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Abstract

We examine the effect of internet diffusion on the uptake of an important public health intervention: the measles, mumps and rubella (MMR) vaccine. We study England between 2000 and 2011 when internet diffusion spread rapidly and there was a high profile medical article (falsely) linking the MMR vaccine to autism. OLS estimates suggest internet diffusion led to an increase in vaccination rates. This result is reversed after allowing for endogeneity of internet access. The effect of internet diffusion is sizable. A one standard deviation increase in internet penetration led to around a 20% decrease in vaccination rates. Localities characterised by higher proportions of high skilled individuals and lower deprivation levels had a larger response to internet diffusion. These findings are consistent with higher skilled and less deprived parents responding faster to false information that the vaccine could lead to autism.

JEL-Codes: D800, I120, L820, L860.

Keywords: vaccines, vaccine hesitancy, internet.

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1 Introduction

The spread of "fake news" and misinformation has became a concern due to the threat it may pose to the proper functioning of democracies and other spheres of life. Fake news might have contributed to Donald Trump's victory against Hillary Clinton in the 2016 US presidential election (Allcott and Gentzkow 2017). More recently, there have been concerns that fake news about vaccines causing vaccine hesitancy may have hampered efforts to contain the COVID-19 pandemic (*e.g.*, Giaccherini et al. 2024).

False or distorted news is not a new thing. It has been part of media history long before the advent of the internet and social media. However, the speed at which information is spread and the magnitude of its influence places the internet in a different category from its historical precedents. In this paper, we focus on the role of broadband internet in a key public health intervention: vaccination against the highly contagious and serious childhood diseases of measles, mumps and rubella (MMR). Immunization against these diseases is crucial for public health, particularly for measles.[1] Yet worldwide vaccination rates against measles are presently at their lowest level since 2008 and if some parents refuse or delay immunisation when a vaccine is available they generate not only harm to their children but also impose an externality on the rest of society.

Although lower vaccination rates have been argued to be the result of the spread of fake news via the internet, establishing this is challenging. A crucial element for any empirical research strategy trying to assess the impact of the internet on vaccine take-up is differential access to the internet. This is why, for example, it is very difficult to study the impact on COVID-19 vaccination rates, despite widespread beliefs that access to information on the internet would impact COVID-19 vaccination take-up (for example, Goel and Nelson

[1] Measles is a highly contagious disease caused by a virus. Complications from measles can result in blindness, encephalitis, severe respiratory infections and even death. During 2000-2018, it is estimated that measles vaccination prevented 23.2 million deaths (WHO, https://www.who.int/en/news-room/fact-sheets/detail/measles)

2021). By 2020, access to broadband internet was de facto ubiquitous in all developed economies. Thus to examine whether access to the internet affected vaccine behaviour we need to go back in time and exploit variation in internet roll out.[2]

We do this here, in combination with an instrumental variables (IV) empirical strategy which allows us to deal with the fact that internet access is not random. Focusing on England during the period in which access to internet broadband was most rapid, we examine whether the internet affected the uptake of the triple vaccine against MMR between 2000 and 2011. The MMR vaccine provides an excellent case-study as it became highly controversial, due to wide and sensationalist media coverage of a paper published in a leading medical journal that linked the 'triple jab' to autism. Subsequently shown to be untrue, this 'false news' event has been argued to have led to vaccine hesitancy and the rise in measles in the UK and other countries (Torracinta et al. 2021). Thus this period and this event has the potential to show whether the internet was one of the channels through which this occurred.

Any study of the effect of the internet needs to deal with the potential endogeneity of internet diffusion. Internet access has been shown to be positively correlated with several observable demographic characteristics, such as income and education, that are also correlated with attitudes toward vaccines. We address this issue with an IV approach that uses rainfall in the previous year as an instrument for internet diffusion. This follows Gavazza et al. (2019) who show that rainfall in a given year affects the supply of broadband the following year, as bad weather affects the costs of providing reliable broadband. Despite its shortcomings (Mellon 2024), this instrument represents a considerable improvement over other instrumental variables based on geography and network topology that are not time-varying.

[2]There are studies which exploit cross sectional variation in internet across countries (*e.g.*, Wilson and Wiysonge 2020) or cross sectional variation across US states (*e.g.*, Goel and Saunoris 2023 and Goel and Nelson 2021); but these studies cannot establish causality.

We show that while OLS estimates suggest that the internet had a positive impact on vaccination rates, this result is biased and actually reversed once the endogeneity of internet diffusion is taken into account. Higher internet penetration resulted in lower vaccination rates in the first decade of the 2000s in England. This is driven by lower vaccination rates in localities that had lower levels of socio-economic deprivation and more high-skilled labour.

We contribute to the literature on vaccine take-up and on the impact of the internet on this and other health behaviours. With respect to the first, Anderberg et al. (2011) analyse the diffusion in the media in 1998 of the initial medical article linking MMR vaccines to autism. Even though this highly cited medical study was later retracted due to false claims, Anderberg et al. (2011) argue that media coverage of this article explains a fall in MMR vaccination rates in the UK. They also find that it had an heterogenous effect on MMR vaccine uptake by education: more highly educated parents reduced their uptake rate by up to 10% more than low educated parents. This heterogeneous effect is not confined to England. Chang (2018) finds, for the US, that more highly educated mothers responded to the MMR-controversy by not immunizing their children or by delaying vaccination and this education gap in MMR take-up seems to have persisted (Tangvatcharapong 2020). Our analysis is consistent with these results and indicates that one avenue for this response was access to the internet.

