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ABSTRACT

Anatomy of a Health Scare: Education, Income and the MMR Controversy in the UK*

One theory for why there is a strong education gradient in health outcomes is that more educated individuals more quickly absorb new information about health technology. The MMR controversy in the UK provides a case where, for a brief period of time, some highly publicized research suggested that a particular multi-component vaccine, freely provided to young children, could have potentially serious side-effects. As the controversy set in, uptake of the MMR vaccine by more educated parents decreased significantly faster than that by less educated parents, turning a significant positive education gradient into a negative one. The fact that the initial information was subsequently overturned and the decline in uptake ceased suggests that our results are not driven by other unrelated trends. Somewhat puzzling, more educated parents also reduced their uptake of other non-controversial childhood vaccines. As an alternative to the MMR, parents may purchase single vaccines privately; the MMR is the only vaccine for which we observe a strong effect of income on uptake.

JEL Classification: H31, I38, J12

Keywords: childhood vaccinations, health outcomes, education

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I Introduction

In February 1998 a paper was published in the highly respected British medical journal *The Lancet*. The article reported on twelve children, referred to the Royal Free Hospital in London, with developmental disorders and a set of bowel symptoms, and suggested a link between autism and the particular gastrointestinal pathologies. While the paper did not claim to have proven any link between the syndromes and the measles, mumps and rubella (MMR) vaccine, the parents of eight of the twelve children blamed the combined vaccine, saying that the symptoms had set in days after receiving the immunization. In the press conference before the publication and in a video release issued to broadcasters Dr Andrew Wakefield, who led the research, suggested that there was a case for administering the three vaccines separately until further research could rule it out as an environmental trigger. Between 1998 and 2002, the claim of a potential link between the particular vaccine and autism was reiterated on a number of occasions by Wakefield. While the government consistently tried to reassure the public about the safety of the vaccine, confidence in the multi-component vaccine declined (see below). Following the initial publication and subsequent coverage by the media, the uptake of the MMR also declined sharply, dropping by over ten percentage points in five years, before eventually picking up again. However, by 2003, a substantial body of research had failed to verify any link between the MMR and autism and the emerging consensus among researchers was that the vaccine was safe to use.

The case of the MMR controversy provides an interesting case where, for a relatively short period of time, some research, publicized in the media, suggested a potential risk of serious side-effects associated with a standard medical procedure and where there was a sharp behavioral response. We consider the controversy from the perspective of health inequalities and the diffusion of information on advances in medical knowledge.

A large literature has documented the positive link between individuals' education and their health outcomes.[1] Indeed, a small number of recent studies, mainly using school leaving age reforms as instruments, have found evidence of a causal link running from education to health.

[1] A literature review is provided in the next section

One of the hypotheses to receive recent attention in the economics literature is that more educated individuals have better understanding of, and more quickly absorb, advances in medicine. The ideal setting to study this hypothesis empirically is situations where new health related information becomes available.

We thus consider whether and how the reaction to the controversy, in terms of vaccine uptake behavior, differed among groups of parents with different levels of education and income. The case of the MMR controversy provides a useful case for studying individuals' behavioral responses to new information for several reasons. First, a set of childhood vaccines are provided free of charge through the National Health Service (NHS); hence parents can either accept or reject them at no monetary cost.[2] Second, the controversy took place over a relatively short period and the response was strong; moreover, the fact that the initial information was subsequently overturned and the decline in uptake ceased gives us confidence that our results are not driven by other unrelated trends.[3] Finally, the information coming from different sources regarding the safety of the MMR vaccine was, at times, contradictory; experimental evidence (Viscusi, 1997) suggests that individuals may give undue weight to high risk information while low risk information, especially when provided by the government, is underweighted.

For our main analysis we use data on the uptake of the MMR, and other childhood immunizations, at the Health Authority area level for the years 1997 to 2005, which we combine with corresponding data on the characteristics of the local populations obtained from the Health Survey for England (HSE). We find that the uptake rate of the MMR among parents who stayed on in education past the age of 18 declined by around ten percentage points more than that for less educated parents over the period 1998 to 2003; most of the relative decline in uptake also appear to have occurred during the early stages of the controversy when media attention was relatively low. We also find, however, that the same group of parents reduced their relative

[2] There are no vaccination requirements in the UK. This contrasts e.g. with the USA where children must have proof of immunization or immunity to certain infectious diseases before they can start school.

[3] It is also known that the trend in aggregate uptake behavior mirrored the trend in parents' perceptions of the safety of the vaccine (see below).

uptake of other "uncontroversial" childhood immunizations, suggesting a "spillover" effect from the MMR controversy.

After analyzing the area level data, we also consider data from the Millennium Cohort Survey (MCS) which follows a set of children born in the UK within a twelve month period starting in September 2000. These children were due the MMR vaccine at the height of the controversy and the survey therefore provides an excellent opportunity for studying in more detail the behavior of parents at that point in time. Analysis of this data allows us to confirm that there was, at the peak of the controversy, a negative education gradient in the uptake of the MMR after controlling for a range of other potentially confounding individual characteristics. Among all the vaccines freely provided through the NHS, the MMR is the only vaccine for which we observe a significant negative effect of income on uptake. The MCS also allows us to explore which parents purchased alternatives to the MMR in the private market.

The outline of the paper is as follows. Section II provides a background, including a research and media timeline. Section III describes the area-level data and the trends in the uptake of childhood immunizations. Section IV presents the results from the analysis of this data while Section V provides further evidence based on the cohort survey data. Finally, Section VI provides a discussion.

II Background

Literature Review

Two theoretical models are often invoked to explain why there may be a causal effect of education on health outcomes. The production efficiency hypothesis (Becker, 1965) states that human capital is effectively a factor of production that allows the individual to obtain a better outcome given a set of inputs. This would imply that more educated individuals would demand fewer inputs into health production while still enjoying better health (Grossman, 2000). Indeed, much of the literature associated with the production efficiency hypothesis is concerned with estimating the demand for health inputs and in particular its relation to education. In contrast, the allocative efficiency hypothesis argues that human capital is not a primary input into health production — it is simply something that allows individuals to make better choices of input mixes (Rosenzweig and Schultz, 1982). A few existing empirical tests of the allocative efficiency hypothesis examine whether the more educated are quicker to absorb information about risks or new medical technologies.[4] Lleras-Muney and Lichtenberg (2002) find that the more educated are more likely to use drugs recently approved by the Federal Drug Administration, at least among individuals who experience repeat prescriptions. In contrast, Goldman and Smith (2005), focusing on hypertension drugs, find no effect of education on the adoption of new medical technologies.

The identification strategy to testing the allocative efficiency hypothesis in our paper concerns the reaction by different groups to information under uncertainty.[5] It is thus related to the work of De Walque (2004) on the U.S. Surgeon General's warning on the health risks associated with smoking, and De Walque (2007) on the provision of AIDS information in Uganda. Both studies find that more educated individuals reacted quicker to new information regarding risk. One extra dimension in our case is that the risk information was "reversed" within a relatively short period of time. This means that the reaction patterns that we observe are unlikely to reflect long-run trends.

Any study of the links between education and several health outcomes (see Grossman (2006) or Cutler and Lleras-Muney (2008) for recent surveys) has to deal with the issue that any realized correlations between education and health may originate from three sources: i) a causal effect of education on health, ii) a common factor explaining both the education and health investment decisions (Fuchs, 1982), iii) reverse causality, where bad health as a child would prevent educational investment (Case et al., 2005). Several studies have attempted to estimate the causal effect of education by relying on natural experiments; see among others Arendt

[4]Innovation in health technology could lead to a temporary increase in health inequality (Victora et al., 2000, Glied and Lleras-Muney, 2008).

[5]Education may alter access, quality or the interpretation of the information. Conditional on intensity of the sources of information used, Blinder and Krueger (2004) find that education improves (economic) knowledge.

(2005) for Denmark, Lleras-Muney (2005) and Mazumder (2006) for the US, and Clark and Royer (2007) for the UK. While the general view, expressed in the reviews of Grossman (2006) and Cutler and Lleras-Muney (2008), is that there is a causal effect of education on health, the accumulated evidence is mixed. Clark and Royer (2007) and Mazumder (2006) for example find no significant impact of education. Moreover, instrumental variable methods often only identify local average treatment effects, as typically the policy changes identifying the effect of education affect only a specific population. As an alternative, Lundborg (2008) uses a representative sample of monozygotic twins and a between-twin fixed effect model to control for genetic and family characteristics, finding that compared to high school dropouts, other individuals have a higher level of self-reported health and fewer chronic health conditions. Regarding the intergenerational effect of education and health, Currie and Moretti (2003), Chou et al. (2007), and Chevalier and O'Sullivan (2008) all report positive effects of maternal education on birth weight, in contrast to the findings of Lindeboom et al. (2006).

A handful of papers in other disciplines have analyzed the determinants of the decision to immunize children using the MMR vaccine, using datasets similar to ours. Middleton and Baker (2003) use Health Authority (HA) data on MMR vaccination at age 2 over an earlier period 1991-2001 and report that MMR coverage fell faster in more affluent areas. However they make no attempt to control for area fixed effects or time varying confounding characteristics of the HA. Wright and Polack (2005) use the same dataset to estimate the determinants of vaccinations in 1997 and 2003. They use the 2001 census to map local area level information on deprivation and education and estimate that between these two years, areas with a greater share of the population with no qualifications experienced less of a decrease in the MMR vaccination rate. Pearce et al. (2008) use the MCS and report that failure to immunize is greater among children with more educated mothers and among higher household incomes. However, they do not account for many observable characteristics of the mother that may explain this correlation. In short, while these papers find that more education and less deprivation are associated with a reduction in the propensity to vaccinate with the MMR after the information on the potential side-effect became available, they do not provide enough evidence that these associations are not due to other characteristics.

The MMR Controversy and a Timeline

In this section we establish a timeline outlining how the MMR controversy developed in the research literature and in the media. The timeline can be summarized as follows. Claims that the MMR was potentially unsafe were made on four occasions between February 1998 and February 2002 by Wakefield and coauthors. Research rejecting any link between the MMR and autism was published in nearly all years, with the majority of studies being published between 2001 and 2003. The media has been identified as a key source of information used by parents concerning potential side-effects of the MMR (Pareek and Pattison, 2000). The media covered all claims of potential side-effects and the majority of the research rejecting such claims; moreover, media coverage was particularly intense from spring 2001 through 2004.

A Research Timeline

The original paper (Wakefield et al., 1998), published in *The Lancet* in February 1998, reported on twelve children referred to the Royal Free Hospital in London with developmental disorders. The paper described a collection of gastrointestinal conditions said to be evidence of a possible novel syndrome (subsequently referred to as "autistic enterocolitis"). While the paper suggested that the connection between the bowel conditions and autism was real, it did not claim to have proven any link between the MMR vaccine and autism. However, the parents of eight of the twelve children claimed that the onset of the conditions had occurred within days of vaccination. At the press conference before the paper's publication, Dr Wakefield said that he thought it prudent to use single vaccines rather than the triple vaccine until further research could rule it out as an environmental trigger.

The claim of a potential link between the MMR and autism was repeated in April 2000 when Dr Wakefield (together with a colleague) presented further evidence at a *US Congressional Hearing* showing that tests on 25 children with autism had revealed that 24 had traces of the measles virus in their gut (U.S. House of Representatives, 2000). In a second journal article published in the spring of 2001, Wakefield and Montgomery (2001) claimed that the MMR vaccine had never undergone proper safety tests, and in a third journal article published in the spring of 2002 Wakefield and others provided further evidence of the presence of measles virus in gut samples from children with autism (Uhlmann et al, 2002).

