The effect of misinformation on vaccine uptake: the case of South Wales

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1. Introduction

Information that hurts

“The spread of SARS-CoV-2, the causative agent of COVID-19, has resulted in an unprecedented global public health and economic crisis” [1]. As a result, the World Health Organization (WHO) declared a pandemic on 11 March 2020. The development of COVID-19 vaccines has been a significant undertaking in fighting the disease; nevertheless, as countries developed vaccines, misinformation spread rapidly through online channels such as news outlets, websites, and social media[2].

Covid-19 is not the only disease where misinformation has spread, “despite the availability of safe and effective vaccines; several European countries are experiencing outbreaks of vaccine-preventable diseases.[3]” The European Observatory on Health Systems and Policies conjectures that one reason for the outbreaks is extensive misinformation about vaccines.

The seriousness of misinformation relies on the public’s vaccine hesitancy; misinformation motivates skepticism towards vaccines and ultimately hesitation on vaccine uptake [4] causing the further spread of the disease and increasing public costs. Therefore, vaccine hesitancy plays an essential role in decreasing vaccination rates.

Due to the danger of vaccine hesitancy, WHO considered it a top ten global threat to public health[5]. That’s why misinformation should be treated as a significant concern in public policy, some countries are currently addressing the misinformation issue, but the effort might not be sufficient.

Literature

The negative (positive) relationship between misinformation and vaccine rate (vaccine hesitancy) is well studied. For example, Lyu, Seng, and Luo (2022)[6] and Pierri, Francesco, Brea Perry, et al. (2021)[7] analyze misinformation in the online discourses and discussions about the COVID-19 vaccines with Twitter. In addition, Wilson, Steven Lloyd, y Charles Wiysonge (2020) globally evaluated the effect of social media and online foreign disinformation campaigns on vaccination rates and attitudes towards vaccine safety[8]. On the other hand, Mason & Donnelly (2000)[9] study the effect of a newspaper media campaign on vaccine uptake in South Wales.

However, we have little evidence of causal relationship between misinformation and vaccine hesitancy (or vaccine rate); the only study that we are aware of that quantifies the effect is the work of Loomba, Sahil, Alexandre de Figueiredo, et al. (2021). They conducted a randomized controlled trial in the UK and the USA to measure how exposure to online misinformation around COVID-19 vaccines affects intent to vaccinate to protect oneself or others[10].

To understand the severity of misinformation, we will contribute to the causal relationship literature by studying the case of Wales, where a local newspaper set a local media campaign against measles, mumps, and rubella (MMR) vaccine in 1997. We endeavor to carry on Mason and Donnelly’s work and further show a causal relation with a differences-in-differences model.

[1] Loomba et al., «Measuring the Impact of COVID-19 Vaccine Misinformation on Vaccination Intent in the UK and USA».

[2] Garett y Young, «Online Misinformation and Vaccine Hesitancy».

[3] European Observatory on Health Systems and Policies et al., «Increasing Vaccine Uptake».

[4] Singh et al., «Misinformation, Believability, and Vaccine Acceptance over 40 Countries».

[5] Garett y Young, «Online Misinformation and Vaccine Hesitancy».

[6] Lyu, Zheng, y Luo, «Misinformation versus Facts».

[7] Pierri et al., «The impact of online misinformation on US COVID-19 vaccinations».

[8] Wilson y Wiysonge, «Social Media and Vaccine Hesitancy».

[9] Mason y Donnelly, «Impact of a local newspaper campaign on the uptake of the measles mumps and rubella vaccine».

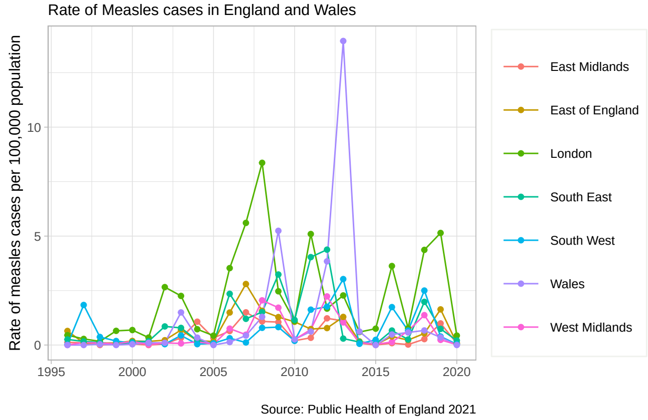
[10] Loomba et al., «Measuring the Impact of COVID-19 Vaccine Misinformation on Vaccination Intent in the UK and USA».

