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Vaccination demand and acceptance

A literature review of key behavioural insights

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Contents

Abstract

This literature review examines key behavioural insights that can help explain and support vaccination demand and acceptance. The report identifies several key behavioural factors that should be considered in designing vaccination policies, including the importance of perceived vaccine safety, the impact of exposure to vaccine-critical information, the role of trust in government and healthcare professionals, the potential impact of forgetfulness and present-biasedness, the influence of prospect theory, the possibility of risk-related trade-offs, and the role of homophily and contagion in shaping vaccination behaviour. The report also notes that while existing literature is useful in understanding attitudes towards COVID-19 vaccines, the unique circumstances of the pandemic limit the generalizability of these findings. The report concludes by emphasizing the need for a new research agenda to build trust in the medical system, government, and pharmaceutical companies, and highlights the importance of healthcare workers in addressing the challenges of vaccination programs, as they are the most trusted source of health information. The report advocates for a multidisciplinary approach that includes insights from the behavioural sciences to shed light on the mechanisms at work when people make decisions about vaccination. Overall, the report provides valuable insights for policymakers seeking to promote vaccination demand and acceptance.

Foreword

Vaccination is one of the most powerful and cost-effective public health measures developed in the 20th century. It remains the main tool for primary prevention of communicable diseases. Yet, despite the overall benefits of vaccination, there are still several key challenges to ensure sustainable, equitable and effective vaccination programmes in all Member States, and to secure that the added benefits of vaccinations are not lost.

The pressing challenges include overcoming vaccination hesitancy, halting the spread of vaccine preventable communicable diseases, sustaining high vaccine coverage, and guaranteeing equal access to vaccination across all ages and populations. A further challenge is today represented by the effects of the COVID-19 pandemic on all aspects of vaccination, as well as the management of vaccination programs against COVID-19.

The World Health Organization's Strategic Advisory Group of Experts on Immunization (SAGE) defines vaccine hesitancy as: "[a] delay in acceptance or refusal of vaccines despite availability of vaccine services. Vaccine hesitancy is complex and context specific, varying across time, place and vaccines. It is influenced by factors such as complacency, convenience, and confidence" (WHO, Report of the SAGE Working Group on Vaccine Hesitancy, 2014).

This definition – known as the "3Cs" model of hesitancy – encapsulates the possible drivers of vaccine acceptance or refusal. While complacency and convenience relate respectively to the perceived risk of disease and the ease with which vaccine services can be reached, vaccine confidence is defined as the trust in the effectiveness and safety of vaccines and trust in the healthcare system that delivers them. Throughout the stream of work linked to the study at stake, confidence will encompass as perceived vaccine safety, effectiveness, perceived importance and religious compatibility of vaccines.

High confidence in vaccination programmes is crucial for maintaining high coverage rates, especially at levels that exceed those required for herd immunity. Across the European Union (EU), however, vaccine delays and refusals are contributing to declining immunisation rates in several countries, leading to increases in disease outbreaks. Recent measles outbreaks – the highest in the EU for seven years – illustrate the immediate impact of declining coverage on disease outbreaks.

Parental acceptance of routine childhood immunization is essential to preserve the efficacy of vaccination. Increasingly, many parents doubt the benefits and safety of vaccines. They question the need for immunization, an attitude known in literature as vaccine hesitancy (VH). Opposition to vaccination dates to the 1800s, when the first vaccine ever became available. It has never faded away despite the public's growing scientific sophistication. A variety of factors contribute to modern vaccine hesitancy, including the layperson's *heuristic thinking* when it comes to balancing risks and benefits as well as several other features of vaccination, including falling victim to its own success. Vaccine Hesitant Parents (VHPs) are a heterogeneous group of individuals who tend to have beliefs that are in between the continuum of immunization acceptance and rejection (Opel et al. (2011)[1]).

VHPs are parents who might reject one or two vaccines, agree on others, delay some, ask for separate shots rather than a combination vaccine, or be unsure about the right thing to do when it comes to vaccinate their children. VHPs often follow the expert advice with their first child but develop a sense of advocacy with subsequent children. These parents often rely on their own (often biased or incomplete) research on immunization to come up with a would-be informed decision, rather than be deferential: for them being a good parent means questioning the expert (or generalized) advice. This type of "fence-sitters" are parents who are uncertain about whether the benefits of vaccines outweigh the risks, and are easily amenable to behaviour change: they might become immunization resistant. The policy concern around VHPs is that hesitancy soon becomes refusal, as suggested by previous instances and studies (Salathé and Bonhoeffer (2008)[2]): when there is refusal, unvaccinated clusters emerge, and disease outbreaks occur. Hesitancy is therefore the steppingstone towards rejection.

[1] Opel DJ, Mangione-Smith R, Taylor JA, Korfiatis C, Wiese C, Catz S, et al. Development of a survey to identify vaccine-hesitant parents: the parent attitudes about childhood vaccines survey. Human vaccines. 2011 Apr;7(4):419-25. PubMed PMID: 21389777. Pubmed Central PMCID: 3360071

[2] Salathé, M. et Bonhoeffer, S. (2008). The Effect of Opinion Clustering in Disease Outbreaks. Journal of The Royals Society Interface, 5:1505–1508.

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Executive summary

Policy context

This literature review aims at identifying key behavioural insights that can explain and support vaccination demand and acceptance. This work started days before the COVID-19 was declared by WHO as a Pandemic and, at the time of writing, EU Member States were involved in gradual, science-based and effective vaccination programs. The European Commission has given seven conditional marketing authorization (even recently converting into standard marketing authorisations sixof them), secured up to 4.2 billion doses of COVID-19 vaccines, delivered 1.7 billion doses so far, reaching a vaccination coverage rate of 83.4% of the adult population[3]. A key component of this process is the understanding of vaccination demand and acceptance: not only to support COVID-19 vaccination programs, but also to support vaccination programs disrupted or otherwise affected by the COVID-19 crisis.

Main findings

This document highlights key behavioural aspects that should be carefully considered when designing public policies around vaccination, as well ask insights that could prove helpful in the management of the COVID-19 crisis and the EU Vaccines Strategy[4].

Fundamental behavioural insights on vaccination demand and acceptance are:

- Key attributes of vaccines are safety (risk of side effects) and accessibility. Perceived vaccine safety is correlated with positive parental response to childhood vaccination. Also, individuals accept higher probabilities of potential side effects as the effectiveness of the vaccine increases.
- Being exposed, even for a limited amount of time, to vaccine-critical information increases vaccine risk perceptions. Being the first voice heard in the vaccination debate, and counteracting false claims and misinformation, are vital actions to combat vaccination hesitancy.
- The greater the trust in government, healthcare systems and professionals, the greater the vaccination acceptance. Healthcare professionals' quality, in particular, is correlated with vaccination uptake. Making sure that healthcare professionals can build good relationships with their patients and know how to deliver complex messages around vaccination is essential to combat hesitancy.
- There is a large potential for forgetfulness, memory issues, and present-biasedness to be drivers of low vaccination coverage rates. Opt-out vaccination appointments and multiple SMS reminders are an easy, yet effective, tool to overcome vaccination barriers.
- Prospect theory can explain a portion of vaccination hesitancy: people overweigh small probabilities (vaccination side effects), and underweight relatively large ones (contracting a vaccine-preventable disease). Also, individuals prefer known risks over unknown risks: the future risk of contracting a known disease might be even preferred to an immediate risk of experiencing the unlikely adverse effects of new vaccine.
- Vaccinated individuals may engage in risk related trade-offs. For example, they could disregard other preventive measures, once they receive the vaccine.
- Homophily (selecting the people to interact with based on similar beliefs) and contagion (how the behaviour of others travels across social networks) are central in understanding vaccination behaviour. In particular, healthcare professionals can have a large impact on vaccination coverage: they are key to positive attitudes.

Findings from existing literature are useful in understanding the attitudes towards COVID-19 vaccines. However, idiosyncrasies of the pandemic limit the scope of this inference. In particular, perceived riskiness of the disease has little effect on demand for vaccination.

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[3]For updated figures: https://ec.europa.eu/info/live-work-travel-eu/coronavirus-response/safe-covid-19-vaccines-europeans_en#figures-on-vaccination and https://vaccinetracker.ecdc.europa.eu/public/extensions/COVID-19/vaccine-tracker.html#uptake-tab

[4] Available at https://ec.europa.eu/commission/presscorner/detail/en/ip_20_1103

1 Introduction

Increasing and stabilizing vaccination coverage has been a public health goal long prior to the COVID-19 pandemic. Neoclassical supply-side factors, such as monetary and non-monetary costs have not been sufficient to address low vaccination coverage. Therefore, researchers have re-focused their efforts on the demand side of vaccination and most recently on behavioural factors that can help explain low coverage and be leveraged for policymakers to increase vaccination coverage with the goal to achieve high enough levels of herd immunity.

While much progress has been made through the lens of neoclassical economic models of rational choice (e.g. see Becker), we know since decades that rational choice does not fully capture the reality we humans live in. Rational choice models are approximations of reality describing humans as machines that make choices by maximizing utility given constraints with an infinite capacity and speed to absorb information under stable preferences. Latest since noble prizes have been given to behavioural economists such as Kahneman, Shiller, and Thaler, researchers and the public alike recognizes the need to move towards models that consider behaviour that violates the fundamental axioms of rational choice.

Behavioural economics has the purpose to overcome biases that we do not fully understand and, hence, categorize as non-rational, or biases that are completely at odds with the model of a rational human being that maximizes utility to make the choice to vaccinate or not. Health economics has been identified as a particularly fruitful place for behavioural economics contributions, since it is a field dominated by high uncertainty and the need to rely on experts to maximize overall societal welfare (Frank, 2004). Behavioural factors such as choice overload, perception biases, uncertainty, unstable preferences over time and the impacts of peers have been recognized over time and they are important determinants of health choices, including decisions concerning vaccines.

We categorize on four broad behavioural factors and a group with behavioural spillover:

1. **Involvement**: being involved in a vaccination decision is a highly important factor since it suggests a state of mindfulness, rational and educated decision making and a motivation to act upon one's intentions. Individuals are often involved in decision-making for others. For example, parents are large subset of individuals who make proxy decisions for their children. They need to be aware of the correct information available. Proxy decisions for the elderly are another important factor to be investigated. They can be crucial for influenza vaccinations to ensure high coverage rates.
2. **Vaccination decisions under uncertainty**: vaccination decision-makers need to evaluate perceived risks of vaccination and non-vaccination. Those perceptions might be different based on whether someone makes decisions for oneself or for others. As hinted upon, vaccination is a decision made under uncertainty. One either faces the uncertain prospects of getting sick due to non-vaccination or the uncertain prospects to get side-effects from the vaccine with a minutely small propensity. Incorrect evaluations of those prospects or ambiguity, i.e. the state of not knowing the probabilities with which events occur, may harm overall coverage rates. Individuals may also make decisions based on knowing the efficacy versus effectiveness of a vaccine. While efficacy is the reduction in disease incidence in a vaccinated compared to an unvaccinated group under optimal conditions, effectiveness measures the propensity to stay healthy when vaccinated in empirical reality. Efficacy is usually higher than effectiveness of any vaccine. If individuals base their beliefs on efficacy studies, their perceptions of the benefits in empirical reality might be distorted and are too high in comparison to reality. This may cause individuals to engage in risky behaviour, i.e. moral hazard, since they might feel more protected than they are.
3. **Vaccination decision-making over time**: some vaccines, like influenza, are recommended to be taken every year due to mutations of the virus strains. Other vaccines only need to be administered during childhood. In either event, the individual might face a trade-off decision between incurring costs now for prevention and receiving benefits in the future of reducing the propensity to become sick while never being able to know the counterfactual state with certainty. Decision-makers might also be present-biased individuals who incorrectly overweight their utility today and underweight their utility in the future. They could change their plans for vaccination today and do not get vaccinated. Reducing procrastination can therefore, assist in increasing vaccination coverage for any vaccine.
4. **Peer effects**: another important behavioural factor that may influence vaccination coverage are peers, such as other parents, friends, colleagues or other close individuals within a network. We know from economic theory that externalities can be generated through peers and that the individual behaviour of others can influence the individual propensity to get vaccinated, e.g. by receiving

additional information, or through social norms. Being a role-model for others might have an impact on overall vaccination coverage.

5. **Healthcare professionals**: as a special group with potential of behavioural spillover are healthcare professional (HCP) and interventions around health care professionals as a behavioural supply side factor of vaccination. Leveraging the trusted source of healthcare professionals is a field with high research potential and it is ripe for behavioural interventions. In general, across all behavioural factors, there is a large potential for future research, which deserved further attention to overcome research gaps that have not yet been fully understood and closed.

The literature of each section is split into suggestive evidence vs causal evidence. With this distinction, we want to highlight the literature that provides a credible methodology – in the spirit of the credibility revolution in economics – to obtain causal effects that are likely to be free of sorting. However, the terminology suggestive evidence should not reduce the value this literature has generated. Exciting ideas from theory and the first tests are usually only possible due to first correlative empirical research. However, we think it is important to highlight causally identified estimates since they can be vastly different from correlates and vaccination intention measures due to social desirability or sorting biases.

This document is structured as follows. Chapter 2 lays out the methodology of the literature review. The behavioural factors of involvement, vaccination choice under uncertainty, vaccination choice over time and vaccination choice under peer effects are covered in Chapter 3, Chapter 4, Chapter 5, and Chapter 6 respectively. Chapter 7 covers the literature around healthcare professionals with a focus on interventions that can increase coverage. Chapter 8 deals with the ways in which our findings on earlier literature apply to the COVID-19 pandemic. Chapter 9 concludes.

2 Methodology

To find the relevant literature for Chapters 2-7, we searched on Google Scholar. Khabsa and Giles (2014) show that Google Scholar finds on average 80-90% of the literature available world-wide. Using a time horizon from the year 2000 until 2020, we employed the following keywords (including initial paper count) for our search strategy:

- childhood vaccination behavioural economics experiment (21,500)
- vaccination hyperbolic discounting (1,950)
- vaccine hesitancy Europe (16,300)
- vaccination 'peer effects' (1,050)
- vaccination 'social norms' Europe (15,800)

We identified 209 papers that are classified as relevant. We included papers that are quantitative, including literature review papers, mixed method papers and a few qualitative papers, as well as theory papers that are in the domain of behavioural economics at the intersection of vaccination. We did not include qualitative papers with a small sample size.

We downloaded each paper that we determined to be relevant according to the Terms of References. we populated the Deliverable 1 database with the variables "File", "Author", "Title", "Source", "Year", "Theoretical Approach", "Outcome variable", "Methodology", "Data Source", "Description of Data Source", "Sample Description", "Keywords", "Geographical Coverage", "DOI", "Topic", and "Abstract/Summary" (see Annex I). Those variable names are in line with the Annex 1 attached to the Terms of References which describes the responsibilities and needs for this project funded by the European Commission. The first column called "File" is a pure unique identifier for the row and each individual paper we extracted. The column "Author" is extracted from the APA format of the Google Citation function for each paper. Simultaneously, we extracted the content for the "Title". From the Citation we extracted the paper or book the paper is published in and added it to the "Source" column. Additionally, we obtained the publication year from Google Scholar and we added it into the "Year" column.