Our findings are supported by recent papers that seek causal estimates of vaccine behaviour. Qian et al. (2020) assess why the persistent trend to delay MMR vaccinations in the US was mainly driven by higher-educated mothers. They argue that exposure to negative information (via newspapers or online) about the vaccine strengthened their biases more strongly than exposure to positive information attenuated them. Giaccherini et al. (2024) examine data from Italy, and find that between 2013 and 2018 exposure of individuals to anti-vax tweets were associated with a decrease in MMR uptake and an increase in vaccine-preventable hospitalizations at a very local level. Closest to our paper, Carrieri et al. (2019) exploit a 2012 court decision in Italy that granted compensation to a family arguing that the MMR vaccine caused autism in their child, after which misinformation and fake news regarding potential links between the vaccine and autism went viral on the internet. The authors combine the court ruling and heterogeneity in regional broadband coverage to show a reduction in children's immunization rates at the regional level. Relative to this paper, our very local data, coupled with the use of an IV instrument, allows us to establish causality and heterogeneity of response across different local areas. Finally, in the context of COVID vaccination, several studies have shown that exposure to information through social media can change COVID vaccination behaviour (*e.g.*, Athey et al. 2023, Larsen et al. 2022, Breza et al. 2021 and Bailey et al. 2024).

In settings other than vaccination, access to the internet has been shown to affect health care behaviour and the effects are often heterogeneous across individuals. For example, Amaral-Garcia et al. (2022) find that better access to the internet resulted in higher C-section rates, driven by lower income first-time mothers who opted more for elective C-sections. Donati et al. (2022) study mental disorders diagnosed in Italian hospitals and find that access to high-speed internet impacts the incidence of mental disorders for young cohorts, but not for older ones. Billari et al. (2019) find that broadband access had a positive effect on highly educated women's fertility. DiNardi et al. (2019) assess the impact of the internet on obesity, finding a small positive effect on white women.[3]

This paper is structured as follows. Section 2 introduces the institutional setting related to the MMR vaccine in England. Section 3 provides an account of the empirical setting and some descriptive statistics. Section 4 analyses the effect of the internet on MMR uptake. Section 5 discusses possible mechanisms. Section 6 concludes.

[3] A number of empirical papers have studied the impact of internet use and diffusion on a variety of other outcomes. Examples include Falck et al. (2014) and Gavazza et al. (2019) who study the effect of the internet on political participation. Geraci et al. (2022) assess the impact of broadband penetration on social capital, and show a decline in civic and political participation.

2 MMR vaccination in England

All childhood vaccines in the UK are provided free of charge by the National Health Service (NHS). The NHS only provides the combined MMR 'triple jab' and the three vaccines combined in MMR (measles, mumps and rubella) are not offered as single vaccines. The childhood MMR immunization schedule for children under the compulsory school age in the UK is as follows. At around 13 months a first dose of the MMR joint vaccine is offered.[4] Subsequently, children receive a second dose of the 'triple jab' before the age of 5. Parents can either accept or refuse the vaccination.[5]

The MMR controversy began in February 1998 when the leading British medical journal, the Lancet, published a paper on developmental disorders and the MMR vaccine.[6] Dr Andrew Wakefield, who led the research, suggested that there was a case for administering the three vaccines separately until further research could rule out the combined vaccine as an environmental trigger. Between 1998 and 2002, the claim of a potential link between the combined vaccine and autism was reiterated widely by Wakefield. For example, in April 2000 Wakefield presented evidence at a US Congressional Hearing showing that tests on 25 children with autism had revealed that 24 of them had traces of the measles virus in their gut (House of Representatives Committee 2020). In the spring of 2001, Wakefield and Montgomery (2001) claimed that the MMR vaccine had never undergone proper safety tests, and in the spring of 2002 Wakefield and others provided further evidence of the presence of the measles virus in gut samples from children with autism (Uhlmann et al. 2002). These negative claims were widely reported in the media in 2001 and 2002, both in print and in online editions of the public broadcaster, the BBC, and the major newspapers (Anderberg

[4] In contrast with some other countries, vaccination is not legally required.

[5] Private purchase of a single vaccination is possible, but parents have to arrange and pay for this themselves, in a context where the use of healthcare for children outside the NHS is rare. The small private sector in the UK focuses on the provision of elective, primarily adult, healthcare for which there are long waiting lists (for example, hip replacements, and cataract surgery).

[6] This account draws on Anderberg et al. (2011).

et al. 2011). After the initial publication in the Lancet, a large number of studies failed to confirm any link between the MMR vaccine and autism in particular, though the Lancet did not retract the original article until February 2010.

A recent review of research on the MMR vaccine and its uptake in the UK concluded that a consistent theme was the effect of misinformation or lack of knowledge and trust in healthcare providers, often stemming from the Wakefield controversy (Torracinta et al. 2021). Pareek and Pattison (2000) studied sources of information used by British parents in the particular context of the MMR. 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 from the media, with television as the most commonly cited source.