2. The case of Wales

Since July 1997, the South Wales Evening Post ran a proacted campaign against the MMR vaccine. The evening newspaper has three daily editions: Swansea, Neath and Port Talbot and Carmarthenshire; specifically, it was sold in parts of two Health Authority areas: Morgannwg and Dyfed Powys [11]. The newspaper used a fraudulent research paper published in the medical journal *The Lancet* that claimed a link between the **MMR vaccine and autism**[12]. Over three months, the paper published various resources that questioned the MMR vaccine safety, specifically: 5 front-page headlines, 3 opinion articles, and 18 other articles [13]

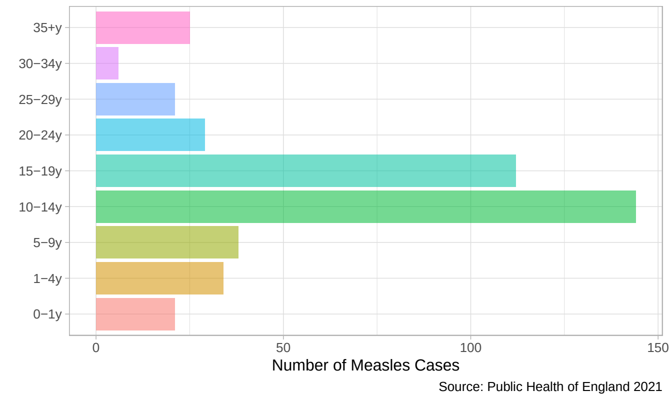
Years later, in 2013, there was a severe measles outbreak in Wales with 1,219 measles notifications in Swansea, Neath Port Talbot, Bridgend, Carmarthenshire, Ceredigion, Pembrokeshire, and Powys. In summary, there were 1,455 measles notifications for the whole of Wales, **664 of which were in Swansea alone**, one of the publication hubs of the South Wales Evening Post.

Figure 1: Wales had the highest rate of measles cases in the nearby districts
Rate of Measles cases in England and Wales



The rate of measles cases in Wales was abnormally high in the 2013 outbreak; the rate was higher than all of London's and South East's records, both of the higher density population zones. In addition, some sources linked the measles outbreak with The Lancet's article and the campaign in the *South Wales Evening Post* against the MMR vaccine[14], as most of those infected were not immunized as infants during the MMR scare.

Figure 2: The most affected age group was supposed to be vaccinated in 1997–1999.
Number of Measles Cases by Age Group in Wales in 2013



The cost of treating the sick and controlling the outbreak exceeded £470,000 ($701,898)[15]. In 2018 WHO Europe announced that the United Kingdom (UK) lost the measles elimination status[16].

[11] Mason y Donnelly, «Impact of a local newspaper campaign on the uptake of the measles mumps and rubella vaccine».
[12] Meikle, «Measles Outbreak Sees "missing Generation" Queuing for MMR Jab».
[13] McCartney, «MMR, Measles, and the South Wales Evening Post».
[14] McCartney, «MMR, Measles, and the South Wales Evening Post».
[15] BBC News «Swansea Measles Epidemic».
[16] Public Health Wales. "UK Loses WHO Measles Elimination Status, but Cases Remain Low in Wales." Public Health Wales.

3. Data and Motivating Evidence

Data

We will use the same data as Brendan Mason and Peter Donnelly on the measles mumps and rubella (MMR) vaccine uptake in the United Kingdom through the COVER/Korner programme, and Nomis' national census data of Wales to control for demographic characteristics.

- The COVER/Korner programme measures uptake of the MMR vaccine for children resident in a district on the evaluation date who reached their second birthday during the previous quarter[17]; children are scheduled to receive the first MMR immunization at 12 months.

- Nomis is a service provided by the Office for National Statistics that contains census data from 1961 to 2011 and other labor surveys[18].

Specifically, the COVER/Korner data specifies quarterly data from 1996 to 1999 on vaccine uptake of various vaccines (from Pollio to MMR). The information was gathered at different health trusts in Wales; the health trusts are spread across diverse regions of Wales. Thus, district-level analysis is available; to assemble the district-level data, we use the 1991 census query of Nomis that contains the district demographics of Wales separated by age group.