Based on reading the abstract of each paper and some in-depth details, we classified them under "Theoretical Approach" either as Neoclassical Economics, Behavioural Economics, Epidemiology or Psychology scientific papers or an intersection thereof. The overwhelming majority, i.e. 203 out of 209 papers (97%) were classified to have some relevance for behavioural economics. 6 out of 209 (3%) of the papers were purely neoclassical economics papers. 2 out of 209 (1%) papers were from the field of psychology and 5 out of 209 (2%) papers were from epidemiology. Papers that receive a neoclassical classification would usually investigate some pure cost-benefit logic or a logic about selfish utility maximization. Papers that were investigating causes of under-vaccination related to vaccine hesitancy, misunderstanding, or misclassifying the risks and benefits and perceptions about vaccines have been classified as behavioural economics articles.

From each paper, we extracted the variables of interest to populate the field "Outcome variable" in the database. Whenever feasible, we made a determination whether the paper is investigating a subjective variable of whether a person intents to get vaccinated or whether the subjects were asked whether they actually were vaccinated, in either a survey form or through administrative records. When we determined the paper is investigating an outcome variable that is hypothetical, we would label this vaccination intention. When the paper investigates an outcome that is an actual vaccination decision, we call this vaccination rate. Other outcome variables classification from the paper were: academic achievement, check-up rates, loneliness, social network, medical exemptions, mortality, work absence, preferences for convenience, psychological stress, social support, quality of service, vaccination attitudes, vaccination beliefs, vaccination benefits, vaccination delay, vaccination doubts, vaccination fear, vaccination hesitancy, vaccination history, vaccination knowledge, vaccination perception, vaccination preferences, vaccination purchase, vaccination reasons, vaccination recommendation, vaccination refusal, vaccination risk, vaccination risk perception, vaccination service. By also including categories that include vaccination hesitancy, we find 86 out of 209 papers (41%) that can be classified as scientific articles about vaccination intention. On the other hand, 151 out of 209 papers (72%) are using the vaccination rate as an outcome variable.

The "Methodology" column was populated with attributes that describe whether the paper was empirical, theoretical or a literature review in nature while employing a more detailed methodological description when the article was empirical. Overall, we differentiated the articles using the following methodological descriptors: Averages, Case-control study, Cluster Analysis, Cluster randomized control trials (RCT), Conjoint

Analysis, Correlation, Intervention, Design and Analysis, Difference-in-Difference Approach (DiD), Difference-in-Difference-in-Difference Approach (DiDiD), Dynamic Model, Econometrics, Empirical Social Network Model, Factor Analysis, Fixed Effects Model, Intervention, Laboratory Experiment, Literature Review, Logistic Regression, Machine Learning, Mixed Methods, Literature Review, Model Fitting, Multivariate analysis, Multivariate Regression, Non-Randomized Correlations: Field to Lab, Observational Study, Opinion, Panel Mixed Logit Model, Pre-Post Intervention, Qualitative, Qualitative and Quantitative Large Intervention, Quantitative Literature Review, Random Utility Model, RCT, RCT Literature Review, RDD, Regression, Simulation, Spatial Autoregressive Probit model, Structural Equation Modelling, Structural Estimation, Theory, Univariate. There are no missing entries. The database contains 18 out of 209 papers (9%) that are explicitly theoretical, with 191 out of 209 papers (91%) being empirical by nature. 53 out of 209 papers (25%) are literature reviews. we employed the term "Quantitative" or "RCT" to provide additional impetus to the reader that this is a worthwhile study to read for this literature review that focusses on quantitative studies.

When the paper was not empirical or when it was not evident that a literature review or opinion piece was done in a systematic way, we would enter "nA" into the "Data Source", "Description of Data Source", "Sample Description" columns. We searched for the Data that are used in the paper either by reading the abstract, the data section or the full paper. We entered data for 146 out of 209 articles (70%) into the "Data Source" column. The "Description of Data Source" was either used to elaborate in a more free-form manner the methodology that is employed to analyse the data, the data itself or it was not used. 139 out of 209 papers (67%) included a description. The "Sample Description" column contains information about the number of papers that were analysed for a literature review or it contains the sample size used in the study. It may also contain the subject pool used, such as caregivers, children, clinicians, college women, employed non-military adults, faculty and staff, freshmen, girls, GPs, healthcare professionals, households, mothers, nurses, panellists, parents, paediatricians, pregnant women, residents, sons, tourists, undergraduate students, women and young adults. The sample size was added to the database for 143 out of 209 papers (68%)

We browsed the content from each paper either within the abstract, or if not directly visible, within the paper to obtain information on the geographic location the paper is covering. Our review is mainly focused on Europe, but we identified some other regions as well. Literature reviews and opinion pieces were mainly classified to have world-wide relevance since they were usually not based on regional restrictions. Within the column "Geographical Coverage" we identified countries and regions. The database includes the following countries: Austria, Belgium, Bulgaria, Canada, China, Croatia, Czech Republic, Denmark, Ecuador, Finland, France, Germany, Ghana, Greece, Hong Kong, Hungary, India, Italy, Japan, Kenya, Kosovo, Malawi, Mexico, Netherlands, Nicaragua, Nigeria, Pakistan, Paraguay, Poland, Romania, Senegal, Serbia, Sierra Leone, Singapore, Slovenia, South Africa, South Korea, Spain, Sweden, Switzerland, Tanzania, Turkey, UK, US. The countries belong to the following regions: America, Asia, Europe and Western Europe and world-wide.

The subject areas for behavioural economics papers were "Childhood Vaccination, Vaccination Hesitancy, Trust, Healthcare Professionals, Hyperbolic Discounting, Peer Effects and Social Norms." During the course of our search, we added the following additional distinct topics which often intersect with the previous large topic areas: Adult Vaccination, Behavioural Nudges, Global Politics, Education, Peer Effects, Spillover, Vaccination Mandates, Defaults, Healthcare, Learning, Social Signalling, Parents, Reference Points, Prosocial Behaviour, Targeted Vaccination, Tourism, Involvement, Uncertainty, Globally, US, Europe, and Italy. we found 87 out of 209 papers (42%) on Childhood Vaccination, 71 out of 209 papers (34%) on Vaccination Hesitancy, 9 out of 209 papers (4%) on Trust, 22 out of 209 (11%) papers on Healthcare Professionals, 6 out of 209 (3%) on Hyperbolic Discounting, and 62 out of 209 (30%) papers on Peer Effects and Social Norms.

To simplify future searches, we searched on the first page of each article for the Digital Object Identifier and keywords. When the DOI was available, we would add it to the "DOI" column, otherwise we would enter "nA". Sometimes, we was able to find the DOI on the journal website even though it was not explicitly mentioned in the paper. When keywords were available, we would add them to the "Keywords" column, otherwise we would enter "nA". Keywords were available in 132 out of 209 articles (63%). DOI were available in 157 out of 209 articles (75%). Finally, we extracted the abstract from each downloaded paper, and we copied it into the "Abstract/Summary" column. This column is complete.

For the employed search terms, we can find a visual structural break in the number of references: we found more papers for the time period of 2013-2020 than for 2000-2013 (see Figure in Appendix). This is not surprising, since behavioural economics is a rather new field and the intersection with vaccination even more novel. Overall, credible causal paper in the domain of vaccination and behavioural economics which go beyond survey measures, i.e. which use administrative data, are rare: 15 out of 210 (7%) articles use administrative data. Without restricting for purely causal inference paper, a restriction to Europe is excluding a substantial

chunk of behavioural papers (140 out of 210 papers remain, 66%). By not restricting the region and by excluding papers that are literature reviews and theory papers, we end up with 138 out of 209 (66 %) empirical references. When we restrict the empirical references to Europe, we identify 71 out of 209 (34 %) papers.

The outbreak of the COVID-19 pandemic marked a tectonic shift in the literature on vaccine acceptance. In most countries, this acceptance turned out to be much lower than for other recommended vaccines, triggering many projects investigating the reasons for this discrepancy. This literature will be reviewed in a separate paper. In the current project, a decision was made to add a chapter focusing on the ways in which the body of knowledge on vaccine acceptance accumulated hitherto is applicable to the context of COVID-19. The methods and findings of this exercise are covered in Chapter 8.

3 Level of involvement

Being involved in the decision to vaccinate implies that individuals act in a state of motivation, interest, and intent. Making conscious and educated decisions about vaccination is a common assumption in the neoclassical world. However, there is ample evidence of the failure of neoclassical models, requiring us to move towards behavioural economic models to improve our understanding of individual decision-making. For example, we know that individuals tend to stick with the default since such a decision requires the lowest cognitive effort (Boehm et al. 2016). Further, the externality generated by vaccination might not be sufficiently internalized by individuals into their decision-making process and, hence, vaccination coverage might be too low (Brito et al. 1991).

We also know from recent theories on information avoidance and utility over beliefs, that more information is not always better (Loewenstein and Molnar, 2018). In the health domain, it has been shown that individuals are not necessarily keen to learn whether they have a certain disease. Individuals who avoid information for certain diseases may incur large negative consequences for themselves and for others. For example, some individuals might not get tested for their underlying health conditions, such as HIV/AIDS where treatment can increase the life span and it can reduce the propensity to transmit the disease to others (Golman et al. 2017). It is reasonable to hypothesize that information avoidance of the risks and benefits for vaccines could lead to detrimental impacts on health and general well-being through under coverage.

Choice overload is another well-documented issue. While the classical economic models assume that a larger amount of choice improves welfare, the human incapability to process information at an infinite speed and infinite amounts leads to the issue that too much choice can reduce welfare. In the context of vaccination, it raises interesting questions, such as how to bundle vaccines optimally, how much information about the risks and benefits should be provided, how exactly should it be provided and ultimately, the biggest question for vaccination choice, whether vaccines should be mandatory to begin with.

Individuals might believe that they could regret their choice of getting vaccinated when they develop side effects. Regret-aversion, in conjunction with over-weighting of small probability events can lead to vaccination aversion. Similarly, fear of vaccinations, for example from the pain of needles, can inhibit vaccination coverage.

The level of involvement is especially important when it comes to the vaccination decision-making for others. Parents will face this issue at an early age of their children since vaccination recommendation start at birth and most vaccinations happen during early childhood. One observation from the literature on decision-making of self and others, is that the level of energy spent, the number of alternatives and attributes examined is larger when individuals make decisions for others in contrast to when they make decisions for themselves.

Further, the duration of the decision-making process is longer when making decisions for others. However, being able to successfully heighten attention and involvement in one area might reduce attention and involvement in another area. This trade-off is due to limited cognitive resources of human beings and a natural limited amount of time. Therefore, it is important to understand how to introduce novel policies that leverage the distinction between decision-making for oneself and for others while staying in the realm of the feasible.

We identified 125 research papers that are related to individual involvement. Eighty-nine of them (71%) are focusing on childhood vaccinations, and, hence, they investigate decision-making for others implicitly or explicitly. Another 29 out of 125 (23%) papers are overlapping with the research on peer effects and social norms. The theme of fear and regret was covered in 8 out of 125 (6%) papers. In 7 out of 125 papers defaults were investigated and a large chunk of 50 out of 125 (40%) articles cover attention, awareness, and perception.

Forty-five out of 125 (36%) papers are not specific to one country of the world, but have global applicability, with a majority being literature review papers. 37 out of 125 (29%) are covering Europe. 25 out of 125 (20%) articles focus on North America. 9 out of 125 (7%) are conducted in Asia and 8 out of 125 (6%) in Africa. Latin America is the place of study in 2 out of 125 (2%) of all studies relating to involvement.

The literature we identify to be suggestive consists of 89 out of 125 (71%) papers. We excluded the peer effects literature which also covers childhood vaccination, since it will be addressed at a later stage. The more causal evidence consists of 13 out of 125 (10%) papers. From those causal papers, 1 out of 13 (8%) is conducted in Europe, 2 out of 13 (15%) in Latin America and the same amount in Africa. 8 out of 13 (62%) articles have study locations in North America.

3.1 Level of Involvement: Suggestive Evidence

A large amount of the literature on involvement is suggestive. The majority includes some impact study where proxy vaccination by parental involvement for child decision-making is the implicit focus. However, studies that investigate the direct consequences of individual decision-making for others in the context of vaccinations are rare. Here we will focus on a few selected suggestive papers on involvement and at the end we will provide a summary of the literature.

Betsch et al. (2010) implements a large-scale online experiment to test whether vaccine-critical websites can change the risk perception, and, hence, the involvement of subjects by reducing vaccination intention. The authors recruited 325 eligible German-speaking individuals to participate in the online experiment where individuals in the treatment group were exposed to a vaccine-critical website and the control group was exposed to a website from the Federal Centre for Health Education with the goal to take a neutral stance on vaccinations.

The authors find that being exposed to the vaccine-critical website for five to ten minutes increased risk perception of vaccines. Exposure further reduced the risk perception from non-inoculation, and it reduced vaccination intention. However, given the gap between intention and actual vaccination, it might be interesting to see whether the results hold beyond intentions.

Verelst et al. (2018) conducted a discrete choice experiment with 1,919 Belgian participants (which respondent for themselves or for their youngest child). The researchers constructed choice sets with attributes such as vaccine effectiveness, side-effects, accessibility, and vaccine preventable burden of the disease, local vaccination coverage, and population vaccination coverage. Respondents were able to choose between several vaccines with varying attributes.

Verelst et al. (2018) identify side-effects and access as the most important attributes. The researchers were mainly interested in possible differences between hypothetical decisions made for themselves and those made for their children. Interestingly, they do not find large substantial difference between those decisions. As before, one might hypothesize that differences in decisions might arise when the stakes are real, i.e. when parents have to make actual vaccination decisions for themselves or other. Therefore, it could be beneficial, to see an innovative intervention for decisions for oneself and others while measuring actual vaccination coverage.

Kahan et al. (2010) investigate the cultural cognition thesis. It states that individuals form risk perceptions based on their commitments to views of what postulates a good society. The authors are interested in why there is such a debate and divergence in the adoption of mandatory HPV vaccinations despite the public health recommendation for girls around 12 years of age to get vaccinated. They hypothesize that cultural views of what constitutes a good society might impact individual risk perception.

The authors run an experimental investigation on 1,538 US Americans. They provided statements to the participants which came from different sources with world-views that were either relatively close or relatively distant to the participant. Kahan et al. (2010) find that the tendency to selectively credit information that confirms and dismiss information that refutes their previous held beliefs can explain the controversy around vaccination. This is reinforced by the notion that information is more likely to be perceived as credible when it comes from in-group sources.