Following the initial claim, a large number of studies, many from epidemiology, failed to confirm any link between the MMR vaccine and autism in particular. Here we will mention only a few of the main studies. One study (Peltola et al., 1998) traces, out all Finnish babies given the MMR since its introduction in 1982, all those who developed gastrointestinal side-effects lasting 24 hours or more. 31 children were identified and it was verified that all recovered and none developed any signs of autistic disorders. Another study traced all children diagnosed with autism within the North-East Thames region in the UK since 1979 and looked for evidence of a change in incidence or age of diagnosis before and after the introduction of the MMR in the UK in 1988; the authors found no evidence of any discontinuity or change in the trend, no evidence of any differences in age of diagnosis between vaccinated and unvaccinated children, and no evidence for any clustering in onset in the months after vaccination (Taylor et al., 1999). Another research design compared the incidence of gastrointestinal disorders in children with autism (prior to their diagnosis) to children without autism and found no differences (Black et al., 2002). Other studies look for discontinuities in the incidence of autism in "natural experiments" settings: e.g. Gillberg and Heijbel (1998) find no differences in incidence of autism among those born before and after the introduction of the MMR vaccine in Sweden in 1982, while Honda et al. (2005) consider the "reverse" experiment in Japan where, for reasons unrelated to autism and bowel disease, the MMR vaccine was withdrawn in 1993, and find no evidence that this reduced the upward trend in diagnosed cases of autism. Virological studies have similarly found no evidence of persistent measles infection in autistic children (D'Souza et al., 2006).

These six studies are all included in the list below of the main studies rejecting a causal link between the MMR and autism. That list contains an additional seven studies which are Kaye et al. (2001), Farrington et al. (2001), Taylor et al. (2002), Donald and Muthu (2002), Madsen et al. (2002), Miller et al. (2003), and Smeeth et al (2004).[6]

There have also been a number of research reviews that have rejected any causal link between the MMR and autistic spectrum disorders, most notably by the US Institute of Medicine of the National Academies (2001, 2004), the American Academy of Pediatrics (Halsey et al. 2001), the UK Medical Research Council (2001), and by Demicheli et al. (2005) for the Cochrane Library.

Sources of Information and Media Coverage

It is of interest to consider where parents obtain information about vaccinations. One of the most authoritative studies to document parents' sources of information is Gellin et al. (2000). The authors conducted a telephone survey in the US with a nationally representative sample of 1,600 expectant parents and parents with young children in 1999. In response to an open-ended question about sources of information ("Where do you get information about immunizations?"), the most frequent answers were doctor (84.2%); other information sources were newspapers or magazines (18.1%), books or journals (12.3%), a nurse (8.2%), a health clinic (7.5%), friends or family members (7.3%), and the internet (7.0%). In the UK, Pareek and Pattison (2000) studied sources of information in the particular context of the MMR using a cross-sectional survey of 295 mothers in Birmingham. They found that mothers consulted a wide variety of sources to obtain *general information* about the MMR vaccine, including health professionals, friends, family, and the media. In contrast, mothers predominantly acquired *information about the potential side-effects* of the MMR vaccine from the media rather than from health professionals, with television the most commonly cited source of information (cited by 35 percent of mothers).

Given this apparent importance of the media in the context of the MMR it is useful to establish the volume and timing of media coverage as part of the general timeline. To this end, we collected time-series statistics on the coverage of the controversy from the online editions of BBC news and four major daily newspapers.[7] For each source we collected, through the

[6] The list of main studies rejecting a causal link was compiled from the summaries of the research provided by the NHS and the BBC.

[7] The four main newspapers considered were the Guardian, the Independent, the Daily Mail, and the Telegraph.

internet, all articles relating to the controversy. For BBC news, articles are available online all the way from the start of the controversy. For the newspapers, articles are generally available online since 1999.

Figure 1 highlights the number of relevant articles, by quarter, appearing in BBC news online in each of the years 1998 to 2006. The figure also highlights the timing of (i) the four claims of a potential risk associated with the MMR noted above, (ii) the main research studies indicating no causal effect of MMR on autism, and (iii) the four main research reviews noted above.

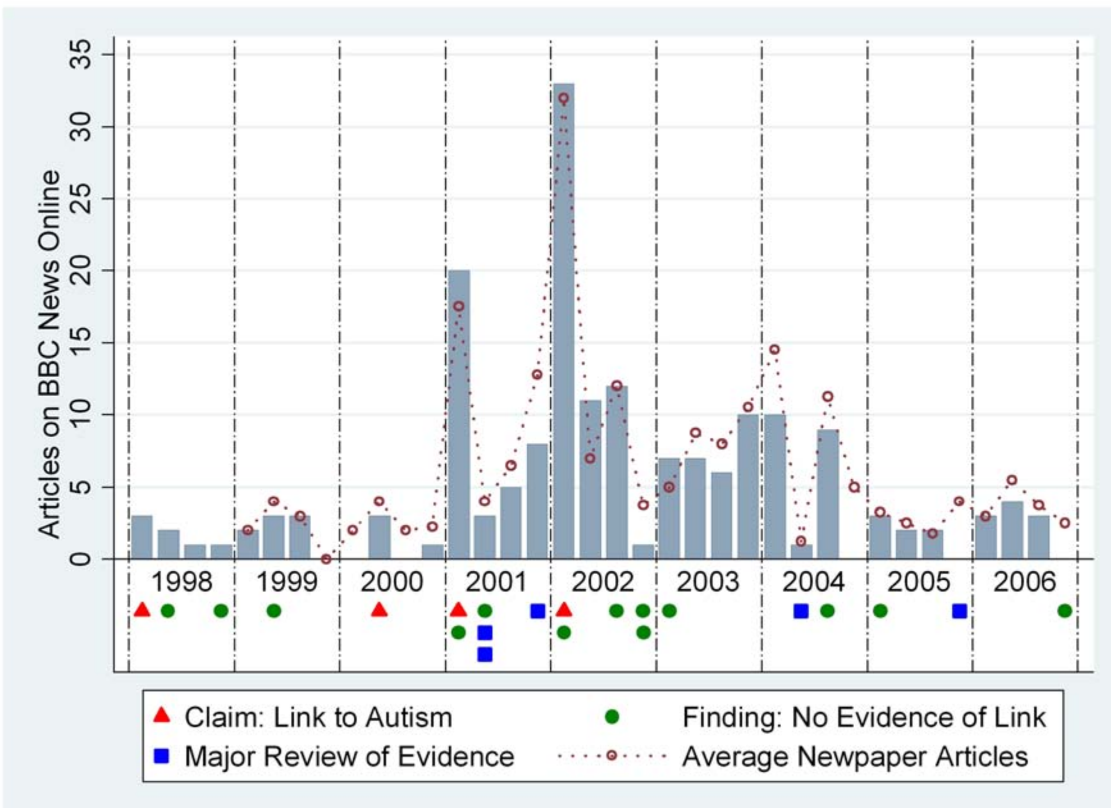

Figure 1: A timeline indicating the number of articles relating to the controversy appearing in BBC news online and in four main newspapers, as well as the timing of the publications of the main relevant pieces of research.

A noticeable feature of the timing of media's coverage was the relatively small number of articles appearing during 1998 and 1999 – a total of 15 articles appearing in BBC news online over two years. This contrasts with the sharp increase in media coverage starting in the spring of 2001, with 20 articles appearing in a single quarter. In terms of content, all four instances of claims of potential side-effects were reported; indeed, the two spikes in media coverage in the spring of 2001 and 2002 were sparked by the two publications appearing at those times (Wakefield and Montgomery, 2001 and Uhlmann et al, 2002). The majority of the aforementioned main studies finding no link between the MMR and autism were also reported.

Other issues covered include news on how the uptake changed, on the increased demand for single vaccines, on government reassurances about the safety of the vaccine, on warnings about future outbreaks, on the increase in the incidence of autism, on the immunization status of the youngest son of the then prime minister Tony Blair, on the rise in the number of confirmed cases of measles. In 2004, there was substantial coverage of the mounting doubts about the initial 1998 study with.the editor of the *Lancet* stating that the article should, with hindsight, not have been published and with news that the General Medical Council was preparing to charge Dr Wakefield with professional misconduct.

In order to verify that the amount of coverage by the BBC is representative, figure 1 also shows the average number of newspaper articles relating to the controversy from 1999 onwards. The volume and timing of coverage is clearly very similar to that of the BBC, again showing how media coverage was relatively low until the first quarter of 2001.

III The Data

We first use area-level data. The areas that will serve as our unit of observation are 95 so-called Health Authorities (HA). The HAs were introduced in April 1996 and were then the lowest health administrative level. In 1999 a lower level of administration, known as the Primary Care Organisations (PCO), was established. In June 2003 the HAs were abolished. However, the three hundred or so PCOs can be aggregated up to reconstruct the HAs after the latter had been abolished.[8]

[8] In 2006 the PCOs were reduced to 152; after this last restructuring it is possible to reconstruct only a subset of the HAs.

The childhood immunization schedule for children in the UK is as follows. Between the ages of two and four months, children receive a primary course (consisting of three doses) of vaccines against diphtheria, tetanus, pertussis (whooping cough), polio and haemophilus influenzae type b ("hib"); then at around 13 months a first dose of the measles, mumps and rubella (MMR) joint vaccine is administered.[9] All these vaccines are provided free of charge through the NHS. In particular, the NHS does not provide single measles, mumps and rubella vaccines: any parent who would prefer to have singles vaccines of any of these three would need to obtain these privately at a significant cost (see below).[10]

The data on area-level uptake rates, available through the NHS Information Centre, is collected by the Health Protection Agency through the Cover of Vaccination Evaluated Rapidly (COVER) data collection programme; the COVER system receives data from the health administration units (the HAs until 2002 and the PCOs thereafter). The programme collects information about the immunization status of all children who reach their second birthday (and other ages) within the specific year, where the year refers to the period April 1st to March 31st of the following year; it reports the fraction of children resident in the geographical unit having received the first dose of the MMR and the fraction of children completing a primary course of the other immunizations.[11]

It is hence important to keep three things in mind. First, the "year" refers to the administrative period April to March. Second, there is nearly a year's gap between the parental decision

[9]Between the ages of three and five years, there are boosters of all the above except the hib. We focus on the uptake of the primary courses and hence do not consider the boosters. A particular hib booster known as "hib extra" was introduced after routine monitoring revealed that the number of cases of hib had gone up in 2001 and 2002. It is given to all children between the age of six months and four years. We consider the "hib extra" in the analysis of the cohort survey data below. In November 1999 a further vaccine against meningitis C was introduced; since uptake data is only available from 2000 onwards we do not consider this vaccine.

[10]The data thus contains information about vaccinations obtained through the NHS, not those obtained through the private market. Hence the statistics may underestimate the total vaccination rate (see below).

[11]Data on immunization uptake is missing for three London HAs in 2005 due to IT problems in the data collection process.

on the MMR and the data collection; hence e.g. the MMR uptake rate in the 2005 data refers to children who reached their second birthday between April 2005 and March 2006 and who were hence eligible for the MMR between May 2004 and April 2005. Finally, there is up to a year's gap between the parental decision on the other vaccines and the MMR.

We combine uptake data with information about the characteristics of the local populations. To this end we use data from the HSE, which is an annual cross-sectional survey monitoring trends in the nation's health. We use the HSE since it is the only survey in the UK that identifies household area information in terms of the administrative health geography.[12] Unfortunately, income data is only available in the HSE from 1997 onwards. Hence we will focus on the years 1997 to 2005.

Demographic Characteristics

We start by establishing that the HAs are diverse. In characterizing the adult populations of parenting age, we include all adults aged 16-55 in the HSE's general population sample and we give each observed adult a weight that depend on his/her age, where the weight is the value of an empirical density function of age among parents to newborn babies.[13] Pooling across years, a total of 63,963 men and women could be allocated to HAs. With 95 areas and nine years, this implies that the average number of adults per cell is 75.[14]

Two key demographic variables for our purposes are education and household income. We focus on simple binary measure of education – the fraction of adults remaining in education until at least age 19, which we label as "high" education.[15] Household income measures not only

[12] We would like to thank the National Centre for Social Research for constructing and providing this information for all years.

[13] The frequency distribution of age among parents to newborn children is obtained from the Millennium Cohort Survey which is described below.

[14] The average number of babies in an area-year cell is 6,106 with a standard deviation of 2,629. Most of this variation is due to area-size differences: the standard deviation in number of babies across areas after pooling across years is 2,604.

