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Information and vaccine hesitancy: the role of broadband Internet *

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Abstract

We study the effect of internet diffusion on the uptake of the measles, mumps and rubella (MMR) vaccine for children in England between 2000 and 2011. OLS estimates suggest that internet diffusion led to an increase in vaccinations but this result is reversed once we instrument for internet access. We find that the effect of internet diffusion on vaccination rates is sizable: a change of one standard deviation in internet take up determined an approximately 20% decrease in vaccination rate. We also find that areas with a higher proportion of high skilled individuals and lower deprivation levels are those with a higher response to internet diffusion in terms of the reduction in MMR vaccination rates. These findings are consistent with higher skilled and less deprived parents responding faster to false information circulated at the time that the vaccine could lead to autism. Even though this information has been proven to be wrong, these parents were those absorbing it more.

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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. When considering electoral outcomes, 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 were concerns that fake news might have hampered efforts to contain the COVID-19 pandemic by spreading false information about COVID-19 vaccines and leading to vaccine hesitancy (e.g., Giaccherini et al. 2022).

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. But 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 analyse the role of broadband internet on vaccine uptake in England during the most rapid phase of internet diffusion in the UK. Immunization is crucial for public health as it reduces or even eradicates devastating infections. If some people refuse or delay immunisation when a vaccine is available they generate not only harm to themselves but also impose an externality on the rest of society.

Having enough variation in the data related to internet access is a crucial element for any empirical research strategy trying to assess the impact of the internet on vaccine take-up. 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 (see, for example, Goel and Nelson 2021). By 2020, access to broadband internet was de facto ubiquitous in all developed economies, including the UK. Thus to examine whether access to the internet affected vaccine behaviour we need to go back in time and exploit exogenous variation in internet roll out.[1]

[1]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 (2022) and Goel and

We do this here. We examine whether the internet affected the uptake of the triple vaccine against measles, mumps and rubella (MMR) in England from 2000 until 2011. Measles is a highly contagious disease caused by a virus. Complications from measles can result in blindness, encephalitis, severe respiratory infections and even death.[2] The MMR vaccine provides an excellent 'case-study' as it became highly controversial, due to high and sensationalist media coverage of a paper published in a leading medical journal that linked the 'triple jab' to autism. This event has been argued to have led to vaccine hesitancy and the rise in measles in the UK (Torracinta et al. 2021). However, to date, there is no robust evidence on whether access to the internet led to this hesitancy and whether the effect of the internet on uptake varied across different population groups.

As noted above, examining the impact of internet access on vaccine uptake is difficult due to potential endogeneity of internet diffusion. Internet take-up is positively correlated with several observable demographic characteristics (such as income and education) that are also correlated with attitudes towards vaccines. Hence unobservable demographic characteristics may be correlated with both internet access and vaccine uptake and so confound any association that exists. We address this issue with an instrumental variables 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.

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. We find that in the first decade of the 2000s vaccination rates were slower in areas characterised by lower socio-economic deprivation and more

Nelson (2021)); but these studies cannot establish causality.

[2]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`, last access December 15, 2022). Even though measles vaccination is one of the most cost-effective health interventions, there are still children in developed countries who are not vaccinated when they could.

high-skilled labour.

Our work is related to a number of empirical papers that have shown how different information channels might influence vaccine uptake. Anderberg et al. (2011) analyse the diffusion in the media in 1998 of the initial medical article linking MMR vaccines to autism, and argue that media coverage of this explains a fall in MMR vaccinatio rates in the UK. Even though this highly cited medical study was later retracted due to false claims, Anderberg et al. (2011) find that it had an heterogenous effect on MMR vaccine uptake according to education levels: more highly educated parents reduced their uptake rate by up to 10% more than low educated parents. These results are in line with the findings in Chang (2018) for the US that more highly educated mothers responded to the MMR-controversy in two ways: by not immunizing their children or by delaying vaccination. Moreover, the education gap in MMR take-up seems to have persisted in the US (Tangvatcharapong 2020). More recently, Giaccherini et al. (2022) find that in Italy, between 2013 and 2018, anti-vax tweets are associated with a decrease in MMR uptake and an increase in vaccine-preventable hospitalizations.