Table A1 summarizes most of the suggestive evidence. A substantial number, namely 38 out of 89 articles are literature reviews. We will exclude these and focus on the remaining 51 studies. The majority of the articles relate to parental decision-making for children but they might to a degree also apply to individual decision-making for one-self. The consensus of the literature is that individuals make sub-optimal decisions. Five papers specifically focus on the broad deviations from individually rational vaccination behaviour and the other articles cover components such as trust, perceptions, beliefs, awareness, anticipated regret, attitudes, skills. Medlin and de Walque (2008) highlight the benefits of conditional cash transfers and its large potential in the health domain and Vikram et al. (2012) find that mothers' communication skills can increase vaccination propensities of children.

Galvani et al. (2007) and Reluga and Galvani (2011) highlight the trade-off between individual decision making and Pareto-optimal decision-making that increases overall welfare. But even beyond the optimality trade-off between individual vs community decision-making, there are behavioural factors which can prevent individuals from making individually rational decisions. Five papers on suboptimal decision-making specifically point out that the vaccination problem might be special in that it is more difficult for individuals to

comprehend than some other types of medical decisions. Due to the nature of health care decisions being surrounded by uncertainty, parental trust in health care providers is identified as essential.

Mistrust of medical professionals and governments in general is correlated with parental vaccine hesitancy, and higher trust in alternative medicine. Since personal interactions with non-vaccine hesitant healthcare professionals can correlate with vaccination intention – identified by 8 out of 51 papers –, it is crucial to increase vaccination knowledge and confidence of healthcare professionals to increase parental involvement. However, when encouraging those interactions, one might want to consider their exact format. For example, according to Opel et al (2015), participatory provider-parent interactions reduce vaccination intention (more on healthcare professionals in section 7).

A large set of papers cover parental attitudes, perceptions and beliefs. Verelst et al. (2018) finds no large differences between own vaccination intention and parental vaccination intention for children, which could imply that some of the results might be transferrable to own intention. However, there is a literature on own versus other decisions, which identifies that there might be differences. Hence, this is a promising avenue that needs to be further explored. For example, Hofman et al. (2014) find that positive parental attitude towards vaccination increases vaccination intention of parents for children.

Ten out of the 51 papers identify the perception that infectious diseases are not serious as a possible driver of reduced vaccination intention. For instance, Funk et al. (2010) identifies incorrect beliefs as a driver of vaccine hesitancy. Similarly, a higher perceived vaccine efficacy is positively correlated with parental vaccination intentions and 8 out of 51 papers support the idea that the perception of side-effect severity is negatively correlated with vaccination intentions.

Vaccine safety concern can increase parental responses of being unsure about childhood vaccination, refusing, or delaying childhood vaccinations. They are correlated with vaccine-hesitancy (Salmon et al. 2005). In particular, some studies find that vaccine hesitant individuals seem to be most concerned about the safety of the varicella vaccine (Gust et al. 2008, Salmon et al. 2005). The literature offers some additional interesting findings. Bauch and Earn (2004) find that the perceived vaccine risk is negatively correlated with vaccination coverage more for secondary infections than primary infections. From a theoretical perspective, Bauch (2005) finds that fluctuations in vaccination coverage over time are more likely when the perceived side-effects of vaccinations are high, and, hence, unstable coverage results.

Two papers find that increasing awareness can increase vaccination coverage. Indeed, this could be a first step to spread information and improve vaccination knowledge. Mascia et al. (2020) identified a particularly promising channel, i.e. the spread of vaccination knowledge from adolescents through informal networks (in particular after-school social ties) which can be further investigated to improve vaccination coverage. Other studies invoke the idea that a lack of parental information is correlated with lower vaccination coverage for children. Confusion about vaccination knowledge can lead to parents questioning their choices to vaccinate their children (Downs et al. 2008). Unfortunately, Downs et al. (2008) find that providing information to parents is not helpful in reducing confusion. Therefore, more work needs to be done into the manner in which vaccination information can be provided in a digestible, credible form that leads to long-term sustainable positive attitudes and actions to improve vaccination coverage.

Interestingly, two articles find that vaccine critical information increases risk perceptions and reduces vaccination intention. However, providing truthful information prior to vaccine critical information can increase vaccination intention for parents of their children (Jolley and Douglas, 2017) and it may inoculate individuals against vaccine conspiracy theories.

Three studies find that anticipated regret positively correlates with low vaccination intention and coverage. Sato and Fintan (2020) study fear of vaccination on female caregivers in Nigeria. They find that 15% of them fear vaccination. Fear is correlated with the lack of vaccination knowledge, and with a lower rate of self-reported vaccination coverage for the children of those caregivers.

3.2 Level of Involvement: Causal Evidence

The causal inference literature on involvement is relatively scarce with 13 articles. Most of those studies use experimental methods or difference-in-difference quasi-experimental methods.

Chapman et al. (2010) studies how defaults affect vaccination behaviour using a field experiment. Large amounts of evidence have already shown that systems where individuals must opt-out lead to higher take-up than those where individuals have to make an involved choice to opt-in.

The authors assigned 480 faculty and staff from Rutgers University to either an opt-out or opt-in condition for vaccination at the University Health Department. In the opt-out condition, the participants were scheduled for a flu shot appointment, with the possibility to change or cancel the appointment. In the opt-in condition, the availability of influenza vaccines was highlighted with a link to the Health Department website to schedule appointments.

Chapman et al. (2010) find that 45% of the employees received a flu shot in the opt-out condition in contrast to 33% in the opt-in condition. Therefore, changing the default increases vaccination coverage by 12 percentage points or an equivalent of 36%. Appointment status was mediating the success of the intervention. From the opt-out group only 8% decided to cancel appointments. The authors conclude that automation of an appointment for the flu-shot as a nudge could be effective in increasing vaccination coverage.

Garrouste et al. (2019) investigate a hepatitis B vaccination campaign in France before the year 2000. They use a quasi-experimental approach to evaluate a 1995 health campaign by the Foreign Ministry of Health and Education which implemented free vaccinations in middle schools. Parents of children in middle schools received a letter with information about the risks of non-inoculation and they also were able to meet doctors and nurses to address questions and concerns. The parents could oppose the vaccination of their child before it was carried out at the school location of their children.

Since the campaign happened in middle schools, only children of the age 11 and above where eligible to receive the injections against hepatitis B. Garrouste et al. (2019) exploits the idea that those children slightly above the age of 11 should not be much different from the ones slightly below the age of 11, aside from the policy. The authors find that a share of 30% of children below the age of 11 were vaccinated against Hepatitis B (HB) while 70% of children above the age of 11 were vaccinated.

The researchers were investigating how involved parents were when they made HB vaccination decisions, by testing parental knowledge of the HB target population (new-borns, middle school pupils or the whole population) and transmission modes (correct mode of transmission, such as blood or semen). Surprisingly, parents with a child that is older than 11 were 21 percentage points less likely to list the correct transmission mode, listing saliva quite often. Garrouste et al. (2019) point out that a large health information campaign in 1994 spread erroneous information which might have been recalled by the treated parents. Therefore, they show that it is important to provide the correct information for parents to make an informed proxy vaccination decision for their child.

Interestingly, the authors find that HB vaccination has a negative spillover on measles, mumps, and rubella (MMR) vaccinations. They hypothesize that this might be driven by parents being more reluctant to administer multiple vaccinations: if vaccinations are close to each and are traded off against each other.

Garrouste et al. (2019) also hypothesize that another behavioural effect could be induced due to salience of the HB vaccination in contrast to the MMR vaccination. Due to the health campaign, parents might put more attention towards the HB vaccine, and they might think that MMR is not as important as HB vaccination. Therefore, the authors show some of the potential drawbacks of providing information and administering health campaigns. Campaigns that focus only on one disease, may lead to higher rates of transmission for another one. Vaccination campaigns that foster knowledge and provide vaccination opportunities for multiple diseases could reduce such negative spillover.

A large-scale study undertaking by Gibson et al. (2017) investigated how to improve vaccination coverage in Kenya using reminder messages and monetary incentives for timely take-up via short message service. Caregivers with children below the age of 5 weeks where eligible to participate if their child did not receive the pentavalent vaccine, i.e. the vaccination against Diphtheria, Pertussis, Tetanus, Hepatitis B and Hib.

The authors scheduled reminders for pentavalent and measles immunization visits for the children. They used a clustered-randomized control trial to allocate 152 eligible villages to treatments and select eligible individuals from villages to either a control, an SMS-reminder, an SMS reminder plus 75 Kenyan Shilling (approx. 70 US Cents on June 1, 2020), and an SMS-reminder plus 200 Kenyan shillings (approx. 1.90 USD on June 1, 2020).

Within one year from 2013 to 2014, they enrolled 2018 caregivers with 1,600 infants. Overall, 86% of the children were successfully followed up and achieved full immunization by the age of one. In the control group, 82% received all vaccines at the 12 months. The reminder SMS only, increased coverage by 6 percentage points with 75 Kenyan shillings not providing any additional increase. Caregivers in the SMS plus 200 Kenyan shillings treatment exhibited a coverage rate of 90%. A stricter measure assesses whether children were

vaccinated in a timely manner against the measles, i.e. within 48 hours of the immunization date. In the control group 41% of all children were inoculated on time, while the SMS reminder increased coverage rates by 7 percentage points. Interestingly, just the existence of a monetary incentive of 75 Kenyan shillings increased coverage to 60 % with an only marginal additional increase of 2 percentage points.

It appears that the SMS reminder might increase attention and improve follow-through of the parents for their child's vaccination. Interestingly, the monetary incentives for timely vaccination work on the extensive margin by increasing coverage by a large 19 percentage points while the intensive margin, i.e. the amount of money of 200 shillings still seems to be an important driver to increase coverage after 12 months.

In an experimental evaluation from Sato and Takasaki (2019a), the authors investigate the psychic costs versus monetary costs of tetanus vaccination for rural Nigerian women. Potential reasons for vaccine-hesitancy in Nigeria are psychic barriers such as the fear of side effects, the fear that their children might get the disease because of the inoculation and disbelief in the benefits of vaccination.

Sato and Takasaki (2019a) varied the amount of money that women would receive to vaccinate their children from 5 naira (3.3 US Cents), 300 naira (2 USD) or 800 naira (5.3 USD) and they varied whether the mothers received the amount by either visiting the clinic or by visiting the clinic and letting the vaccination be administered to their children. In a third condition called "scarred straight", the authors showed the consequences of having tetanus to random subset of women, i.e. they primed the disease severity.

The authors find no difference in vaccination uptake between women who are required to get vaccinated before receiving the monetary reward, and those who get the reward without conditions (other than going to the clinic). They conclude that there are no substantial psychic costs from vaccination in Nigeria. They do find out however that amount of the monetary reward is key to improve coverage: with 5 naira the coverage increases to 54%, with 300 naira to 74.1%, and with 800 naira to 83%. 800 naira is 13% of the monthly household earning and a substantial share for participants in the study. Therefore, this incentive should be large enough to outweigh opportunity costs of vaccination for the Nigerian mothers. Keep in mind that there was no framing of the monetary incentives with respect to loss of income or the costs of going to the clinic. Interestingly, the authors did not find any effect from priming individuals on the disease severity on tetanus vaccination coverage despite a change in the perceived risk severity.

It would be interesting to know whether those results can be replicated beyond Nigeria and whether the fear of vaccination might not be substantial enough to matter or might matter more in different contexts. It further could be the case that priming the perceived risk severity alone just with a few pictures is not enough to increase the perceived risk severity to a threshold severity that allows for coverage to change. However, this might be different in other countries were risk perceptions and responsiveness from health-related triggers could be higher, such as for African Americans that are primed on their identity (Benjamin and Choi, 2010). Therefore, it is crucial to see researchers using innovative causal inference methods, such as the ones applied by Sato and Takasaki (2019a) to obtain behavioural factors in an indirect manner.

Schaller et al. (2019) show indirectly that the hypothesis that just an image might not be enough to scare individuals. The authors calculate the time gap from vaccination to birth, and estimate the impact from pertussis outbreaks when the infant is not yet born on the timely inoculation against diseases. They find that vaccination coverage for infants is increased for pertussis and other diseases (such as polio or influenza) when pertussis outbreaks happen during pregnancy.

They hypothesize that salience of the disease risk is increased due to the outbreaks which is the channel through which vaccination coverage increases. This is a credible mechanism. However, the strengths of the exposure shock might matter, which is why Sato and Takasaki (2019a) might not have found an effect from disease priming while Schaller et al. (2019) found an effect from actual credible disease outbreaks. It is therefore crucial to provide a strong and credible treatment that can change the salience of vaccination coverage.

Finally, Table 1 summarizes the literature from the causal effects on individual involvement as a behavioural factor. Barham and Maluccio (2009) find that conditional cash transfers work very well to increase vaccination coverage for a number of vaccines and they can be used to reach herd immunity thresholds. Similarly, Gertler and Boyce (2001) find that a conditional cash transfer, which includes inoculation requirements for infants and children, increases preventive health care visits.

Deuson et al. (2001) uses a pre- and post-intervention all-encompassing approach to increase hepatitis B vaccination coverage. They educate parents, enrol physicians into the campaign, and they visit children due

for vaccinations. The whole package is positively correlated with a 12 percentage point increase for 3 completed vaccination doses.

Felt et al. (2000) administered a behavioural intervention to the parents of 57 out of 102 randomly assigned infants. The parents were provided with information about how to help their infant during the immunization process, prior to the vaccination. The authors find that both infants and parents who received the behavioural intervention prior to immunization, where less distressed and more comfortable immediately after immunization. Psychic costs seem to exist for infants and more personal parental nudges might be an effective way to reduce those costs.

Hair et al. (2020) study personal belief exemptions in the United States, specifically in Arkansas and Texas. They find that such belief exemptions decrease vaccination coverage for black and low-income pre-schoolers from 16.1% to 8.3%, and they reduce standardized tests scores in middle schools. We hypothesize that one channel could be that personal-belief exemptions might be especially detrimental for individuals with little knowledge of vaccinations or higher perceived risks. To compensate for the belief exemptions a substantial amount of work is required to get back to previous coverage levels.

Lawler (2018) studied vaccination choice in the United States. She finds that vaccination recommendations and mandates significantly increase coverage for young children and high school students. On top of the coverage increase, she documents substantial spillover effects from vaccine mandates for middle school to adulthood. Those mandates that reduce choice are further effective to reduce disease incidence. Given the behavioural literature on choice overload, as well as potential misperceptions of the propensity of sickness and the likelihood of side-effects, it is reasonable to hypothesize that there are overall positive welfare effects by reducing choice.