[15] We also tried other threshold values but found that 19 provided the best fit; this choice of threshold is also

earnings but also benefit income, maintenance, and interest from savings etc. We also include a number of further characteristics of the adults of parenting age, some of which have previously been found to be related to uptake of childhood vaccines (see e.g. Samad et al. (2006)); these include controls for ethnic composition, the average number of children per household, the fraction of females that are lone parents, and the fraction of adults that ever smoked (since smokers may have different health risk attitudes). It has been suggested in the literature that uptake of the MMR might also be related to the quality of health care provision (Middleton and Baker, 2003). In order to control for this we include two further area-level variables: the numbers of General Practitioners/physicians (GPs) per thousand babies, and the average age among adults living in the area (as a proxy for the demand for health care).[16]

The first column of Table 1 shows the mean across all areas and years and the standard deviation across area-year cells. The standard deviations indicate substantial diversity. The second column of Table 1 shows the aggregate annual trend in each variable (obtained by regressing the annual means on time). Hence e.g. we see that the educational attainment of adults of parenting age increased significantly over time. Similarly, there was substantial income growth (about 2 percent/year), the number of GPs relative to babies grew substantially, there were some ethnic compositional changes, the number of children per household declined slightly, and there was some degree of ageing among the adult population.

The geographical variation in educational attainment is illustrated in the left panel of Figure 2. This figure shows the percent of adults in each HA that stayed in full-time education until the age of 19 or above when we pool the data across all years. The right panel of Figure 2 presents a similar description of the variation in household income. Comparing the two panels of Figure 2, one can see that, as expected, there is a positive correlation between education and income, with clusters of high education and income in the south of the country.

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corroborated by our finding for the MCS below.

[16] We would like to thank the NHS Information Centre for providing the information on the number of GPs.

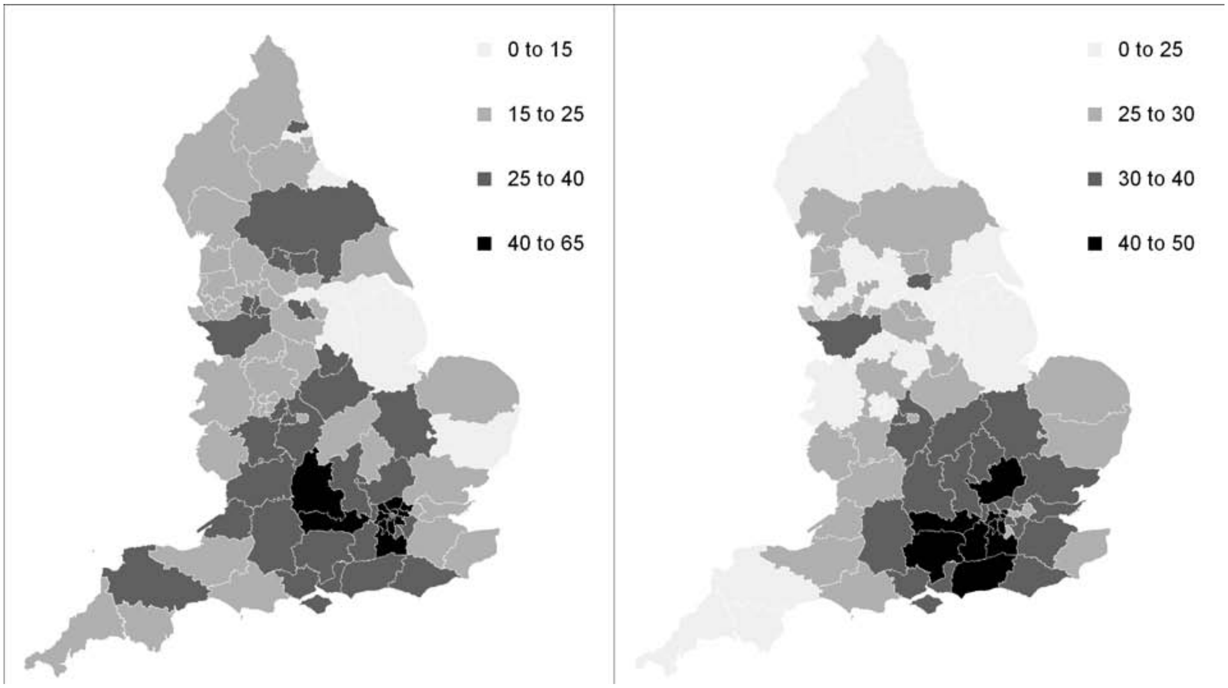

Figure 2: Percent of adults of parenting age staying on in full time education until age 19 or above (left panel) and average household income in thousands, 2000 prices (right panel).

Uptake of Childhood Immunizations

The MMR is the childhood immunization that has seen the largest variation in uptake over the last decade. This is illustrated in the left panel of Figure 3 which shows how the uptake rate of the MMR has varied since 1992. The vertical lines identify four phases: (i) a pre-controversy phase, (ii) an early controversy phase (during which there was some decline and low media coverage), (iii) a phase of sharp decline and intense media coverage, and (iv) a recovery phase. The right panel shows the corresponding uptake of the other childhood vaccines.[17] The figure illustrates how the uptake of the MMR was already, prior to the controversy, low relative to that of the other vaccines and below the target rate of 95 percent required for herd immunity against measles, mumps and rubella. The uptake of the MMR drops in the 1998 data; this data point contains children born between April 1996 and March 1997; since the MMR is administered

[17]The Hib vaccine was introduced in 1992. It's first measured uptake in 1993, which was 75.1 percent, is not included in the figure order to make the other trends more visible.

after the age of 13 months, this means that little less than one third of the children that make up this data point would have been due the MMR in February 1998 or later. After this initial drop, the MMR uptake rate levelled off somewhat in the 1999 and 2000 data; it then dropped again sharply in the 2001 to 2003 data before finally picking up in the last two years of data. Even though the uptake of the other vaccines has been more stable, it is clear that they too have shown some variation over time; indeed, in all cases we see a general reduction lasting until 2004.

The trend in the uptake rate for the MMR is closely related to the perceived safety of the vaccine. Parental attitudes towards immunizations have been tracked across time through a monitoring programme that surveys around 2,000 mother per year (Yarwood et al. 2005, Smith et al. 2007). The respondents are asked, inter alia, to assess the safety of a number of immunizations by rating them on a four point scale: 'completely safe', 'slight risk', 'moderate risk' and 'high risk'. To illustrate the strong correspondence between uptake and perceived safety, Figure 3 (left panel, right scale) illustrates the proportion of mothers saying that the MMR was completely safe or posing a slight risk. The strong correlation between perceived safety and uptake of the MMR strengthens the idea that the measured changes in uptake over time are mainly driven by changes in parental beliefs about the safety of the vaccine.

Figure 4 shows the uptake of the MMR across HAs prior to the controversy and at its peak. The figure shows how, in the 1997 data, there were no areas with uptake rates below 75 percent with the vast majority of areas at 90 percent or above. In contrast, in the 2003 data, all areas except one have uptake rates less than 90 percent and 15 areas are below 75 percent.

In order to see more clearly the variation across time in the uptake of the MMR, Figure 5 shows the change from 1997 to 2003 and from 2003 to 2005. This figure shows how the uptake of the MMR dropped more in the south than in the north, and in the London region in particular.

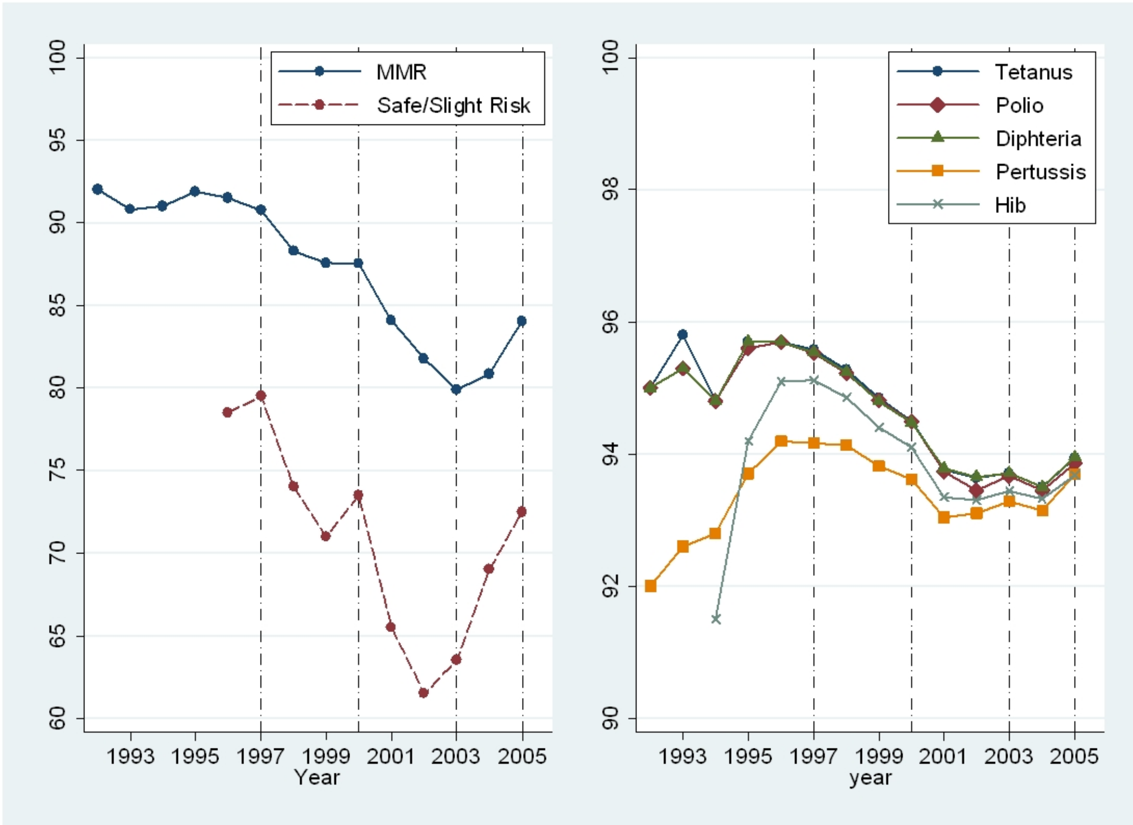

Figure 3: Trends in the uptake of immunizations; data for children who reach their second birthday and the proportion of mothers with young children who perceive the MMR vaccine to be either "completely safe" or pose a "slight risk". (Source: Smith et al., 2007).

IV The Model and Results

The main hypothesis that we wish to test is whether there were different responses to the MMR controversy for parents with different levels of education in terms of uptake of the freely provided combined vaccine. However, we do not want to focus too narrowly on education. One option available to parents rejecting the MMR would be to purchase single vaccines (see below). However, single vaccines would come at a substantial cost to the parents, which would suggest a potentially important role played by household income.

