demographic factors and parental knowledge, attitudes and beliefs". In: *Human Vaccines & Immunotherapeutics* 14 (4), pp. 868–874. DOI: 10.1080/21645515.2017.1412899.

Pischke, Jörn-Steffen (2007): "The impact of length of the school year on student performance and earnings: Evidence from the German short school years". In:

*The Economic Journal* 117 (523), pp. 1216–1242. DOI: 10.1111/j.1468-0297.2007.02080.x.

Poethko-Müller, C.; R. Kuhnert and M. Schlaud (2007): "Durchimpfung und Determinanten des Impfstatus in Deutschland". In: *Bundesgesundheitsblatt - Gesundheitsforschung - Gesundheitsschutz* 50 (5-6), pp. 851–862. DOI: 10.1007/s00103-007-0248-0.

Poethko-Müller, Christina; Ute Ellert; Ronny Kuhnert; Hannelore Neuhauser; Martin Schlaud and Liane Schenk (2009): "Vaccination coverage against measles in German-born and foreign-born children and identification of unvaccinated subgroups in Germany". In: *Vaccine* 27 (19), pp. 2563–2569. DOI: 10.1016/j.vaccine.2009.02.009.

Puhani, Patrick A. (2012): "The treatment effect, the cross difference, and the interaction term in nonlinear "difference-in-differences" models". In: *Economics Letters* 115 (1), pp. 85–87. DOI: 10.1016/j.econlet.2011.11.025.

Ramsay, Mary (1999): *A strategic framework for the elimination of measles in the European Region, February 1997*. Tech. rep. Copenhagen: WHO Regional Office for Europe.

Rieck, Thorsten; Marcel Feig; Tim Eckmanns; Justus Benzler; Anette Siedler and Ole Wichmann (2013): "Vaccination coverage among children in Germany estimated by analysis of health insurance claims data". In: *Human Vaccines & Immunotherapeutics* 10 (2), pp. 476–484. DOI: 10.4161/hv.26986.

Robert Koch Institute (2008): "Impfquoten bei der Schuleingangsuntersuchung in Deutschland 2006". In: *Epidemiologisches Bulletin* 16, pp. 143–154.

— (2009): "Impfquoten bei der Schuleingangsuntersuchung in Deutschland 2007". In: *Epidemiologisches Bulletin* 16, pp. 137–146.

— (2010): "Impfquoten bei der Schuleingangsuntersuchung in Deutschland 2008". In: *Epidemiologisches Bulletin* 7, pp. 53–60.

— (2011): "Impfquoten bei der Schuleingangsuntersuchung in Deutschland 2009". In: *Epidemiologisches Bulletin* 16, pp. 129–138.

— (2012): "Impfquoten bei der Schuleingangsuntersuchung in Deutschland 2010". In: *Epidemiologisches Bulletin* 16, pp. 125–132.

— (2013): "Impfquoten bei der Schuleingangsuntersuchung in Deutschland 2011". In: *Epidemiologisches Bulletin* 16, pp. 131–138.

— (2014): "Impfquoten bei der Schuleingangsuntersuchung in Deutschland 2012". In: *Epidemiologisches Bulletin* 16, pp. 129–142.

Robert Koch Institute (2015): “Impfquoten bei der Schuleingangsuntersuchung in Deutschland 2013”. In: *Epidemiologisches Bulletin* 16, pp. 131–138.

— (2016): “Impfquoten bei der Schuleingangsuntersuchung in Deutschland 2014”. In: *Epidemiologisches Bulletin* 16, pp. 137–148. DOI: 10.17886/epibull-2016-024.

— (2017): “Impfquoten bei der Schuleingangsuntersuchung in Deutschland 2015”. In: *Epidemiologisches Bulletin* 16, pp. 135–142.

— (2018): “Impfquoten bei der Schuleingangsuntersuchung in Deutschland 2016”. In: *Epidemiologisches Bulletin* 16, pp. 151–160. DOI: 10.17886/EpiBull-2018-020.

Robertson, Chris and Peter Boyle (1986): “Age, period and cohort models: The use of individual records”. In: *Statistics in Medicine* 5 (5), pp. 527–538. DOI: 10.1002/sim.4780050517.