Lawler (2019) is one of the few studies investigating vaccination recommendations effects on the demand and supply-side. She finds a substantial increase of 21 percentage points from vaccination recommendations of meningococcal vaccine which is largely driven by physician's following the recommendation and not as much by patients asking for vaccinations.

Finally, Stockwell (2014) send automated text messages for 5 weeks to low income pregnant women to remind them about influenza vaccinations. The reminders improved coverage by more than 30% after adjusting for gestational age and the number of clinic visits. Hence, automated text messages, as a low-cost nudge, has the potential to increase salience of vaccination and increase vaccination coverage for a high-risk group.

We conclude that there is some room to investigate psychic costs and salience. Also, decision-making for individuals themselves versus decision-making for others leaves large scope for interesting innovative interventions.

Table 1 Causal literature on verifiable vaccination coverage and level of involvement

Reference	Country	Mechanism	Method	Effect on Vaccination Demand
Barham and Maluccio (2009)	Nicaragua	Opportunity Costs	DiD	The demand-side incentive of conditional cash transfers increases vaccination coverage for multiple vaccines. Mechanism: Opportunity costs
Chapman et al. (2010)	US	Cognitive Load	RCT	Making vaccination appointments the default increases vaccination coverage by 12pp. Mechanisms: Cognitive effort
Deuson et al. (2001)	US	Attitudes, Knowledge, Perceptions Opportunity costs	Pre-Post Intervention	Vaccination coverage by educating parents on hepatitis B vaccination, enrolling physicians into a vaccination program, and visiting children who are due for a vaccination increased vaccination (over time) for 3 completed doses by 12 percentage points. Mechanisms: Attitudes, Knowledge, Perceptions Opportunity costs
Felt et al. (2000)	US	Psychic costs, Fear	RCT	Infants whose parents received a behavioural intervention prior to immunization, where less distressed and more comfortable immediately after immunization. Mechanism: Psychic costs Fear
Garrouste et al. (2019)	France	Price Effect, Attention/Salience, Trade-off of Vaccines,	RDD	Middle school HB vaccination campaign increases vaccination coverage by 40 pp. The campaign also reduced MMR vaccination Mechanism: Trade-off between vaccines since it might be perceived dangerous to inoculate close together Attention/Salience of HB vaccine vs MMR vaccine was shifted due to the campaign
Gertler and Boyce (2001)	Mexico	Opportunity Costs	RCT	Conditional cash transfer for immunization of infants (up to 24 months) and children (24-60 months) increases preventive health care visits Mechanism: Opportunity Costs

Gibson et al. (2017)	Kenya	Attention, Salience. Recall, Planning	RCT	SMS reminder jointly with monetary incentives increase vaccination coverage over 12 months and the reminders by itself increase timely vaccination against the measles. Mechanism Attention, Salience Recall, Planning
Hair et al. (2020)	US	Beliefs, Effort	DiD	Personal belief exemptions decrease vaccination coverage for black and low-income pre-schoolers from 16.1% to 8.3% and they reduce standardized tests scores in middle schools. Mechanism: Beliefs Effort
Lawler (2018)	US	Salience, Attention, Information, Choice Overload	DiD	Vaccination recommendation increase hepatitis A vaccination rates among young children by 20 percentage points with mandates increasing coverage by an additional 8 percentage points. Vaccines mandates from middle school have spillover to adulthood and reduce disease incidence. Mechanisms: Salience, Attention, Information Choice Overload
Lawler (2019)	US	Physicians	DiD	Vaccination recommendation of the meningococcal vaccine increased vaccination by 21 percentage points (133%). Mechanisms: Changing provider behaviour
Sato and Takasaki (2019a)	Nigeria	Psychic costs, Fear, monetary incentives,	RCT	Psychic costs do not seem to matter for vaccination coverage. Monetary rewards improve vaccination coverage Disease priming does not change coverage but only the risk perception. Mechanism: Fear of vaccination

Schaller et al. (2019)	US	Psychic costs, Fear	DiD	Pertussis outbreaks increase pertussis, influenza, and polio immunizations Mechanisms: Fear of the disease
Stockwell et al. (2014)	US	Attention, Salience. Recall, Planning	RCT	Women who received the intervention where 30% more likely to vaccinated against influenza (after adjustment for gestational age and clinic visits). Mechanisms: Attention, Salience. Recall, Planning

4 Choices under uncertainty

The uncertain benefits and costs of vaccination and disease incidence are major components of the complexity around optimal vaccination decisions. Uncertainty is commonly split into ambiguity and risk. Vaccination decision-making under ambiguity implies that disease disutility and vaccination utility or disutility is not known, but different values of utilities can be obtained in different states of the world, and it is not clear whether a state of the world will occur or not. Under ambiguity, the individual decision-maker has no idea about the probability with which each state of the world will occur. In contrast, a phenomenon more often assumed in the theoretical literature and investigated heavily in the empirical literature is that of risk. Risk implies that the individual decision-maker has the capacity to formulate propensities with which each state of the world occurs or even better, that there are objective propensities that the individual knows in order to decide whether to vaccinate or not.

Imagine there is no vaccine against influenza. The flu season could be very mild, mild, severe or very severe. Depending on the flu season, the symptoms could be more or less severe (on average) and the propensity of infection could change as well. The flu season is correlated with temperatures (which can vary over time within a region) because the virus can survive longer during lower temperatures and lower humidity (Lowen et al. 2007); moreover, it can spread more easily when people spend more time indoors. Now imagine a world, where the vaccine against influenza is introduced. Let's imagine the correlation temperatures-flu is the main factor under consideration for an individual to get vaccinated and, for simplicity, there is no herd immunity. An individual making a decision to vaccinate, might have no idea whether the winter is going to be mild or severe, and, hence, he might have a difficult time deciding what the best course of action is. If he cannot formulate propensities, the individual is in a state of ambiguity. If he can formulate subjective propensities or knows objective propensities, he is in a state of risk.

One may wonder, whether it is crucial to push the boundaries of economic ambiguity models for vaccination choice to reconcile findings from the empirical literature. A commonly known phenomenon is that individuals prefer known risk over unknown risks, i.e. they are ambiguity averse. Just providing propensities can therefore encourage hesitant individuals to get vaccinated. If we do know vaccination efficacy propensities, we might be more likely to get vaccinated in contrast to when we do not know them (see Ellsberg 1961).

Another example of uncertainty arises due to uncertain benefits of vaccination. For each season, researchers target strains from the influenza viruses and create a mixture of those strains. However, researchers do not know in advance the exact strains in circulation, due to random mutations of influenza. Therefore, some years the match of the vaccine might be particularly good, in other years, the match might be bad. While a flu shot usually has very low monetary costs, the ex-ante evaluation of possible states of the world of vaccine efficacy in combination with the anticipated sickness in each state, might lead some individuals to not getting vaccinated. One could imagine a similar example with vaccine side-effects. However, one should keep in mind that, empirically, most of the sub-optimal decisions might simply arise because individuals overestimate small probabilities.

When considering risk, for each state of the world, some individuals might be more risk-averse than others. It means that the same sickness would be transferred into higher disutility for an individual who is more risk-averse than an individual who is more risk-seeking. Or stated more simply, for the same amount of risk, i.e. the same propensity of vaccine efficacy, individuals that are more risk-averse, are more likely to get vaccinated, compared to risk-neutral individuals.

One popular way to elicit risk preferences in an experiment is to let subjects make decisions over a battery of paired lotteries. The first choice has a lower variance in payoffs than the second choice. Holt and Laury (2002) run through the probabilities of each payoff in increments of 1/10 to construct what is commonly known as "multiple price lists". The idea is that initially the lower variance choice, the safe choice, is most desirable. However, as one goes down the battery of lotteries, the probability of the most desirable outcome in the high-variance risky payoff increases, until the risky option becomes a safe option. As a result, most subjects choose the safe option in early choices but at some point switch to the risky one. The point when an individual switches is a measure of individual preference for risk. An individual who sticks longer to the low variance lottery is considered to be more risk averse.

There is large literature exploring to what extent measures of risk-aversions are stable over time, and whether they are general vs. domain-specific. Overall, it calls for caution, as re-takes of the same task only show moderate stability (Schildberg-Hörisch 2018), consistency across methods can be very low (Pedroni et al., 2017) and laboratory measures tend to be poor predictors of behaviours in the outside world (Charness et al., 2020). However, in the domain of vaccination, only scant evidence of incentivized risk preference

parameters can be found, and most commonly preference measures are elicited through discrete choice experiments where individuals state their hypothetical choices over two options which are varied in their attributes. For example, a subject can be presented with two vaccines for the same disease. Vaccine A might have a vaccine efficacy of 80% and side-effects of 0.005% while Vaccine B may have a vaccine efficacy of 90% but side-effects of 0.008%. Efficacy and side-effects are the characteristics which are varied over two observable options and from those hypothetical choices the desirability of certain attributes is derived.

Even when objective propensities are known, they might be perceived in a distorted manner. Prospect theory has become widely known as a theory that takes into account how individuals commonly overweigh small probabilities, such as winning in the lottery or vaccination side-effects, while underweight relatively large propensities, such as the probability to get sick. This behavioural model also postulates that disutility from losses looms larger than utility from equivalent gains. To the extent that the lack of vaccines is the reference point so that vaccines bring gains (reduction of risk of dying) and losses (side-effects), loss aversion might make them relatively unattractive. Clearly, however, more research into the role of prospect theory in explaining vaccine hesitancy is needed.

Finally, a model of regret aversion introduced by Loomes and Sugden (1982) is a potential avenue for in-depth research tying vaccination choice to experiential risk aversion. Individuals considering a decision to get vaccinated or vaccinate their children, might anticipate potential regret from side-effects of the vaccine if they engage in vaccination. By not vaccinating, they avoid anticipated regret. . If an individual gets vaccinated and develops side effects, they know for sure that they would not have those health complications without the vaccine. The outside option when an individual does not get vaccinated is an increased likelihood of sickness. Since vaccines have commonly imperfect efficacy, it is unclear whether an individual that is not vaccinated would actually be sick. Regret aversion could lead to reduced risk-taking, but interestingly, in particularly in the domain of vaccination when the side-effects are emphasized, it might actually lead to more risk-taking since not vaccinating is often not the objectively rational choice that maximizes individual or societal welfare.

4.1 Choices under Uncertainty: Methodology

To focus on vaccination choice under uncertainty, we browsed through all abstracts containing the following key words: risk, uncertainty, ambiguity. We found 57 out of 209 (27%) articles that cover risk in some manner. 28 out of 57 (49%) of the papers that cover risks, are intersecting with the previous literature on involvement. 30 out of 57 (53%) of the studies are conducted in Europe, 1 out of 57 (2%) in Africa, 5 out of 57 (9%) in Asia and 8 out of 57 (14%) in North America with no studies in Latin America. Finally, 15 out of 57 (26%) have an applicability world-wide with the main composition including literature reviews and theoretical research.

We classify 54 out of 57 (95%) studies as suggestive studies. Hence, there is a large potential to contribute to causal inference behavioural research. For the causal inference literature, we focus on RCT, observational studies and those with a difference-in-difference design. We further limit the relevant literature to the studies that leverage actual vaccination coverage as an outcome instead of vaccination intention. We find only 3 out of 57 (5%) of the articles that fit those criteria. Interestingly, the causal inference studies are geographically well dispersed with one study being in Europe, one in Africa, and one in North America.

4.2 Choices under Uncertainty: Suggestive Evidence

Abhyankar et al. (2008) test components of prospect theory using message framing to investigate vaccination coverage of measles, mumps and rubella (MMR). In a between-subject design, females received messages that were either framed in a loss or gain frame. The women were recruited through convenience sampling from public places such as leisure centres, libraries, bus or railway stations, or airports. Those of them who had no children were asked to imagine that they did. They were randomly assigned to the Gain Frame or the Loss Frame and received the following message (with the underlined words only appearing in the Gain Frame and the words in bold only appearing in the Loss Frame: “By vaccinating/not vaccinating your child against mumps, measles and rubella, you will be able to/fail to protect your child against contracting these diseases and take/will fail to take advantage of a safe and lifelong immunization, which will make you feel less anxious/anxious and safe/unsafe.” Abhyankar et al. (2008) find that vaccination intention for MMR inoculation increased for the loss frame over the gain frame, which is consistent with the idea of prospect theory that losses loom larger than gains. Interestingly, the interaction of framing and actually having an offspring was not significant, which could mean that the intervention was enough to create a state of mind where females make a vaccination decision for someone else. It would be great if this could be confirmed

through further studies and if more research could confirm that the result on vaccination intention extends to actual vaccination coverage. It would further be interesting to see how the under- and over-estimation of probabilities from prospect theory are affected based on small and large losses and gains.

Tsutsui et al. (2012) investigated influenza vaccination intention in Japan using a survey from Osaka University. Two years later, they followed up with questions about actual vaccination status, to check whether intentions and actions were aligned. They found they were. The authors introduced risk aversion of an individual evaluating the risks of getting influenza and the risks of exhibiting side-effects due to vaccination. Based on a theoretical framework, they hypothesize that risk aversion increases the propensity to get the flu shot when the perceived risk of getting the flu is greater than the perceived risks of side-effects.

To elicit absolute risk-aversion, they ask subjects whether they prefer a lower wage with lower risk, or a higher wage with relatively high risk. In particular, they follow a method by Barsky et al. (1997). Respondents have a choice between two options: a) "Your monthly income has a 50% chance of increasing by 30%, but also has a 50% chance of decreasing by 10%" or b) "Your monthly income is guaranteed to increase by 5%." Subjects who choose the high-risk option a), are asked the same question but the chance of the increase of the monthly wage is lowered to 20%. Individuals who chose option b) have to answer an altered subsequent question where the increase is heightened to 50%. The idea here is that individuals who require higher income increases when they are in a lottery situation versus a sure bet, are more risk averse. The authors find that risk aversion affects the intention to vaccinate through the risk of side-effects and the risk of getting influenza.

Similarly, Binder and Nuscheler (2017) focus on the risk-trade-off between susceptibility to the disease and side-effects from immunization. The authors conduct a real effort experiment in the experimental economics laboratory at the University of Augsburg in Germany between November 2015 and June 2017. The authors introduced four framings, a vaccination frame, a surgery frame, a neutral complex frame and a neutral simple frame while individuals had to make decisions between a risky and safe choice. They hypothesized that vaccination is different from other decisions and that, in particular, risk preferences is a driver. Interestingly, the authors find a gender effect where females make less consistent choices in the game framed as vaccination game in contrast to a surgery frame. Hence, the authors conclude that there is something special about vaccinations that inhibits optimal choices.