In order to consider the role of education and household income in shaping the response to the MMR controversy we adopt a flexible empirical model where education and income potentially affect the time-path of the MMR uptake rate. We model the uptake rate in area j at time t as

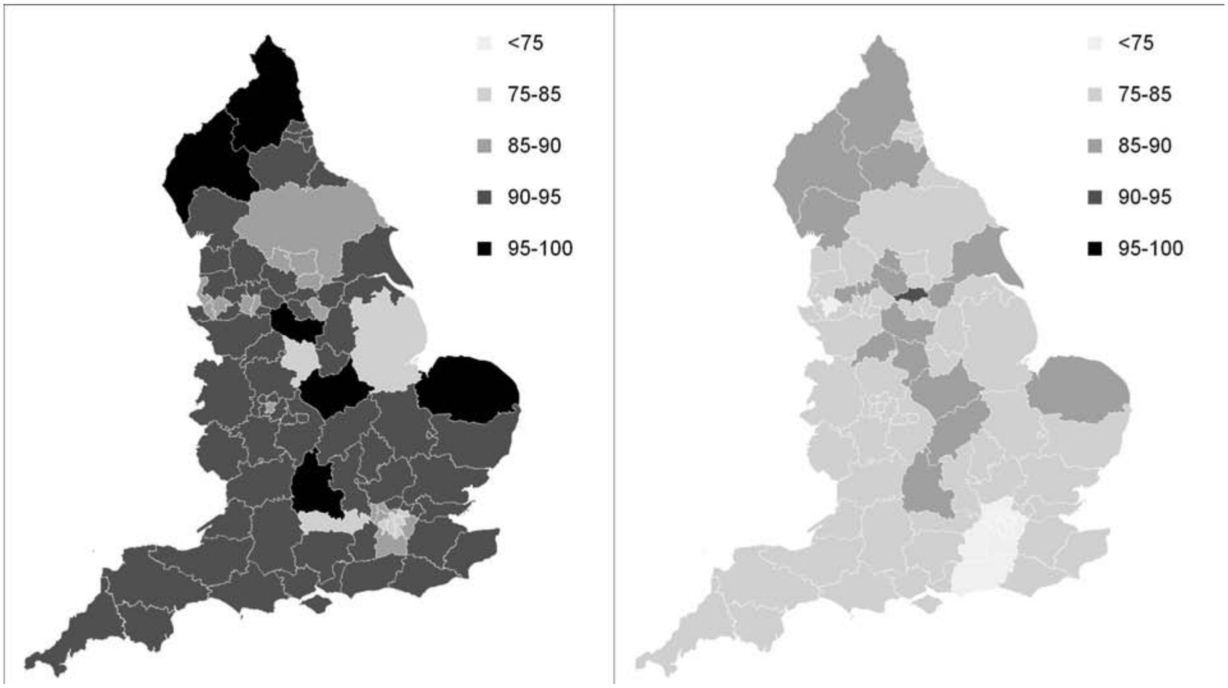

Figure 4: The MMR uptake rate in 1997 and 2003 across Health Authorities for children who reached their second birthdays.

follows:

$$MMR_{jt} = \delta_t D_t + \zeta_j D_j + \alpha^z z_{jt} + \alpha^y y_{jt} + \boldsymbol{\alpha}^x \mathbf{x}_{jt} + \beta_t^z D_t z_{jt} + \beta_t^y D_t y_{jt} + \varepsilon_{it}. \quad (1)$$

In this specification D_t is a dummy variable for the year being t; hence δ_t is a year fixed-effect (with 1997 as the omitted reference year). Similarly, D_j is a dummy for area j; hence ζ_j is a HA area fixed effect. The area fixed effects control for any time-invariant differences across HAs associated with level differences in uptake rates. The variable z_{jt} measures the fraction of adults of parenting age in area j at time t who stayed on in education until age 19 or above; hence α^z measures the impact of education on the baseline uptake rate. Similarly, y_{jt} is the average household income in area j at time t; hence α^y measures its impact on the baseline uptake rate. The vector $\mathbf{x}_{jt}$ contains our remaning controls; the vector $\boldsymbol{\alpha}^x$ hence measures the impact of these variables on the uptake rate.[18]

[18]Since the model includes area- and year fixed-effects the α-coefficients are identified from the fact that the change over time in educational attainment, income, ethnicity, smokers, number of children in households, pro-

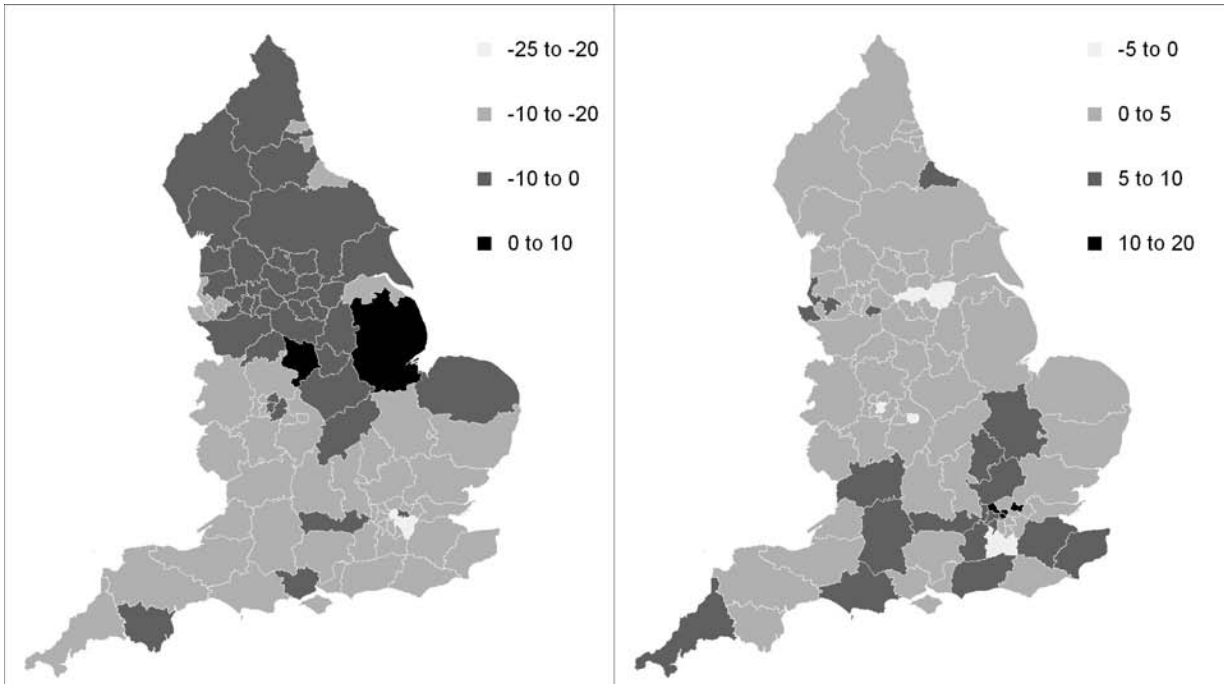

Figure 5: The change in the uptake of the MMR between 1997 and 2003, and between 2003 and 2005, for children who reached their second birthdays.

Our main interest concern the β coefficients; these are the coefficients on the interactions between education and income, respectively, with the year dummies. These measure how education and household income affected the time trend in uptake. In all our estimates of equation (1) the observations are weighted by the number of babies and we apply a robust fixed effects estimator (Wooldridge, 2002, Ch. 10).

Analysis of the Uptake of the MMR

Table 2 presents estimates of various versions of equation (1). The first specification includes only year- and area-fixed-effects. The time dummies in this specification are very similar to the aggregate trend observed in figure 3: an initial drop of 2-3 percentage points in 1998 to 2000 was followed by a sharp drop in 2001 to 2003, making the total drop between 1997 and 2003 in the order of eleven percentage points, and followed by an increase of about 4 percentage points in the last two years of data.

portion of lone parents, number of GPs, and average age of adults, has not been uniform across areas.

The second specification adds education to the regression. Educational attainment has a large positive and significant effect, close to nine percentage points, on the baseline uptake rate. The coefficients on the year dummies now measure the change in the uptake rate across time by parents who left education before the age 19. The coefficients on the interactions between education and the year dummies measure the additional response across time for parents who did stay on in full time education until age 19 or higher. Hence, adding the coefficients for any one year gives the change in uptake, relative to the base year 1997, for parents with high education. E.g. for 1998, the uptake rate by high educated parents was five $(1.799 + 3.195)$ percentage points lower than in the base year 1997.

These results suggest that parents with low education responded relatively less to the MMR controversy, both in its initial phase and at it peak. E.g. for the years 1999 to 2001, the reduction in uptake by low educated parents is about half of the observed aggregate reduction in uptake; when the uptake by low educated parents reached its lowest point it was only about 8 percentage points lower than their uptake prior to the controversy. In contrast, the results indicate a much stronger response by high educated parents, increasing rapidly from a five percent reduction in 1998 to a nearly 17 percentage point reduction by 2001 and 21 percentage points reduction by 2003.

The third specification in Table 2 adds household income as an explanatory variable. Controlling for income generally reduces the estimated responses among low-educated parents, particularly for the years 1998 to 2000. Indeed, for this group and these years, the estimated response is effectively zero; only from 2002 onwards do we estimate responses for low educated parents that are sizeable and statistically significant. In contrast, the estimated additional responses by high educated parents remain negative and sizeable from 1999 onwards and statistically significant for the years around the height of the controversy. Controlling for income reduces the estimated downward trends in uptake for both educational categories but does not overturn the general pattern of larger responses by high educated parents.

Higher income, while having zero effects on the baseline uptake rate, appears to be associated with a faster decline in uptake for all years, but is only statistically significantly so for the years around the height of the controversy. We argue below, based on results from the MCS, that the income effect is consistent with parents declining the freely provided combined vaccine in favor of buying single vaccines on the market. However, the size of the income responses is fairly modest: at the height of the controversy, increasing household income from the 25th to the 75th percentile of the income distribution would decrease the uptake rate by little less than four percentage points.

The fourth specification in Table 2 adds further controls. Adding these controls has a negligible impact on the other estimated coefficients. As for the controls themselves the results suggest a positive effect of the number of GPs and, possibly, a lower uptake among blacks and smokers; however the coefficients are only significant at the 10 percent level.[19]

The estimates suggest that the decrease in relative uptake of the MMR by high educated parents was particularly pronounced in the early stages of the controversy: this is reflected in the coefficients on the interactions between time and education generally growing (in absolute value) between 1998 and 2001 and becoming strongly significant in the last of these years. In contrast, from 2001 until 2003 the estimates suggest that the decline in uptake among lower educated parents was more or less on par with that for high educated parents. In order to consider this in more detail, and also for parsimony, we re-estimate the model using a set of linear splines instead of year dummies, allowing for four subperiods with knots at 1998, 2000, 2003. As noted above 1998 is the first year of data for which some children – about one-third – would have been due the MMR after the start of the controversy. The choice of 2000 as a second knot is natural for two reasons. First, from the aggregate data we know that uptake decreased only slowly up until 2000 and fell sharply thereafter (see Figure 3). Second, from the timeline we know that media coverage of the controversy was relatively low until the spring of 2001. Finally, the choice

[19]The uptake response to the controversy could potentially be related to local infection risk. To explore this we estimated a further specification where we used data on uptake in 1996 (as a proxy for the local immunity rate at the onset of the controversy) interacted with time. These interactions were not statistically significant and the point estimates were positive. This is the opposite of what would be expected if part of the decline in uptake was due to initial high immunity rates. Furthermore, adding these controls, did not alter much the estimated differential response by high and low educated parents.

of 2003 as a knot is natural since this is the year when the MMR uptake reaches it lowest point. The results are shown in Table 3. Focusing on the main specification (4), the coefficient on each subperiod in this regression measures the annual change in the vaccine uptake rate by low educated parents. Similarly, the coefficient on the interactions between education and a given subperiod measures the additional annual change in uptake by highly educated parents. In the spline specification, again, we see no significant response by low educated parents until after 2000 (i.e. the first significant response occurs in the third subperiod); in contrast, for high educated parents we see a sharp decline in the second subperiod, i.e. from 1998 onwards. Moreover, in the third and fourth subperiods there are no statistically significant differences in trends across the two educational groups.

The results again suggest that high educated parents reduced their uptake of the MMR relative to that of low educated parents; in other words, the results suggest that the education gradient in the uptake of the MMR changed as the controversy evolved. To see this more clearly we contrast the model's predictions as we vary parental education. In particular, consider the predicted aggregate uptake rate in two counterfactual scenarios: (i) a "high education" scenario where all parents stay on in education until at least age 19, and (ii) a "low education" scenario where no parents stay on.[20] In constructing the predictions we rely on the most general of our estimated models: model (4) in Table 2. Figure 6 shows the time paths for these predicted counterfactual uptake rates along with the actual aggregate uptake rate. The figure shows how, prior to the controversy, high education was associated with a markedly higher uptake rate; this reflects the estimated seven percentage points impact of high education on the baseline uptake rate. This positive education gradient for uptake was then gradually eroded over the following years, so that for the years 2001 to 2003, the uptake rate among high educated parents was about one to three percentage points below that of the less educated parents. In contrast the model suggests that, by 2005, the two educational groups had the same uptake rate of 84

[20]In practical terms we use the model to predict the takeup rate in each area-year cell under the two counterfactual scenarios, and then compute the mean of the predictions for each year by taking the weighted average across HAs. The predictions are based on the final model specification (4) in Table 4.

percent.[21] It should be noted, however, that these predictions are effectively extrapolations (or "out-of-sample" predictions) since there are no areas where no- or all adults have high education. One reason for using the cohort survey data below is to verify these predictions at one point in time.

