Confirmatory Bias in Health Decisions: Evidence from the MMR-Autism Controversy[*]

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Abstract

Since Wakefield et al. (1998), the public was exposed to mixed information surrounding the claim that measles-mumps-rubella vaccine causes autism. A persistent trend to delay the vaccination during 1998–2011 in the US was driven by children of college-educated mothers, suggesting that these mothers held biases against the vaccine influenced by the early unfounded claim. Consistent with *confirmatory bias*, exposures to negative information about the vaccine strengthened their biases more than exposures to positive information attenuated them. Positive online information, however, had strong impacts on vaccination decisions, suggesting that online dissemination of vaccine-safety information may help tackle the sticky misinformation.

Keywords: MMR vaccine; Autism; Confirmatory bias; Media; Misinformation

JEL classification: I12; I18; I26

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1 Introduction

Mass media health information, especially in the form of information campaigns which oftentimes convey a homogeneous message, has been documented to be successful in effecting desirable changes in health behavior.[1] Less is known about the effects, however, when the media presents mixed or even conflicting health information to the public. A case in point is the media coverage on the safety of the measles-mumps-rubella (MMR) vaccine. Psychologists have documented in the laboratory that, when presented with ambiguous or mixed evidence, people tend to select and interpret information in a way that confirms their existing positions, a tendency termed *confirmatory bias* (e.g., Oskamp, 1965; Darley and Gross, 1983). In this paper, we utilize the controversy over the link between the MMR vaccine and autism as a natural experiment to investigate how health decisions respond to mixed information and whether there is evidence that they are affected by confirmatory bias.

The MMR-autism controversy was initiated by Wakefield et al. (1998). Based on a self-selected sample of 12 children, the study claimed to have found a connection between the measles virus and the inflammatory bowel disease found in autistic children. The connection was somehow promoted as an evidence linking the MMR vaccine to the risk of developing autism. A substantial body of subsequent studies based on more rigorous research protocols and larger samples consistently reached an opposite conclusion (e.g., Taylor et al., 1999; Madsen et al., 2002). In 2004, based on a systematic review of research studies, the Institute of Medicine (IOM) issued its final report concluding that no convincing evidence exists for the casual MMR-autism link.[2] In the same year, Wakefield et al. (1998) was partially retracted, followed by a complete retraction in 2010 in which the journal's editor noted that "it was utterly clear, without any ambiguity at all, that the statements in the paper were utterly false." While by 2004 the issue was beyond debate in the scientific community, the public was still presented with conflicting messages, ranging from celebrities' anti-vaccination speeches to emotional stories from parents of autistic children to assurances of vaccine safety from authorities.

Figure 1 presents, for the period 1998 to 2011, the annual proportion of children between

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[1] Wakefield et al. (2010) surveyed evidence on the outcomes of mass media health campaigns and concluded that they could result in positive changes or prevent negative changes in health behavior. For example, they documented that campaigns aimed at reducing tobacco use and preventing cardiovascular diseases could produce measurable health benefits. See also Jacobsen and Jacobsen (2011) who documented the effectiveness of awareness campaigns in promoting earlier detection of diseases.

[2] The IOM was the predecessor of the Health and Medicine Division of the National Academies of Sciences, Engineering, and Medicine. At the request of the Centers for Disease Control and Prevention and the National Institutes of Health, the Immunization Safety Review Committee was formed by the IOM to examine the safety of vaccines. The committee issued in total eight reports. The first report on the MMR-vaccine link appeared in 2001. While ruling out the link at the population level, this first report recommended further research to investigate rare individual cases. The 2004 report reached the conclusion that the existing body of epidemiological evidence favors rejection of a causal effect between the MMR vaccine and autism and that the potential biological mechanisms for vaccine-induced autism proposed so far are sheer theoretical.

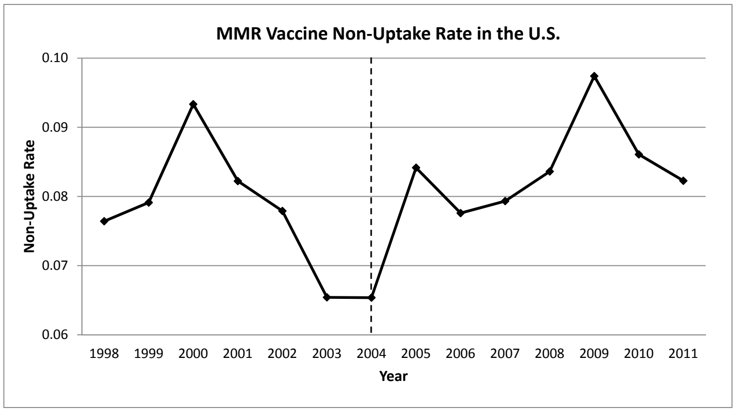

Figure 1: MMR Vaccine Non-Uptake Rate in the US, 1998–2011

19 and 35 months of age whose immunization records indicated delay in the MMR immunization. The percentage, which represents our outcome variable, the *MMR vaccine non-uptake rate*, increased after Wakefield et al. (1998) was published. It went back down as studies disapproving the MMR-autism link were accumulating. Interestingly, the rate climbed back up drastically after 2004, the year when the IOM issued its final report and when the public began to receive increasingly more mixed information about the safety of the vaccine.

Prior studies using UK data indicated that more educated parents held stronger biases against the vaccine. The increase in the MMR vaccine non-uptake rate in the UK in response to Wakefield et al. (1998), from 1997 up to 2005, was found to be driven by children of more educated parents (e.g., Wright and Polack, 2006; Anderberg et al., 2011). A contemporaneous study by Chang (2018), which covered the period from 1995 to 2006, documented a similar educational gap in the US. Using 1998 as the base year, we evaluate annual changes in the MMR vaccine non-uptake rate in the US till 2011, dividing the sample by the college-education status of the mother. As the starting point of our principal investigation, we find that the educational gap in the US was persistent and became even wider after the periods covered by these other studies. The finding suggests that the biases held by the more educated US mothers against the vaccine did not subside—in fact strengthened—after consensus was reached in the scientific community that the vaccine does not cause autism.

We estimate the differential time trend of the MMR vaccine non-uptake rate of the college-educated group. Interpreting the differential trend as measuring the strength of the educated mothers' biases, we investigate how exposures to information with different positions about the safety of the vaccine influence the biases. Our identification strategy exploits state-year variations in a set of active and passive exposures to broadly defined media information. We measure active exposures by the search intensity indexes of related topics obtained from Google Trends. For passive exposures, we manually review and classify relevant newspaper coverage retrieved from LexisNexis Academic and collect reported incidences of autism and MMR from the Office of Special Education Programs and the Morbidity and Mortality Weekly

Report. We classify all information exposures in our sample into positive, ones that encourage immunization, and negative, ones that discourage immunization.

Our main finding is the substantial asymmetry in the responses to positive and negative information about the MMR vaccine. A one-standard-deviation increase in exposures to negative information strengthened the biases of the college-educated mothers by more than 35%; by contrast, a one-standard-deviation increase in exposures to positive information attenuated the biases by no more than 10%. The college-educated group responded more strongly to information consistent with their biases against the vaccine (e.g., news reports of unexplained increase in autism cases) than to information that is in opposition to the biases (e.g., reports citing the conclusion reached by the IOM). The finding provides population-level evidence of confirmatory bias at work in the rising trend of the MMR vaccine non-uptake rate in the US.[3]

Our study contributes to the literature on education gradients that are observed in a variety of health outcomes (e.g., Currie and Moretti, 2003; Lleras-Muney, 2005; de Walque, 2007; Cutler and Lleras-Muney, 2010). The study that is closest to ours in this literature is Chang (2018). We both documented an extended educational gap in the US in the responses to the MMR-autism controversy, partially corroborating the previous UK findings.[4] Chang (2018) also studied the impacts of the media, focusing on newspapers, radio, and television. She found that the educational gap increased with greater media attention to the controversy. We differ in a number of ways. Some of the less crucial differences are the longer periods we cover and our different media data, which include traditional newspaper coverage as well as online searches. With online information becoming an indispensable source of information for many people, our inclusion of this type of media provides a fuller picture of the information that may influence vaccination decisions.

The primary difference between the two studies, however, lies in the different questions addressed. While Chang (2018) did not distinguish between positive and negative media coverage, our principal inquiry concerns the different impacts of information with alternative positions about the MMR vaccine. A common explanation for health-related education gradients is that education allows more effective absorptions of medical information, which are reflected in health behavior (Grossman, 1972). Our findings point to a downside associated with this better ability to absorb information: the initially absorbed information may

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[3] Using a randomized controlled trial, Nyhan et al. (2014) obtained a complementary finding in which they showed that the effectiveness of pro-vaccine messages may vary depending on parents' existing attitudes.

[4] Covering the period 1993–2004, Wright and Polack (2006) found that the MMR non-uptake rate increased significantly in almost all areas of England since 2000, where the non-uptake rate increased more slowly in areas with higher proportion of population with lower education. Anderberg et al. (2011) covered the period 1997–2005 and similarly documented an educational gradient since 1999. They, however, found that the UK educational gap vanished by the end of the period covered, whereas both Chang (2018) and our study found that in the US the gap persisted well into 2005 and beyond. A US study preceding our studies is Smith et al. (2008). They found a decline in MMR immunization in 1999 and 2000 and a limited influence of newspaper coverage of the controversy during that period of time.

hinder subsequent absorptions of more up-to-date and accurate information in the presence of cognitive biases. Our finding on the asymmetric responses to information suggests that the persistent decline in the MMR immunization of the more educated group, even after the vaccine has been proved safe, may be a consequence of this effect. While Chang (2018) left the educational gap as a puzzle and discuss possible explanations, we provide a theoretical model and empirical evidence pointing to asymmetric responses to information, as would be driven by confirmatory bias, as a plausible culprit.[5]

This brings us to another contribution of our study. While laboratory evidence documents the existence of confirmatory bias, few studies have examined such biases in a real-world setting. To the best of our knowledge, our study presents the first naturally occurring evidence consistent with the presence of confirmatory bias in health decisions.[6]

Our study also contributes a policy suggestion for what may be an effective channel to counter the misinformation surrounding the MMR vaccine and for correct information to take root. We find that among the different types of information considered online information has the strongest impact on vaccination decisions, and this is true not only for negative information but also for positive information. The finding suggests that online dissemination of vaccine-safety information may be an effective way to tackle the adverse consequences of the previously circulated misinformation that lingered under the documented biases.