Table A2 summarizes the results of all papers that cover uncertainty. The majority of the papers do not identify risk-preferences in a classical economic sense. We find that risk perceptions of side effects dissuade individuals from taking up coverage based on 20 out of 54 articles, while an increased perception in the riskiness of the diseases or an increase in the efficacy is likely to increase coverage, according to 21 out of 54 articles. Any bad experience with vaccines in the past can have long run consequences, even after the risk perceptions return to baseline (2 out of 54 papers). One paper finds that vaccination risk perceptions are influenced simply by a limited exposure to vaccine-critical websites, making it crucial to counteract incorrect information. However, only providing messages that there is no risk, increases risk perceptions, according to Betsch and Sachse (2012). Additionally, there is some evidence that parents might not act upon risk messages from the media (Petts and Niemeyer, 2004). One may hypothesize that the media dramatizes recommendations, generating a black-and-white perception. Therefore, as a policy recommendation, transparent and accessible communication on risks linked to vaccine preventable diseases, without incurring in to extreme fear inducing messaging, should be tested, and if successful promoted.

In line with the idea that healthcare professionals are critical influencers for their patients (section 7), even doctors who are not vaccine-hesitant fear vaccination side effects (Verger et al. 2016). Based on 3 out of 54 papers, unfavourable perceptions about vaccination risks reduces the likelihood of doctors to recommend vaccination.

Additionally, there is some evidence that social norms are followed more when one has to decide for others, rather than for the self (Petrova et al. 2016). As is well known, some groups such as the elderly, children, or immune-compromised are high-risk individuals that are more likely to suffer deleterious infection consequences. There is still an open debate, whether at-risk groups require mandatory vaccinations. Generally, most developed nations opted for a system of recommendations to preserve individual choice (Zimmerman 2006). Targeting specific risk groups, in particular children, might help other risk groups. Behavioural methods (Embry 2004) as well as machine learning warning systems can be used (Schmid et al. 2017) to improve coverage for those groups and provide warnings about vaccine-hesitant individuals who might indirectly harm those at risk-groups.

Further, the cost of vaccination can induce free riding. One of the cost of vaccinations are the side-effects which may increase free-riding and reduce coverage (Betsch et al. 2013). One might use economic incentives, such as conditional cash transfer to compete against those risk perceptions or low risk perceptions for a disease. However, the effects of conditional cash transfer for vaccinations are ambiguous (Medlin and de Walque 2008, Bassani et al. 2013). Dubov and Phung (2015) state that the preference of known risk over unknown risk might lead to individuals not obtaining coverage. Known risk from a known disease might be preferred to a new vaccine. This in effect can lead to pessimism and lower coverage. However, given the state of the literature, an in-depth investigation of low vaccination coverage due to ambiguity aversion is still required.

4.3 Choices under Uncertainty: Causal Evidence

There are only three studies which are considered causal studies of uncertainty for vaccination choice. We present all three of them here. For the study from Schaller et al. (2019) on possible changes in risk-perceptions due to disease outbreaks as driver for vaccination coverage, we refer to the section on involvement.

The most relevant study covers vaccination and risk-preferences in Germany and was conducted by Nuscheler and Roeder (2016). While technically observational studies are not causal, we generously go along with the interpretation that the evidence is causal since this is one of the more rigorous studies on risk preferences where the authors not only tied the empirical literature to a theoretical framework but also tested the stability of their results using controls. The authors develop a model to rationalize individual decisions to get vaccinated based on quasi-hyperbolic discounting, information, and, most importantly here, on risk aversion. Based on the theoretical framework where individual decisions are partially driven by the perceived expected loss from side-effects and the perceived expected loss from not being protected due to forgoing influenza vaccinations, the authors do not have a clear prediction of risk-aversion on the propensity of vaccination.

In a German survey, the authors were able to embed questions to elicit risk-preferences. They asked respondents to state the smallest amount they must be given to choose the second alternative out of the following two alternatives: a) “Consider a lottery, where you have a 50% chance of winning 50 Euros. With the remaining 50% chance, you win 200 Euros.” b) “You receive some amount with certainty.” The amount from option b) is called the certainty equivalent. The average of the lottery is 125 Euros. It is the point of risk-neutrality. Hence, whenever individuals state an amount below 125 Euros, they are classified as risk averse. The authors do not find any aggregate effect from risk preferences on the propensity to obtain the flu shot. Interestingly, they find that risk preferences for women do not have a significant impact on vaccination decisions. In contrast, for men an increase in risk aversion is significantly positively associated with the demand for vaccination. Nuscheler and Roeder (2016) find that a 10 Euro increase in the certainty equivalent reduces the probability to vaccinate by 1.2 percentage points. They conclude that this small change cannot be driven by the fear of side-effects which leads to a reduction of the propensity to vaccinate by 17%. Also they found that well informed individuals have a much higher willingness to pay to be vaccinated compared to poorly informed individuals.

As covered in the section on involvement, Gibson et al. (2017) ran a SMS reminder campaign in Kenya for young mothers to increase vaccination coverage for infants over 12 months of their life. Their study is not about risk preferences in the classical sense. However, it could be about ex ante moral hazard, i.e. the propensity to engage in more risky behaviour after being vaccinated In particular, Gibson et al. (2017) measured the “proportion of fully immunised children by 12 months of age, defined as receiving BCG, three doses of polio vaccine, three doses of pentavalent vaccine, and measles vaccine.” They find that the relative risk of diseases for reminder short messages in combination with the highest monetary incentive of 200 Kenyan shillings, is 1.09. It implies that the risk is slightly increased to get a disease when one receives the treatment in contrast to being in the control. The change cannot be attributed to harmless SMS, since they do not cause diseases. It could be the case that this is due to a behavioural change where individuals engage in more risky behaviour which might be directly related to risk preferences. However, we do not want to over-interpret the 5% significance level.

For more evidence on such a change in behaviour due to risk-benefit trade-offs of individuals after vaccination, see Hoffmann et al. (2020) who document ex-ante moral hazard under vaccination and warn against the potential side-effects from what is also known as the Peltzman effect. Hoffmann et al. (2020) run a field experiment in a company-setting to investigate the causes and consequences of flu vaccination in Ecuador. The authors find evidence consistent with the notion that individuals may engage in risk-related

trade-off decisions. They find that employees who are more likely to get assigned a vaccination appointment during working hours, are also less likely to visit the doctor for non-flu related respiratory diseases, in a month when the government warns the whole population to see a doctor for any kind of symptoms they feel. This behavioural test implies that employees who are vaccinated feel protected against the flu, and they are forgoing doctoral visits for other diseases that they will have with the same likelihood as employees who did not get vaccinated.

To conclude, there is still a lot of room left to study vaccination choice under uncertainty in a causal manner using quasi-experimental, experimental but also structural methods that connect theory with empirical data. Ambiguity as well as moral hazard are just two promising research areas that have the potential to generate novel and promising research and innovative policy responses.

Table 2 Causal literature on verifiable vaccination coverage and risk preferences

Reference	Country	Mechanism	Method	Effect on Vaccination Demand
Gibson et al. (2017)	Kenya	Moral Hazard	RCT	Risk ratios for individuals with SMS-reminders and 200 Kenyan shillings incentives to vaccinate is slightly increased in comparison to the control group. Mechanism: (My Suggestion) Moral Hazard
Nuscheler and Roeder (2016)	Germany	Risk-Aversion	Observational, Theory-driven	- For women: risk preferences do not have a significant impact on vaccination decisions. - For men: An increase in risk aversion is significantly positively associated with the demand for vaccination.
Schaller et al. (2019)	US	Psychic costs, Fear	DiD	Pertussis outbreaks increase pertussis, influenza, and polio immunizations Mechanisms: Fear of the disease

5 Choices over time

The study of choices over time is relevant in all domains where individuals make choices to engage in a certain action either now, or later. This applies to the broad domain of health and specifically for vaccination choices over time.

Initially, economists were focused on a model of exponential discounting with the key parameter δ. When deciding on the benefits versus the costs, over the present and the future, individuals will use δ to discount the future more than the present and they will discount benefits and costs that are even further in the future by even more. Individuals might have different discount factors. When deciding on the benefits versus the costs over the present and the future, individuals will use δ to discount the future more than the present and they will discount benefits and costs that are even further in the future by even more. Individuals might have different discount factors. Those with a high discount factor δ, are more patient than those with a low discount factor. Hence, in the context of vaccination, the costs are in the present, when vaccination should be done, but the rewards are all in the future. Hence, one might expect that an individual with a higher discount factor is more likely to vaccinate immediately, than an individual with a low discount factor, who discounts the future rewards of not getting sick by a lot.

As discussed, the discount factor remains a key parameter for economists when considering vaccination choices over time. However, exponential discounting makes one strong assumption. Imagine you are standing in period t and you evaluate based on your discount factor that it is beneficial to get vaccinated in period t+2. When period t+2 arrives, you will not have changed your evaluation, but it will still be the best action to get vaccinated, and as a rational agent you are going to do so. The agent will make time-consistent vaccination choices when exponential discounting is assumed. However, in reality it is often observed that individuals plan to get vaccinated in the future, but when the time comes, they are not going to do it. This type of irrational time-inconsistent vaccination behaviour cannot be explained with a model of exponential discounting.

Therefore, behavioural economists, have introduced a model that explains time-inconsistent behaviour through hyperbolic discounting. The most commonly used form to model time-inconsistent behaviour is quasi-hyperbolic discounting (Laibson, 1997) where a parameter β is introduced additionally to δ. This parameter β defines present-biasedness and it will lead to irrational behaviour over time. An individual that made a choice to vaccinate in the future, can plausibly deviate from vaccinating since he is present-biased. When the future comes, the present costs of vaccination are higher than anticipated in the past, and the agent will procrastinate and not engage in vaccination. This type of procrastination might continue and the individual might never get vaccinated even though he evaluates the action to be ex ante beneficial.

The present-biasedness β can be differentiated into two types: those that never recognize their own procrastination behaviour – naïve individuals – and those that do recognize their time-inconsistent choices – sophisticated individuals (O'Donoghue and Rabin, 1999). While the naïve individual can make a choice in the future to get vaccinated, she will always delay getting vaccinated and never notice that there is a violation of intentions and actions. On the other hand, a sophisticated individual recognizes the gap, knowing she will engage in time-inconsistent behaviour. This sophistication allows her to use a commitment device to bind her future self to engage in the desirable action to vaccinate. While the factor β is commonly defined between zero and one, Nuscheler and Roeder (2016) point to an interesting alternative in the context of vaccination: β could be above one which implies that an individual is future-biased. It implies that a person who intended not to get vaccinated, might choose to get vaccinated. Another issue related to time as a determinant for vaccination intention-behaviour gap, is imperfect memory. Individuals might simply forget to get vaccinated. They might also lie asymmetrically, i.e. they could be more likely to lie when they intent to vaccinate but less likely when they intent to not vaccinate. Finally, they might not have formed a plan that they perceive as binding enough to follow through.

5.1 Choices over Time: Methodology

After restricting the articles to time preferences, we identify 7 out of 209 (3%) papers that investigate the issue of vaccination choices over time as their main study goal. We classify 3 out of 7 (43%) papers as more suggestive evidence of vaccination choices over time that are either theoretical, or correlational papers and/or use vaccination intention and not actual vaccination behaviour. 1 out of 3 (33%) of those papers are conducted in North America, and the other 2 out of 3 (67%) are applicable world-wide. Of the world-wide papers, one paper is a literature review and the other is a theory paper.

In a second step, we restrict the review to more causal studies. Those studies include randomized control trials or observational data with an identification of time preferences parameters and with measures of actual vaccination coverage beyond vaccination intention. We focus on 4 out of the 7 (57%) articles. The studies are widely geographically dispersed: 2 out of 4 (50%) of the studies have been conducted in North America, 1 out of 4 (25%) in Asia, and 1 out of 4 (25%) in Europe.

5.2 Choices over Time: Suggestive Evidence

We identified three papers that are focusing on vaccination choices over time. Reluga and Galvani (2016) use a combination of mechanistic population-scale models, Markov decision process theory and game theory to provide a model with individuals that are discounting in a hyperbolic manner to align epidemiological models of aggregate macro behaviour of populations and the interests of the community, with individual micro behaviour and self-serving interests in immunization.

While in the past high disease incidence aligned the interest of the community with selfish interests (due to a high propensity of sickness and high sickness costs, including mortality), nowadays low disease incidence reduces the perception of a need to get vaccinated (complacency). Despite the change in individual interests, the community interests are still the same, i.e. to get as many people vaccinated as possible to provide herd immunity. The authors find that the more individuals are impatient, the lower the costs of infection become, reducing vaccination decisions.

Story et al. (2014) reviews the literature investigating whether intertemporal discounting can explain unhealthy behaviour. They find that high monetary discount rates, and sometimes food and drug rewards are associated with unhealthy behaviours such as substance abuse and vaccination hesitancy. They point to a study by Chapman and Coups (1999) who shows that 85 percent of employees in the study were future-oriented and did not significantly discount the flu illness.

Monetary time-preferences mattered: 45 percent of those who did not discount the future relative to the present, got vaccinated at the workplace health centre, while only 29 percent of those who discounted the future monetary losses got vaccinated. However, health discount rates of flu-like illness did not predict health behaviour. It appears that the general monetary measure might be a better predictor for health than the domain-specific measure.

Jarmolowicz et al. (2018) uses multiple versions of a hyperbolic discounting model to evaluate hypothetical scenarios varying benefits and side-effects of vaccines using Amazon MTurk participants. The authors examined hypothetical vaccination decisions based on a weighing of the potential side effects to one's child across different likelihoods of preventing disease for both one's child and individuals, at various social distances.

The models performed well in explaining the results that subjects accept higher probabilities of potential side effects when the effectiveness of the vaccine increases, the benefiting individual is socially close and the side-effects are not as severe. The authors also find that discounting rates were higher under moderate to severe side effects in contrast to mild side effects. While discounting in their environment is used not only to model delay to a reward with present biasedness, it also includes the odds that a reward might occur or the social distance of the person receiving a reward. Therefore, Jarmolowicz et al. (2018) provide a helpful example of the flexibility that discounting models provide and the possibilities to expand those models to other areas.

5.3 Choices over Time: Causal Evidence

Currently, even the most rigorous evidence on the relationship between vaccination choices over time and time preferences is sparse, and, hence, it is difficult to draw robust conclusions from a set of four papers. However, those four papers are very revealing.

Bronchetti et al. (2015) conducted a large-scale natural field experiment at six colleges with a sample size of 9,358 students. Individuals were not informed that they were in a study, to minimize Hawthorne effects. The authors track whether subjects open emails about the flu vaccines, how long they read an e-mail, and they elicit intentions to get vaccinated. The records are matched with data from health centres about actual flu vaccination take-up for each individual. Students were able to get the vaccine from October to December prior to the peak of the flu season mainly via walk-in or prior appointments.