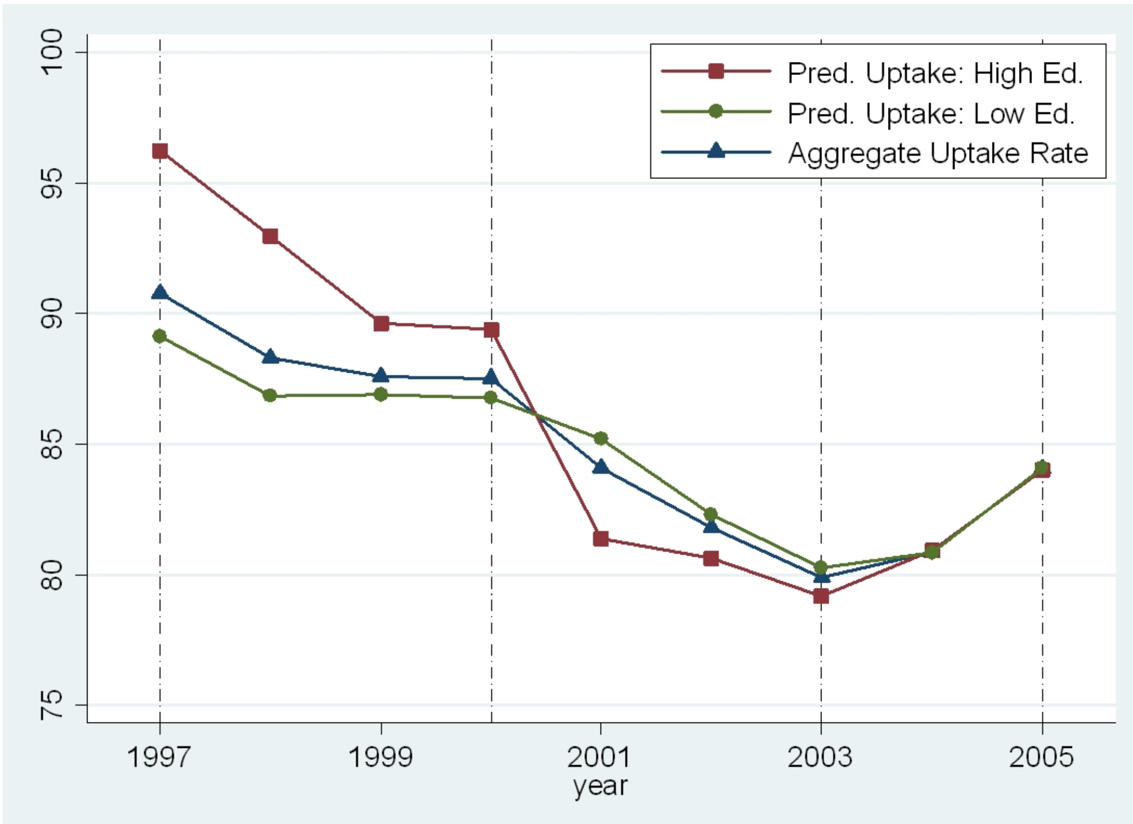

Figure 6: The predicted uptake rates in the counterfactual scenarios of high- and low-educated populations.

[21]Two previous studies, mentioned above, from other disciplines present related results partially based on the same data. Middleton and Baker (2003) focus on a subset of 60 HAs for the period 1991-2001, grouping areas into "deprived", "affluent", "neither" according to a deprivation index. They find that after 1997 there was a faster decline in the more affluent areas. Wright and Polack (2005) also use data on uptake rates at the HA level which they combine with data on demographic characteristics obtained primarily from the 2001 census. The estimate a model where the dependent variable is the change in uptake rate between 1997 and 2003 – an implicit area-fixed effect model – and find that having no qualifications is associated with a lower decline in uptake. However that the authors measure the educational attainment of the economically active population rather than that of the adult population of parenting age which could result in a substantial bias.

Other Immunizations

While Figure 3 shows the dramatic decline and subsequent recovery in uptake for the MMR, it also suggests that there have also been smaller declines in the uptake of the other childhood immunizations. Given that the controversy was MMR-specific these declines are somewhat puzzling. Two main explanations can be conceived. First, it could be that these declines were unrelated to the MMR controversy and were driven by changes in the demographic composition of the population. Second, there could be "spillover effects" in the sense that some parents, as a response to the MMR controversy, also rejected other "uncontroversial" vaccines. We will argue here that the second explanation is more likely.

Three predictions would be associated with the spillover hypothesis. If the decline in the other childhood vaccines were due to spillover effects of the MMR controversy, then we should see that (i) the change in behavior should occur within the same subgroups of the population, (ii) the time pattern of the uptake rates for the other vaccines should similar to that for the MMR, possibly with an extra lag of one year due to the nature of the data collection process,[22] (iii) since the option of purchasing single vaccines in the private market applied specifically to the MMR, we should expect to see income effects that are particular to that vaccine.

In order to explore these predictions we estimate the same equation (1), this time on the other childhood immunizations. All regressions use the same specification as specification (4) in Table 2 and the results are presented in Table 4.

The predictions are largely borne out. First, the results indicate that the changes in uptake behavior are particularly strong in the high education group. For the low education parents there are generally speaking no statistically significant changes in behavior, although the point estimates suggest a decline in the uptake rate of about three percentage points between 2000 and 2005. In contrast, the coefficients on the interactions between the year dummies and education are, from 1999 onwards, negative and, for the last four years in particular, always statistically

[22] Recall that there is one year's lag between the MMR decision and the data collection and nearly a two-year lag between the parental decision on the other vaccines and the data collection. Note also that we cannot distinguish between cohort effects and pure year effects.

significant, indicating an additional decline of around six to seven percentage points. Second, with respect to timing, there is no negative response for either low- or high educated parents in 1998; this is consistent with the spillover hypothesis since the decisions that are measured in the 1998 data would have been taken between the summer of 1996 and the summer of 1997, i.e. before the start of the controversy. Finally, with respect to income, the estimated effects on the change in uptake across time are very small and generally not statistically significant.

It could potentially be argued that the downward relative trend in the uptake of vaccinations by high educated parents simply reflects a more general phenomenon of reducing inequality of access and use of health care. This is unlikely for two reasons. First, the vaccinations saw absolute reductions in uptake by parents. Second, the decline in relative uptake appears to be particular to childhood vaccinations. To illustrate this we present in the last column of Table 4 a corresponding regression for the rate of cervical screening tests ("smear tests").[23] Smear tests provide a suitable comparison in that women are invited to participate in a programme designed to prevent a particular disease; moreover, the uptake rate is similar to that for childhood vaccinations and there was no controversy about its efficacy. Women aged 25 to 65 are invited for screening every three to five years and the dependent variable used in the regression measures the number of women screened within the year as a fraction of the eligible population. The regression shows a pattern that is directly opposite to that for childhood vaccinations: high education is associated with both a relative and absolute increase in uptake.

Hence, we conclude that, in line with the spillover hypothesis, we see changes in behavior that are particularly strong in the high education group, occurring only for those due for the early childhood vaccines from 1998 onwards, and with little role played by income.

V Further Evidence

Three main results were obtained in the analysis above. First, we found that the uptake of the MMR declined particularly among high educated parents. Indeed, our estimates suggest

[23]We would like to thank Amanda Gosling for the suggestion to look at the uptake of smear tests.

that this relative decline was strong enough to overturn the positive education gradient that existed prior to the controversy. A finding of a negative education gradient at the height of the controversy is exceptional: a routine observation in the literature is that parents with high levels of education have the highest uptake rates of childhood immunizations (see e.g. Streatfield et al., 1990 and, more recently, Lee, 2005). Second, we found that the MMR controversy appears to have had spillover effects onto the other main childhood vaccinations; specifically, the estimates suggested that high educated parents also reduced their relative uptake of these immunizations (but not of other non-vaccination health services). Third, we found a negative effect of income on the uptake of the MMR while there was little or no evidence of any such effect on the other childhood immunizations. In this section we will use data from a cohort survey dataset to provide further evidence on these three findings.

The Millennium Cohort Survey Data

The MCS follows the lives of a set of children born in the United Kingdom within a set period of time, collecting information about their parents and their development in a wealth of dimensions, including health, and education family circumstances. We will use data from the first two sweeps. The first sweep, at nine months of age, recorded the circumstances of pregnancy and birth, and the early months of the cohort members' lives. The second sweep was carried out at around the age of three; this sweep contains, inter alia, detailed information on the immunization status of the cohort members, as reported by the mother.

Since our earlier analysis pertained to English HAs will use all MCS children who were born in England; these children were all born between September 2000 and August 2001 which means that they were due the MMR between the autumn of 2001 and the autumn of 2002. This timing of the survey makes it ideal for considering in detail the behavior of parents precisely at the height of the controversy. In terms of the timing of the previous NHS administrative data, the MCS children would have had their second birthdays within the period September 2002 to August 2003, implying that little over half of the cohort would be recorded in the 2002 data and the remainder in the 2003 data.

While the MCS contains information about the personal characteristics of the parents, the information on fathers is often missing or incomplete; hence we will focus on the personal characteristics of the cohort member's mother. In order to conform with the previous analysis, we use the same measure of education, i.e. staying on in full-time education until at least age 19.

The MCS has a rich set of variables that allow us to control for a range of potentially confounding factors. We include information on ethnicity, the mother's age when the child was born, (equivalized) household income, the gender of the child, the marital status of the mother, whether English is spoken in the household, smoking and drinking habits by the mother, the number of siblings of the cohort member at the time of birth, whether the child has been in private childcare, and whether or not the household had an internet connection (either in the house or through work), frequency of contact with the grandmother, the mother's perception of the quality of the neighborhood, whether the mother worked in the NHS before the birth of the child, whether the mother worked in a "scientific occupation", whether she voted for the Tory party in the 2001 general election, whether the mother is catholic or muslim. We also control for area-effects using the nine Government Office Regions – the lowest level of area information available in the survey. Descriptive statistics on the sample used are provided in Table 5.[24,25]

Immunization Takeup at the Height of the Controversy

Table 6 (first column) provides the results from a probit model of the MMR uptake. The regression confirms the lower MMR uptake by high educated parents; the point estimate of a

[24]The uptake of the MMR in the MCS is significantly higher than the corresponding national average at the time. There are two potential explanations for this. First, in the MCS the question is asked at the age of three which is higher than the age at which the NHS data is collected; hence insofar as parents reacted to the controversy by delaying the uptake of the MMR we would expect a higher observed uptake rate in the MCS. Evidence that the controversy has led parents to delay their uptake of the MMR is provided in Cameron et al. (2007). Second, given that the social norm is to vaccinate there is a possibility that parents may over-report their uptake.

[25]The variables measuring the frequency of contact with the grandmother and the mother's perception of the quality of the area are presented here in binary form; in the regressions a finer set of categories are used.

2.5 percentage points gap is only slightly larger than the estimated gap that was illustrated in Fig. 6 for the relevant years (2002 and 2003). This observed negative education gradient for the MMR contrasts with that for the other immunizations for which there are, largely speaking, no observed differences in uptake rates among high- and low educated mothers. This latter absence of a positive gradient is also consistent with the analysis above, that prior to the controversy there was, for each of the other main vaccines, a four to five percentage positive education gradient which, by the time of the MCS cohort, had disappeared.

The estimated impact of household income on MMR uptake is negative, as in the above analysis. The point estimate suggests that increasing income so as to move a family from 25th to the 75th percentile of the income distribution would reduce the MMR uptake by around two percentage points; this estimate is slightly lower than the close to four percentage points lower uptake predicted by the analysis above. A negative income effect for the MMR sharply contrasts with the estimates for the other vaccines for which we find either zero or positive income effects.