Roodman, David (2009): “Fitting fully observed recursive mixed-process models with cmp”. In: *The STATA Journal* 11 (2), pp. 159–206. DOI: 10.1177/1536867x1101100202.

Rosian-Schikuta, Ingrid; Barbara Fröschl; Claudia Habl and Heidi Stürzlinger (2007): “Die Masern-Mumps-Röteln-Impfung aus gesundheistpolitischer und ökonomischer Sicht”. In: *Köln: DIMDI*.

Sächsiche Landesärztekammer (2018): “Empfehlungen der Sächsichen Impfkommssion zur Durchführung von Schutzimpfungen im Freistaat Sachsen – Stand: 01.01.2018”. In: *Impfempfehlung E1* 15, pp. 97–108.

Salmon, Daniel A.; Michael Haber; Eugene J. Gangarosa; Lynelle Phillips; Natalie J. Smith and Robert T. Chen (1999): “Health Consequences of Religious and Philosophical Exemptions From Immunization Laws”. In: *JAMA* 282 (1), p. 47. DOI: 10.1001/jama.282.1.47.

Schmitt, Heinz-J. (2001): “Factors influencing vaccine uptake in Germany”. In: *Vaccine* 20, S2–S4. DOI: 10.1016/s0264-410x(01)00304-8.

Schönberger, Katharina; Maria-Sabine Ludwig; Manfred Wildner and Benedikt Weissbrich (2013): “Epidemiology of Subacute Sclerosing Panencephalitis (SSPE) in Germany from 2003 to 2009: A Risk Estimation”. In: *PLoS ONE* 8 (7). Ed. by Jean-Pierre Vartanian, e68909. DOI: 10.1371/journal.pone.0068909.

Siedler, Anette (2005): “Measles outbreaks in Hessen and Bavaria, Germany, 2005”. In: *Weekly releases (1997–2007)* 10 (30). DOI: 10.2807/esw.10.30.02757-en.

Siedler, Anette; Wiebke Hellenbrand and Gernot Rasch (2002): "Measles outbreaks in Germany". In: *Weekly releases (1997–2007)* 6 (12). DOI: 10.2807/esw.06.12.02098-en.

Siedler, Anette; Monika Hermann; Heinz-Josef Schmitt and Rüdiger von Kries (2002): "Consequences of delayed measles vaccination in Germany". In: *The Pediatric Infectious Disease Journal* 21 (9), pp. 826–830. DOI: 10.1097/00006454-200209000-00008.

Siedler, Anette; Annedore Tischer; Annette Mankertz and Sabine Santibanez (2006): "Two outbreaks of measles in Germany 2005". In: *Eurosurveillance* 11 (4), pp. 9–10. DOI: 10.2807/esm.11.04.00615-en.

Smith, Louise E.; Richard Amlôt; John Weinman; Jenny Yiend and G. James Rubin (2017): "A systematic review of factors affecting vaccine uptake in young children". In: *Vaccine* 35 (45), pp. 6059–6069. DOI: 10.1016/j.vaccine.2017.09.046.

STIKO (1974): "Empfehlungen zur Masernschutzimfpung". In: *Bundesgesundheitsblatt* 19. Ed. by Bundesgesundheitsamt.

— (1980): "Impfempfehlungen der Ständigen Impfkommssion des Bundesgesundheitsamtes (STIKO) – Stand: Juni1980". In: *Bundesgesundheitsblatt* 31 (10), pp. 97–108.

— (1988): "Impfempfehlungen der Ständigen Impfkommssion des Bundesgesundheitsamtes (STIKO) – Stand: September 1988". In: *Bundesgesundheitsblatt* 23 (19/20), pp. 314–317.

— (1991): "Impfempfehlungen der Ständigen Impfkommssion des Bundesgesundheitsamtes (STIKO) – Stand: Juli 1991". In: *Bundesgesundheitsblatt* 34 (8), pp. 384–388.

— (1995): "Impfempfehlungen der Ständigen Impfkommssion (STIKO) am Robert Koch-Institut – Stand: Oktober 1994". In: *Bundesgesundheitsblatt* 38 (3), pp. 108–114.