The rest of the paper proceeds as follows. Section 2 provides a more detailed account of the MMR-autism controversy, bringing to view the prevalence of mixed information during the period. Section 3 describes the data and the sample. Section 4 examines the differential trend of the MMR vaccine non-uptake rates between children of college-educated and non-college-educated mothers. The trend analysis establishes the biases held by the more educated group against the vaccine. Section 5 analyzes, both theoretically and empirically, the asymmetric responses to mixed information about the MMR vaccine. Section 6 concludes with discussion

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[5] Our findings should not, however, be interpreted as suggesting that education contributes or leads to confirmatory bias. Psychologists consider confirmatory bias as a fundamental trait of human reasoning, and cognitive psychological studies provide no clear evidence that education levels are associated with higher or lower degree of the bias (e.g., Griggs and Ransdell, 1986; Jackson and Griggs, 1988; Calikli and Bener, 2015). This common human bias may or may not manifest in observed decisions. Education, by potentially creating differential absorptions of information among the more and the less educated, provides a medium through which the bias can be registered in naturally occurring data, in a sense not too dissimilar to psychological studies using controlled laboratory tasks to detect the bias in experimental data. The interpretation of our findings in this regard should be limited to that the documented asymmetric responses to positive and negative information by the college-educated group relative to the non-college-educated group provide evidence that different education levels allow confirmatory bias to exert different influences on them.

[6] Since we do not observe actual information exposures at the individual level, our empirical method has relied on the assumption of homogeneous information exposures within states. The results we obtain are therefore "intent-to-treat" estimates, and our finding supporting the presence of confirmatory bias in vaccination decisions is a population-level evidence. Given that individual data on information exposures are unlikely to be available short of a controlled environment, this is probably the farthest one can go for studies relying on naturally occurring data. Andrews et al. (2018) presented evidence on confirmatory bias in the Associated Press Top 25 College Football Poll in which expert pollsters are tasked with assessing team quality.

Table 1: Major Events Surrounding the MMR-Autism Controversy, 1988–2011

Year		Event	Classification
1998	(a)	Wakefield et al. (1998) was published in *Lacent.*	Negative
2001	(b)	Thimerosal ceased to be used as a preservative for childhood vaccines.	Positive
	(c)	The Institute of Medicine (IOM) issued its first report on the MMR-autism link, ruling out a causal relationship between the two.	Positive
2004	(d)	The IOM concluded in its final report that the existing body of epidemiological evidence rejects a causal link between the MMR vaccine/thimeorsal and autism.	Positive
	(e)	Wakefield et al. (1998) was partially retracted.	Positive
2005	(f)	*Evidence of Harm: Mercury in Vaccines and the Autism Epidemic: A Medical Controversy* was published by journalist David Kirby.	Negative
	(g)	"Deadly Immunity – Government Cover-Up of a Mercury/Autism Scandal" by environmental lawyer Robert Kennedy was published on *Rolling Stone* and *Salon.com.*	Negative
2006	(h)	Multi-state outbreaks of mumps.	Positive
2007	(i)	*Louder than Words: A Mother's Journal in Healing Autism* was published by actress Jenny McMcathy.	Negative
2008	(j)	The Office of Special Masters of the US Court of Federal Claims (the "Vaccine Court") awarded its first compensation for an autism case filed for Hannah Poling.	Negative
	(k)	*Autism's False Prophets: Bad Science, Risky Medicine, and the Search for a Cure* was published by pediatrician Paul Offit.	Positive
	(l)	*Mother Warriors: A Nation of Parents Healing Autism Against All Odds* was published by actress Jenny McMcathy.	Negative
	(m)	Actress Amanda Peet became spokeswoman of Every Child By Two, a non-profit organization that advocates childhood vaccination.	Positive
	(n)	An outbreak of measles in San Diego.	Positive
2009	(o)	The Vaccine Court ruled that the combination of the MMR vaccine and thimerosal-containing vaccines does not cause autism.	Positive
	(p)	"Fearmongering Will Not Make Parents Vaccinate" by Actress Holly Robinson Peete arguing for a possible vaccine-autism link was published on Essence.	Negative
	(q)	"The Judgement on Vaccines is in?" by Actor Jim Carrey calling for caution against claims that vaccines are safe was published on The Huffington Post.	Negative
2010	(r)	Wakefield's medical license was revoked.	Positive
	(s)	Wakefield et al. (1998) was completely retracted.	Positive
2011	(t)	*The Panic Virus: A True Story of Medicine, Science, and Fear* was published by science writer Seth Mnookin.	Positive

Note: For the classification of events, "Positive" ("Negative") refers to that the event conveys information to the public that is deemed to encourage (discourage) vaccination.

of some limitations of our findings.

2 Mixed Information during the MMR-Autism Controversy

Table 1 summarizes the major events surrounding the MMR-autism controversy during the period 1998 to 2011. We classify an event according to the perspective that it conveys to the public about the safety of the vaccine, whether it is positive (encouraging vaccination) or negative (discouraging vaccination).

The classified events in Table 1 reveal that mixed information was prevalent during the controversy. Those who sent positive information to the public included health authorities, mainstream scientists, and the Office of Special Masters of the US Court of Federal Claims, commonly referred to as the “Vaccine Court.”[7] They all refuted the claim that childhood vaccines cause autism, by either conducting new and reviewing existing research, publishing books, or delivering ruling decisions [events (c), (d), (e), (k), (o), (r), (s), and (t)]. The outbreaks of mumps and measles in 2006 and 2008 among unvaccinated persons (Omer et al., 2009) also should have reminded the public of the importance of adhering to the childhood vaccine schedule [events (h) and (n)]. In fact, these outbreaks caused health organizations to actively advocate the benefits of the MMR vaccine.

Despite the assurance from the mainstream entities, ever since the publication and the media coverage of Wakefield et al. (1998), the conception that the MMR vaccine and autism are related took root among certain group of parents. Through articles and books, activists and celebrities promoted their views or personal experiences that the vaccine-autism link was real [events (f), (g), (i), (l), (p), and (q)]. The skepticism even fueled some conspiracy theory; a 2005 Rolling Stone article, which purported that health agencies colluded with pharmaceutical companies to cover up the risk of vaccines, almost threw the government into a trust crisis. The compensation made by the Vaccine Court for Hannah Poling, who suffered from a rare pre-existing disease with resulting developmental disorders that were ruled as worsened by vaccines, was perceived by some parents as tacit acknowledgement by the government that vaccines cause autism [event (j)]. Perhaps because there were no readily available explanations for the drastic increase in autism cases during the period, the purported link to the MMR vaccine was appealing to many parents and received wide publicity (Dannetun et al., 2005).

To appreciate the scope of conflicting information prevailed during the controversy, it is useful to review two other claims about the risks of childhood vaccines. One of the claims concerns thimerosal, a preservative that has ceased to be used in childhood vaccines since 2001.[8] It has been suggested that the mercury-based preservative is linked to autism. Although the connection has been disputed by scientists (Stehr-Green et al., 2003; Verstraeten et al., 2003; Price et al., 2010), and thimerosal was never used in the MMR vaccine, the MMR-autism and the thimerosal-autism links were frequently referred to together. Some even mistakenly reported that the MMR vaccine contains thimerosal.

The other claim concerns the immunization schedule. It has been suggested that the commonly followed schedule, which administers a large number of vaccines early in a child’s

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[7] The Vaccine Court administers the Vaccine Injury Compensation Program, a no-fault compensation program established under the National Childhood Vaccine Injury Act of 1986, for persons allegedly injured by compulsory childhood vaccines. The court provides individuals with an alternative to the often costly and lengthy civil court proceedings.

[8] Baker (2008) discusses the interplay of concerns over vaccine preservatives, mercury poisoning, and autism that created the controversy over childhood vaccines.

life, overwhelms and weakens the child's immune system. This, however, was also disputed by scientists (Offit et al., 2002). Since most information refers to the vaccine-autism link without differentiating the different hypothesized causes, these claims, though not directly related to the MMR vaccine, may also affect its non-uptake rate.

3 Data and Sample

We proceed to describe our data, which consist of immunization records and a set of self-constructed measures of information exposures.

3.1 Immunization Records

Our outcome variable, the MMR non-uptake rate, is obtained from the immunization records of the National Immunization Surveys (NIS). The NIS are a group of phone surveys used to monitor vaccination coverage among children and teens in the US. Sponsored and conducted annually by the National Center for Immunization and Respiratory Diseases, the surveys randomly select phone numbers and enroll one or more age-eligible child or teen from the selected households. During the phone interviews, parents or guardians are asked a series of questions regarding their children's vaccinations. Demographics data are also collected. With the consent of parents, a questionnaire is further mailed to each child's vaccination provider(s) to collect information regarding the child's vaccination history.

We obtain immunization records of children between 19 and 35 months of age.[9] To ensure reliability of the self-reported vaccination status, we restrict our sample to those with valid provider information.[10] In addition to the child's current vaccination status, the immunization records contain the following individual characteristics that we use in our analysis: the demographics of the child and the mother at the time of the survey, the socioeconomic status of the household, the type of the child's health care facility, and a state identifier.

The sample covers the period 1988 to 2011, with observations of 271,487 children. Table 2 presents the summary statistics of the whole sample and of the sub-samples of children with college-educated and non-college-educated mothers. Children of college-educated mothers have a lower average MMR non-uptake rate.[11] The group is also more likely to be Caucasians,

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[9] The Centers for Disease Control and Prevention recommends children to receive two doses of MMR vaccine, the first between 12 and 15 months and the second between 4 and 6 years of age. We allow for temporary delays by using 19 months as the cutoff; children who meant to be on the immunization schedule would have received the first dose of the vaccine by the time they reached 19 months of age.

[10] The NIS began to include cell phone numbers in their surveys enrollments in 2011. For consistency with other years, we restrict our 2011 sample to landline data.