56 percent of the students who read the email stated that they intend to get vaccinated. Of those 56%, only 27% follow through. This implies that there is a large potential for forgetfulness, memory issues or present-

biasedness to be the driving force of low coverage. An alternative explanation the authors gave is that individuals could be lying about their intentions to get vaccinated but could be truthful when they do not want to get vaccinated. However, Bronchetti et al. (2015) argue that this is unlikely since follow-through is observed by the health centre, and, hence social desirability should actually reinforce vaccinations for students who intend to get vaccinated. Interestingly, out of the ones who did not intend to get vaccinated, 99.6 percent did not show up to the clinics. However, inaction might be easier than action, i.e. defaults matter, and therefore this might not be a surprise. It is interesting though, that 44 percent of the vaccination abstention does not seem to be driven by a failure to optimize over time.

Milkman et al. (2018) is a classic paper, where the authors leverage a field experiment to successfully form implementation intentions for influenza vaccination behaviour when the monetary costs of the vaccine is zero. The authors do not cover hyperbolic discounting, but they do suggest how to tighten the link of vaccination coverage and vaccination intention by improving planning. They targeted an older population of 3,272 employees within a large US firm that were either above the age of 50 or reported chronic health conditions to be more at risk for influenza.

Those employees randomly received one of three mailers. The control group received information about the dates and times to be able to get vaccinated at the company clinic locations. In one treatment group individuals were prompted additionally to write down the date they intended to get vaccinated. In a second treatment group, individuals were prompted to not only write down the date but also the time they planned to get vaccinated. Milkman et al. (2018) find a baseline level to get vaccinated of 33.1%. Just writing down the date to get vaccinated resulted in a statistical insignificant coverage rate increase of 1.5 percentage points. However, a more specific prompt of date and time, resulted in a significant 4.2 percentage point increase with respect to the baseline.

Interestingly the authors find that some of the workplace vaccinations coverage through the inexpensive nudge displaced vaccination coverage that would have happened elsewhere. 0.4 (0.5) out of 1.5 (4.2) percentage points from the date (date-time) treatment, i.e. 25 (12) percent of the treatment effect, are displacing vaccinations that would have happened anyways outside of the company. An avenue that is interesting is to further tighten the connection between vaccination intentions and behaviour. The authors do not seem to have measured vaccination intention, but purely used the reduced form of intention prompts with the assumption that the intention prompts work through intentions and affect behaviour. A possible mechanism could be that social desirability or social status concerns at the company when making a commitment, might drive the follow through after stating explicitly the time and date. In either event, the study provides a novel addition on how to improve coverage over time.

Nuscheler and Roeder (2016) combine the classical model of quasi-hyperbolic discounting from Laibson (1997) with the dual theory from Yaari (1987). They were able to add their own questions on influenza immunization and financial trade-offs to an annual German survey on health, health care, and health behaviours.

To elicit time preferences, they ask the two following questions: a) “Suppose you can choose between receiving 500 Euros today or some other amount in 1 year from now. What is the smallest amount you must be given in 1 year for which you would prefer to wait 1 year rather than receiving 500 Euros today?”, b) “Suppose you can choose between 500 Euros in 10 years or some other amount in 11 years from now. What is the smallest amount you must be given in 11 years for which you would prefer to wait 11 years rather than receiving 500 Euros in 10 years?”

The authors calculate the discount factor δ by dividing 500 by the amount requested in 11 years for the second question and they calculated present biasedness β by dividing the amount requested in 11 years by the amount requested in 1 year. The authors find that time preferences do not matter for vaccination choices of women at all. For males, present-biased individuals reported similar flu vaccination behaviour as exponential discounters. However, future-biased males were more likely to report to be vaccinated than exponential discounters.

From the Nuscheler and Roeder (2016) paper it would be interesting to move beyond subjective measures which may contain socially desirable responses which could lead to measurement error and potentially bias the estimates. The authors find that more future oriented individuals, i.e. those with a relatively high discount factor δ, have a lower vaccination rate and this is driven by males. One may speculate that this could be due to measurement error. Therefore, we suggest for future research to compare how the results might change when time preferences are not elicited in a hypothetical manner but in an incentivized manner, to encourage

truthful reporting. Similarly, administrative information on the flu shot would be a useful future avenue to reduce the socially desirable reports of flu shots.

Alternatively, future orientation might be an interesting phenomenon to study since Chapman and Coups (1999) also found evidence of future-orientation for influenza vaccinations and Story et al. (2014) report about this phenomenon that can be observed in a significant proportion of individuals in health interventions generally.

Andreoni et al. (2018) pay healthcare professionals for completing a certain number of vaccinations over two days so that they reach a vaccination target. If they fail to reach their vaccination amount on either one of those two days, the incentive will not be paid. The authors ask a random set of workers in advance how many individuals they want to vaccinate on day 1 and day 2 and another random set was able to state their target at day 1. They document that vaccinators are present-biased, i.e. even though the healthcare professionals stated they want to vaccinate a certain number of individuals on day 1, they actual vaccination numbers were lower. Andreoni et al. (2018) successfully design an optimal interest rate to offset the individual discount rate to smooth coverage across the two days.

Their paper is different from the other papers in so far as they focus on health care professionals and they are configuration incentives to overcome present biasedness using an experiment in conjunction with a structural approach. They leverage a novel approach of convex time budgets by Andreoni and Sprenger (2012) to elicit preferences over uncertain choices and preferences over time simultaneously which allows them to obtain preference estimates which are in line with theoretical expectations. Due to its overlap with health care worker interventions, the study will be discussed in more detail in section 7.

We conclude that time preferences in the domain of vaccination are highly understudied. There is a lot of room to connect vaccination intentions stronger with vaccination behaviour over time. Leveraging incentives via contracts, as done by Andreoni et al. (2018), is also a possibility how to increase coverage from the supply-side. Alternative demand-side interventions are possible. Further, studying the exact causes of the differences between intention and vaccination rates, while accounting for social desirability, might lead to new and exciting ways to improve coverage.

Table 3 Causal literature on verifiable vaccination coverage and time preferences

Reference	Country	Mechanism	Method	Effect on Vaccination Demand
Andreoni et al. (2018)	Pakistan		RCT, Structural	Targeting vaccination contracts to individual discounting increases health professionals' efforts to increase vaccination coverage.
Bronchetti et al. (2015)	United States	Hyperbolic Discounting, Inattention, Forgetfulness, frequent updating of beliefs, unstable preferences	RCT	Only 27 percent of students who intent to vaccinate follow through on vaccination. Mechanism: This might be due to present biasedness
Milkman et al. (2018)	United States	Lack of a concrete plan, hyperbolic Discounting	RCT	Planning the vaccination by writing down the date and time improves vaccination coverage by 4.2%
Nuscheler and Roeder (2016)	Germany	Hyperbolic Discounting	Observational, Theory-driven	- For women: time preferences do not have a significant impact on vaccination decisions. - For men: while present-biased individuals behave like exponential discounters, future-biased men vaccinate with a significantly higher probability than exponential discounters.

6 Peer effects

Despite considerable efforts to reduce the costs of vaccination and increase accessibility and the supply of vaccines, we are struggling to reach recommended levels of coverage for numerous vaccines around the world. Herd immunity is crucial to curb the spread of a disease which reduces mortality among high risk groups, such as children, the elderly and immune-compromised individuals. Since supply-side factors cannot by themselves explain low vaccination rates, we focus on the demand side. We are particularly interested in peer effects on the demand side of vaccination, i.e. how does the vaccination behaviour of others affect the individual vaccination behaviour? The imitation of the behaviour of others is such a common phenomenon that the discipline of network theory was founded to study phenomena such as information spread, virus spread and clustering of groups, among others. A group that has been observed in clusters, are vaccine hesitant individuals. The declaration of the World Health Organization that name vaccine-hesitant individuals as a global health threat (WHO, 2019) emphasizes the urgency to understand peer effects.

A common problem in networks is that its members select each other on the basis of similar beliefs. For example individuals with similar beliefs over the benefits of vaccination will interact more closely with each other than those with dissimilar beliefs. This phenomenon is called homophily. In contrast, behaviour of others travels across a network and is called contagion. A highly interconnected individual has the potential to spread unsubstantiated information or beliefs about vaccines which leads to a social contagion of vaccination beliefs and, lower vaccination responses, and, it can lead to disease outbreaks through a disease contagion. Homophily in addition to contagion can facilitate or hinder the spread of positive behaviour in a network (Golub and Jackson 2010; Jackson and Lopez-Pintado 2013). Therefore, it is important to disentangle homophily from contagion, or effect from cause which has been done only in a very limited manner in the vaccination literature (Brewer et al. 2017). We are interested in the causal non-endogenous behavioural economics literature that moves beyond correlations but due to the limited number of publications at the intersection of behavioural economics, vaccination demand and peer effects, we include any interesting reference that has a behavioural flair.

We review the literature of peer effects in the context of vaccination, i.e. we ask what the impact of peers on the own propensity to get vaccinated. We broadly interpret peers, as any set of agents that surrounds another individual and that have the chance to influence the decision-making process. Among them are household members, friends, and colleagues from work, healthcare providers and other members of a social network. There are theoretical arguments that peers impact the own propensity to vaccinate either positively, negatively or not at all. On the one hand, a neoclassical economic perspective is that vaccination is a public good, where the more others are vaccinated, the smaller is the individual incentive to get vaccinated. This reduces vaccination coverage leading in the worst case down to a zero take-up equilibrium.

On the other hand, behavioural factors such as social norms have been recently recognized as a reason why individual vaccination coverage can increase when peers' coverage increases. Social norms are informal collective agreements governing the behaviour of society and aggregate expressions of what is deemed socially acceptable in individual and group conduct. Vaccinations are generally perceived to be beneficial, and vocal subsets of the population, such as healthcare professionals, researchers and activists, recognize the benefits of vaccination and they promote them through various channels, such as the media and in universities. Social norms are commonly split into descriptive and injunctive norms: descriptive norms describe observable behaviour, while injunctive norms describe what other individuals ought to do. While descriptive social norms are implicitly or explicitly used to explain vaccination coverage, fewer inroads have been made at the intersection of injunctive norms and vaccination demand.

Given the two opposing forces we identified, i.e. free-riding and social norms, it is ex ante unclear whether vaccination coverage increases or decreases with exposure to exogenously vaccinated peers and, therefore, whether we arrive at an equilibrium that is further away or closer to optimal herd immunity levels. Finally, other peer vaccination mechanisms that can change own propensity to obtain coverage are information spillovers, social learning, reduced costs through peer assistance, a preference to coordinate decisions with friends and compositional change, to name a non-exclusive set.

This chapter is organized as follows. In chapter 6.1 we explain the methodology. In section 6.2, we review the suggestive literature of vaccination demand and peer effects and in section 6.3 we emphasize studies with a credible causal methodology. We highlight free-riding as an often-mentioned neoclassical peer mechanism, social norms, as a behavioural phenomenon and finally, some other mechanisms through which peers can impact the decision to vaccinate.

6.1 Peer Effects: Methodology

After a first broad literature review on peer effects and vaccination demand, we identified 62 out of 209 (30%) articles on peer effects on vaccination coverage. 48 out of 62 (77%) are papers that we classify to provide suggestive evidence about peer effects on vaccination demand, i.e. they are either theoretical, or correlational papers and/or use vaccination intention and not actual vaccination behaviour. 10 out of 48 articles (21%) are theory-focused while 38 out of 48 (79%) papers are empirical, employing wide-ranging methodologies such as univariate statistics, correlations, logistic regressions, and factor analysis. While the review is focused on quantitative research, one identified study also uses the qualitative approach. 11 out of 48 (23%) of the studies have been conducted in Europe, 17 out of 48 (35%) in North America, 4 out of 48 (8%) in Asia, and 2 out of 48 (4%) in Africa. The other 15 out of 48 (31%) studies are applicable globally, since they are either other literature reviews or theoretical/simulation papers[5].

For the causal methodology papers, we identified 14 out of 62 (23%) peer effects references using relatively objective vaccination coverage measures which we call verifiable vaccination coverage. I.e. those studies exclude vaccination intentions or self-reported coverage. The studies are globally widely dispersed. 3 out of 14 (21%) studies have been conducted in North America, 4 out 14 (29%) in Latin America, 4 out of 14 (29%) in Africa, 2 out of 14 (14%) in Asia, and 1 out of 14 (7%) in Europe.

6.2 Peer Effects: Suggestive Evidence

We can split the suggestive evidence literature into two categories: theory-based papers, and empirical papers. First, we cover some of the theory papers. Then, we remove the literature reviews from the empirical papers to arrive at 25 out of 48 empirical papers.

The 10 out of 48 papers that are theory papers sometimes additionally contribute to the literature on peer effects via a simulation or model-fitting component. We will highlight a few of those papers here.

Chen and Fu (2019) use a theoretical model including agent-based simulations to show that imitation of peer behaviour might lead to low vaccination coverage when vaccination only confers partial protection due to multiple equilibria below a certain threshold of vaccine effectiveness. Hence, it is important for policymakers to consider the interaction between vaccination effectiveness and peer effects. Similarly, Tassier et al. (2015) finds multiple equilibria when they introduce peer effects in a Nash equilibrium model which is calibrated to explain contacts of hospital workers at a large university hospital. They find evidence for large difference in vaccination rates of hospital worker groups and that peer effects might, depending on the parameters, increase or reduce vaccination rates.

Fu et al. (2017) recognize and model the fact that disease contagion usually does not happen in isolation but jointly with social contagions. Using Harvard College data, they illustrate the feedback loops that biological contagions, i.e. the spread of a disease, can have with social contagions, i.e. the peer effect on vaccination behaviour. Through a model of duelling contagions, their research suggests that the social contagion might be even more important than the biological contagion to reduce the spread a virus.

Oraby et al. (2014) goes a step further and suggests that peer effects are crucial even when the disease prevalence is zero, and hence, biological contagion does not exist anymore. The idea is that eliminating a disease requires high vaccination rates, even after the disease is eradicated or prevalence is close to zero. Using a model of social norms allows the authors to explain pertussis vaccination coverage of the United Kingdom not only during low but also high coverage years over decades. While social norms have the potential to increase coverage, depending on the parameters, they can also suppress vaccination coverage even though outbreaks might be frequent. Therefore, we need to understand the empirical reality well enough of the impacts of peers on the own propensity to vaccinate.

From the suggestive empirical studies on peer effects in Table A3, 3 out of 25 (12%) studies find some evidence that free riding could be a problem that reduces vaccination coverage. Ibuka et al. (2014) used a computerized experimental game to study vaccination choices and interactions by peers in the context of influenza. They found evidence of free riding in the game: a high past vaccination rate of the peers in the game reduced own individual propensity to get vaccinated in the following round. Attari et al. (2014) ran an Mturk online survey with US participants and they find that individuals who deviate from socially optimal

[5] The cumulative percentages are slightly above 100% since one study is cross-continental

behaviour in social dilemma situations such as vaccination, are doing it for selfish reasons. Through social networks and mailing lists, Betsch et al. (2013) recruited German subjects to an online experiment in which individuals randomly received information about herd immunity and about the benefits to themselves to get vaccinated in the treatment group and no information about herd immunity in the control group. Emphasizing individual benefits under herd immunity, reduced the intention to get vaccinated.