3 Setting and data

All residents in the UK are entitled to free healthcare under the NHS. Primary care is provided by family doctors, known as General Practioners (GPs). GPs are organised into small groups, known as GP practices. Practices provide, or are the gatekeeper for, all community-based care and all non-emergency room hospital care. All individuals can only be registered with one practice and, in the period we examine, patients had little choice of GP practice and almost always registered with a practice close to their home address. Practices administer the MMR vaccine. Children receive one vaccine between the ages of 0-1 and another before the age of 5.

To identify the effect of the internet on MMR uptake we combine data from different sources. The vaccination data are from the Royal College of General Practitioner Survey for England (RCGPs). This is one of the longest established surveys of GP Practices and covered around 100 General Practices with just over 1m registered patients in 2015.[7] For each practice that is in the RCGP sample, and for each year, the data contain the number of children aged 0-1 and 2-5 years old registered with the practice and the share of children aged 0-1 receiving the vaccine (first dose) and aged 2-5 receiving the vaccine (second dose).

For the purposes of data anonymisation the precise geographical coordinates of the practice were suppressed. The practice data were linked to a small geographical area in which the practice is located, the Lower Layer Super Output Area (LSOA). These are the second smallest Census administrative areas that contain on average around 1500 people or 650 households (the range is between 400 and 1200 households). The average GP practice covers a larger area than the average LSOA as the number of GP practices in England is approximately 6,500 (the number varies between years) while the number of LSOAs in England is roughly 32,800. The boundaries of the former are not based on the latter. Thus the overlap between a GP practice's catchment areas (the local area they draw patients from) and an LSOA is not always one-to-one because an LSOA might be served by more than one GP practice. However, for each LSOA we know the number of children linked to the practices that we observe and the number of children receiving the vaccine. Thus we are able to compute vaccination rates at the LSOA level. We restrict our sample to LSOAs that have at least 5 children linked to the practices in the RGCP survey. Overall, we include 3,763 LSOAs, which represent almost 11.5% of all LSOAs in England. In Figure 2 in Appendix A, we show a map of England with the LSOAs that are served by the network of GPs in our data.

We match data on vaccination rates with 2011 Census data. This provides data on the socio-economic and demographic characteristics of each LSOA. Table 1 reports descriptive statistics for the LSOAs for which we have vaccination rates and compares them with all

[7] Correa et al. (2016) show the representativeness of the RCGP network against the UK population. They conclude that the network is representative, with only small differences with the national population.

LSOAs. As shown in the table, the mean of the demographic characteristics such as total population, mean age, share of the population younger than 14 years old, proportion of white population, full-time workers, part-time workers, unemployment rate and high skill workers is very similar between our sample of LSOAs and all LSOAs.

Table 1: Descriptive statistics on socio-demographic characteristics: All LSOAs and vaccine sample

LSOA Demographics characteristics	**Full sample N=32,844**				**Vaccine sample N=3,763**	
Variable	Mean	SD	Min	Max	Mean	SD
Population	1614.71	301.97	983	8300	1636.54	334.21
Mean Age	39.58	5.28	20.40	63.40	39.68	5.01
Share 0-14 years old (%)	17.59	4.52	0.50	44.40	17.83	4.21
White (%)	86.17	18.76	0.60	100.00	86.83	18.66
Full-time workers (%)	38.61	7.75	3.30	79.10	38.74	7.35
Part-time workers (%)	13.91	2.73	0.90	27.80	14.09	2.62
Unemployment rate (%)	4.38	2.42	0.20	20.50	4.04	2.32
High skill workers (%)	33.87	6.20	10.70	86.80	34.85	5.85
Internet penetration	0.38	0.07	0.14	0.67	0.38	0.07

Notes: descriptive statistics based on all LSOAs in England (left) and on the sub-sample of LSOAs covered by the network of GPs (right). The table reports socio-demographic characteristics collected by the 2011 UK census. *Internet penetration* is the average internet penetration in the LSOA between 2000 and 2011.

Finally, we match the vaccination and Census data with data on internet diffusion which contains detailed information on the broadband communications infrastructure and on internet take up over time. This data is provided by Ofcom, the UK telecommunication regulator. These data have been used in previous studies, such as Nardotto et al. (2015) and Ahlfeldt et al. (2017). It reports information on the topology of the broadband network – such as the location of the nodes of the broadband network, called local exchanges (LEs) and their catchment area with high precision[8] – and, importantly, the internet penetration (measured as the number of internet subscribers on the total number of households) in each area served by the LEs. This enables us to calculate internet penetration for each LSOA.

Table 2 shows descriptive statistics for our sample of LSOAs. On average, each LSOA

[8] Catchment areas are the geographical areas that connect to the internet through the LE.

has 10 children between 0 and 1 years old, and 22.55 children aged 2-5 years old who are registered in a practice. In a given year in our sample, on average, respectively, 36% of children between 0 and 1 receive the first dose of MMR vaccine and approximately 21% complete the MMR prescribed (according to guidelines) vaccination within 5 years. We label the sum of the two shares as *Share 0 to 5* thereafter. The mean internet penetration in our sample is very similar to the mean for all LSOAs (see Table 1).