[11] Our focus on mothers' education is shaped by data availability, in which the immunization records contain only the education level of the mothers. Nevertheless, with mothers typically playing a major role in child-

Table 2: Summary Statistics: MMR Non-Uptake Rate
and Other Observable Characteristics

	All	College-Educated Mothers	Non-College-Educated Mothers
MMR non-uptake	0.076 (0.266)	0.061 (0.239)	0.087 (0.282)
Male	0.512 (0.500)	0.512 (0.500)	0.511 (0.500)
First born	0.420 (0.493)	0.452 (0.498)	0.397 (0.489)
Mother married	0.739 (0.439)	0.917 (0.276)	0.617 (0.486)
Moved from a different state	0.081 (0.274)	0.087 (0.283)	0.077 (0.489)
Child's age			
19 – 23 months	0.297 (0.457)	0.293 (0.455)	0.300 (0.458)
24 – 29 months	0.352 (0.478)	0.353 (0.478)	0.352 (0.478)
30 – 35 months	0.351 (0.477)	0.354 (0.478)	0.348 (0.476)
Child's race			
White	0.599 (0.490)	0.743 (0.437)	0.499 (0.500)
Black	0.125 (0.330)	0.071 (0.257)	0.161 (0.368)
Hispanic	0.194 (0.395)	0.094 (0.290)	0.264 (0.441)
Other	0.082 (0.275)	0.092 (0.289)	0.076 (0.265)
Mother's education			
$<$ 12 years	0.123 (0.329)	–	0.209 (0.407)
12 years	0.249 (0.432)	–	0.420 (0.494)
$>$ 12 years (non-college)	0.220 (0.414)	–	0.371 (0.483)
college or above	0.408 (0.491)	–	–
Mother's age			
$\leqslant$ 19	0.024 (0.155)	0.001 (0.037)	0.040 (0.198)
20 – 29	0.393 (0.488)	0.198 (0.398)	0.527 (0.499)
$\geqslant$ 30	0.583 (0.493)	0.801 (0.399)	0.433 (0.495)
Family income			
$\leqslant$ 30k	0.327 (0.469)	0.100 (0.300)	0.483 (0.500)
$>$ 30k and $\leqslant$ 50k	0.187 (0.390)	0.158 (0.364)	0.207 (0.405)
$>$ 50k	0.425 (0.494)	0.719 (0.449)	0.223 (0.416)
unknown	0.061 (0.239)	0.023 (0.150)	0.087 (0.282)
Facility type			
private	0.576 (0.494)	0.688 (0.463)	0.499 (0.500)
public	0.129 (0.336)	0.059 (0.236)	0.177 (0.382)
mixed	0.085 (0.278)	0.070 (0.255)	0.095 (0.293)
others	0.210 (0.407)	0.183 (0.386)	0.229 (0.420)
Sample size	271,478	110,688	160,790

Note: Samples are obtained from the immunization records of the National Immunization Survey, covering the period 1988 to 2011. The sampled children are divided according to whether the child's mother has received college education. Standard deviations are in parentheses.

be married, and have a higher household income.

3.2 Information Exposures

Using the state identifiers in the immunization records, we link the children in our sample to a set of state-level measures of information exposures. These self-constructed measures,

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caregiving, this data limitation does not pose a strong restriction for our purpose.

which quantify the intensity of exposures to immunization-related information in each state and year, include 1) the prevalence rates of relevant diseases, 2) the counts of relevant coverage in local newspapers, and 3) the intensities of relevant online searches. We classify information exposures into positive and negative: the former refer to those that would encourage vaccinations, potentially lowering the MMR vaccine non-uptake rate; the latter are expected to have the opposite effect. We also distinguish between passive and active exposures. Disease prevalence and newspaper coverage are considered passive exposures, while online searches represent active exposures.

We describe in details the constructions of each of these variables, the summary statistics of which are reported in Table 3. Our identification strategy exploits the variations in these variables over time in each state to assess their impacts on the MMR vaccine non-uptake rate. The underlying presumption is that the vaccination decisions of mothers in years with more frequent onsets of the diseases, more relevant newspaper coverage, and/or more intense online searches of related topics are more strongly affected. Table A.1 in the Appendix reports the between- and within-state variations in each variable. There are considerable variations within states over time, which serve our identification well.

Prevalence Rates of Relevant Diseases. We use autism and the three diseases preventable by the MMR vaccine as the relevant diseases for constructing measure of one set of passive information exposures. We obtain data on autism from the Office of Special Education Programs, which maintains state counts of children with 13 types of disabilities who receive free public education under the Individual with Disability Education Act. The data on measles, mumps, and rubella are obtained from the Morbidity and Mortality Weekly Reports, which are compiled based on reports by state and territorial health departments to the Centers for Disease Control and Prevention as part of the National Notifiable Diseases Surveillance System.

For each state-year, we calculate the rate of autism out of the 13 disability counts to capture the prevalence of the disease. We expect that a higher prevalence of autism contributes to a stronger concern over the MMR vaccine; it is considered a negative passive exposure. For the prevalence of MMR, we calculate the rate of the three diseases relative to the number of state residents in each state-year. Philipson (1996) documented that a higher prevalence of measles induced a higher demand for measles vaccine. We similarly expect that a higher prevalence of the three diseases would result in a lower MMR vaccine non-uptake rate; the prevalence of MMR is considered a positive passive exposure.

Newspaper Coverage. We search for and identify relevant newspaper coverage in the LexisNexis Academic database, which contains records of 295 US newspapers and was used in previous studies on media coverage of vaccines (e.g., Smith et al., 2008; Clarke, 2008). We search for news articles from 1998 to 2011 that contain the following five sets of key-

Table 3: Summary Statistics: Measures of Information Exposures

	Data Source	Mean (SD)	Classification
A. Passive Exposures			
Prevalence Rates of Relevant Diseases			
Measles, mumps, and rubella (% in thousand residents)	Morbidity and Mortality Weekly Reports	0.471 (2.936)	Positive
Autism (% of all disability cases)	Office of Special Education Programs	3.037 (2.121)	Negative
Newspaper Coverage			
Position supporting immunizations (% of news counts)	LexisNexis Academic	15.137 (28.424)	Positive
Health authorities or scientific evidence (% of news counts)	LexisNexis Academic	11.680 (23.455)	Positive
Anecdotes against immunizations (% of news counts)	LexisNexis Academic	3.165 (12.025)	Negative
Autism (% of news counts)	LexisNexis Academic	9.627 (22.287)	Negative
B. Active Exposures			
Online Searches			
“Measles,” “mumps,” and “rubella”	Google Trends	74.632 (21.308)	Positive
“Autism”	Google Trends	90.131 (6.631)	Negative
“Vaccine and autism”	Google Trends	91.854 (8.167)	Negative
MMR autism controversy (search topic)	Google Trends	55.419 (30.032)	Negative

Note: The sample size is 271,478. The frequencies of measles, mumps, and rubella are total counts of the three diseases normalized by resident population at the state-year level. The frequencies of autism are counts of the disability normalized by total counts of 13 types of disabilities at the state-year level. For newspaper coverage, the frequencies are counts of news of particular types (the four types of coverage are not mutually exclusive) normalized by total counts of identified news at the state-year level. For online searches, the statistics are search indices obtained from Google Trends for each state-year, which range from 0 to 100, with higher values indicating greater search volumes. The index for “measles,” “mumps,” and “rubella” is a summary index averaged across the indices obtained separately for the three diseases. Standard deviations (SD) are in parentheses.

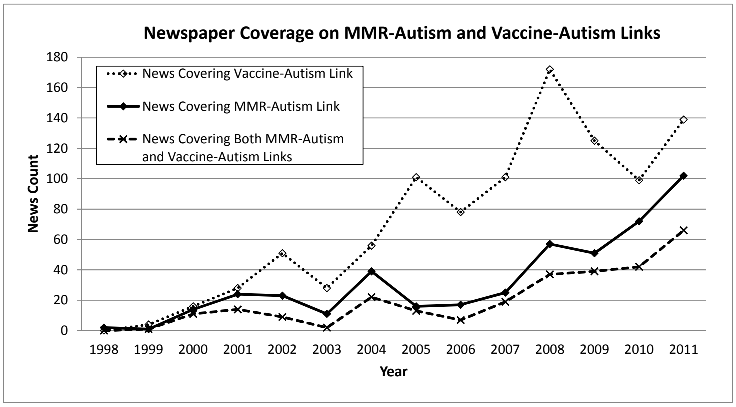

Figure 2: Newspaper Coverage on MMR-Autism and Vaccine-Autism Links, 1998–2011

words: 1)“MMR” and “autism”; 2) “vaccine” and “autism”; 3) “measles” and “autism”; 4) “thimerosal” and “autism”; and 5) “mercury” and “autism.” We manually review each article to ensure that it covers the MMR-autism link or a more general vaccine-autism link. We screen out articles that focus solely on the link between autism and a specific vaccine other than the MMR (e.g., the flu and the Hib vaccine). Since these excluded articles are at best indirectly related to the MMR vaccine, they presumably have little impact on the non-uptake rate of the MMR vaccine. A total of 1,232 counts of news articles are identified as a result.

Figure 2 presents the annual counts of identified coverage on the MMR-autism and vaccine-autism links.[12] Two patterns are apparent from the figure. First, most coverage on the MMR-autism link also covers the general vaccine-autism link. Second, although most coverage on the vaccine-autism link does not cover the MMR-autism link, there is an increasing trend that it does. It is plausible that coverage on the other hypothesized risks of childhood vaccines—the thimerosal preservative and the intense immunization schedule—may affect the MMR vaccine non-uptake rate as well.[13] This observation justifies the inclusion of all 1,232 counts of coverage, some of which are obtained with keywords such as thimerosal and mercury, in evaluating the impacts of newspaper coverage on the MMR vaccine non-uptake rate.

We use four attributes to characterize the contents of the identified newspaper coverage. For each coverage, we determine whether it has one or more of the following attributes and assign count to the applicable attribute(s): 1) an overarching position supporting immunization; 2) citing health authorities and/or scientific evidence to support immunization; 3) citing anecdotal evidence against immunization; and 4) reporting increasing cases of autism and/or describing hardship in taking care of an autistic child. We aggregate the attribute counts by

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[12] A news coverage is considered to be on the MMR-autism link if it mentions the MMR vaccine or the study by Wakefield et al. (1998). If it covers other childhood vaccines, with or without mentioning the MMR vaccine, it is considered to be on the vaccine-autism link.

[13] The spillover may also work in the opposite direction, in which the MMR-autism controversy may affect the non-uptake rates of other childhood vaccines. As will be shown below, we find evidence for this direction of spillover. Chang (2018) also obtained a parallel finding.

the release year of the news and the location of the news outlet.[14] We then construct four variables by calculating the percentage of each of the four attributes in each state-year. The geographical and time variations in the variables are exploited for identification. We consider the percentages of news with attributes 1) and 2) as positive passive exposures and those with attributes 3) and 4) as negative passive exposures.

Online Searches. We use the search indices from Google Trends to capture the intensity of online searches of immunization-related information. Launched in 2004, Google Trends compiles an index for a term after its search volume reaches a certain threshold. The qualified search volumes, which exclude repeated queries from the same user in close temporal proximity, are normalized by the total searches on all topics of the region and time that the data points lie. The index ranges from 0 to 100 with a higher value indicating more intensive searches.