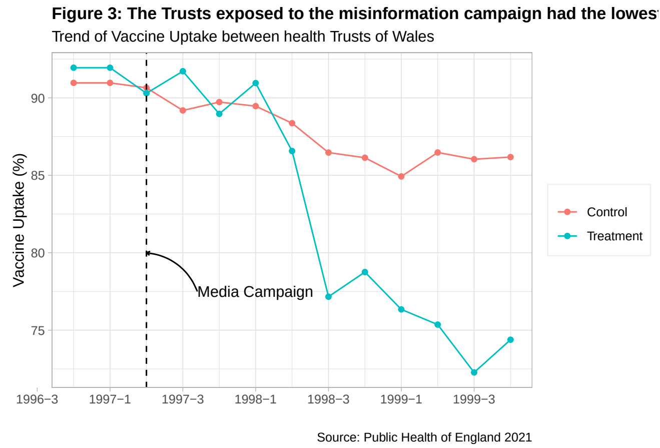
Motivating Evidence

Mason & Donnelly investigated MMR uptake in parts of two health authority areas, Morgannwg and Dyfed Powys, where the South Wales Evening Post was sold. They found that uptake declined by 13.6% in the distribution area of Swansea, Neath, Port Talbot, and Llanelli and by 2.4% in the rest of Wales[19]. They concluded that the South Wales Evening Post campaign had a measurable and unhelpful impact over and above any adverse national publicity. However, it could not show a causal relation as an observational study.

[17] Mason & Donnelly, «Impact of a local newspaper campaign on the uptake of the measles mumps and rubella vaccine».

[18] «Dataset Selection - Query - Nomis - Official Labour Market Statistics».

[19] Mason & Donnelly, «Impact of a local newspaper campaign on the uptake of the measles mumps and rubella vaccine».



Nevertheless, separating the health trusts in Wales by exposure to the local media campaign, we can observe that the Trust that had exposure to the misinformation campaign (treatment) has considerably less vaccine uptake than the others (control). The uptake gap and the similar trend before the media campaign suggest that the misinformation campaign negatively affected vaccine uptake.

We design a classic 2X2 model for this first approach to motivate the possible causal relationship. The estimator equation is given by:

$$\widehat{\delta}_T^{2\times 2} = \left(\bar{y}_T^{\text{post}} - \bar{y}_T^{\text{pre}}\right) - \left(\bar{y}_U^{\text{post}} - \bar{y}_U^{\text{pre}}\right)$$

$\widehat{\delta}_T^{2\times 2}$ is the estimated *average treatment effect on the treated (ATT)* for the group T, and $\bar{y}_T$ is the sample mean for that group in a particular period. The suffixes T, U refer to the treatment and untreated groups.

Table 1: *Vaccine Uptake Estimates*

	Treated	Control	Treatment - Control
After	81.25	87.3	-6.05
	(2.36)	(1.55)	(2.19)
Before	91.4	90.86	0.53
	(0.55)	(2.83)	(4.01)
Change in mean	**-10.15**	**-3.57**	**-6.58**
		(3.23)	(4.57)

The first naive estimate showed a reduction of -6.58% in vaccine uptake if the Trust had exposure to a misinformation campaign. However, even though it's an excellent first lead, none of the estimates were significant. Also, as Mason & Donelly state, an alternative explanation for the association between the adverse local publicity and the fall in uptake is possible; therefore, we need a more robust design to prove the causal effect.

4. Estimation Strategy

What affects vaccine uptake?

Ideal covariates are correlated with both Treatment and outcome; furthermore, data before the Treatment is needed in difference-in-difference. The Nomis data provides us with data from 1991, before the misinformation campaign in 1997. On the other hand, the health literature has explored vaccine uptake factors. Therefore, based on the health literature, we propose one main covariate:

- **Literacy (education) of women:** individuals' literacy is what mainly suggests their resilience to misinformation and disposal to vaccinate[20]. Further, the literacy of the mother heavily influences vaccine uptake in children[21].

The 1991 census provides district-level data to construct such variables. Also, considering the average age of a mother at childbirth in the UK was 27.7 years in 1991[22] we select the following variables:

- **Table L08 Economic position: Residents aged 16 and over.** Specifically, female students 20-30 years old share in the district for literacy covariate.