Table 2: Descriptive statistics on vaccination – Vaccine sample

Panel A: Vaccination, N=3,763, T=12				
Variable	Mean	SD	Min	Max
Number of children 0 to 1	10.30	8.57	0.00	123.00
Number of children 2 to 5	22.55	17.68	0.00	203.00
Share of children 0 to 1 receiving vaccine	0.36	0.22	0.00	1.00
Share of children 0 to 5 receiving vaccine (combined)	0.57	0.26	0.00	1.80
Panel B: Broadband variables and instruments				
Variable	Mean	SD	Min	Max
Internet penetration	0.38	0.26	0.00	1.00
Total yearly rain (mm)	813.97	235.30	392.80	3349.84
Elevation of the LE	65.65	49.59	0.95	304.43

Note: Descriptive statistics based on the sub-sample of LSOAs covered by the network of GPs between 2000 and 2011. The *Share of children 0 to 1 receiving vaccine* is the share of children between 0 and 1 year old receiving their first dose of vaccine. The *Share of children 0 to 5 receiving vaccine* is the share of children between under 1 year old receiving their first dose of vaccine plus the share of children between 2 and 5 receiving the second dose of vaccine. *Internet penetration* is the share of household that have a broadband internet connection. *Total yearly rain (mm)* is the amount of rainfall in the year. *Elevation of the LE* is the altitude (in meters) at which the LE is located.

In Figure 1 we show the evolution of MMR vaccine rates from 2000 to 2011 and broadband penetration. This is a period of rapid growth in internet diffusion in the UK. The black curves show the vaccination rate for children aged between 0 and 1, and the combined shares of those between 0 and 5, while the blue curve reports the broadband penetration over the same time period. There are similarities in the trends shown in the vaccination rates for both age groups, namely the declining trend in the first part of the 2000s which is reversed in the second part of the decade when the internet diffused rapidly. There is an increase in the vaccination rate in the last years of the sample, with the share of 0-1 year old children receiving the first dose of MMR vaccine passing the 40% threshold. As for broadband penetration, the figure shows an increase in all years, going from less than 10% in the early 2000s to reaching almost 70% in 2011.

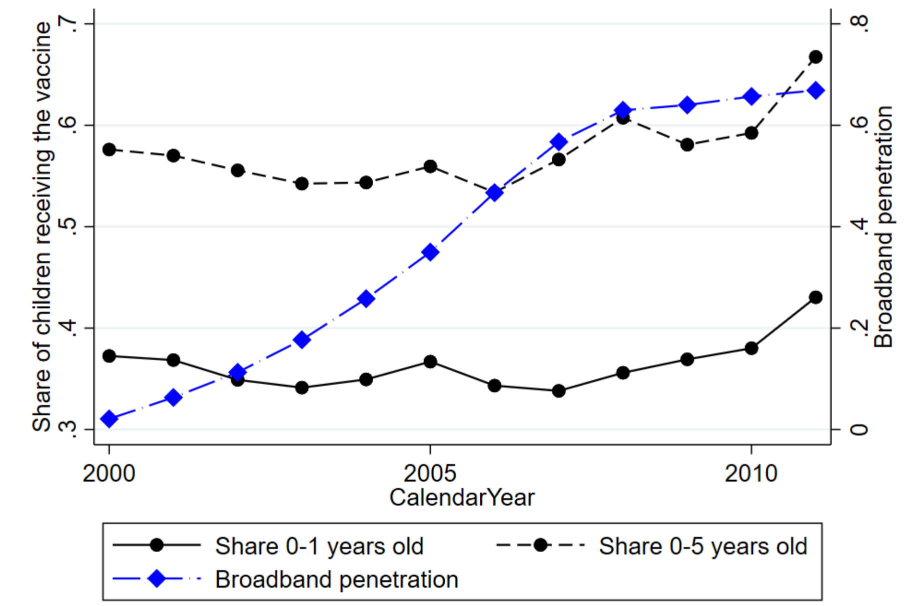

Figure 1: Share of MMR vaccination (left axis) and diffusion of broadband (right axis) over time.

4 Empirical Approach

Our focus is to assess whether internet access might influence the likelihood of MMR vaccine uptake. If internet access was random, we could estimate a model as in equation (1):

$$ShareVax_{it} = \beta_1 + \beta_2 Internet_{it} + LSOA_i + Time_t + \varepsilon_{it} \tag{1}$$

where the dependent variable *ShareVax* is the share of 0-1 years old, or 0-5 years old, vaccinated children in LSOA i at time t. *Internet* is a measure of internet penetration;

LSOA are area fixed-effects to control for time-invariant unobserved factors at the level of the local area, and *Time* are time fixed-effects.