For each state-year, we obtain the available indices for the following terms or phrases: "autism," "measles," "mumps," "rubella," "MMR autism controversy," and "vaccine and autism."[15] For missing values prior to 2004 or due to low search volumes, we use indices predicted based on time-varying state characteristics.[16] The indices for "measles," "mumps," and "rubella" are averaged to create a summary index for the diseases that the MMR vaccine seeks to prevent.[17] Online searches for the three infectious diseases are considered as positive

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[14] While some national newspapers, such as *The New York Times*, have nationwide readership, the readership may vary across states in a way that correlates with our outcome variable, the MMR non-uptake rate. In our main analysis, we therefore assign geographic areas to the news articles based on the immediate locations of the news outlets, counting, e.g., articles from *The New York Times* for New York only. We supplement this by performing robustness checks, excluding articles from the top national news outlets, which potentially offers a cleaner state-level variation in news exposures.

[15] "MMR autism controversy" is a rather specific phrase. The phrase in this exact form may not be searched as often as other relevant terms. Accordingly, unlike the other terms, for "MMR autism controversy" we obtain the index for the *search topic* instead of the search term. Search topics from Google Trends include all search terms that are related to the topic. In our analysis below, we also perform robustness check by excluding "MMR autism controversy" from the construction of measures of online information exposures.

[16] We first estimate a linear regression model with the available data in and after 2004, regressing the search indices on a wide range of time-varying state characteristics. We then use the estimated coefficients to predict the values of the search indices prior to 2004 based on the state characteristics in those earlier years. The state characteristics (data sources) include proportions of uninsured children under 18 among all uninsured people (Current Population Survey Annual Social and Economic Supplement), percentages of immigrants among state residents (Yearbook of Immigration Statistics), percentages of households with internet access (Current Population Reports on Computer and Internet Use in the United States), percentages of high school graduates (Current Population Reports on Educational Attainment in the United States), and levels of GDP (US Bureau of Economic Analysis). Since the extent of information seeking is likely to be affected by news coverage (Niederdeppe et al., 2008), the state characteristics also include passive information exposures to capture the search interests of each keyword. The passive exposures that are included are counts of newspaper articles on the MMR-autism and the vaccine-autism links, autism prevalence rates, and reported cases of measles, mumps, and rubella at the state and year levels. We also make allowance for flexible time effects, including a linear, quadratic, and cubic time trends in the estimation. For the years with available data, the predicted indices are highly correlated with the actual data, which suggests that the imputed values provide reliable substitutes for the missing data. The correlations range from 0.5163 to 0.8146, with a mean value of 0.6817. In our analysis below, we also perform robustness check by omitting altogether the data before 2004.

[17] The search volume for "measles" is substantially higher than those for "mumps" and "rubella" during the period covered. This is perhaps not surprising given that the MMR-autism controversy was initiated on

active exposures, while those for “autism,” “MMR autism controversy,” and “ vaccine and autism” represent negative active exposures.

4 Biases of College-Educated Mothers

As the first step of our analysis, we demonstrate that, relative to non-college-educated mothers, the college-educated held biases against the MMR vaccine. We divide our sampled children into two groups according to whether the child’s mother is college educated (with a bachelor degree or above) or not and estimate the following equation separately for each group:

$$y_{ist} = \boldsymbol{X}_{ist}\gamma + \boldsymbol{\lambda}_{st} + \boldsymbol{\tau}_s + \boldsymbol{\eta}_t + \varepsilon_{ist}, \tag{1}$$

where the outcome of interest, y_{ist}, is an indicator of delayed MMR immunization of child i living in state s in year t, $\boldsymbol{X}_{ist}$ is a vector of individual characteristics, $\boldsymbol{\lambda}_{st}$ is a vector of time-varying state characteristics, $\boldsymbol{\tau_s}$ is the state fixed effects capturing time-invariant heterogeneity across states, $\boldsymbol{\eta_t}$ is the year fixed effects, and ε_{ist} is the idiosyncratic error term.

The year fixed effects, $\boldsymbol{\eta}_t$, are the key variable of interest. They represent the annual changes in the estimated MMR vaccine non-uptake rates relative to those in 1998. The vector of individual characteristics, $\boldsymbol{X}_{ist}$, the summary statistics of which are reported in Table 2, includes the child’s gender, first-born status, age, race, and medical facility type (private, public, or mixed). It also includes the mother’s martial status and age at the time of the survey, family income, and an indicator if the child has relocated from a different state.[18] The vector of time-varying state characteristics, $\boldsymbol{\lambda}_{st}$, which is also used in estimating the missing values of the Google Trends indices, includes proportions of uninsured children under 18, percentages of immigrants, and state population.

Figure 3(a) plots the estimated coefficients of the year fixed effects for the two groups of children. Figure 3(b) plots the group-differences in those coefficients. The differences indicate a widening education gradient over time. The MMR vaccine non-uptake rates of both groups increased after the publication of Wakefield et al. (1998). While these initial increases were brief, lasting till 2001, the increase was more substantial for the college-educated group. By contrast, in the following years in which the non-uptake rates of both groups declined, a more substantial decrease was observed for the non-college-educated group.

Interestingly, the subsequent assurance of vaccine safety by the medical community in

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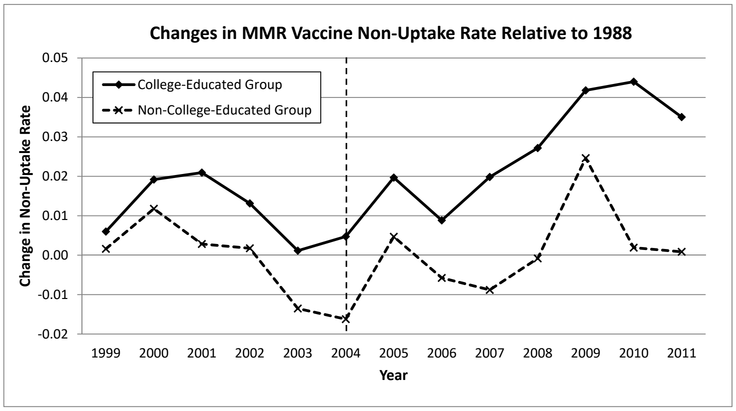
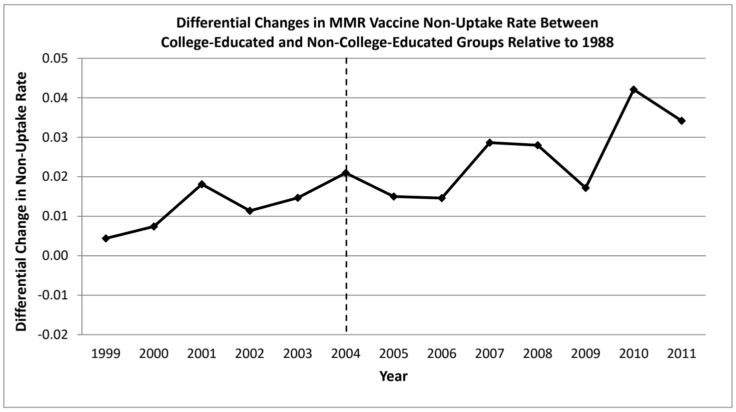
the connection between the measles virus and autism. While our main analysis uses a summary index covering the three terms, we perform robustness check by excluding “mumps” and “rubella” from the construction of measures of online information exposures.

[18] Since dummy variables for mother and child age categories at the time of the survey are included in the regressions, the mother’s age at child’s birth is implicitly accounted for.



(a) Changes in MMR Vaccine Non-Uptake Rates



(b) Differential Changes in MMR Vaccine Non-Uptake Rates

Figure 3: Annual Changes in MMR Vaccine Non-Uptake Rates Relative to 1998

2004 was met with an unfavorable response: the non-uptake rates climbed back up again in 2005. While the non-college-educated group showed no distinctly clear trend afterwards, the upward trend perpetuated for the college-educated group. The drastic increases for this group after 2006, which was not covered by Chang (2018), further deepened the difference between the two education groups. The college-educated group contributed to most of the post-2004 increases in the overall MMR vaccine non-uptake rate as shown in Figure 1.

The differences in the annual changes of the non-uptake rates between the two groups suggest that, relative to the non-college-educated, the college-educated mothers held biases against the MMR vaccine. To evaluate the magnitude of the biases, we estimate the following equation using the full sample:

$$y_{ist} = \alpha[college \times \ln(t - 1998)] + \beta(college \times post_{2004}) + \boldsymbol{X}_{ist}\gamma + \boldsymbol{\lambda}_{st} + \boldsymbol{\tau}_s + \boldsymbol{\eta}_t + \varepsilon_{ist}. \quad (2)$$

Equation (2) extends on (1) by including two additional interaction terms, $college \times \ln(t-1998)$ and $college \times post_{2004}$, where $college$ is a dummy variable taking the value of one if the child's mother is college-educated and $post_{2004}$ is another dummy variable taking the value of one for years after 2004.

Table 4: Differential Trends of the MMR Vaccine Non-Uptake Rates

	(1)	(2)	(3)	(4)
$college \times \ln(t - 1998)$	0.0137***	0.0134***	0.0135***	0.0134***
	(0.004)	(0.004)	(0.004)	(0.004)
$college \times post_{2004}$	0.0014	0.0009	0.0007	0.0011
	(0.005)	(0.005)	(0.005)	(0.005)
Sample size	271,478	271,478	271,478	271,478
Area-specific year fixed effects	None	Region–Year	Division–Year	State–ln(year)

Note: The outcome variable is an indicator for delayed MMR immunization. *college* is a dummy variable for children with college-educated mother. The time trend, $\ln(t - 1998)$, starts at time zero, which is year 1998. $post_{2004}$ is a dummy variable for years after 2004. Columns (1)–(4) report estimation results from four different specifications of area-specific year fixed effects: none, region-specific year effects, division-specific year effects, and state-specific log-linear year effects. Regions and divisions are assigned based on the common practice of the Census. Standard errors clustered at the survey strata level are in parentheses. *** indicates significance at the 1% level, ** at the 5% level, and * at the 10% level.

The term $college \times \ln(t - 1998)$ is the key variable of interest in equation (2). It is the differential time trend of the non-uptake rate of the college-educated group, in which a log time trend is adopted to reflect the decreasing rate at which the differences between the two groups increased over time, as is shown in Figure 3(b).[19] We use this differential trend to capture the biases of the college-educated group formed since 1998; its estimated coefficient is interpreted as the *strength of the biases*. The other interaction term, $college \times post_{2004}$, identifies any deviation from the differential trends following the release of conclusive information in 2004 assuring the safety of the MMR vaccine.