Among other background factors, we note that never married mothers appear to have a lower uptake of vaccines than currently married mothers, although the effect is not precisely estimated for the MMR. Ethnicity has a substantial impact on the uptake of the MMR but not on the other vaccines; for the MMR, whites have an 8 to 9 percentage point lower uptake rate than either asians or blacks.[26] The gender of the baby has no significant impact on the uptake of any vaccine, except possibly for a lower uptake of the MMR for boys. The presence of older siblings has a positive effect on the uptake of the MMR, but not for the other vaccines (except for the case of four or more siblings where we observed negative impacts). This suggests that mothers who had previous experience with the MMR may have been less influenced by the controversy. Internet access, as a further source of information, was found to have a negative effect on the uptake of the MMR, but not for the other vaccines.

Finally, in order to check for a trend within the twelve month sampling period, we divided the period into three subperiods of equal length according to month of birth (subperiod 1 = September - December 2000, subperiod 2 = January - April 2001, subperiod 3 = May - August

[26] This contrasts the results from the analysis where we did not obtain any precisely estimated effects of ethnicity.

2001). The children born in the first subperiod would have been eligible for the MMR in the autumn of 2001 whereas those children born in the subsequent two subperiods would have been due the MMR starting in January 2002. The estimates suggest that the MMR uptake rate was falling over time. The estimated drop in uptake from the first subperiod to the third of two percentage points would translate into an annual trend of 3 percentage points which is similar to the two percentage annual reduction observed in the aggregate data (Fig. 6).[27] Most of the drop in the uptake rate occurred from the first to the second subperiod. This is consistent with the due date for the MMR for the first subgroup occurring before the peak in the media attention in the first quarter of 2002. We see no corresponding negative trends for the other vaccines; indeed, there is some suggestion that uptake was particularly low in the first subperiod; recall however, that these immunizations would have been due about a year prior to the MMR.

In Table 7 we provide further robustness checks on the education and income effects by considering alternative specifications. Specification (1) is the same as the same as in column 1 in Table 6 except it excludes income, while Specification (2) instead excludes education. In each case the estimated effect is increased, as we would expect given that income and education are positively correlated and both are negatively associated with MMR uptake.

Specification (3) adds additional covariates. These include indicators for whether the child attends private childcare (which may increase the pressure on the parent to have the child vaccinated), whether English is not spoken at home (since language barriers may make parents less susceptible to controversies covered in the media), the child has some some long-standing illness or asthma, whether there is frequent contact with the grandmother (since older generations may have more experience with the diseases against which the vaccines offer protection), the mother's perceptions of the suitability of the area for bringing up children, whether the mother voted for the Tory party in the last general election (which is likely to be related to attitudes towards public services), whether the mother worked in the NHS or worked in a "scientific" occupation, and whether she is catholic or muslim. Adding these covariates slightly increases the estimated

[27]We have also interacted the subperiods with mother's education; this reveals no difference in trends, which is also consistent with the parallel trends for the two educational groups around that time illustrated in Fig. 6.

effects of education.

Parents with different levels of education may differ systematically with respect to their willingness to take health risks; if so it could be that the estimated negative effect of education partly reflects unobserved differences in risk attitudes. In order to consider this, specification (4) adds indicators of the mother's current smoking and drinking behavior as proxies for health risk attitudes. Introducing these proxies slightly reduces the estimated effect of education, but does not remove the negative education gradient.

Similarly, it could be that parents differ in unobserved generic preferences towards immunization and that those preferences are correlated with education; if so, we should expect that the parents who choose not to take up the MMR would also be more likely to not take up the other childhood vaccines. To consider this, specification (5) add indicators for the number of previous vaccinations administered to the same child; the coefficients for education and income then measure the impact on the uptake of the MMR for parents who behaved in the same way with respect to the vaccines provided at an earlier age. Controlling for earlier vaccine uptake for the same child again has a minor impact on the estimated education, and does not remove the negative education gradient. Specification (6) includes all the above.[28]

The Option of Single Vaccines

So far we have focused on takeup of the MMR as the relevant outcome. However, a parent who does not take up the MMR has two options: either to let the child be unvaccinated or to obtain single vaccines. We have argued above that the significant negative income effect on MMR uptake is likely to be, at least in part, driven by the single vaccines option – for the other vaccines, for which there were no alternatives available in the market, we saw income effects that were either negative but not significant (in the NHS data) or positive and, in some cases,

[28] In addition to the above regressions we have also considered specifications where education is disaggregated into five levels of qualifications, corresponding to the standard ISCED classification. The results from these regressions, which are available from the corresponding author by request, indicating a threshold effect qualifications that are typically obtained at the age of 18 or above.

significant (in MCS).

The Medicines and Health Care Products Regulatory Agency (MHRA) is responsible for issuing licenses for the manufacture and importation of drugs/vaccines in the UK. No single measles, mumps or rubella vaccines are licensed for either manufacture or general sale in the UK. Nevertheless, certain brands of single antigen vaccines can be ordered on a named-patient basis through private clinics. A typical price for a single jab (including consultation) is currently in the order of £80 - £100; hence the cost of a complete set of three single jabs is substantial, typically well above £200.

Data on the frequency of single vaccines is generally not available – it is not recorded in the NHS administrative data. The MCS, however, provides an opportunity to document the demand for single vaccines at the height of the controversy since parents were queried about this in the survey interview. The percent of children in the MCS having had single jabs of measles, mumps and rubella are 5.3, 2.9 and 4.9 percent respectively; that corresponds to 24 to 45 percent of parents who rejected the MMR. More or less any parent choosing some single jab opts for the measles vaccine and also the rubella; however, nearly half choose not to take the mumps (which is generally perceived to be a less dangerous disease).

Our main aim here is to document the demand for single vaccines, especially the roles played by income and education. Table 8 shows the results of three probit regressions. In the first column the population is all children and the outcome is having had at least one single vaccine; the second regression considers the probability of having had at least one single vaccine conditional on not taking up the MMR; the third regression considers the probability of having had a complete set of three single vaccines conditional on having had at least one single jab.

The first regression is essentially the mirror image of the regression for the uptake of the MMR presented in Table 6 above. Income has a significant positive effect; mother's education has a positive sign but is not statistically significant. A strong income effect is also evident when we consider the choice between obtaining single jabs versus letting the child be unvaccinated conditional on turning down the MMR (column 2); moving a family from the bottom income quartile to the top income quartile increases the probability of the family choosing single jabs by up to 30 percentage points. The final column considers the choices made by those parents who decided to obtain at least one single jab. Here there is some weak evidence that higher income implies a higher probability of obtaining a complete set of three vaccines. There is also some suggestion that more educated mothers were more selective and more often chose not to take up one of more vaccine (typically the mumps vaccine).

VI Discussion

Immunization is a proven tool for controlling and even eradicating disease, sparing people from suffering, disability, and death. The World Health Organization estimate that in 2002 immunization averted about two million deaths. The importance of trust in vaccines can hence hardly be overstated.

In this paper we have considered a recent episode when trust in one particular vaccine, the combined measles, mumps, and rubella (MMR) vaccine, was eroded due to a number of claims by some researchers, starting in early 1998, linking the vaccine to the development of autism in children. Over the following five years, the claims of a link were met with counterclaims and with government reassurances about the safety of the vaccine; by 2003 the claims had been thoroughly and resoundingly rejected by subsequent research. The controversy spread confusion among parents: the perceived safety of the vaccine declined sharply between 1998 and 2002, as did the uptake of the freely provided multi-component vaccine.

We considered this episode from the point of view of the debate on the link between education and health. One argument put forward in that debate is that more educated individuals more quickly absorb new health related information.[29] We hence hypothesized that the decline of

[29]The idea that individuals with more education are faster to adopt new technologies is certainly not a novel one. In his pioneering book "Diffusion of Innovation" Everett Rogers (2003, originally published in 1962), building on the earlier work by Ryan and Gross (1943) on the diffusion of hybrid seed corn in Iowa, identified different types of adopters in the diffusion process – "innovators", "early adopters", "early majority", "late majority", and "laggards" – and noted that the first two types are often more educated.

the MMR uptake rate should have been more pronounced among high educated parents.[30] We found that this was indeed the case: our findings suggest that, from the start- to the peak of the controversy, high educated parents reduced their uptake rate by about 10 percent more than did low educated parents. In fact, the relative decline in uptake for the high educated parents was so strong that what used to be a significant positive education gradient in uptake turned into a negative one. Interestingly we also find that most of the relative decline in uptake by high educated parents occurred in the first two years of the controversy – a period in which media's coverage of the story was relatively low.[31]

The finding of a sharp relative decline in uptake is clearly consistent with the hypothesis that high educated parents absorbed the new information more rapidly. It does not, on the other hand, prove rationality of parents' behavior. Indeed, we found evidence that the controversy generated a "spillover" effect, leading high educated parents to also reduce their uptake of other "uncontroversial" vaccines. The viability of such a spillover effect may have obtained from an argument in the debate which stated that "too many" immunizations in general, and multi-component vaccines in particular, could "overload" the child's immune system.[32] Nevertheless, given that the claims of a link to autism pertained particularly to the MMR, the existence of

[30] One would also expect that the recovery in the uptake rates should be more pronounced for high educated parents once it was clear that the claims could not be substantiated. While the data does suggest that this may indeed have been the case, it cannot be verified with only two years of data for the recovery phase.

[31] There is no indication that the controversy had any effect on fertility decisions. Fertility in the UK was declining throughout the 1990s but started increasing around 2001. Brewer, Ratcliffe and Smith (2007) suggest that part of this reversal in the fertility trend may be attributed to changes in tax-benefit policy and show that, consistent with that hypothesis, the increase in fertility was stronger among females with low education and income. Similarly, using the current data to perform an area-level analysis of the change in the number of births suggests that, for low educated adults, fertility declined until 2001 and increased thereafter, while for high educated adults fertility was essentially flat over the whole period 1997 to 2005.

[32] Indeed, the "overload" theory was articulated by Dr Wakefield in the media; when interviewed on the BBC Panorama program on February 3, 2002, he argued that: "You do not combine three live viruses into one vaccine and assume that it is a benign process."

a spillover effect onto other vaccines suggests a possible element of "alarmist reaction".[33] This possibility has also been considered in the behavioral-theoretical literature: Viscusi (1997) uses experimental data to show that individuals give undue weight to high risk information and that the low risk information, especially when provided by the government, is underweighted.[34] As noted by Viscusi (1997) "the media and advocacy groups often highlight the worst case scenarios, which will tend to intensify the kinds of biases [in risk assessment] observed here". A section of the British press has indeed been accused of promoting scares over MMR and mis-informing the public (Fitzpatrick, 2005).

Our findings regarding the changes in relative uptake behavior is nonetheless clearly consistent with the main hypothesis that parents with different levels of education absorbed the information differently. However, does it prove that they did so? Stated differently, could it be that high- and low educated parents updated their beliefs about the safety of the vaccine in the same way but simply responded differently to the same information? This would require parents to differ in some other characteristic, correlated with education, that could induce differential responses. A prime candidate would be risk-attitudes; indeed there is some evidence in the literature suggesting that education is positively correlated with risk-aversion.[35] While differences in risk-attitudes would be largely consistent with our main finding of a differential

[33]Indeed, some have suggested that part of the problem is that people lack knowledge, not only about the safety record of vaccines, but also about the seriousness of the very diseases that they protect against. Dr David Salisbury, head of the Government's Immunization Policy Unit at Department of Health, in a keynote speech at a conference on public understanding of vaccination argued that: "The more successful our vaccine programmes become, the less we see the diseases they protect against and we can therefore become complacent about the risk of these diseases. Fear of disease is then replaced with fear over vaccine safety." (Conference on "Public Understanding of Vaccination", April 1-3, 1998, Monaco).

[34]Mistrust in governmental health messages in the UK may also have been increased by the handling of the information of the risk associated with the "Mad Cow" diseases in the mid-Nineties and the allegation of cover up by the government (Adda, 2007, Bartlett, 1998).

[35]Harrison et al. (2007) for example find that higher educated Danes are more risk averse than others. Shroeder et al (2007) highlight the difference between risk perception and risk aversion and note the correlation between education and risk perception.

uptake response (both for the MMR and for other vaccines), we consider it unlikely to be the entire explanation for the observed behavior for three reasons.