However, examining this relationship is difficult due to the potential endogeneity of internet diffusion. Internet subscription is correlated with several observable demographic characteristics (such as income and education) that are also correlated with health care use. Therefore, unobservable demographic characteristics might be correlated with both internet access and healthcare use. We address this issue with an IV approach that uses rainfall as an instrument for internet access. There is a large body of evidence that rainfall impacts the reliability of broadband (as described, for instance, by Openreach, the regulated network operator that runs and maintains the LEs, and by the regulator Ofcom; see Gavazza et al. 2019). Bad weather conditions contribute to fault levels in the network, due to water ingress into failed joints and cables (Ofcom 2011). As a result, connections tend to slow for people living in affected areas. As shown in Gavazza et al. (2019), rainfall in a given year affects the supply of reliable broadband the following year, given that the weather affects the costs of providing reliable broadband.

Based on this evidence, we instrument for internet in Equation (1) using the previous year's rainfall. We also include the quadratic term $Rain^2$ to allow rainfall to affect the costs of supplying broadband in a non-linear way and additionally control for the interaction between the absolute elevation of the LE above the sea level ($Elevation$) and $Rain$.[9] The first-stage equation is as follows:

$$\begin{aligned} Internet_{it} = & \alpha_1 + \alpha_2 Rain_{it} + \alpha_3 Rain_{it}^2 + \alpha_4 Elevation_i \times Rain_{it} + \\ & + LSOA_i + Time_t + u_{it}. \end{aligned} \tag{2}$$

[9] We extend the analysis performed in other papers that instrument broadband penetration using weather variables (see Gavazza et al. 2019). In previous papers only internet penetration after 2005 was used: here we also include internet penetration from 2000 to 2011. In order to do so, from 2000 to 2005, we use the model-predicted internet penetration at the LSOA level.

Regression results are reported in Table 3. Columns (1) and (2) show the OLS estimates of internet diffusion on MMR vaccination shares. According to these results, the coefficient for the internet is positive and therefore it seems that the internet had a positive impact on vaccination rates for both 0-1 year-old and 0-5 year-old children.

Table 3: Vaccination rate and internet penetration.

	OLS		IV			
Dep var:	Share vax 0-1 years (1)	Share vax 0-5 years (2)	Internet (3)	Share vax 0-1 years (4)	Internet (5)	Share vax 0-5 years (6)
Internet	0.059***	0.105***		-0.344**		-0.432**
	(0.021)	(0.027)		(0.174)		(0.209)
Rain			-0.190***		-0.189***	
			(0.017)		(0.017)	
$Rain^2$			0.054***		0.054***	
			(0.008)		(0.008)	
Elevation × rain			0.105**		0.106**	
			(0.044)		(0.044)	
LSOA FEs	YES	YES	YES	YES	YES	YES
Year FEs	YES	YES	YES	YES	YES	YES
F-test				63.445		63.323
Observations	41056	41054	41056	41056	41054	41054

Notes: *Internet* is the internet penetration in the LSOA, defined as the number of broadband subscribers over the total number of lines. *Rain* is the total amount of rain (in meters) that fell during the year. *Elevation* is the elevation of the LE to which the LSOA is connected.

However, after allowing for the potential endogeneity of internet diffusion, the IV regression results show that OLS estimates are biased. Columns (3) and (5) report the first-stage results for 0-1 years old and 0-5 years old, respectively, and show that rain negatively affects internet penetration in a statistically significant way. Columns (4) and (6) report the IV results for 0-1 years old and 0-5 years old. These show a negative and statistically significant impact of the internet on vaccination rates for both groups, *i.e.*, we find evidence that internet access *decreased* MMR vaccine uptake in both age groups. The estimated effect of internet diffusion on the vaccination rate is sizable. Based on the estimated coefficients in columns (4) and (6), a one-standard deviation change in internet penetration -

which amounts to 25% - would reduce vaccination rates of children aged between 0 and 1 (the first dose) and children aged between 0 and 5 by 23.8% and 19.1% respectively.

4.1 Heterogeneous effects

Previous research has shown differential vaccine hesitancy across demographic groups and by socioeconomic status (SES) in many countries (see for example, Anderberg et al. 2011 and Goel and Saunoris 2023), including, as noted above, for the MMR vaccine. There is also evidence of differential responses in healthcare use to internet penetration in the UK by SES (Amaral-Garcia et al. 2022). We thus examine whether the internet might have had a heterogeneous effect on MMR vaccination rates, focusing on whether individuals with different socio-economic characteristics had different vaccine behaviour when exposed to broadband internet. To do so we include in our regressions two Census measures of SES at the LSOA level: a measure of the proportion of high-skilled labour and a measure of lower deprivation[10] which we interact with broadband internet penetration. As these two measures are time invariant at the LSOA level, they would drop out of the regression if we included LSOA fixed effects. Thus we estimate a model as in equations 1 and 2, but include MSOA fixed effects in place of LSOA fixed effects.[11]

Tables 4 and 5 show the regression results for the heterogeneity analysis according to high-skill and lower deprivation, respectively. Both tables show a higher level of vaccination take-up in areas with more high-skilled people or in areas that are less deprived. Both the coefficient of *High-skill* and *Lower deprivation* are positive and highly significant

[10]The UK Office of National Statistics produces an index of multiple deprivation as a weighted combination of, mainly, income, employment, health deprivation and disability, education, skills, and crime. It is offered at various levels of aggregation, including the LSOA, and in a reverse scale, meaning that less (more) deprived areas have a higher (lower) index.