Table 4 reports the estimated coefficients of the two interaction terms under four different specifications of area-specific year effects.[20] The positive and significant coefficients of the time trend interaction, $college \times \ln(t - 1998)$, suggest that the strength of the biases of the college-educated mothers increased over time: relative to the non-college-educated, these mothers were on average more and more reluctant over time to subject their children to the MMR vaccine. This finding, which is robust to the different area-specific year effects, corroborates the rudimentary analysis based on Figure 3 above. The coefficients of $college \times post_{2004}$ are, on the contrary, small and insignificant: the assurance of vaccine safety by the IOM, the partial retraction of Wakefield et al. (1998), and the other events happened in or after 2004, did not result in any meaningful deviation from the increasing trend of the MMR non-uptake rate of the college-educated group.

We also estimate equation (2) using the non-uptake rates of other childhood vaccines and obtain similar findings for hepatitis and pertussis immunizations. The result, which is reported in Table A.2 in the Appendix, suggests a spillover effect of the MMR vaccine controversy to

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[19] The time trend starts at time zero (year $t = 1998$). The functional form is not critical to our results, which are robust to alternative specifications such as linear or quadratic time trend.

[20] The regressions are weighted using the survey weights to obtain representative results. Standard errors are clustered at the survey strata level.

other childhood vaccines.

5 Asymmetric Responses to Mixed Information

The differential trend of the MMR non-uptake rate of the college-educated group not only did not subside but in fact strengthened after the release of conclusive evidence in 2004 proving the safety of the vaccine. This raises the question of why such biases could sustain in the presence of information that is at odds with the biases. It is conceivable that mothers with different education levels were exposed to different information. However, meaningful responses were observed from both groups in 2004, suggesting that differential availability of information is unlikely to be the major explanation for the perpetuating differential trend.

An alternative explanation would be that the two groups of mothers responded to information differently. Psychologists have long documented people's tendency to interpret information in ways that are partial to their existing beliefs. A consequence of this *confirmatory bias* is that those who are susceptible to it respond to new information differently from those who are immune or less susceptible, and how the responses are different depends on the orientation of the information, whether it is in line or at odds with existing beliefs.[21] In this section, we investigate how the documented differential trend of the MMR non-uptake rate interacts with different information about vaccine safety.

In Section 5.1, we utilize a stylized model of vaccination decisions to articulate the linkage between bias in information interpretation and asymmetric responses to positive and negative information. In Section 5.2, we examine empirically how college-educated mothers' vaccination decisions responded to positive and negative information asymmetrically in a way that is consistent with the implications of confirmatory bias. Having established the presence of these asymmetric responses to information, we further investigate from a policy vantage which type of information exposures has better potential to counter the adverse consequences of misinformation. Section 5.3 reports results from various robustness checks.

5.1 A Stylized Model of Vaccination Decisions

We model the initial uncertainty about the safety of the MMR vaccine by two equally likely states of the world, S, which represents that the vaccine is safe, and H, which represents that it is harmful. Parents make vaccination decisions for their child, fully internalizing the child's interests in deciding whether to obtain the vaccine, y, or not, n. For expositional convenience, we assume that there is only one child in each household and hereafter refer to "parent" and

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[21] Nickerson (1998) provides an informative review of this arguably most common bias in human reasoning and its manifestations in a variety of individual and social phenomena.

"household" interchangeably.[22]

A child receives immunization benefit, z, from taking the vaccine regardless of whether it is safe or harmful. On the other hand, taking the vaccine imposes a health cost, a, if and only if it is harmful. The utility from taking the vaccine is therefore $u(S, y) = z$ if it is safe and $u(H, y) = z - a$ if it is harmful. A child who is not vaccinated does not receive the immunization benefit and also is not exposed to any health risk. The utility from not taking the vaccine is therefore zero, i.e., $u(S, n) = u(H, n) = 0$. We assume that $a \geqslant z \geqslant 0$, which means that the immunization benefit does not justify taking the vaccine if it turns out to be harmful. Health benefit and cost of vaccinations typically depend on a number of individual factors such as living conditions and the child's intrinsic proneness to diseases. We further assume that z and a, while satisfying the parameter restriction above, are heterogeneous across households. Each household is identified by its benefit-to-cost ratio, $\frac{z}{a} \in [0, 1]$.[23]

Households receive information about the safety of the vaccine, modeled as noisy informative signals about the state. To capture the historical development of the MMR-autism controversy, marked by the publication of Wakefield et al. (1998) and the subsequent studies drawing opposite conclusion, we assume that there are two instances of signal transmission. The two signals partition the time frame of our analysis into three periods: before the first signal ($t = 0$), in-between the two signals ($t = 1$), and after the second signal ($t = 2$).

We consider two groups of households, a *biased* (b) and an *unbiased* (u) groups. In each of $t = 0, 1, 2$, a unit mass of each group of households makes vaccination decisions in that period based on all *previously and currently available* information. We assume that the households in each group, represented by their benefit-to-cost ratio, $\frac{z}{a}$, are uniformly distributed on $[0, 1]$.

Each of the two signals, which is independently distributed, has binary realizations, s and h, with distribution $\Pr(s|S) = \Pr(h|H) \in (\frac{1}{2}, 1)$. Realized signal s is interpreted as a positive news and realized signal h a negative news regarding the safety of the vaccine.[24] Misperception of signal informativeness lies at the core of our model, which generates asymmetric responses to positive and negative news as a Bayesian outcome. The unbiased parents always objectively perceive that $\Pr(s|S) = \Pr(h|H) = p \in (\frac{1}{2}, 1)$. For the biased parents, there are three possibilities: 1) if their existing beliefs are that S and H are equally likely, they are objective like the unbiased parents, 2) if their existing beliefs are that S is more likely, they

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[22] The one-child assumption is innocuous. It is very likely that a household will have the same vaccination decisions for all its children, and the parent's altruistic preferences can then be defined over the average of the children's welfare.

[23] We use the weak inequality $a \geqslant z \geqslant 0$ instead of the strict inequality $a > z > 0$ for the parameter restriction out of technical consideration. It allows us to have the closed unit interval as the domain for the benefit-to-cost ratio.

[24] If we consider, e.g., the publication of Wakefield et al. (1998) and its subsequent retraction as the two signals, they are clearly not independent. Given that our objective is not on modeling the information sources but the responses to information, assuming the independence provides us with a parsimonious environment to focus on the issue of interests.

misperceive that the signal is more informative than it objectively is when signal s is received, i.e., $\Pr(s|S) = \Pr(h|H) = p' > p$, and less informative than it objectively is when h is received, i.e., $\Pr(s|S) = \Pr(h|H) = p'' < p$, and 3) if their existing beliefs are that H is more likely, the opposite holds where they misperceive that $\Pr(s|S) = \Pr(h|H) = p' > p$ when h is received and that $\Pr(s|S) = \Pr(h|H) = p'' < p$ when s is received. The biased parents' misperception inflates or deflates the informativeness of the signals when their existing beliefs assign non-uniform probabilities to the two states.[25]

Parents choose y if and only if the expected utility from choosing y is no less than that from choosing n, and this reduces to the condition that the benefit-to-cost ratio is no less than the probability assessment that the vaccine is harmful. In period $t = 0$, this condition for taking the vaccine under the prior is $\frac{z}{a} \geqslant \frac{1}{2}$. Defining the proportion of parents in a group who choose n as the group's vaccine non-uptake rate, N, we obtain the following baseline case against which the impacts of the signals are evaluated:

Observation 1. *In period $t = 0$, the vaccine non-uptake rate of the biased group, N_b^0, and that of the unbiased group, N_u^0, coincide at $\frac{1}{2}$.*[26]

Upon receiving a signal, parents update their beliefs. The publication of Wakefield et al. (1998) is tantamount to the realization of an h signal in $t = 1$. Parents making decisions in this period update beliefs from the uniform prior to $\Pr(H|h) = p$. The threshold for choosing y becomes $\frac{z}{a} \geqslant p$. Given that those households with $\frac{z}{a} < p$ choose n, we obtain the following comparison:

Observation 2. *After exposure to a signal h indicating that the vaccine is harmful, the vaccine non-update rates of both biased and unbiased groups increase from $N_0^b = N_0^u = \frac{1}{2}$ in period $t = 0$ to $N_1^b(h) = N_1^u(h) = p > \frac{1}{2}$ in period $t = 1$.*

In the empirical estimations, we interpret the size of the differential trend of the vaccine non-uptake rate as the strength of the college-educated group's biases against the vaccine. The model counterpart of this is a difference-in-difference, $D_t = (N_t^b - N_{t-1}^b) - (N_t^u - N_{t-1}^u)$, which we use to evaluate the impact of a signal on the biased group relative to that on the unbiased group. Given that $N_0^b = N_0^u = \frac{1}{2}$ and $N_1^b(h) = N_1^u(h) = p$, we have that $D_1(h) = 0$. The initial negative news in period $t = 1$ has the same impact on the biased group as on the unbiased group, because the biased parents making decisions in this period perceive the informativeness of the h signal as objectively as the unbiased parents. This is no longer the case, however, in period $t = 2$. The biased parents making decisions in this last period of the

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[25] We use this rather *ad hoc* yet convenient approach to model the effect of confirmatory bias. See Rabin and Schrag (1999) for the pioneering theoretical work on confirmatory bias in economics.

[26] An non-uptake rate of 50% is certainly not an accurate reflection of reality. Our focus, however, is on the *qualitative changes* in the non-uptake rates in response to new information, not their absolute levels.

model, having been exposed to all previously available information, hold non-uniform beliefs about the two states, and their misperception kicks in.