— (1997): "Impfempfehlungen der Ständigen Impfkommssion (STIKO) am Robert Koch-Institut – Stand: März 1997". In: *Epidemiologisches Bulletin* 10, pp. 411–415.

— (1998): "Impfempfehlungen der Ständigen Impfkommssion (STIKO) am Robert Koch-Institut – Stand: April 1998". In: *Epidemiologisches Bulletin* 15, pp. 101–114.

STIKO (2001): “Impfempfehlungen der Ständigen Impfkommssion (STIKO) am Robert Koch-Institut – Stand: Juli 2001”. In: *Epidemiologisches Bulletin* 28, pp. 203–218.

— (2006): “Impfempfehlungen der Ständigen Impfkommssion (STIKO) am Robert Koch-Institut – Stand: Juli 2006”. In: *Epidemiologisches Bulletin* 30, pp. 235–254.

— (2016): “Standard Operating Procedure of the German Standing Committee on Vaccinations (STIKO) for the systematic development of vaccination recommendations”. In: *Version 3.0 (March 16th 2016), Berlin*.

— (2018): “Impfempfehlungen der Ständigen Impfkommssion (STIKO) am Robert Koch-Institut – Stand: August 2018”. In: *Epidemiologisches Bulletin* 34, pp. 335–382. DOI: 10.17886/EpiBull-2018-042.3.

Uzicanin, Amra and Laura Zimmerman (2011): “Field effectiveness of live attenuated measles-containing vaccines: a review of published literature”. In: *The Journal of infectious diseases* 204 (suppl_1), S133–S149. DOI: 10.1093/infdis/jir102.

Viscusi, W. Kip and Jahn K. Hakes (2008): “Risk bliefs and smoking behavior”. In: *Economic Inquiry* 46 (1), pp. 45–59. DOI: 10.1111/j.1465-7295.2007.00079.x.

Waaijenborg, S.; S. J. M. Hahne; L. Mollema; G. P. Smits; G. A. M. Berbers; F. R. M. van der Klis; H. E. de Melker and J. Wallinga (2013): “Waning of Maternal Antibodies Against Measles, Mumps, Rubella, and Varicella in Communities With Contrasting Vaccination Coverage”. In: *Journal of Infectious Diseases* 208 (1), pp. 10–16. DOI: 10.1093/infdis/jit143.

Walton, Suzanne; Mario Cortina-Borja; Carol Dezateux; Lucy J. Griffiths; Karen Tingay; Ashley Akbari; Amrita Bandyopadhyay; Ronan A. Lyons and Helen Bedford (2017): “Measuring the timeliness of childhood vaccinations: Using cohort data and routine health records to evaluate quality of immunisation services”. In: *Vaccine* 35 (51), pp. 7166–7173. DOI: 10.1016/j.vaccine.2017.10.085.

Weinstein, Neil D. (1982): “Unrealistic optimism about susceptibility to health problems”. In: *Journal of Behavioral Medicine* 5 (4), pp. 441–460. DOI: 10.1007/bf00845372.

— (1987): “Unrealistic optimism about susceptibility to health problems: Conclusions from a community-wide sample”. In: *Journal of Behavioral Medicine* 10 (5), pp. 481–500. DOI: 10.1007/bf00846146.

WHO, World Health Organization (2002): "Global measles mortality reduction and regional elimination, 2000-2001". In: *Weekly epidemiological record* 77 (7), pp. 49–56.

— (2005): *Eliminating measles and rubella and preventing congenital rubella infection: WHO European Region Strategic Plan 2005-2010.* WHO Regional Office Europe.

— (2013): *Global vaccine action plan 2011-2020.* World Health Organization.

— (2017): "Measles vaccines: WHO position paper". In: *Weekly epidemiological record* 17 (92), pp. 205–228.

Wu, Sheng; Catherine M. Crespi and Weng Kee Wong (2012): "Comparison of methods for estimating the intraclass correlation coefficient for binary responses in cancer prevention cluster randomized trials". In: *Contemporary Clinical Trials* 33 (5), pp. 869–880. DOI: 10.1016/j.cct.2012.05.004.

Zweifel, Peter; Friedrich Breyer and Matthias Kifmann (2009): *Health Economics.* 2nd ed. Springer-Verlag GmbH. ISBN: 3540278044.