The last two studies, i.e. 2 out of 25 (8%) studies also investigated whether prosocial preferences can improve vaccination coverage. Betsch et al. (2013) communicated the social benefits in one treatment arm and found that it reduced free-riding and increased vaccination intention under low vaccination costs. Therefore, one could cautiously hypothesize that positive peer effects might outweigh negative effects from peers if individuals have stronger social preferences. Attari et al. (2014) find in their Mturk experiment that cooperation in a vaccination social dilemma situation is positively correlated with altruism and reciprocity. Co-operators are more likely to have punitive attitudes towards free riders. This reinforces the ideas that social norms could have a significant impact on the individual propensity to get vaccinated.

Indeed, many studies, i.e. 10 out of 25 (40%) papers, found positive correlations from social norms with the intention to get vaccinated or self-reported vaccination measures. An additional 7 out of 25 (28%) articles found positive peer correlations on the own propensity to vaccinate without investigating the specific channel. It means that the majority of the correlative articles, i.e. 17 out of 25 (68%) find some support for the idea that peers might have a positive impact on the individual vaccination decision and mainly reject the idea of free-riding behaviour.

The association of peers and own vaccination is additionally reinforced by 1 out of 25 (8%) studies that leverage peer messaging as a tool to increase vaccination coverage. Hopfer (2012) finds that using a combination of a medical expert together with a peer to appeal to women for HPV vaccinations through a video almost doubled self-reported vaccinations two months after the intervention. On the other hand, a study using confederates as peers, i.e. parents versus a spokesperson from a government health organization, did not lead to marked differences in vaccination intention (Langley et al. 2015). One might hypothesize that the treatments were too weak or that both messages worked but that a control treatment with no identity might have highlighted potential positive correlations.

Since peer effects do not operate only through peer pressure to vaccinate but also through disease incidence, we highlight a study by Curtis et al. (2013) who showed that the network of healthcare professionals matters and that the disease spreads more rapidly in contact networks as compared to random networks of similar size and density. They recommend that targeted vaccination of mobile healthcare professionals, i.e. a subset of the network, would effectively alleviate disease spread.

Finally, peers might not only impact the decision to vaccinate but they might have impacts after the vaccination. 2 out of 25 (8%) studies have shown that having more friends and being less lonely increases the amount of antibodies that are formed once the individual gets vaccinated, or that stress, depression, loneliness, and poor health behaviours can impair the immune system's response to vaccines, and this effect may be greatest in vulnerable groups such as the elderly. All those studies taken together highlight that peers are not only relevant for disease spread, for vaccination take-up but even for biological responses to immunization.

6.3 Peer Effects Causal Evidence

The most common neoclassical economic prediction of theoretical models of the voluntary provision of public goods is that individual's free ride on the contributions of others (Warren 1983, Bergstrom et al. 1986). Since vaccination is considered to be non-exclusive and non-rivalrous (Ibuka et al. 2018), it is generally treated as a public good. When there are either monetary or non-monetary costs (e.g. opportunity costs, travel costs) to get vaccinated, individuals have an incentive to not get coverage when others around them increase their coverage. They avoid the costs of consuming the good while receiving the benefit from society through herd immunity. In the field of epidemiology, this problem is also known as the theory of the prevalence elasticity which hypothesizes that agents are responsive to the marginal change in individuals that become sick from a disease (Staben 2016). While free-riding is individually optimal, it is not Pareto-optimal and can lead to a Nash equilibrium with low coverage where the externality benefits arising from others are the driver for the low take-up, but they are never realized if everyone acts strategically.

While free riding may take place theoretically and seems to show up in online experiments where vaccination intentions are measured (e.g. see Betsch et al. 2013), we cannot find large support in field environments where researchers observe actual vaccination coverage decisions. Of course, any null results or even any

positive peer effect, can still be attenuated by free riding. However, there are only three papers in our literature review with null findings – with explanations beyond free-riding – and the positive peer findings at a minimum suggests that any free-riding behaviour in equilibrium is outweighed by mechanisms that increase the individual propensity to get vaccinated when others get vaccinated exogenously.

Ibuka et al. (2018) label the behaviour of free riding, which is the main explanation for negative peer effects, as non-conforming behaviour. In contrast, conforming peer pressure can be observed when individuals are surrounded by others who exert strong pressure to vaccinate or not to vaccinate. This will lead to positive peer effects. While free riding on the vaccination is often hypothesized as a peer effects mechanism, it has not been confirmed to matter that much in the limited amount of credible causal studies available. Empirically, increased peer vaccination coverage does not reduce individual vaccination coverage, but it often increases it (see e.g. Hoffmann et al. 2020, Rao et al., 2007 and Sato and Takasaki, 2019b).

For example, Hoffmann et al. (2020) randomly assign employees in a company to the workweek or the weekend to receive vaccinations during an influenza vaccination campaign. Individuals assigned to the weekend have higher opportunity costs since a vaccination campaign provider would vaccinate employees at the company location and employees would have to alter their plans and incur transportation costs to take up the vaccinations. This exogenous variation in coverage for the individual resulted also in random variation within each work-unit where geographically close peers work on similar tasks. The authors find that an increase in the probability of vaccination from the work unit peers does not decrease but substantially increases own propensity to get vaccinated in the company.

In a simple form, conforming peer effects can be modelled with one parameter in the utility function that measures the preference to conform to others that are vaccinated or not-vaccinated (Bodine-Baron et al. 2013). In other domains, such as worker productivity, similar parametrizations have been used (see Falck and Ichino 2006) to model conforming behaviour. Ibuka et al. (2018) explores economic models of vaccination coverage with peer effects and find that Stackelberg sequential contribution models do not improve upon the simultaneous standard voluntary public goods model, but that it might even exacerbate free riding. The authors provide predictions for positive peer effects that are in line with their causal estimates from Japanese neighbourhoods, by employing a joint production model of the public good health through vaccination. Alternatively, the authors argue that the standard summation technology is not in line with how vaccination provides a public good. Therefore, they introduce a weakest-link model, where spillover from peers are generated non-linearly when the person with the lowest contribution to the public good is getting vaccinated.

There are numerous mechanisms for positive peer effects on the own propensity to get vaccinated. A prominent explanation from psychology is that descriptive or injunctive social norms of peers can increase vaccination coverage. The descriptive norm is the observable behaviour of peers that an individual will use to deduce what is a correct action. On the other hand, injunctive norms are expectations of peers of what ought to be. While the literature on vaccination mainly focused on the former, less attention has been given to the injunctive norm.

Alternatively, the bandwagon effect is another label for positive peer effects. This metaphorical terminology is closely tied to social norms and peer pressure. Explanations that induce the bandwagon effects are group-think, a desire to be right, and a need to be included.

Warm-glow, i.e. altruism might also drive positive vaccination coverage. Mussio et al. (2018) find a positive impact from using posters highlighting the social benefits to advertise a vaccination campaign at a university in the United States. On the other hand, Hoffmann et al. (2020) do not find an impact from e-mail messages to employees at an Ecuadorian firm when providing information about the social benefits. Differences in the literature might arise due to different samples, different messages, or different populations. Therefore, more research on the effectiveness of different messaging, using random assignment is important to understand the target groups and the reasons why those nudges might or might not work in the domain of vaccination.

Other mechanisms that might explain why peers have a positive or negative impact on own vaccination rate, are through social status and prestige concerns, signalling the quality of the public good, information spillover through communication, through learning from peers or through assistance from peers. One may imagine that peers learn from other peers about the benefits and costs of vaccination through communication. They might also learn the benefits of vaccination from an observable event, such as the death of an unvaccinated peer. Finally, peers, especially in the same household, might provide reminders to get vaccinated or schedule appointments for other household members, such as spouses and children, which

will lower the costs of vaccination. While credible causal papers on vaccination coverage and its mechanisms are rare, there are even fewer papers that have convincingly explored the other mechanisms.

Table 4 shows the 14 causal studies on peer effects that are included in this literature review. One study is included that improves the quality of physicians which is likely to have indirectly impacted vaccination coverage by randomly assigning physicians to be monitored by their peers (Brock et al. 2012). For comparability, we exclude this study from our descriptive statistics for causal evidence on vaccination demand.

Most of the studies, i.e. 10 out of 13 (77%), find positive spillover from peer vaccination on own propensity to get vaccinated. The remaining three articles find no spillover effect. In part, it can be suspected that this is due to weak ties and measurement at an aggregate level for those studies. Only Bouckaert et al. (2019) reports a negative spillover from the elderly parents to the children which they suspect is not driven by strategic consideration (free-riding) but by the perception that informing the elderly about an immunization campaign transmits information to the children that they are not eligible for the campaign, and hence, do not need to vaccinate.

Investigating the causal impact of peer effects on vaccination demand is a highly understudied research area. It is essential to be able to split any selection from the true effect, i.e. homophily from contagion, and only few studies convincingly succeed in this endeavour. In this literature review, we can observe that field studies which causally investigate the impact of peers on the demand of vaccination by a large majority provide evidence against free-riding on the benefit of herd immunity and in favour of conformity behaviour when peers are vaccinated. The explanation of social norms is often invoked in those studies; however, the mechanisms are highly understudied.

The field is ripe to further our understanding of peer effects on our own propensity to vaccinate. Peers such as healthcare professionals, parents, children, co-workers and many more can substantially alter the way we perceive the benefits of vaccination. For this purpose, we need to overcome selection biases and general endogeneity concerns. However, not only pure causal inference approaches are needed.

Combining theoretical models with randomized control trials or quasi-experimental approaches jointly with structural estimation, can provide unique valuable insights and push the field forward. The study by Karing (2018) is a great example of how to contribute to the literature, how to move the field forward through multiple methods allowing us to move beyond the direction of the peer estimate towards mechanisms. The author introduces bracelets to signal vaccination coverage of children which was introduced by the healthcare professionals and she structurally quantifies the value of social signalling after introducing experimental bracelet treatments in the field. She finds that parents' valuation of signalling is equivalent to 7 to 10 miles of a walking distance to the clinic in Sierra Leone.

Table 4 Causal literature on verifiable vaccination coverage and peer effects

Reference	Country	Mechanism	Method	Effect on Vaccination Demand
Barham and Maluccio (2009)	Nicaragua	Information Provider-Spillover	DiD	No peer effects from vaccination
Bouckaert (2014)	Mexico	Mutual Institutions	IV	No peer effects from vaccination Mechanism (Suggested by Me): - Program did not increase vaccination coverage for the treated individuals
Bouckaert et al. (2019)	Netherlands	Information about Benefits and Information about not being in the Program	RDD	1 A partner becomes 10 pp more likely to get vaccinated if their partners get vaccinated. 2 However, there are negative peer effects from parents on children Mechanism: 1 Information about Benefits 2 Information about not being in the Program
Brock et al. (2012)	Tanzania	Monitoring	Fixed Effects	Peer observability does (not) increase questions from physicians about vaccination history by 27 pp. (patient's child vaccination). Mechanism: - Hawthorne effect - Reduction of moral hazard problem (my suggestion)
Bronchetti et al. (2015)	US	Information	RCT	Peer endorsement does not affect vaccination coverage Mechanism (Suggested by Me): - scripted peer messaging from an institution is close to advertisement and quite unnatural and not perceived as a true peer endorsement
Hoffmann et al. (2020)	Ecuador	Social Norms	RCT	A worker becomes 7.9 pp more likely to get vaccinated if an additional 10 percent of her peers get vaccinated. Mechanism: Increasing the proportion of work peers who are vaccinated exogenously by 10% increases the own propensity to get vaccinated by 7.9 pp. Positive impacts from social norms measured via same-gender effects of vaccination. If free riding exists, then it is outweighed by social norms adjustments.
Ibuka et al. (2018)	Japan	Unclear Social Norms, Social Status Desire, Avoiding Social Stigma, Gaining Social	RDD	Increasing the proportion of people in the neighbourhood by 10 pp. increases the own propensity to get vaccinated by 1-4 pp (admin data). Adding one more household member to the household, increases the own propensity to get vaccinated by 4-9 pp (admin data).

		Prestige, Bandwagon Effect		Having one more 65+ year old person in the HH, increases the own propensity to get vaccinated by 7.6 pp (survey). Mechanisms: - Social Norms are consistent with the models presented.
Janssens (2011)	India	Unclear	IV	Positive peer effects from vaccination for different vaccines (Polio, TB, Measles, DTP) Mechanism (Suggested by Me): - Information of Best Practices, since this is a training program for female empowerment
Jones (2009)	Senegal	Unclear Economic of scale Social learning	Fixed Effects	Children which are closer together in age are 2-3 pp. more likely to be immunized for each non-sibling age-mate than children who are further away in age. Mechanism: - Economies of scale - (As to the researchers one admission, two assumptions need to hold which she argues does, but which actually might not)
Karing (2018)	Sierra Leone	Social signalling, Social learning, salience, Consumption utility	RCT	Peer vaccination has a positive impact on individual vaccination. Mechanism: Peer vaccination has a stronger positive effect when the benefits of the vaccine are stronger
Lawler (2018)	US	Unclear		Suggestive evidence of behavioural peer effects from vaccination (based on mandatory vaccinations for young children) of 1.3-2.3 pp. on older children and 1.1-1.2 pp. on adults [FN 77] Mechanism: - Unclear but could also be due direct awareness due to the policy
Rao et al. (2007)	US	Social learning Other Suggested: Peer Pressure Companionship (Preference for coordination)	RCT	A student becomes up to 8.3 pp. more likely to get immunized if an additional 10 percent of her friends get vaccinated. Mechanism: We find that a 10 percent rise in the share of friends in residences with clinics raises overall valuations of the vaccine by $10.92 among students with no recent flu experience, where 85 percent of this increase can be attributed to social learning about medical benefits. […] while learning from peers may be the main social determinant of vaccination decisions, other social interactions like peer pressure and companionship appear to influence locational choices.

Sato and Takasaki (2019b)	Nigeria	Unclear Suggested: Psychologic and Financial Costs, Information	RCT	Having a friend who gets vaccinated increases the likelihood that a woman receives a vaccination by 14.4-19.1 pp. Mechanism: Authors state that they cannot identify mechanisms.
Teixeira et al. (2011)	Paraguay	Unclear	DiD	No peer effects from vaccination Mechanism (Suggested by Me): - Network links across treatment and control villages might have not been large enough - Alternatively, positive and negative mechanisms cancel each other out (i.e. free-riding and social norms are equally strong opposing forces)

7 Healthcare professionals

Healthcare professionals are one of the most important supply-side factors. Among them are physicians, nurses, aides, helpers, laboratory technicians and other health-related professionals. They are often interacting with patients and provide vaccinations or are recommending them. Healthcare professionals are at the frontlines of health crisis, such as the COVID-19 pandemic. Therefore, trust in those professionals is essential. However, those professionals can be prone to behavioural biases which researchers can try to address through interventions.