During the subsequent stage of the MMR-autism controversy, parents were exposed to both positive and negative information about the vaccine. For the signal in period $t = 2$, we accordingly consider both s and h and examine their impacts *separately*.[27] Consider first the case where the second signal is s. Having been exposed to the previous h signal, the parents' existing beliefs are that the vaccine is more likely to be harmful than safe. When receiving the second s signal, the biased group discounts the signal informativeness and updates beliefs according to

$$\Pr(H|h, s; b) = \frac{p(1-p'')}{p(1-p'') + (1-p)p''}.$$

On the other hand, with one h and one s signals objectively perceived, the unbiased group's updated beliefs in period $t = 2$ coincide with the uniform prior:

$$\Pr(H|h, s; u) = \frac{p(1-p)}{p(1-p) + (1-p)p} = \frac{1}{2}.$$

Consider next the case where the second signal is h. The biased parents inflate the informativeness of the signal. The updated beliefs of the two groups of parents are, respectively,

$$\Pr(H|h, h; b) = \frac{pp'}{pp' + (1-p)(1-p')},$$

and

$$\Pr(H|h, h; u) = \frac{p^2}{p^2 + (1-p)^2}.$$

Parents in period $t = 2$ choose y if and only if $\frac{z}{a} \geqslant \Pr(H|h, \text{second signal}; \text{bias status})$. Given that those households with $\frac{z}{a} < \Pr(H|h, \text{second signal}; \text{bias status})$ choose n, we have the following profile of vaccine non-uptake rates in period $t = 2$: $N_2^b(h, s) = \Pr(H|h, s; b)$, $N_2^u(h, s) = \Pr(H|h, s; u)$, $N_2^b(h, h) = \Pr(H|h, h; b)$, and $N_2^u(h, h) = \Pr(H|h, h; u)$. The informativeness-discounting condition, $p'' < p$, implies that $N_2^u(h, s) < N_2^b(h, s) < p$, while the informativeness-inflating condition, $p' > p$, implies that $p < N_2^u(h, h) < N_2^b(h, h)$. Also recall from Observation 2 that $N_1^b(h) = N_1^u(h) = p$. These relations imply that $D_2(h, h) > 0$ and $D_2(h, s) > 0$, which give us the following main result of our theoretical analysis:

Proposition 1. *Under the misperception of signal informativeness by the biased parents in period* $t = 2$, *exposure to* h *signal raises the vaccine non-uptake rate of the biased group more than that of the unbiased group, while exposure to* s *signal lowers the non-uptake rate of the biased group less than that of the unbiased group.*

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[27] One can consider a model with three or more signals, evaluating, e.g., the effect of a third h signal after a first h signal and a second s signal. To keep the analysis simple while bringing out the gist of the matter, we separately evaluate the effects of a second s and a second h signals.

Since the impact of the h signal on the vaccine non-uptake rate is an upward impact, $D_2(h, h) > 0$ means that it raises the non-uptake rate of the biased group more than that of the unbiased group. On the other hand, since the impact of the s signal is a downward impact, $D_2(h, s) > 0$ means that the impact on the non-uptake rate of the biased group is less negative, i.e., smaller in magnitude, relative to that of the unbiased group. There are *asymmetric responses to positive and negative news* in that, relative to the responses of the unbiased group, the biased group responds more strongly to the negative news than to the positive news.

5.2 The Effects of Information Exposures

We proceed to the empirical analogue of the theoretical analysis, investigating the effects of positive and negative information exposures described in Section 3.2. To promote the comparability of different types of exposures measured in different ranges of values, we use z-scores in our estimations.[28] We average the z-scores of all exposures of the same classified views to construct composite measures of positive and negative exposures for each state-year. Figure 4 illustrates the geographical variations in these composite measures in 1998, 2004, and 2011, in which the states are colored according to the quartiles of the composite exposures in the given year. The figure shows sufficient variations within states over time in the relative levels of both positive and negative composite information exposures.

We augment equation (2) to include two additional interaction terms, $college \times \ln(t - 1998) \times pos\_info_{st}$ and $college \times \ln(t - 1998) \times neg\_info_{st}$, where pos_info_{st} and neg_info_{st} are composite measures of positive and negative information exposures in state s and year t. Recall that the estimated coefficient of $college \times \ln(t - 1998)$ is interpreted as the strength of the biases held by the college-educated group; the coefficients of the new interaction terms therefore measure changes in the bias strength when the value of pos_info_{st} or neg_info_{st} increases by one.

Table 5 reports the estimation results, which provide evidence of asymmetric responses to the positive and negative information exposures. In all four specifications of area-specific year effects, the coefficients of $college \times \ln(t - 1998) \times neg\_info_{st}$ are positive and significant, whereas those of $college \times \ln(t - 1998) \times pos\_info_{st}$ are negative, insignificant, and minimal in magnitudes. In relation to the coefficients of $college \times \ln(t - 1998)$ reported in Table 4, these coefficients imply the following: a one-standard-deviation increase in exposures to negative information leads to at least 35.07% ($\frac{0.0047}{0.0134}$) increase in the strength of the college-educated

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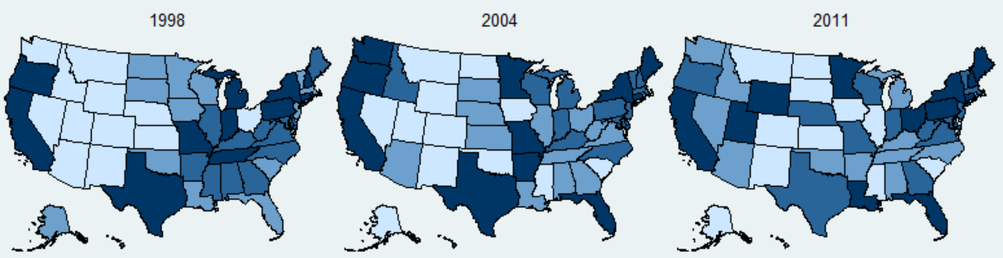
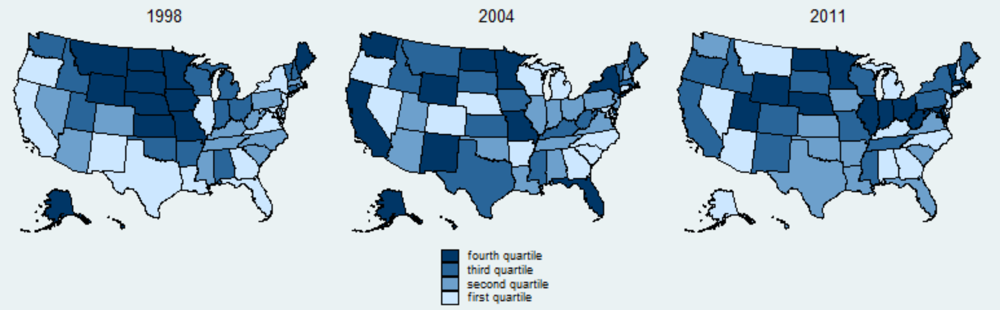
[28] Dafny and Dranove (2008) use the same standardization to study the effects of different quality measures reported in HMO report cards on the enrollment choices of Medicare plans. The z-scores are variables with a mean of zero and a standard deviation of one, obtained by dividing the difference between original variable value and the sample mean by the sample standard deviation.



(a) Composite Negative Exposures



(b) Composite Positive Exposures

Figure 4: Geographical Variations in Composite Information Exposures in 1998, 2004, and 2011

Table 5: Changes in Differential Trends of the MMR Vaccine Non-Uptake Rates in Response to Information Exposures

	(1)	(2)	(3)	(4)
$college \times \ln(t-1998)$	0.0128***	0.0126***	0.0127***	0.0127***
	(0.004)	(0.004)	(0.004)	(0.004)
$college \times \ln(t-1998) \times pos\_info_{st}$	−0.0002	−0.0011	−0.0014	−0.0004
	(0.001)	(0.001)	(0.001)	(0.001)
$college \times \ln(t-1998) \times neg\_info_{st}$	0.0050***	0.0050***	0.0053***	0.0047***
	(0.002)	(0.002)	(0.002)	(0.002)
$college \times post_{2004}$	0.0020	0.0015	0.0014	0.0017
	(0.005)	(0.005)	(0.005)	(0.005)
Sample size	271,478	271,478	271,478	271,478
Area-specific year fixed effects	None	Region–Year	Division–Year	State–ln(year)

Note: The outcome variable is an indicator for delayed MMR immunization. *college* is a dummy variable for children with college-educated mother. The time trend, $\ln(t-1998)$, starts at time zero, which is year 1998. pos_info_{st} and neg_info_{st} are average z-scores of, respectively, the positive and negative information exposures described in Section 3.2. $post_{2004}$ is a dummy variable for years after 2004. Columns (1)–(4) report estimation results from four different specifications of area-specific year fixed effects: none, region-specific year effects, division-specific year effects, and state-specific log-linear year effects. Regions and divisions are assigned based on the usual practice of the Census. Standard errors clustered at the survey strata level are in parentheses. *** indicates significance at the 1% level, ** at the 5% level, and * at the 10% level.

group's biases; by contrast, a one-standard-deviation increase in exposures to positive information leads to no more than 10.37% ($\frac{-0.0014}{0.0135}$) and as low as 1.45% ($\frac{-0.0002}{0.0137}$) decrease in the strength of the biases. Exposures to negative information strengthened the biases of the college-educated group more than exposures to positive information attenuated them.

Confirmatory bias and the implied asymmetric responses to information contribute to the persistence of misinformation. The effects of misinformation linger when people amplify incoming information that confirms their erroneous beliefs but discount information that contradicts them. This could have alarming implications on many levels. In the case of vaccinations, since immunizations create positive externality in building herd immunity, withholding vaccinations is not simply a matter of personal choice but has immense societal consequences.[29]

Given the scope of the potential impacts, a study on misinformation cannot be complete without shedding some light on how to counter or mitigate the adverse consequences of misinformation and the associated biases. We extend on the above findings and investigate from a policy vantage which type of information exposures, traditional newspaper coverage or online information, may provide a more effective channel to tackle the biases against the MMR vaccine.[30] We re-estimate equation (2) with separate sets of interaction terms for the positive and negative exposures of each type of exposures considered.

Table 6 reports the estimation results. Online searches are found to have stronger impact on the biases of college-educated mothers than does newspaper coverage. Importantly, both positive and negative exposures of online searches have a significant effect, although the effect of negative exposures remains dominant, about 2.29–2.45 times of that of positive exposures. By contrast, for newspaper coverage, the effects of both positive and negative exposures are insignificant and minimal in magnitude. The effect of the prevalence of measles, mumps, and rubella as positive exposures and that of autism as negative exposure are both insignificant.

Echoing Smith et al. (2008), this additional finding indicates that traditional newspaper coverage had limited impacts on immunization decisions. Negative coverage did not exacerbate the college-educated mothers' biases against the MMR vaccine, but neither did positive coverage offer much help in reducing the biases. This is in contrast to online searches.[31] While negative online searches significantly strengthened the biases, our finding suggests that online searches are a "double-edged sword": unlike the findings based on composite measures, positive exposures to online searches alone did significantly attenuate the biases. The policy

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[29] Another contemporary issue that has been impacted by misinformation is global warming. Despite the confirmation by science that global warming is a real concern, some people including political elites still erroneously believe the otherwise (e.g., McCright and Dunlap, 2011). Any resulting delay in implementing mitigating actions could have adverse consequences not only at a societal level but also on a global scale.

[30] Lewandowsky et al. (2012) review the cognitive factors that contribute to the stickiness of misinformation and recommend debiasing strategies based on cognitive psychological theory.

[31] During the period covered in our study, newspaper readerships declined at an annual rate capped at 6%. The volumes of Google searches, on the other hand, increased quickly, though at a decreasing rate. In 2011, e.g., the growth rate was around 11%. Despite this contrast between online and traditional media exposures, our use of z-scores allows us to capture the relative levels of information exposures across states in a given year. Figures A.1 and A.2 in the Appendix present the geographical variations in the information exposures to newspaper coverage and online searches.