Several papers have assessed how better access to information might affect patients' choices.[3] Overall, the evidence is mixed and there is research which finds evidence of unintended negative consequences of better access to health information. The literature also finds differential impacts across demographic and socioeconomic group. Gaynor et al. (2016) test whether greater access to information on quality and waiting times in English hospitals helped patients make more informed choices. Their findings indicate that patients became more responsive to clinical quality and mortality rates decreased. They also found that sicker (and poorer) individuals benefited most. Amaral-Garcia et al. (2022) find that

[3] 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 straightforward. In principle, having more access to information should lead to better decisions, but the effects of more information in healthcare are complex (e.g., Phelps (1992).

better access to the internet resulted in higher C-section rates. The effect was heterogeneous and driven by first-time mothers who opted more for an elective C-sections. They argue that the internet empowered some demanders (lower income/less educated mothers) to close the ”selective C-section gap” they had compared to other groups, even though the higher costs associated with C-sections did not result in better health care outcomes for either mothers or newborns. 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. Bundorf et al. (2009) find that patients respond to quality report cards when choosing providers of assisted reproductive therapies. Price and Simon (2009) find that mothers respond to new medical information on vaginal birth after delivery, with young mothers being more responsive.

A number of empirical papers have studied the impact of internet use and diffusion on a variety of outcomes. Gavazza et al. (2019) study the effect of the internet on both political participation and on the size of the government. Falck et al. (2014) estimate the effect of internet diffusion 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. Billari et al. (2019) find that broadband access had a positive effect on high educated women's fertility. DiNardi et al. (2019) assess the impact of internet on obesity, finding a small positive effect on white women. Brown and Goolsbee (2002) find that internet use lowers the price of term life insurance by 8 to 15%, and Scott Morton et al. (2003) find that internet consumers pay less for their cars. Akerman et al. (2015) study the impact of broadband internet on labour productivity.

This paper is structured as follows. Section 2 describes the institutional setting related to MMR vaccine and vaccination in England. Section 3 provides a description of the empirical setting and some descriptive statistics. Section 4 analyses the effect of the internet on MMR uptake. Section 5 concludes.

2 MMR vaccination in England

All childhood vaccines in the UK are provided free of charge by the National Health Service (NHS). The NHS does not provide a single measles, mumps and rubella vaccines but only provides the 'triple jab'. 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 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 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 et al. 2011). After the initial publication in the Lancet, a large number of studies failed to

[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 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, cataract surgery).

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

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 in the research was the effect of misinformation or lack of knowledge and trust in healthcare, 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 the most commonly cited source (cited by 35% of mothers).

3 Setting and data

Every individual resident in the UK is entitled to free care under the NHS. Primary care is provided by family doctors, known as a 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.

In order to identify the effect of the internet on MMR uptake we combine data from different sources. Our vaccination data are from the Royal College of General Practitioner Survey for England (RCGPs). This is the 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 was suppressed. The practice data were linked to a small geographical area in which the practice is located, the Lower Layer Super Output Area (LSOA). This is 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. But the boundaries of the former are not based on the basis of the latter. Thus the overlap between a GP practice's catchment areas (the local area they draw patients from) and a LSOA is not always one-to-one because an LSOA might be served by more 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 can 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 complement the data on vaccination rates with 2011 Census data. The Census 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

[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.

compares them with all LSOAs. As shown in the table, the mean of the demographic characteristics such as total population, mean age, share of 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 our 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. Such data has been used in previous studies, such as Nardotto et al. (2015) and Ahlfeldt et al. (2017), and it reports detailed 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

[8]By catchment area we mean the geographical areas, and so the premises, that connect to the internet through the LE.

households) in each area served by the LEs. This enables us to calculate internet penetration in each LSOA.[9]

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

[9]More in detail, our measure of internet penetration is based on the following steps: i) First, the data we obtained from Ofcom covers the period between 2005 and 2011 (quarterly) and it reports the exact internet penetration within the catchment area of each LE; ii) To reconstruct the internet penetration between 2000 and 2004 we estimate (and then project) an auto-regressive model for broadband internet penetration that includes demographic characteristics, the (best) internet technology available in the LE and factors influencing suppliers' investments in broadband (such as population density); iii) We then compute internet penetration in the LSOA taking the internet penetration of the LE that serves the LSOA (assigning pro-quota using population weights when an LSOA is served by more than 1 LE).