First, including proxies for the mother's health risk behaviors in the form of measures of smoking and drinking behavior had only a minor impact on the estimated effect of education on MMR uptake in the MCS data. (Similarly, controlling for other unobserved differences in general attitudes towards vaccinations by analyzing the MMR uptake behavior of mothers who behaved similarly with respect to the other childhood vaccines did not diminish the estimated effect of education). Second, the finding that the relative decline in the uptake of the MMR by high educated parents was particularly pronounced in the early phase of the controversy when media coverage was low (and that trends were close to parallel once media coverage became substantial) similarly suggest that the observed differential responses were due to high educated parents picking up the story earlier than low educated parents; if all parents had absorbed the information at the same rate, we would have expected the uptake rates by high- and low educated parents to continue to diverge until the eventual turning point in 2003. Finally, the UK surveys tracking parental attitudes towards vaccines suggest that perceptions of the safety of the vaccine did indeed develop differently across different groups of parents in a way that is consistent with our main hypothesis: in particular, the findings in Smith et al. (2007) strongly suggest that parents from higher social grades grew more worried about the vaccine relative to parents from lower social grades up to the peak of the controversy (and that the gap closed thereafter).

Overall the results demonstrate that, consistent with the main hypothesis, high- and low educated parents responded differently to the controversy in terms of their uptake behaviors; moreover, we have argued that these differential responses are likely to have been driven by the two groups of parents updating their beliefs about the safety of the vaccine at different rates. If, generally, the rate at which individuals absorb new health technology information is indeed related to their levels of education, this has important policy implications. In particular, it suggests that a policy that attempts to improve health outcomes by providing more information may induce larger inequalities in health outcomes, at least in the short run. Moreover, the current case is particular in that individuals obtained very different risk assessments from different sources. The government's policy throughout the controversy was to reassure the public about the safety of the MMR, and this may well have been the best policy given the circumstances. Nevertheless, gaining a deeper understanding of how people react when different information sources provide different risk assessments is important. In the case of the MMR, empirical evidence suggest that some parents rejecting the vaccine had also developed a sense of distrust in government policy (Casiday et al, 2006). The institutional setup in this context can also matter. Information provided by the government may not necessarily be the most effective for tackling cases such as the MMR controversy; institutions representing the research community that are independent of government, such as the American National Academies, or the National Institute for Health and Clinical Excellence in the UK, may be more successful in convincing the public about which research claims are generally supported by evidence and which are not.

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Table 1: Characteristics of the Adult Population of Parenting Age in the Health Survey for England, 1997 to 2005.

Variable	**Aggregate Mean**	**Annual Trend**
	(Std. Dev. Across Area-Year Cells)	(Std. Err.)
Education: LFE at age ≥ 19 (%)	28.1	1.79**
	(16.9)	(0.11)
Household Income (£1,000)	29.0	0.67**
	(9.1)	(0.11)
Ethnicity: White (%)	91.8	-0.39
	(12.4)	(0.07)**
Ethnicity: Black (%)	2.7	0.06
	(5.7)	(0.08)
Ethnicity: Asian (%)	5.6	0.33
	(9.5)	(0.08)**
Smoker: Current or Ex (%)	53.5	-0.18
	(11.7)	(0.15)
Nr of Children in the Household	1.1	-0.02**
	(0.35)	(0.01)
Lone Parent: Females (%)	12.8	0.08
	(10.0)	(0.11)
GPs/Thousand Babies	52.2	1.53**
	(10.3)	(0.12)
Average Age of Adult Population	47.5	0.28**
	(3.4)	(0.08)

Significance levels: ** : 1% * : 5% † : 10%.

Table 2: Linear Regression Models for the Uptake of the Combined Measles, Mumps and Rubella Vaccine.

Variable	**(1)**	**(2)**	**(3)**	**(4)**
Year = 1998	-2.504	-1.799	-0.269	-0.018
	(0.252)**	(0.644)**	(1.101)	(1.062)
Year = 1999	-3.148	-1.700	-0.568	-0.389
	(0.334)**	(0.747)*	(1.082)	(1.105)
Year = 2000	-3.245	-1.660	0.083	0.208
	(0.430)**	(0.920)†	(1.176)	(1.181)
Year = 2001	-6.656	-3.252	-1.990	-2.083
	(0.443)**	(0.922)**	(1.206)†	(1.241)†
Year = 2002	-8.912	-5.717	-3.353	-3.355
	(0.490)**	(0.893)**	(1.184)**	(1.223)**
Year = 2003	-10.790	-6.756	-2.862	-3.243
	(0.550)**	(1.123)**	(1.383)*	(1.497)*
Year = 2004	-9.838	-7.788	-6.939	-7.029
	(0.579)**	(1.216)**	(1.363)**	(1.450)**
Year = 2005	-6.912	-5.330	-4.571	-4.791
	(0.502)**	(1.156)**	(1.140)**	(1.195)**
Education (Age LFE $\geq$ 19)		8.848	7.214	7.106
		(2.903)**	(3.190)*	(3.220)*
Education $\times$ 1998		-3.195	-1.085	-0.973
		(2.433)	(2.897)	(2.848)
Education $\times$ 1999		-6.440	-4.893	-4.361
		(2.560)*	(3.139)	(3.090)
Education $\times$ 2000		-7.221	-4.729	-4.481

Continued on next page...

... table 2 continued

Variable	**(1)**	**(2)**	**(3)**	**(4)**
		(3.217)*	(3.318)	(3.353)
Education × 2001		-13.538	-11.624	-10.910
		(3.346)**	(3.713)**	(3.833)**
Education × 2002		-12.588	-9.304	-8.789
		(3.227)**	(3.614)*	(3.666)*
Education × 2003		-14.867	-8.626	-8.178
		(3.788)**	(4.239)*	(4.445)†
Education × 2004		-8.847	-7.349	-7.019
		(4.084)*	(4.677)	(4.718)
Education × 2005		-7.548	-6.406	-7.197
		(3.711)*	(4.292)	(4.537)
Household Income (£1,000)			0.036	0.038
			(0.033)	(0.033)
H-Hold Income × 1998			-0.075	-0.081
			(0.048)	(0.049)†
H-Hold Income × 1999			-0.055	-0.064
			(0.046)	(0.046)
H-Hold Income × 2000			-0.083	-0.091
			(0.035)*	(0.036)*
H-Hold Income × 2001			-0.061	-0.066
			(0.042)	(0.041)
H-Hold Income × 2002			-0.108	-0.123
			(0.043)*	(0.044)**
H-Hold Income × 2003			-0.192	-0.194
			(0.049)**	(0.048)**

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... table 2 continued

Variable	**(1)**	**(2)**	**(3)**	**(4)**
H-Hold Income × 2004			-0.043	-0.054
			(0.048)	(0.049)
H-Hold Income × 2005			-0.036	-0.030
			(0.041)	(0.042)
Ethnicity: Black				-4.598
				(2.353)†
Ethnicity: Asian				-0.325
				(1.250)
Smoker (Current or Ex)				-1.128
				(0.681)†
Nr Kids in H-Hold				0.296
				(0.241)
Lone Parent (Females)				-0.349
				(0.764)
GPs/1,000 Babies				0.049
				(0.026)†
Average Age of Adults				-0.025
				(0.032)
Area-Fixed-Effects	Yes	Yes	Yes	Yes
Number of Observations	852	852	852	852

Significance levels: $**$: 1% $*$: 5% $\dagger$: 10%.

Table 3: Linear Spline Models for the Uptake of the Combined Measles, Mumps and Rubella Vaccine.

Variable	**(1)**	**(2)**	**(3)**	**(4)**
Subperiod 1 (1997-1998)	-2.537	-1.790	-0.365	-0.093
	(0.259)**	(0.623)**	(1.042)	(0.997)
Subperiod 2 (1998-2000)	-0.542	0.076	0.039	-0.045
	(0.180)**	(0.348)	(0.632)	(0.665)
Subperiod 3 (2000-2003)	-2.572	-1.960	-1.374	-1.493
	(0.129)**	(0.313)**	(0.495)**	(0.478)**
Subperiod 4 (2003-2005)	2.070	0.763	-0.750	-0.706
	(0.147)**	(0.417)†	(0.558)	(0.496)
Education (Age LFE $\geq$ 19)		12.432	8.708	8.383
		(4.877)*	(5.417)	(5.430)
Education $\times$ Subperiod 1		-3.387	-1.373	-1.120
		(2.312)	(2.786)	(2.766)
Education $\times$ Subperiod 2		-2.714	-2.789	-2.699
		(1.098)*	(1.176)*	(1.245)*
Education $\times$ Subperiod 3		-1.833	-0.897	-0.785
		(1.098)†	(1.119)	(1.127)
Education $\times$ Subperiod 4		3.918	1.853	1.120
		(1.337)**	(1.447)	(1.398)
Household Income (£1,000)	No	No	Yes	Yes
Other Area Characteristics	No	No	No	Yes
Area-Fixed-Effects	Yes	Yes	Yes	Yes
Number of Observations	852	852	852	852

Significance levels: $**$: 1% $*$: 5% $\dagger$: 10%.

Table 4: Linear Regression Models for the Uptake of Childhood Immunizations other than the MMR and of Cervical Screening Tests ("Smears").

Variable	**Polio**	**Diph.**	**Hib.**	**Tetanus**	**Pert.**	**Smear**
Year = 1998	0.913	0.930	0.815	0.949	1.425	-1.421
	(0.696)	(0.690)	(0.683)	(0.692)	(0.695)*	(0.449)**
Year = 1999	0.577	0.566	0.679	0.630	1.162	-2.472
	(0.842)	(0.828)	(0.848)	(0.829)	(0.839)	(0.499)**
Year = 2000	1.419	1.415	1.268	1.430	2.230	-2.197
	(1.167)	(1.149)	(1.133)	(1.146)	(1.116)*	(0.393)**
Year = 2001	1.061	1.083	0.829	1.143	2.047	-0.768
	(0.921)	(0.912)	(0.945)	(0.921)	(0.931)*	(0.483)
Year = 2002	0.781	0.993	0.691	1.033	2.066	-1.557
	(1.429)	(1.412)	(1.393)	(1.423)	(1.396)	(0.482)**
Year = 2003	0.404	0.411	0.146	0.379	1.795	-3.525
	(1.000)	(0.988)	(1.043)	(0.989)	(1.011)+	(0.724)**
Year = 2004	-0.518	-0.572	-0.621	-0.569	0.915	-1.794
	(1.104)	(1.080)	(1.101)	(1.086)	(1.089)	(0.647)**
Year = 2005	-1.194	-1.189	-1.371	-1.193	0.482	-1.255
	(1.259)	(1.213)	(1.309)	(1.208)	(1.236)	(0.789)
Education (Age LFE $\geq$ 19)	4.570	4.444	4.464	4.505	4.936	-3.053
	(1.889)*	(1.902)*	(1.851)*	(1.904)*	(1.914)**	(1.069)**
Education $\times$ 1998	1.013	1.211	0.990	1.174	1.091	1.904
	(2.598)	(2.622)	(2.572)	(2.600)	(2.517)	(1.630)
Education $\times$ 1999	-2.123	-2.167	-2.218	-2.180	-2.530	4.125
	(1.947)	(1.953)	(1.962)	(1.946)	(1.912)	(1.403)**
Education $\times$ 2000	-4.000	-3.971	-4.390	-4.046	-4.654	3.172

Continued on next page...