Table 6: Changes in Differential Time Trends of the MMR Vaccine Non-Uptake Rates in Response to Information Exposures by Information Types

	(1)	(2)	(3)	(4)
$college \times \ln(t - 1998)$	0.0106***	0.0109***	0.0112***	0.0109***
	(0.004)	(0.004)	(0.004)	(0.004)
Prevalence Rates of Relevant Diseases				
$college \times \ln(t - 1998) \times pos\_info\_dis_{st}$	0.0005	−0.0003	−0.0005	0.0002
	(0.001)	(0.001)	(0.001)	(0.001)
$college \times \ln(t - 1998) \times neg\_info\_dis_{st}$	0.0008	0.0007	0.0008	0.0013
	(0.001)	(0.001)	(0.001)	(0.001)
Newspaper Coverage				
$college \times \ln(t - 1998) \times pos\_info\_news_{st}$	−0.0002	−0.0002	−0.0002	−0.0001
	(0.001)	(0.001)	(0.001)	(0.001)
$college \times \ln(t - 1998) \times neg\_info\_news_{st}$	−0.0008	−0.0003	0.0001	−0.0003
	(0.001)	(0.001)	(0.001)	(0.001)
Online Searches				
$college \times \ln(t - 1998) \times pos\_info\_online_{st}$	−0.0022***	−0.0019**	−0.0017*	−0.0017*
	(0.001)	(0.001)	(0.001)	(0.001)
$college \times \ln(t - 1998) \times neg\_info\_online_{st}$	0.0054***	0.0045***	0.0043***	0.0039***
	(0.001)	(0.001)	(0.002)	(0.002)
$college \times post_{2004}$	0.0038	0.0030	0.0028	0.0030
	(0.005)	(0.005)	(0.005)	(0.005)
Sample size	271,478	271,478	271,478	271,478
Area-specific year fixed effects	None	Region–Year	Division–Year	State–ln(year)

Note: The outcome variable is an indicator for delayed MMR immunization. *college* is a dummy variable for children with college-educated mother. The time trend, $\ln(t - 1998)$, starts at time zero, which is year 1998. $pos\_info\_dis_{st}/pos\_info\_news_{st}/pos\_info\_online_{st}$ and $neg\_info\_dis_{st}/neg\_info\_news_{st}/neg\_info\_online_{st}$ are average z-scores of, respectively, the positive and negative information exposures of the corresponding types of information described in Section 3.2. $post_{2004}$ is a dummy variable for years after 2004. Columns (1)–(4) report estimation results from four different specifications of area-specific year fixed effects: none, region-specific year effects, division-specific year effects, and state-specific log-linear year effects. Regions and divisions are assigned based on the usual practice of the Census. Standard errors clustered at the survey strata level are in parentheses. *** indicates significance at the 1% level, ** at the 5% level, and * at the 10% level.

implication is that online dissemination of correct and up-to-date information about the MMR vaccine, which public campaigns could target at, may be an effective avenue to counter the adverse effects of the misinformation about the MMR-autism link.

5.3 Robustness Checks

We perform five sets of robustness checks. The two major ones concern the data on information exposures. For the first set of robustness checks, we consider separately four alternative constructions of measures of information exposures: 1) given that the search volume for "measles" is substantially higher than "mumps" and "rubella," we exclude the search indices for the latter two from the measure of positive active exposures; 2) since the specific phrase "MMR autism controversy" has a relatively lower search volume, we exclude its search index from the measure of negative active exposures; 3) since national newspapers have readership that spans across states, in an attempt to obtain a cleaner state-level variation in news exposures, we exclude top four news outlets from our data on news coverage; and 4) we take a further step to exclude the top ten news outlets. The estimation results under these alternative constructions are reported, respectively, in Columns (1), (2), (3), (4) of Table A.3 in the Appendix. Our second robustness check concerns the missing data from Google Trends. Since Google Trends was not launched until 2004, the data prior to 2004 are imputed based on state characteristics. While the strong correlations between the imputed and the actual values after 2004 suggest that the imputation should provide reliable substitutes for the missing data before 2004, it is conceivable that some measurement errors are introduced. Table A.4 in the Appendix reports estimation results from using only observations in 2004 and onwards. Our main findings in Section 5.2 survive the above two sets of robustness checks.

We further examine the robustness of our findings with respect to three sample restrictions. First, to address the potential confound from exposures to information in a different state, we exclude those who have relocated across states. Second, we restrict our full sample, which includes children of all races, to non-Hispanic white and black children, thus excluding Hispanic and Asian Americans. Mothers whose native language is not English may be less likely to be exposed to the vaccine information we consider; to the extent that reading fluency in English is correlated with education levels, our findings may be driven by variations in information availability across the two groups of mothers rather than their different responses to information. The sample restriction to non-Hispanic white and black children, whom we consider to be the major English-speaking population in the sample, is an attempt to address this potential confound. Finally, to focus more narrowly on the most relevant news, we use articles that cover only the MMR-autism link to construct the measure of information exposures for newspaper coverage. Our findings are robust to all three sample restrictions.[32]

6 Conclusion and Discussion

The study by Wakefield et al. (1998), which linked the measles virus to the inflammatory bowel disease found in autistic children, initiated the infamous MMR-autism controversy and fueled an ongoing anti-vaccine movement that continued through today. Consistent with the findings from prior studies, we find that the persistent trend to delay the MMR immunization since 1998 to 2011 in the US was driven by children of college-educated mothers. A differential trend of the MMR vaccine non-uptake rate of the college-educated group relative to the non-college-educated group was observed. More importantly, the differential trend perpetuated even after scientific consensus had been reached that the MMR vaccine does not cause autism.

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[32] The detailed estimation results from these three robustness checks are available upon requests.

We examine the interactions between this differential trend and exposures to information about the safety of the MMR vaccine. The primary contribution of our study is the documentation of an asymmetric response to positive and negative information. Interpreting the size of the differential trend as the strength of the college-educated mothers' biases against the MMR vaccine, we find that exposures to negative information about the vaccine strengthened their biases more than exposures to positive information attenuated them. This finding provides non-experimental evidence consistent with the implications of confirmatory bias documented by psychologists. In the presence of such common bias in human reasoning, misinformation, once planted, is hard to eradicate. On the policy front, we obtain further finding suggesting that disseminating correct information online may present the best chance to counter the sticky misinformation and erroneous beliefs about the MMR vaccine.

We conclude by discussing two potential issues in our empirical methods. Our policy implication hinges on the finding that the isolated impacts of online information exposures, both positive and negative, are significant. Yet it is plausible that simultaneity bias exists for online searches, which results in an overestimation of the impacts. Parents who are uncertain about the safety of the MMR vaccine may actively search for information online. As a result, there may be a positive correlation between vaccination decisions and the intensity of online searches, leading to the overestimation.

We formally test the endogeneity of positive and negative online exposures by using the Hausman test to compare the estimates from an ordinary least squares (OLS) and an instrumental variable (IV) models. We use two plausible instrumental variables for the two potentially endogenous variables of positive and negative online exposures. They are 1) the percentage of households with internet access, and 2) the average time spent on computer for leisure among individuals living in households with children under 18 years old.[33] Both instruments have a stronger relationship with developments of the internet industry and changes in lifestyles rather than strengths of opinions against the MMR vaccine. Comparing the estimates from the OLS and the IV models using the Hausman test, we fail to reject the null hypothesis that the positive and negative online information exposures are exogenous.[34]

In assessing the impacts of different types of information on the MMR vaccine non-uptake rate, we categorize information in terms of its forms of transmission, whether it is through traditional newspapers or the internet. It is equally valid to consider a taxonomy based on,

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[33] The first variable is obtained from the Current Population Reports on Educational Attainment, and the second variable is estimated using the American Time Use Survey (ATUS). Both variables are state-year level variables. The internet-access variables are also used in imputing the missing Google Trends indices for years prior to 2004, while the earliest year that the ATUS was available was 2003. Due to these restrictions, for this test of endogeneity we only consider observations in and after 2004.

[34] The IV models are estimated using two-stage least squares estimators. In all four specifications of area-specific year effects that we adopt throughout the estimations in the paper, the power of the IV for both endogenous variables exceeds the conventional minimum of $F = 10$, with a minimum value of 17.106 and a maximum value of 159.981. The p-values from the Hausman test range from 0.357 to 0.989.

e.g., the sources of information, whether news about vaccine safety comes officially from the government or informally from social networks. To the extent that different sources of information may be differentially associated with different media formats, our findings in terms of the latter may in part be driven by responses to the former. Without pretending to offer a complete answer to this potential confound, we nevertheless note that, for information obtained through social networks, the vast development of social media platforms like Facebook and Twitter has turned a substantial volume of social networking activities online. Our measure of online information as a type of information may capture the information obtained through social networks reasonably well, preserving the validity of our findings in spite of the potential confound. Examining more generally the interactions between media and sources of vaccine information on vaccination outcomes would be a natural step for future research.

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Appendix – Additional Tables and Figures

Table A.1: Variations in Measures of Information Exposures between and within States during 1998-2011

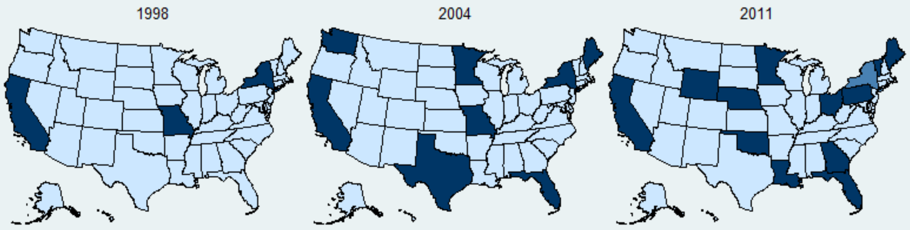
		Standard Deviation		
	Mean (1)	Overall (2)	Between (3)	Within (4)
A. Passive Exposures				
Prevalence Rates of Relevant Diseases				
Measles, mumps, and rubella (% in thousand residents)	0.519	(3.334)	(0.915)	(3.208)
Autism (% of all disability cases)	3.164	(2.196)	(1.112)	(1.900)
Newspaper Coverage				
Position supporting immunizations (% of news counts)	14.482	(29.214)	(13.943)	(25.741)
Health authorities or scientific evidence (% of news counts)	10.751	(23.648)	(10.869)	(21.053)
Anecdotes against immunizations (% of news counts)	2.804	(12.034)	(4.311)	(11.251)
Autism (% of news counts)	7.979	(20.742)	(8.840)	(18.802)
B. Active Exposures				
Online Searches				
"Measles," "mumps," and "rubella"	75.042	(20.835)	(7.448)	(19.484)
"Autism"	90.901	(5.935)	(3.238)	(4.993)
"Vaccine and autism"	91.515	(8.193)	(1.501)	(8.057)
MMR autism controversy (search topic)	53.137	(30.553)	(12.302)	(28.016)

Note: The sample is made up of a panel of 51 states over a period of 14 years from 1998 to 2011. The sample size is therefore 714. The frequencies of measles, mumps, and rubella are total counts of the three diseases normalized by resident population at the state-year level. The frequencies of autism are counts of the disability normalized by total counts of 13 disabilities at the state-year level. For newspaper coverage, the frequencies are counts of news of particular types (the four types of coverage are not mutually exclusive) normalized by total counts of identified news at the state-year level. For online searches, the statistics are search indices obtained from Google Trends for each state-year, which range from 0 to 100, with higher values indicating greater search volumes. The index for "measles," "mumps," and "rubella" is a summary index averaged across the indices obtained separately for the three diseases. Standard deviations are in parentheses.