In Figure 1 we show the evolution of MMR vaccines rates from 2000 to 2011 and broadband penetration. This is a period of rapid growth in internet diffusion in the UK, especially post-2005. 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 very 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 reach almost 70% in 2011.

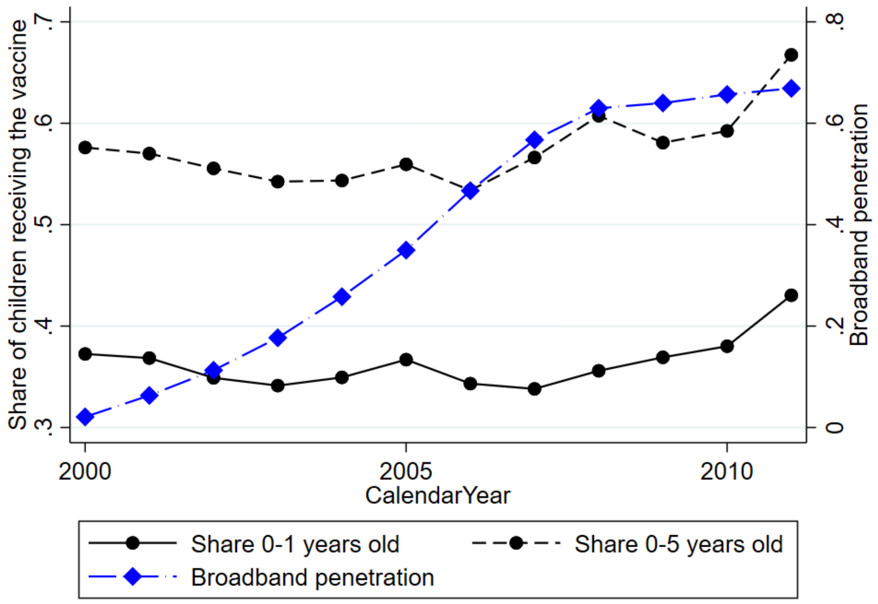

Figure 1: Share of MMR vaccination (left axis) and diffusion of broadband (right axis) over time.

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 health care use. We address this issue with an instrumental variables approach that uses rainfall as an instrument to 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, namely due to water ingress into failed joints and cables (Ofcom 2014). 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 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 LE above the sea level ($Elevation$) and $Rain$.[10] The first-stage equation is as follows:

$$Internet_{it} = \alpha_1 + \alpha_2 Rain_{i,t} + \alpha_3 Rain^2_{it} + \alpha_4 Elevation * Rain_{it} + \\ + LSOA_i + Time_t + u_{it} \quad (2)$$

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 internet is positive and therefore it seems that the internet had a positive impact on vaccination rates for both 0-1 year olds and 0-5 year old.

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.

[10]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.

However, after allowing for the potential endogeneity of internet diffusion, the IV regression results show 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 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% - is estimated to reduce vaccination rates of children between 0 and 1 (the first dose) and children 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 2022), including, as noted above, for the MMR vaccine. There is also evidence of differential responses in health care use to internet penetration in the UK by SES (Amaral-Garcia et al. 2022). We thus examine whether the internet might have had an 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,[11] which we interact with broadband internet penetration. As these two

[11] 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.

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.[12]

Tables 4 and 5 show the regression results for the heterogeneity analysis according to high-sill or lower deprivation.

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.

Both tables imply a higher vaccination take up in areas with more high-skill people or areas that are less deprived. Both the coefficient of *High-skill* and *Lower deprivation* are positive and highly significant in columns (2) and (4) of Tables 4 and 5, indicating that more affluent and educated areas have, on average, higher vaccination rates. However, the interaction with internet penetration consistently indicates a negative response in terms of

[12]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.

vaccination rates in LSOAs with more high-skilled and less deprived populations during the period of internet diffusion in the UK. Thus, individuals in such areas were more receptive to the (false) news about the MMR vaccine that spread in these years.

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.

The heterogeneity of 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 in terms of vaccination to an increase in internet penetration (of 1 standard deviation) in the more affluent areas is approximately 3.4% larger than the average, a sizable difference.

5 Conclusion

Our analyses exploit the exogenous roll-out of internet broadband in England to examine the 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 on the heterogeneity of the impact of the internet on the uptake of the MMR vaccine is contrary to the more familiar pattern in which low educational achievement and socioeconomic deprivation correlate positively with poorer - and from a public health perspective - less undesirable health behaviours and outcomes. It is also inconsistent with findings from a recent causal analysis of the effect of the internet on healthcare utilisation in the UK which found that those of lower SES made poorer maternity healthcare choices when exposed to the internet (Amaral-Garcia et al., 2022).