[11]The average MSOA contains approximately 8,000 inhabitants. In the 2011 UK Census, which is the one we consider here, there are 6,791 MSOAs and 32,844 LSOAs in England. Thus each MSOA comprises, on average, roughly 5 LSOAs.

Table 4: Vaccination rate and internet penetration: heterogeneity according to skills.

	0-1 years		0-5 years	
Dep var:	Internet	Share vax	Internet	Share vax
	(1)	(2)	(3)	(4)
Internet × High-Skill		-0.008*		-0.010*
		(0.004)		(0.005)
High-skill	0.358***	0.004**	0.358***	0.005***
	(0.006)	(0.002)	(0.006)	(0.002)
Rain	-7.191***		-7.188***	
	(0.664)		(0.664)	
Rain^2	1.822***		1.822***	
	(0.276)		(0.276)	
Elevation × rain	3.654**		3.657**	
	(1.691)		(1.691)	
MSOA FEs	YES	YES	YES	YES
Year FEs	YES	YES	YES	YES
F-test		46.107		46.059
Observations	41056	41056	41054	41054

Notes: *Internet* is the internet penetration in the LSOA, defined as the number of broadband subscribers over the total number of lines. *High-skill* is the percentage of high-skilled workers in the LSOA. *Rain* is the total amount of rain (in meters) that fell during the year. *Elevation* is the elevation of the LE to which the LSOA is connected.

in columns (2) and (4) of Tables 4 and 5. However, the interaction with internet penetration consistently indicates a negative response in terms of vaccination rates in LSOAs with more high-skilled and less deprived populations during the period of internet diffusion in the UK. This is consistent with individuals in such areas being more receptive to the fake news about the MMR vaccine.[12]

The heterogeneity in the effect of the internet on vaccination is not small. If we consider a change in internet penetration of one standard deviation, and we move from the most deprived to the least deprived LSOA in the UK, the reduction in the vaccination rate for children between 0 and 5 years old is 22.4%, compared to the average decline of 19% that we obtain from the estimates in column 6 of Table 3. In other words, the overall response

[12] Additional regression results can be found in Appendix A, Tables 6 and 7 where we look at the heterogeneous impact of other indexes. Results are less precise, but still suggest a negative response of vaccination rates in local areas with higher education and more employment, as the internet rolled out.

Table 5: Vaccination rate and internet penetration: heterogeneity according to local deprivation.

	0-1 years		0-5 years	
Dep var:	Internet	Share vax	Internet	Share vax
	(1)	(2)	(3)	(4)
Internet × Lower deprivation		-0.003*		-0.005*
		(0.002)		(0.003)
Lower deprivation	0.353***	0.002**	0.353***	0.002**
	(0.004)	(0.001)	(0.004)	(0.001)
Rain	-14.770***		-14.748***	
	(2.355)		(2.354)	
Rain^2	3.777***		3.771***	
	(0.836)		(0.835)	
Elevation × rain	0.423		0.449	
	(3.905)		(3.903)	
MSOA FEs	YES	YES	YES	YES
Year FEs	YES	YES	YES	YES
F-test		18.106		18.037
Observations	41056	41056	41054	41054

Notes: *Internet* is the internet penetration in the LSOA, defined as the number of broadband subscribers over the total number of lines. *Lower deprivation* is the index of multiple deprivation LSOA centile (where the first centile is the most deprived and the last centile is the least deprived). *Rain* is the total amount of rain (in meters) that fell during the year. *Elevation* is the elevation of the LE to which the LSOA is connected.

in terms of vaccination to an increase in internet penetration (of one standard deviation) in the more affluent areas is approximately 3.4% larger than the average, a sizable difference.

5 Discussion and Potential Mechanisms

Our results indicate that access to the internet increased vaccine hesitancy, with heterogeneous effects according to levels of deprivation and skills. We cannot observe the direct mechanisms through which the internet impacted the decision of parents to vaccinate their children or not, as for the period we examine (chosen to enable us to establish causality), individual-level data on parental internet searches on MMR vaccines is not available. But our results fit with greater access to the internet (i) giving access to potentially incorrect information and (ii) this information being more salient to more educated parents.

Greater access to the internet might allow parents to obtain information about vaccines, which in turn might affect the decision to vaccinate their children. Fear of autism is a major reason why parents say no to having their children vaccinated against MMR (Novilla et al. 2023). One explanation for this is that there is an erroneous belief that being affected by the disease is less risky than suffering adverse vaccine effects (Goodson and Larson 2021). In the case of the UK, the (false) link between the MMR vaccine and autism was highly salient as the Wakefield studies were carried out in England (Yaqub et al. 2014). Further, the period we study was not a time when public health authorities used the internet extensively to provide medical information. Therefore, it seems plausible that the information about the MMR vaccine obtained through the internet was more likely to be negative than positive.

Our findings that the internet had a greater impact on parents with higher levels of skills and living in less deprived areas is supported by a recent review of the literature on the social determinants of vaccine hesitancy (Novilla et al. 2023). This finds that vaccine hesitancy was greater in medium and high-income areas, and among mothers with a college degree or higher who seem to prefer internet and social media narratives over physician-based vaccine information. College-educated and high-income parents tend to be the type of parents who express concerns about safety of vaccines (Smith et al. 2004). Moreover, wealthier parents are the first to take up practices perceived to be protective of their children (Victora et al. 2000). When the Wakefield study was published, the practice of not vaccinating children against MMR was perceived to be protective among those parents who decided not to vaccinate their children.