... table 4 continued

Variable	Polio	Diph.	Hib.	Tetanus	Pert.	Smears
	(2.289)+	(2.287)+	(2.319)+	(2.275)+	(2.227)*	(1.185)**
Education × 2001	-5.017	-4.733	-5.216	-4.695	-4.806	3.566
	(2.346)*	(2.332)*	(2.395)*	(2.336)*	(2.375)*	(1.252)**
Education × 2002	-6.000	-5.582	-5.608	-5.648	-5.998	3.547
	(2.283)**	(2.284)*	(2.376)*	(2.297)*	(2.297)**	(1.415)*
Education × 2003	-6.984	-6.946	-6.495	-7.092	-7.556	4.427
	(2.654)**	(2.618)**	(2.838)*	(2.637)**	(2.640)**	(1.357)**
Education × 2004	-6.088	-6.231	-5.871	-6.180	-6.705	2.304
	(2.605)*	(2.655)*	(2.510)*	(2.670)*	(2.682)*	(1.397)+
Education × 2005	-6.722	-6.699	-6.723	-6.767	-7.314	3.940
	(2.672)*	(2.610)*	(2.651)*	(2.614)**	(2.628)**	(1.434)**
Household Income (£1,000)	-0.001	0.000	-0.005	0.001	0.010	0.011
	(0.018)	(0.018)	(0.018)	(0.018)	(0.018)	(0.015)
H-Hold Income × 1998	-0.052	-0.055	-0.047	-0.055	-0.062	0.017
	(0.033)	(0.033)+	(0.033)	(0.033)+	(0.033)+	(0.021)
H-Hold Income × 1999	-0.029	-0.029	-0.032	-0.031	-0.034	0.004
	(0.028)	(0.027)	(0.029)	(0.027)	(0.028)	(0.023)
H-Hold Income × 2000	-0.056	-0.057	-0.046	-0.057	-0.062	-0.018
	(0.034)+	(0.033)+	(0.033)	(0.033)+	(0.032)+	(0.018)
H-Hold Income × 2001	-0.058	-0.061	-0.047	-0.065	-0.073	-0.014
	(0.028)*	(0.028)*	(0.029)+	(0.029)*	(0.030)*	(0.021)
H-Hold Income × 2002	-0.055	-0.060	-0.048	-0.063	-0.066	-0.027
	(0.053)	(0.052)	(0.051)	(0.053)	(0.053)	(0.019)
H-Hold Income × 2003	-0.028	-0.028	-0.018	-0.027	-0.038	0.007
	(0.033)	(0.032)	(0.036)	(0.032)	(0.032)	(0.029)

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... table 4 continued

Variable	**Polio**	**Diph.**	**Hib.**	**Tetanus**	**Pert.**	**Smears**
H-Hold Income × 2004	-0.014	-0.010	-0.004	-0.012	-0.022	-0.004
	(0.035)	(0.035)	(0.034)	(0.035)	(0.035)	(0.022)
H-Hold Income × 2005	0.021	0.022	0.034	0.021	0.009	-0.027
	(0.033)	(0.032)	(0.035)	(0.031)	(0.033)	(0.027)
Ethnicity: Black	-4.386	-4.609	-4.404	-4.748	-4.723	-1.746
	(2.326)+	(2.255)*	(2.334)+	(2.246)*	(2.224)*	(1.089)
Ethnicity: Asian	-0.200	-0.272	0.169	-0.399	-0.273	-0.783
	(1.065)	(1.068)	(1.108)	(1.061)	(1.101)	(0.524)
Smoker (Current or Ex)	-1.537	-1.480	-1.492	-1.536	-1.305	-0.113
	(0.410)**	(0.408)**	(0.426)**	(0.412)**	(0.407)**	(0.418)
Nr Kids in H-Hold	0.007	0.012	0.000	0.031	-0.006	-0.027
	(0.166)	(0.168)	(0.166)	(0.169)	(0.169)	(0.141)
Lone Parent (Females)	-0.506	-0.520	-0.690	-0.552	-0.448	0.302
	(0.393)	(0.377)	(0.383)+	(0.378)	(0.382)	(0.576)
GPs/1,000 Babies	0.065	0.068	0.067	0.068	0.065	-0.001
	(0.019)**	(0.018)**	(0.021)**	(0.018)**	(0.018)**	(0.008)
Average Age of Adults	-0.028	-0.026	-0.031	-0.026	-0.026	-0.019
	(0.019)	(0.019)	(0.019)	(0.019)	(0.018)	(0.013)
Area-Fixed-Effects	Yes	Yes	Yes	Yes	Yes	Yes
Number of Observations	852	852	852	852	852	852

Significance levels: $**$: 1% $*$: 5% † : 10%.

Table 5: Descriptive Statistics for the Millennium Cohort Survey Sample. (Standard deviations not reported for binary variables.)

Variable	**Mean**	**St.Dev**	**Variable**	**Mean**	**St.Dev**
MMR Triple	0.884	-	Mother Married	0.668	-
Measles Single	0.053	-	Never Married	0.257	-
Mumps Single	0.029	-	Mother Separated	0.075	-
Rubella Single	0.049	-	Internet Access	0.669	-
Polio	0.976	-	Siblings = 0	0.251	-
Diphtheria	0.975	-	Siblings = 1	0.468	-
Tetanus	0.974	-	Siblings = 2	0.185	-
Pertussis	0.969	-	Siblings = 3	0.065	-
Hib	0.964	-	Siblings $\geq$ 4	0.030	-
Hib Extra	0.740	-	Subperiod 1	0.345	-
Mother's LFE at age $\geq$19	0.249	-	Subperiod 2	0.324	-
H-hold Eq. Inc.	0.667	0.541	Subperiod 3	0.331	-
Mother's Age	32.026	5.745	Not English at Home	0.158	-
Ethnicity: White	0.823	-	Mother Doesn't Smoke	0.726	-
Ethnicity: Asian	0.111	-	Mother Drinks 3+/week	0.178	-
Ethnicity: Black	0.044	-	Mother worked as "Scientist"	0.049	-
Ethnicity: Other	0.022	-	Mother worked in NHS	0.062	-
Private Childcare	0.121	-	No. Other Vacc $\leq$1	0.022	-
Gender (Male)	0.508	-	No. Other Vacc 2 - 5	0.023	-
Mother Catholic	0.094	-	No. Other Vacc = 6	0.233	-
Mother Muslim	0.090	-	No. Other Vacc = 7	0.722	-
Mother Voted Tory	0.107	-	Area: Good/Excellent	0.664	-
Asthma	0.118	-	See Grandmother Every Week	0.401	-

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... table 5 continued

Variable	Mean	St.Dev	Variable	Mean	St.Dev
Long-Standing Illness	0.164	-			
Nr. Observations = 7,909					

Table 6: Probit Models for the Uptake of Childhood Immunizations in the Millennium Cohort Survey (Marginal Effects and Standard Errors).

Variable	**MMR**	**Polio**	**Diph.**	**Tet.**	**Pert.**	**Hib**	**Hib+**
Mother age FTE ≥ 19	-0.025	0.004	-0.001	0.003	-0.003	-0.008	-0.013
	(0.010)**	(0.004)	(0.004)	(0.004)	(0.005)	(0.005)	(0.013)
Eq. H-hold Income (£10,000)	-0.022	0.006	0.007	0.001	0.011	0.012	-0.012
	(0.008)**	(0.004)	(0.004)†	(0.004)	(0.005)*	(0.005)*	(0.013)
Mother's Age	0.008	0.003	0.004	0.005	0.004	0.006	0.035
	(0.007)	(0.002)	(0.002)*	(0.002)**	(0.002)†	(0.003)*	(0.008)**
Mother's Age Sq./100	-0.018	-0.005	-0.007	-0.008	-0.007	-0.009	-0.047
	(0.010)†	(0.003)†	(0.003)*	(0.003)**	(0.004)*	(0.004)*	(0.013)**
Ethnicity: Asian	0.086	-0.005	0.000	-0.002	0.002	0.000	-0.006
	(0.019)**	(0.005)	(0.005)	(0.005)	(0.006)	(0.007)	(0.021)
Ethnicity: Black	0.093	0.008	0.005	-0.001	0.012	-0.007	-0.072
	(0.025)**	(0.007)	(0.007)	(0.007)	(0.009)	(0.010)	(0.028)*
Ethnicity: Other	0.012	0.002	-0.004	-0.001	-0.001	-0.006	-0.014
	(0.030)	(0.012)	(0.011)	(0.012)	(0.014)	(0.014)	(0.037)
Marital Stat.: Never Married	-0.017	-0.012	-0.013	-0.014	-0.016	-0.015	-0.065
	(0.011)	(0.003)**	(0.003)**	(0.004)**	(0.004)**	(0.005)**	(0.014)**
Marital Stat.: Prev. Married	-0.024	-0.009	-0.011	-0.013	-0.010	-0.011	-0.066
	(0.015)	(0.005)†	(0.005)*	(0.005)*	(0.006)†	(0.007)†	(0.020)**
Access to Internet	-0.020	0.005	0.005	0.005	0.003	0.008	0.009
	(0.010)†	(0.003)	(0.003)	(0.003)†	(0.004)	(0.004)†	(0.013)
Gender: Male	-0.017	-0.002	0.000	-0.001	-0.002	-0.002	-0.014
	(0.008)*	(0.003)	(0.003)	(0.003)	(0.003)	(0.004)	(0.010)
Nr. Siblings = 1	0.028	0.001	0.000	0.002	0.003	-0.004	0.007

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... table 6 continued

Variable	**MMR**	**Polio**	**Diph.**	**Tet.**	**Pert.**	**Hib**	**Hib+**
	(0.010)**	(0.004)	(0.004)	(0.004)	(0.004)	(0.005)	(0.014)
Nr. Siblings = 2	0.038	0.000	0.003	0.003	0.002	-0.005	-0.048
	(0.013)**	(0.004)	(0.005)	(0.005)	(0.005)	(0.006)	(0.017)**
Nr. Siblings = 3	0.024	-0.004	-0.006	-0.005	-0.010	-0.014	-0.098
	(0.020)	(0.006)	(0.006)	(0.006)	(0.007)	(0.008)†	(0.024)**
Nr. Siblings $\geq$ 4	0.009	-0.018	-0.019	-0.020	-0.022	-0.032	-0.126
	(0.026)	(0.007)**	(0.007)*	(0.008)**	(0.009)*	(0.010)**	(0.033)**
Subperiod = 2	-0.018	0.004	0.006	0.007	0.011	0.018	0.020
	(0.010)†	(0.003)	(0.003)	(0.004)*	(0.004)**	(0.004)**	(0.013)
Subperiod = 3	-0.021	0.003	0.003	0.007	0.013	0.019	0.001
	(0.010)*	(0.003)	(0.003)	(0.004)†	(0.004)**	(0.004)**	(0.013)
Gov. Off. Reg.	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Number of Observations	7,909	7,909	7,909	7,909	7,909	7,909	7,909

Significance levels: $**$: 1% $*$: 5% $\dagger$: 10%.

Table 7: Probit Models for the Uptake of the MMR the Millennium Cohort Survey. Alternative Specifications (Marginal Effects and Standard Errors).

Variable	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
Mother age left FTE $\geq$ 19	-0.031		-0.028	-0.022	-0.022	-0.022
	(0.009)**		(0.010)**	(0.010)*	(0.009)*	(0.009)*
Eq. H-hold Income (£10,000)		-0.028	-0.022	-0.022	-0.023	-0.020
		(0.008)**	(0.009)**	(0.009)**	(0.008)**	(0.008)*
Additional Covariates	No	No	Yes	No	No	Yes
Maternal Risk Behavior	No	No	No	Yes	No	Yes
Previous Vaccines	No	No	No	No	Yes	Yes
Gov. Off. Reg.	Yes	Yes	Yes	Yes	Yes	Yes
Number of Observations	7,909	7,909	7,909	7,909	7,909	7,909

Significance levels: $**$: 1% $*$: 5% † : 10%.

Table 8: Probit Models for the Uptake of Single Measles, Mumps and Rubella Vaccines in the Millennium Cohort Survey (Marginal Effects and Standard Errors).

Variable	**Some single jab**	**Some single jab given MMR rejection**	**Three single jabs given some single**
Mother age left FTE $\geq$ 19	0.008	-0.054	-0.100
	(0.006)	(0.046)	(0.056)†
Eq. H-hold Income (£10,000)	0.022	0.136	0.079
	(0.005)**	(0.042)**	(0.042)†
Demographics	Yes	Yes	Yes
Subperiods	Yes	Yes	Yes
Gov. Off. Reg.	Yes	Yes	Yes
Number of Observations	7,669	889	432

Significance levels: $**$: 1% $*$: 5% $\dagger$: 10%.