Model Set-Up

We propose the difference-in-differences regression of interest based on the **Library of Statistical Techniques LOST:**

$$Y_{it} = \alpha + \sum_{t=T_0}^{T_1} \beta_t \cdot T_{it} + \eta_i + \sum_{t=T_0}^{T_1} \gamma_t \delta_t \cdot x_i + \epsilon_{it}$$

where

- y_{it} is the vaccine uptake of Health Trust i at time t;
- T_{it} is the treatment of interest, i.e. the exposure to the newspaper campaing in Health Trust i at time t.
- Specifically, T_{it} equals 1 if the observation's periods relative to the group i's first treated period is the same value as k; 0 otherwise (and 0 for all never-treated groups).
- T_0 and T_1 are the lowest and highest periods relative to treatment; i.e., if we have data 5 years prior treatment then $T_0 = -5$.
- η_i is a vector of fixed effects (dummies) for each unit i
- δ_t is a vector of fixed effects (dummies) for each time t
- ε_{it} is the error.
- x_i is a covariate for each unit i

[20] Khairat, Zou, y Adler-Milstein, «Factors and Reasons Associated with Low COVID-19 Vaccine Uptake among Highly Hesitant Communities in the US».

[21] Forshaw et al., «The global effect of maternal education on complete childhood vaccination».

[22] Statista. "UK Average Age of Mothers 2020".

Standard Errors

In this setting, the variability of vaccine uptake is expected to be unequal depending on the exposure to misinformation. Also, since we examine districts within a country, the communities are likely related. Due to the previous characteristics, we propose three methods for robustness:

1. Robust standard errors to deal with the variability of vaccine uptake, i.e., heteroskedasticity. However, clustering is the usual approach to adjusting the inference.

2. Clustered standard errors would be ideal for treating the variability across districts; nevertheless, due to the few clusters (health trusts) and observations, the conventional asymptotic inference and clustering methods might not be suitable.

3. Wild-Bootstrap is an alternative to provide robustness to the test. The wild bootstrap is implemented for regression models with heteroskedasticity of unknown form, and it has been extended to models estimated where the error terms are multi-way clustered[23]. Although, Wild-Bootstrap is suitable either with a "large" number of clusters or when the number of clusters is "small," and the observations per cluster are "large" [24]; two conditions that the data doesn't meet.

Even though neither of the methods is a perfect fit for the inference, the patterns of the estimations will give us insights into the validity of the effect of interest.

[23] MacKINNON, "Bootstrap Methods in Econometrics*".

[24] Canay, Santos, y Shaikh, 2021 «The Wild Bootstrap with a "Small" Number of "Large" Clusters».

5. Main Results

I. Robust Standard Errors

In Table 2, we report the first robustness check results. The coefficients called "treat_" are the effect of misinformation in percentage at the time relative to treatment; the rest are the effect of the proxy of higher literacy in mothers as a percentage.

Table 2: *Dynamic Difference in Difference*

Coefficient	Estimate	Std.Error	t.value	Pr(>|t|)
(Intercept)	83.635	0.818	102.198	0 ***
treat_[-2]	0.968	0.769	1.260	0.21
treat_[-1]	0.968	0.769	1.260	0.21
treat_[1]	3.602	1.123	3.207	0.002 **
treat_[2]	-0.649	0.801	-0.810	0.419
treat_[3]	2.840	1.032	2.752	0.007 **
treat_[4]	-0.953	0.784	-1.215	0.226
treat_[5]	-7.939	0.791	-10.036	0 ***
treat_[6]	-6.001	1.109	-5.412	0 ***
treat_[7]	-5.576	0.878	-6.347	0 ***
treat_[8]	-8.897	0.967	-9.199	0 ***
treat_[9]	-12.146	1.152	-10.548	0 ***
treat_[10]	-9.251	0.818	-11.305	0 ***
female_students:d_1	1.153	0.107	10.760	0 ***
female_students:d_2	1.153	0.107	10.760	0 ***
female_students:d_3	1.046	0.129	8.141	0 ***
female_students:d_4	0.704	0.167	4.205	0 ***
female_students:d_5	0.939	0.113	8.320	0 ***
female_students:d_6	0.704	0.152	4.622	0 ***
female_students:d_7	0.610	0.110	5.552	0 ***
female_students:d_8	0.230	0.111	2.071	0.04 **
female_students:d_9	0.176	0.165	1.064	0.289
female_students:d_10	-0.270	0.126	-2.137	0.034 **
female_students:d_11	0.098	0.141	0.691	0.491
female_students:d_12	0.123	0.172	0.713	0.477

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

First, we notice that a year after the misinformation campaign (treat_4), there is a significant and consistent negative effect on vaccine uptake. The most severe effect was an approximately -12.146 % decrease in vaccine uptake; yet, the standard errors might not be as small due to health trust relations.