From a theoretical standpoint, our findings can be rationalized by a stylized model of vaccination decisions as developed by Qian et al. (2020). In their model there is uncertainty about the safety of the MMR vaccine: it can be safe or harmful. Parents decide whether to vaccinate their children or not, depending on the information they receive. Parents may be biased or unbiased. When parents receive information about vaccine safety, the absorption of this information differs between biased and unbiased households. In particular, the biased households will react more to a signal that the vaccine is harmful and less to a signal that the vaccine is safe. In this model, the negative information that followed the Wakefield study could change parents' beliefs about the safety of the MMR vaccine and have a greater impact on biased parents.

While some parental characteristics may allow more effective absorption of medical information (*e.g.*, education, skills, lower deprivation), a downside associated with this is that once a piece of information is absorbed, it is more difficult to have more accurate absorption of new information in the future. In our case, those who were biased and responded most to the initial false information were the higher-skilled parents and those living in less deprived areas. They were also subsequently slower to absorb new information refuting the claim that the MMR vaccine was linked to autism.

This interpretation is corroborated by the fact that, while increasing access to information about health-related issues (including vaccines) is often considered a priority given the existence of information asymmetries, the effects of having more access to information are not always positive. In principle, having more access to information should lead to better decisions, but it has long been argued that the effects of more information in healthcare are complex (*e.g.*, Phelps 1992) and the quality of information difficult to interpret (Eysenbach et al. 2002).

6 Conclusion

Our analyses exploit the exogenous roll-out of internet broadband in England to examine the causal impact of access on the take-up of what was a highly controversial healthcare intervention: the triple-jab MMR vaccine. We find that access to the internet increased vaccine hesitancy. This is consistent with findings from less causal analyses that look at access to social media and vaccine hesitancy and find that greater access is associated with greater hesitancy.[13]

We also find that this hesitancy was greater in small areas characterised by higher shares of higher SES households. This finding contrasts with the more familiar pattern in which low educational achievement and socioeconomic deprivation correlate positively with poorer - and from a public health perspective - less desirable health behaviours and outcomes. However, whilst we are not able to observe the exact information that individuals were accessing on the internet, our findings are supported by earlier studies of MMR hesitancy that showed that more educated parents reacted more to the false news on autism in the UK (*e.g.*, Anderberg et al. 2011). This may be because parents with a higher level of skills and SES were more swayed by information that was published in a reputable medical journal and widely reported in the more serious media and so were more affected by the misinformation. Our results suggest that one channel for this greater take-up of false news was internet access. More broadly, our analyses support the research that shows that access to the internet can cause changes in behaviour and that those changes may not be desirable from a social perspective.

[13]For example, Wilson and Wiysonge (2020) found, based on analyses of a large number of countries, a strong association between the use of social media to organise offline action to be highly predictive of the belief that vaccinations are unsafe, with such beliefs mounting as more organisation occurs on social media.

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A Appendix

In this Appendix we present additional heterogeneity results using alternative local indexes, to complement the results on deprivation and skills. Findings are reported in Tables 6 and 7. Rain as an instrument still works but it is weaker compared to the main results (see the various F-tests in the tables). Keeping this caveat in mind, we find that there was a negative response, as the internet diffused, in terms of vaccination rates in LSOAs with more educated people (i.e., those with a low *Education deprivation* index; Table 6), and in those with more employment (i.e., those with a low *Employment deprivation* index; Table 7, columns (1) and (2)). The interpretation of these results is in line with the findings and discussion in the main text. We also find a weak response in areas with less crime and disorder (the result is not statistically different from zero; Table 7, columns (3) and (4)).

Table 6: Vaccination rate and internet penetration: heterogeneity according to local deprivation in education.

	0-1 years		0-5 years	
Dep var:	Internet	Share vax	Internet	Share vax
	(1)	(2)	(3)	(4)
Internet × Education deprivation index		0.017*		0.022**
		(0.009)		(0.011)
Education deprivation index	0.333***	-0.006**	0.333***	-0.008**
	(0.006)	(0.003)	(0.006)	(0.004)
Rain	3.262***		3.259***	
	(1.042)		(1.042)	
Rain^2	-0.412		-0.411	
	(0.302)		(0.302)	
Elevation × rain	-1.287		-1.291	
	(2.074)		(2.074)	
MSOA FEs	YES	YES	YES	YES
Year FEs	YES	YES	YES	YES
F-test		6.452		6.439
Observations	33159	33159	33158	33158