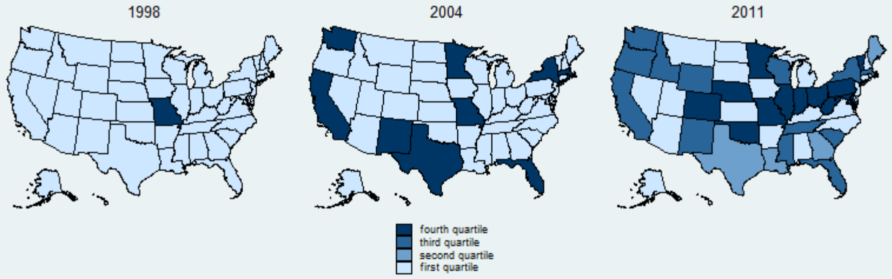
Table A.2: Differential Time Trends of the Non-Uptake Rates of Other Mandatory Childhood Vaccines

	Hepatitis	Hib	Polio	Pertussis
$college \times \ln(t-1998)$	0.0088**	−0.0032	0.0076**	0.0024
	(0.004)	(0.003)	(0.004)	(0.005)
$college \times post_{2004}$	0.0067	0.0082	0.0062	0.0099
	(0.006)	(0.005)	(0.006)	(0.007)
Sample size	271,478	271,478	271,478	271,478

Note: The outcome variables are indicators for delayed hepatitis, hib, polio, and pertussis immunizations respectively. *college* is a dummy variable for children with college-educated mother. The time trend, $\ln(t-1998)$, starts at time zero, which is year 1998. $post_{2004}$ is a dummy variable for years after 2004. Division-specific year fixed effects are controlled for in all four estimations. Standard errors clustered at the survey strata level are in parentheses. *** indicates significance at the 1% level, ** at the 5% level, and * at the 10% level.

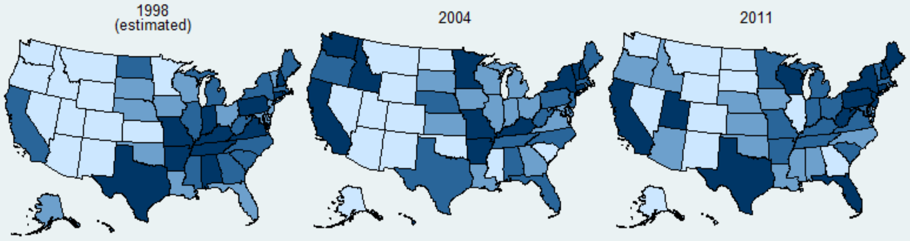


(a) Negative Passive Exposures: Newspaper Coverage

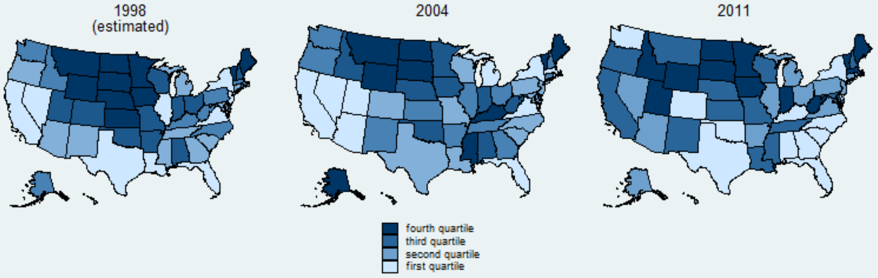


(b) Positive Passive Exposures: Newspaper Coverage

Figure A.1: Geographical Variations in Passive Information Exposures (Newspaper Coverage) in 1998, 2004, and 2011



(a) Negative Active Exposures: Online Searches



(b) Positive Active Exposures: Online Searches

Figure A.2: Geographical Variations in Active Information Exposures (Online Searches) in 1998, 2004, and 2011

Table A.3: Robustness Checks: Alternative Constructions of Measures of Information Exposures

	(1)	(2)	(3)	(4)
Panel A				
$college \times ln(t-1998)$	0.0126***	0.0129***	0.0127***	0.0126***
	(0.004)	(0.004)	(0.004)	(0.004)
$college \times ln(t-1998) \times pos\_info_{st}$	−0.0010	−0.0011	−0.0006	−0.0004
	(0.001)	(0.001)	(0.001)	(0.001)
$college \times ln(t-1998) \times neg\_info_{st}$	0.0050***	0.0046***	0.0046**	0.0043**
	(0.002)	(0.002)	(0.002)	(0.002)
$college \times post_{2004}$	0.0018	0.0015	0.0016	0.0019
	(0.005)	(0.005)	(0.005)	(0.005)
Panel B				
$college \times ln(t-1998)$	0.0106***	0.0113***	0.0109***	0.0109***
	(0.004)	(0.004)	(0.004)	(0.004)
Prevalence Rates of Relevant Disease				
$college \times ln(t-1998) \times pos\_info\_dis_{st}$	0.0002	0.0001	0.0002	0.0002
	(0.001)	(0.001)	(0.001)	(0.001)
$college \times ln(t-1998) \times neg\_info\_dis_{st}$	0.0014	0.0013	0.0013	0.0013
	(0.001)	(0.001)	(0.001)	(0.001)
Newspaper Coverage				
$college \times ln(t-1998) \times pos\_info\_news_{st}$	−0.0002	−0.0003	−0.0001	−0.0000
	(0.001)	(0.001)	(0.001)	(0.001)
$college \times ln(t-1998) \times neg\_info\_news_{st}$	−0.0003	−0.0003	−0.0005	−0.0006
	(0.001)	(0.001)	(0.001)	(0.001)
Online Searches				
$college \times ln(t-1998) \times pos\_info\_online_{st}$	−0.0020***	−0.0017*	−0.0018*	−0.0018*
	(0.001)	(0.001)	(0.001)	(0.001)
$college \times ln(t-1998) \times neg\_info\_online_{st}$	0.0038**	0.0035***	0.0040***	0.0039***
	(0.002)	(0.001)	(0.002)	(0.002)
$college \times post_{2004}$	0.0039	0.0024	0.0030	0.0029
	(0.005)	(0.005)	(0.005)	(0.005)
Sample size	271,478	271,478	271,478	271,478
Area-specific year fixed effects	State-ln(year)	State-ln(year)	State-ln(year)	State-ln(year)

Note: Each column in each panel represents a separate regression. The outcome variable is an indicator for delayed MMR immunization. Standard errors clustered at the survey strata level are in parentheses. In all specifications, state-specific log linear year trends are controlled. In Column (1), online search indices for mumps and rubella are excluded from positive exposures. In Column (2), online search indices for MMR-autism controversy are excluded from negative exposures. In Column (3), news articles from the top 4 national newspapers are excluded from exposures for newspaper coverage. In Column (4), news articles form the top 10 national newspapers are excluded from exposures for newspaper coverage. *** indicates significance at the 1% level, ** at the 5% level, and * at the 10% level.

Table A.4: Robustness Checks: Using Only Observations in 2004 and Onwards

	(1)	(2)	(3)	(4)
Panel A				
$college \times ln(t-2004)$	0.0090***	0.0085**	0.0083**	0.0081**
	(0.003)	(0.003)	(0.003)	(0.003)
$college \times ln(t-2004) \times pos\_info_{st}$	−0.0017	−0.0033	−0.0035	−0.0024
	(0.002)	(0.002)	(0.002)	(0.002)
$college \times ln(t-2004) \times neg\_info_{st}$	0.0081**	0.0079**	0.0084**	0.0076**
	(0.003)	(0.003)	(0.004)	(0.004)
Panel B				
$college \times ln(t-2004)$	0.0067**	0.0065*	0.0065*	0.0063*
	(0.003)	(0.003)	(0.003)	(0.003)
Prevalence Rates of Relevant Disease				
$college \times ln(t-2004) \times pos\_info\_dis_{st}$	0.0004	−0.0007	−0.0010	−0.0004
	(0.001)	(0.001)	(0.001)	(0.001)
$college \times ln(t-2004) \times neg\_info\_dis_{st}$	0.0020	0.0017	0.0017	0.0028
	(0.002)	(0.002)	(0.002)	(0.002)
Newspaper Coverage				
$college \times ln(t-2004) \times pos\_info\_news_{st}$	−0.0010	−0.0010	−0.0008	−0.0009
	(0.001)	(0.001)	(0.001)	(0.001)
$college \times ln(t-2004) \times neg\_info\_news_{st}$	−0.0014	−0.0009	−0.0004	−0.0011
	(0.001)	(0.001)	(0.001)	(0.001)
Online Searches				
$college \times ln(t-2004) \times pos\_info\_online_{st}$	−0.0042**	−0.0041**	−0.0038**	−0.0028
	(0.002)	(0.002)	(0.002)	(0.002)
$college \times ln(t-2004) \times neg\_info\_online_{st}$	0.0065***	0.0062**	0.0061**	0.0056**
	(0.003)	(0.003)	(0.003)	(0.003)
Sample size	142,236	142,236	142,236	142,236
Area-specific year fixed effects	None	Region-Year	Division-Year	State-ln(year)

Note: Each column in each panel represents a separate regression. Only observations in 2004 and onwards are included in the analysis. Columns (1)-(4) report estimation results from four different specifications of area-specific year fixed effects: none, region-specific year effects, division-specific year effects, and state-specific log-linear year trends. Regions and divisions are assigned based on the usual practice of the Census. Standard errors clustered at the survey strata level are in parentheses. *** indicates significance at the 1% level, ** at the 5% level, and * at the 10% level.