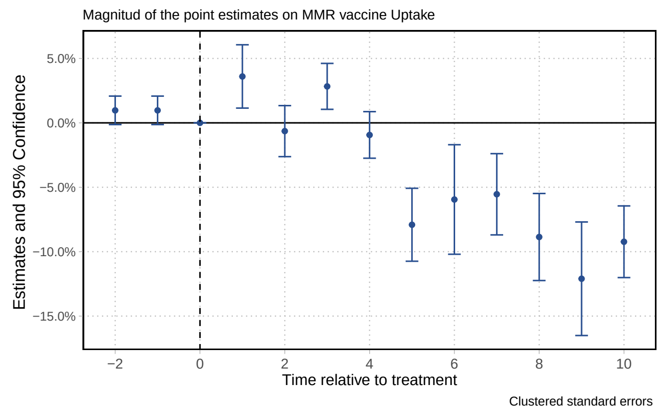
Second, the proxy of higher literacy has a small persistent positive effect on vaccine uptake within the first years after the treatment. The only discrepancy is two years after treatment with a negative estimate, but the confidence interval shows that the negative effect is practically zero.

The first approach suggests that the misinformation campaign did harm the vaccine uptake rate of the MMR vaccine. Further, the point estimates are consistent with the negative effect; even with additional robustness checks of the standard errors, the insight of the potential harm is alarming enough.

II. Clustered Standard Errors

We proceed with the second robustness check, the usual approach with clustered standard errors. The clusters are defined as the Health Trusts; Health Trusts in Wales cover different districts of Wales, which means that the people that attend a specific Health Trust live close enough to be a part of a similar community. We present the main findings in Figure 4.

Figure 4: There's a significant negative effect of misinformation on vaccine uptake



There are two main features of Figure 4:

1. The pre-treatment coefficients are nearly on the zero line with small standard errors. The nearly zero coefficients imply a precisely estimated zero difference between Health Trusts in the two groups before the misinformation campaign.

2. A year after treatment, the effect of misinformation on vaccine uptakes becomes significantly negative; even with wider confidence intervals, the previous insights remain: misinformation harmed.

However, it is important to notice that there are only 14 Health Trusts available in the data, which means that the number of clusters is not "large" enough for the method to be suitable. This nuance leads us to our third robustness check, the Wild-Bootstrap.

III. Wild-Bootstrap

As a final robustness check, we implement the Wild bootstrap. The standard specification is as follows: For a model with independent but possibly heteroskedastic errors, the wild bootstrap data generating process is

$$y_t^* = \boldsymbol{X}_t \hat{\boldsymbol{\beta}} + f(\hat{u}_t)\, v_t^*,$$

where $f(\hat{u}_t)$ is a transformation of the t^{th} residual $\hat{u}_t$, and v_t^* is a random variable with mean 0 and variance 1. One possible choice for $f(\hat{u}_t)$ is

$$f(\hat{u}_t) = \frac{\hat{u}_t}{(1-h_t)^{1/2}}$$

where h_t is the t^{th} diagonal of the "hat matrix".

To specify the distribution of the v_t^*, we use the simplest:

$$v_t^* = 1 \text{ with probability } \frac{1}{2}; \quad v_t^* = -1 \text{ with probability } \frac{1}{2}.$$

The main results are reported in Table 3.

Table 3: *Wild Bootstrap Estimates*

term	estimate	statistic	p.value	conf.low	conf.high
treat_[-2]	0.968	2.347	0.465	-13.123	13.544
treat_[-1]	0.968	2.347	0.465	-13.123	13.544
treat_[1]	3.602	3.652	0.358	-29.283	27.442
treat_[2]	-0.649	-0.829	0.525	-29.618	22.648
treat_[3]	2.840	4.159	0.364	-19.160	22.004
treat_[4]	-0.953	-1.291	0.429	-26.600	18.725
treat_[5]	-7.939	-7.049	0.293	-49.398	27.292
treat_[6]	-6.001	-3.860	0.527	-71.812	50.090
treat_[7]	-5.576	-4.493	0.334	-53.618	39.729
treat_[8]	-8.897	-6.951	0.415	-59.541	37.987
treat_[9]	-12.146	-7.381	0.442	-75.920	43.435
treat_[10]	-9.251	-8.419	0.252	-49.245	28.824

In contrast with the previous method, the Wild Bootstrap suggests no significant effect or harm regarding misinformation. Nevertheless, recall that the method is suitable with "few" clusters that are "large" enough, implying that the damage is plausible in this setting. Then again, the insight of the potential harm is alarming enough.

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