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 which have shown 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 in a reputable medical journal and widely reported in the more serious media and so were more affected by the misinformation. 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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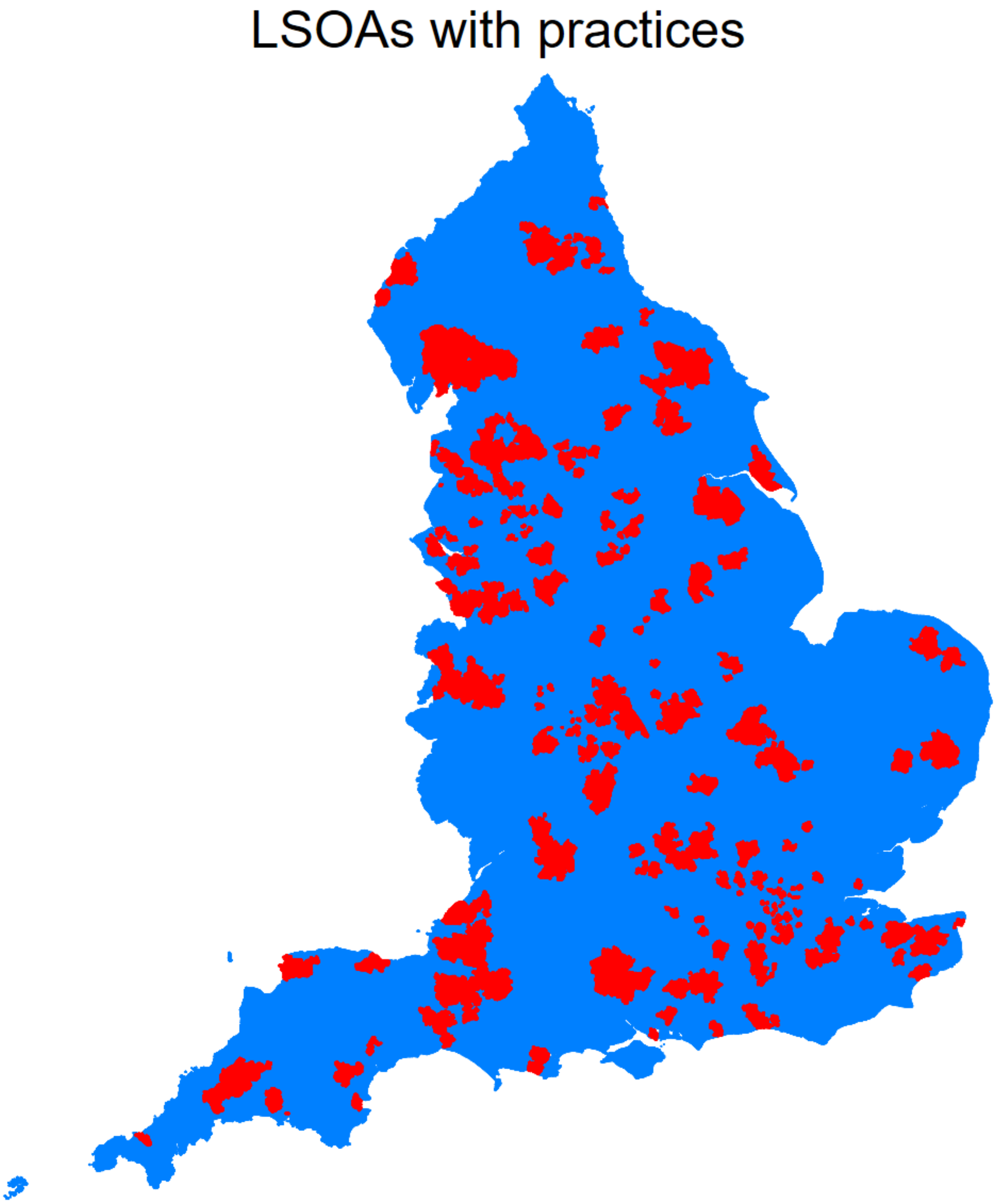
A Additional graphs and tables

Figure 2: Map of LSOAs



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