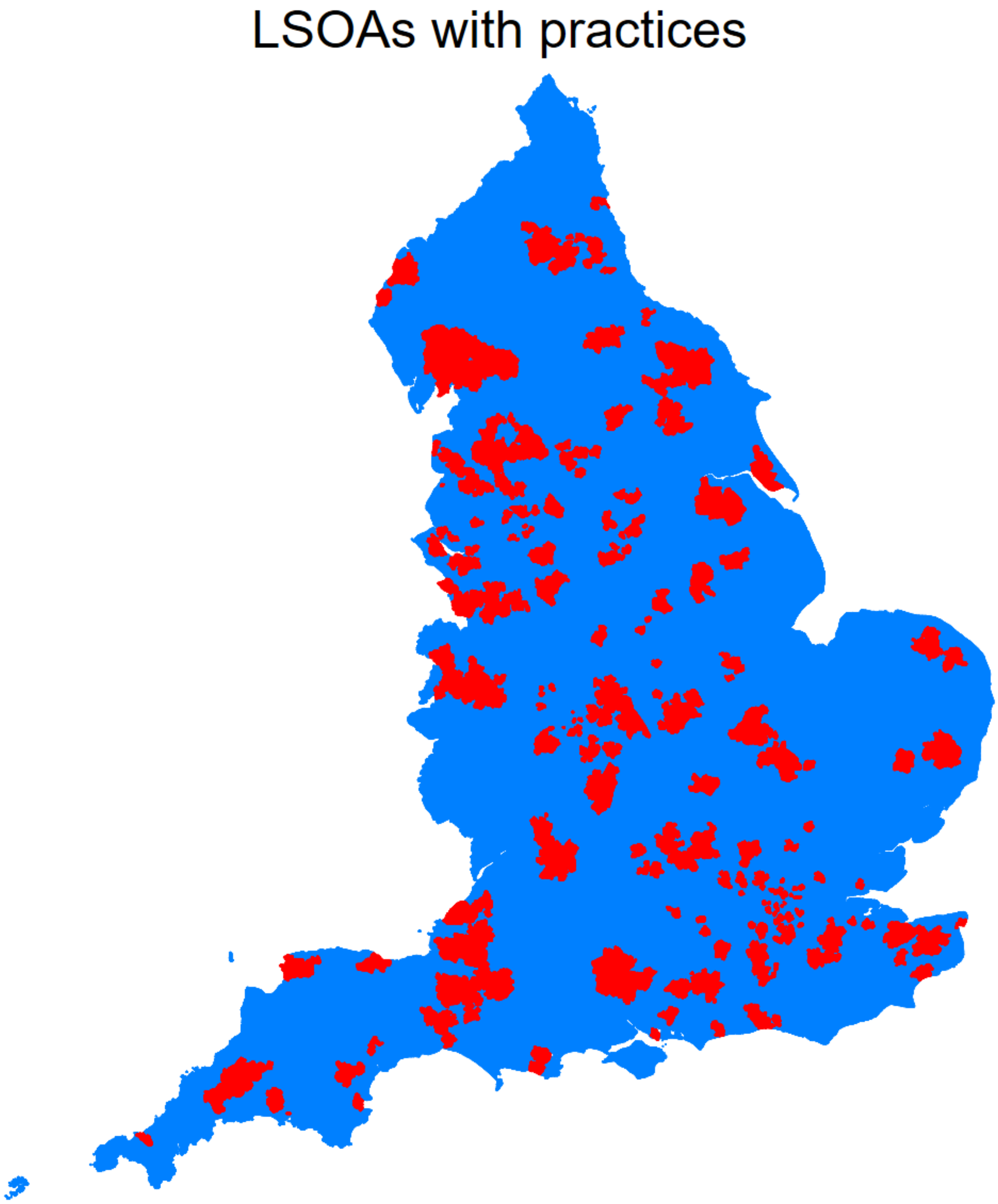
Notes: *Internet* is the internet penetration in the LSOA, defined as the number of broadband subscribers over the total number of lines. *Education deprivation index* is the index of multiple deprivation based on education attainments, with the most deprived (less educated) areas having a higher rank (i.e., the variable decreases with better education). *Rain* is the total amount of rain (in meters) that fell during the year. *Elevation* is the elevation of the LE to which the LSOA is connected.

Table 7: Vaccination rate and internet penetration: heterogeneity according to local deprivation in employment and in crime and disorder (only 2SLS second stages reported).

Dep var:	Share vax 0-1 years (1)	Share vax 0-5 years (2)	Share vax 0-1 years (3)	Share vax 0-5 years (4)
Internet × Employment deprivation index	4.801*	6.613*		
	(2.852)	(3.402)		
Employment deprivation index	-1.776*	-2.470**		
	(0.941)	(1.124)		
Internet × Crime deprivation index			-0.252	-0.292
			(0.158)	(0.184)
Crime deprivation index			0.080	0.087
			(0.058)	(0.067)
LSOA FEs	YES	YES	YES	YES
Year FEs	YES	YES	YES	YES
F-test	7.422	7.406	4.359	4.376
Observations	33159	33158	33159	33158

Notes: *Internet* is the internet penetration in the LSOA, defined as the number of broadband subscribers over the total number of lines. *Employment deprivation index* is the index of multiple deprivation based on employment, with the most deprived areas having a higher rank (i.e., the variable decreases with more employment). *Crime deprivation index* is the index of multiple deprivation based on crime, with the most deprived areas having a higher rank (i.e., the variable increases with more crime).

Figure 2: Map of LSOAs



Notes: The figure reports in red the 3,763 LSOAs (out of a total of 32,844) covered by the practices that belong to the network in our data.