There are several ways in which healthcare professionals can influence the vaccination coverage behaviour of the population. One factor with a large potential impact is the vaccination coverage of the healthcare professionals. Vaccination coverage of those professionals does not only reduce their own likelihood of getting sick, but it also has the potential to result in herd immunity at places where diseases are common and could easily spread, i.e. in hospitals and physicians' practices. Therefore, healthcare worker vaccination has the side-effect of not only providing protections to other healthcare professionals but also to patients. Healthcare professionals' vaccination would essentially reduce nosocomial infections, i.e. infections transmitted when going to the hospital. Beyond the disease effects, we expect behavioural contagion effects in line with the literature on peer effects from vaccination. Healthcare professionals might transmit information about the benefits of vaccination most credibly when they are vaccinated themselves. They are role models for the population and their behaviour might get imitated by everyone else.

Despite those triple benefits, influenza vaccination coverage of healthcare professionals in the European Union is spectacularly low, ranging from 6 to 54% (Kassianos, 2015). Outside of Europe, vaccination coverage of healthcare professionals also varies dramatically, with the United States exhibiting coverage around 81% during the influenza season of 2018-2019 (CDC, 2020) and Chinese vaccination coverage at around 11.6% during the same year (Liu et al., 2020). While there are some improvements over time, environments with high-risk groups such as the ones healthcare professionals are exposed to, should be close to effective threshold herd immunity recommendation levels for high-risk groups, which are around 90% (Plans-Rubió, 2012).

Beyond peer effects from healthcare professionals, a subset of them, including general physicians, have the authority and task to provide vaccination recommendations. Their trust in physicians is generally perceived to be highly important. However, trust in vaccination has not been shown to correlate with vaccination uptake from the general population (Brewer et al., 2018). How the message is transferred might be highly important. Are physicians themselves confident in the benefits of the vaccines or are they vaccine-hesitant? If they are vaccine-hesitant, they might provide fewer recommendations to get vaccinated for some or all vaccines. Especially the sub-group of homoeopathic health practitioner is known to belong to the vaccine-hesitant group which can depress take-up.

From an economist's viewpoint, the most natural way to increase coverage for the population is to adjust the incentives. For example, in Germany physicians are getting reimbursed when they vaccinate their patients. If one investigates incentives, one has to decide whether one views a physician as purely profit-maximizing, purely altruistic – in the sense that she cares for her patients – or a mixture of both. Due to the Hippocratic Oath, one might be inclined to think that doctors are acting more altruistic than the general population. However, in more capitalistic societies, one could be inclined to model physicians closer to profit-maximizers. Maurer (2009) argues in favour of a model of pure altruism in the context of vaccination. In his research, evidence is collected to support the idea of the importance of physician agency in vaccination take-up, highlighting the important role of family physicians for the delivery of responsive health care: policy interventions aimed at improving the quality of physicians' agency is a key initiative to support information campaigns.

7.1 Healthcare Professionals: Methodology

We identified 24 out of 209 (13%) scientific articles that are studying healthcare professionals in the context of vaccinations. Overall, 3 out of 24 (11%) studies focused on Asia, 4 out of 24 (15%) on North America, 2 out of 24 (7%) on Africa, and 2 out of 24 (11%) are literature reviews with world-wide applicability. The

other 16 out of 24 (73%) studies on healthcare professionals are from Europe representing 16 regions from Germany and the Netherlands, to France, Italy and Romania, among others[6].

The majority of those studies are providing suggestive evidence on how healthcare professionals can be leveraged to increase vaccination coverage. 20 out of 24 (77%) studies are classified as suggestive studies. A vast majority of those studies, i.e. 12 out of 20 (57%) employ regression analyses. 4 out of 20 (19%) are presenting descriptive statistics such as averages and correlations, 3 out 21 (14%) are literature reviews. 2 out of 20 (10%) papers use structural modelling methods.

From the overall identified healthcare worker literature, 4 out of 24 (23%) of the studies provide some more causal evidence which leaves significant space to improve upon more credible causal evidence by employing field experiments and quasi-experimental methods. The studies cover difference-in-difference and randomized control trials, including trials with structural estimation methods.

7.2 Healthcare Professionals: Suggestive Evidence

This section will summarize the suggestive evidence on healthcare professionals and highlight a few studies. Most of the evidence for healthcare professionals arises from correlation studies.

A notable exception from correlational evidence in this section is Boehm et al. (2016) who uses an online experiment to understand whether prosocial behaviour is relevant for vaccination decisions. However, the authors only obtain vaccination intentions which can be markedly different from actual vaccination decisions. They interpret vaccination as prosocial behaviour due to the benefits of herd immunity while vaccinations are too low for healthcare professionals. The authors implement a large-scale cross-cultural field experiment in South Korea and the United States which are, among others, different in being either more collectivist or individualistic societies. Subjects from both countries were recruited online for a vaccination game with 1/3 of the subjects being assigned to be health care professionals and 2/3 being patients. Only the health care professionals have an option to be vaccinated but their decisions also affect the patients.

The subjects were assigned to treatments with different herd immunity thresholds. Lower thresholds allow individuals to reach the collective optimum faster. Vaccinations are individually costly but if the immunity threshold is reached, the patients benefit beyond and above the costs incurred by the vaccinated health care professionals. Decisions to vaccinate may thus be understood as pro-social.

As the main factor, they investigate the effects of individualistic or collectivistic views of society on vaccination uptake. They find that individuals are more likely to intend to vaccinate in the game when they originate from a collectivist culture. Individuals who understood vaccination as a prosocial act, as measured by a non-incentivized question about the beliefs to protect others when getting vaccinated, were more likely to get vaccinated in the game. They also investigated whether vaccination opt-in matters and found that a policy of opt-out could easily substitute the effects from prosocial preferences. An extension of this study could investigate incentivized prosocial behaviour and the impact on actual vaccination coverage of health care professionals outside of the relatively fast-paced game environment.

Schmitz and Wübker (2011) highlight the importance of physician quality from the supply-side to understand the determinants of influenza vaccination coverage of the elderly Europeans using the Survey of Health, Ageing, and Retirement, also known as SHARE. The researchers create a refined measure of physician quality by obtaining information on the frequency of doctors asking patients about exercising, falling and balance checks as well as drug usage and weighting by observable patient health characteristics. As a robustness check, the researchers also used an alternative indicator of research quality consisting of questions to the patients about the frequency with which a doctor explains results from medical examinations, treatment options, and takes into account the patient's preferences when making treatment decisions. Using an ordinary least squares regression with controls, the authors find that physician's quality is correlated with vaccination coverage and, if interpreted causally, it implies that an increase from the lowest possible physician's quality score to the highest possible score, increases the propensity to get vaccinated against influenza by 6.5-12.3 percentage points.

Curtis et al. (2013) points to the important role that mobile healthcare professionals have in the network of healthcare professionals for vaccination choices. They use electronic medical records from the University of Iowa Hospitals and Clinics, an institution with 700 beds and 8,000 healthcare professionals and they analyse

[6] The percentages do not add up to 100% due to cross-continental studies.

approximately 20 million contact data points over 21 months. They construct and validate 9,000 healthcare worker networks which can be seen as a representation of actual movement patterns and which are very similar to networks in other settings. Curtis et al. (2013) reveal in comparison to random networks, diseases can spread more rapidly in those constructed networks and they recommend that especially mobile healthcare professionals should be targeted by policy-makers.

In our overview, we find in Table A4 that healthcare professionals' perception is likely not based completely on scientific evidence (Le Marechal et al. 2018) and interestingly, specialist physicians might be more likely to be vaccine-hesitant (Kassianos et al. 2018).

2 out of 24 studies find some evidence that prosocial behaviour might matter to increase vaccination coverage among healthcare professionals. According to 3 out of 24 studies, from the healthcare professionals' perspective, knowledge about the efficacy and safety of the vaccines could increase vaccination intention. 4 out of 24 studies report that perception of large side-effects is negatively correlated with vaccination intention of healthcare professionals. For example, Lim et al. (2019) find that healthcare professionals' vaccination intention compliance for influenza increases when the vaccine is perceived as safe and effective. On the other hand, they find that healthcare professionals who believed in common side effects were less likely to be compliant. Furthermore, 4 out 24 studies report that trust is in healthcare professionals or the healthcare system is, in general, an important determinant for vaccination take-up.

Peers of healthcare professionals, that is the society as a whole or their colleagues, might have an impact on healthcare professionals' decisions to recommend vaccinations. 3 out of 24 studies report either that healthcare professionals are recommending fewer vaccinations for controversial vaccines or that societal endorsement and support from colleagues increases vaccination recommendation. This perception is reinforced by 2 out of 24 studies which find that HCP are influencers with a lot of control to improve coverage rates within the population. 3 out of 24 studies also shows that vaccination hesitancy of healthcare professionals is negatively correlated with trust in health authorities, which is a hierarchical peer of the workers.

5 out of 24 studies identify healthcare workers' knowledge, in particular about vaccination safety and efficacy, as a major potential driver to increase vaccination coverage, since an increase in knowledge is positively associated with higher recommendations. Therefore, interventions can target healthcare professionals' information about vaccines. Interestingly, there are 2 out of 24 studies that report that there are differences in vaccine hesitancy based on the vaccines and disease. Genovese et al. (2019) find that vaccine hesitancy among health care professionals was generally low but that relatively high levels were found for polio, hepatitis B, tetanus and diphtheria. This leads to the notion that knowledge and information of vaccine safety and efficacy could be improved in a targeted manner.

7.3 Healthcare Professionals: Causal Evidence

Healthcare professionals are a centrepiece of a solid healthcare system that allows vaccination coverage to happen in a timely and trustworthy manner. Therefore, it is crucial to understand how to leverage healthcare professionals and how to improve causally upon worker-patient interactions. We identified six studies that focus on healthcare professionals which we will discuss in detail.

Incentivizing healthcare professionals correctly, is a large issue in health economics. One bias that Andreoni et al. (2018) identified in the context of vaccination is hyperbolic discounting from the supply-side. It is not only present-biased patients from the demand-side who irrationally might put off vaccination to do it later, but healthcare professionals might put off work to a later point which might reduce coverage. It is crucial to provide an optimal contract to individuals so that the healthcare professionals as agents work in the interest of the principal, i.e. a campaign, the government or society as a whole. This is especially crucial in this setting, since vaccinations have been tested to a great extent and approval of the vaccines implies that the benefits of vaccination outweigh the costs and that coverage increases are Pareto-efficient.

However, it is not clear ex ante who is present-biased and who is not. Therefore, Andreoni et al. (2018) elicit preferences of healthcare professionals, identifying individual discounting parameters to match them with individualized incentive-compatible contracts to improve vaccination coverage. The authors used a smartphone application to monitor the productivity of workers over two days during a polio vaccination campaign for children. Funded by the Department of Health, every month Lady Health Workers conduct polio vaccination drives in Lahore, Pakistan. The researchers implemented and analysed vaccination drives in November and December while setting a target across the two days in each month. Not reaching their target on one of the two days would result in a sizable opportunity cost of losing ten times the daily vaccinator

wage. Despite the sizable implied penalty, and despite lowering the requirement from 100% to reaching 90% of the vaccination tasks, still, only 51.5% of the subjects successfully completed their tasks. Individually tailored interest rates were set to exactly mirror the discount factor βδ to smooth vaccination coverage provision over time. Indeed, when the authors exclude outliers, they find that tailored contracts bring vaccination coverage six percentage points closer to equal vaccination supply, which is in line with inducing vaccination coverage smoothing.

Reflecting on this insightful project, it would be interesting to see whether the incentive-compatible contracts are vastly different for males in contrast to females. Allowing us to observe the incentives we need would provide a cost-efficient solution and it could tell us whether males have differential discount factors than females. For example, one could imagine that males are more present-biased and require larger incentives than females. This could raise the question which population we want to target as healthcare professionals to provide the common good most efficiently. However, such implied gender-targeted incentives on the supply-side could immediately raise trade-off questions of gender equality and the supply of vaccines. On another note, it is not clear that consumption smoothing, in terms of supply smoothing over time of vaccines is the ideal goal since sequential provision of vaccinations might aggravate the theoretical problem of free riding (Ibuka et al. 2018)). Therefore, it would be interesting to see whether other contracts can be tailored that alleviate the potential free-riding problem on the demand side.

Brock et al. (2013) study intrinsic incentives, intrinsic preferences and their relationship to physician quality in Tanzania. Indicators of quality of care are questions about the child's vaccination status and vaccination history upon the physician visit. Questions should be raised more than 80% of the time to suggest high quality of care of the physician in this domain. The authors are interested whether generosity and quality of care correlate and if the quality of care increases with randomly assigned intrinsic incentives such as peer observability or encouragement. As shown in Table 4, they find that peer observability in the field leads to increases in physician quality. Peer observability does increase questions from physicians about vaccination history by 27 percentage points but it does not change questions about the patient's child vaccination. An encouraging scripted statement from a medical professional increases questions about the child's vaccination status by 15.5 percentage points and it increases questions about the history of vaccination by 20 percentage points.

The authors provided information on vaccination recommendations in a field setting while combining an incentivized dictator game laboratory experiment with a field experiment on peer observability. They measure generosity through the dictator game where the physician was matched with a non-physician and she could decide to allocate 15,000 Tanzanian Shilling (approx. $12) between herself and the other party. The allocation is implemented and the game is used as a proxy for generosity to evaluate impact heterogeneity of the peer and encouragement treatments. The authors find that overall physicians are highly intrinsically motivated to provide quality of care. Whether physicians are more or less generous in the laboratory experiment does not alter their responsiveness to the peer monitoring and peer encouragement treatments in the field. While there is no heterogeneity by social preferences, we can conclude from this study that overall quality of care of physicians is improved when peer monitoring and peer encouragement is applied in the field.

Hopfer (2012) studies the impact of peer messaging on human papillomavirus (HPV) vaccination on female college students using a randomized controlled experiment in the laboratory with a follow-up question two months later. It is a high priority for women to get vaccinated against HPV since under-coverage can significantly increase the likelihood of cervical cancer while the vaccine is almost 100%efficient to reduce cervical cancer. Therefore, the authors leveraged messaging from peers and health experts through a narrative video approach. 1000 female subjects sampled from a University Health Centre were invited to voluntarily participate in the study and received a six-dollar lunch coupon. Subjects went to a laboratory and watched vaccination videos uninterruptedly which either randomly included a peer only, medical expert only or a combined speaker to transmit the video content. 2 months after the intervention, the researchers contacted the college women and asked them about their HPV vaccination coverage. The video content was either presented in a narrative manner or in a purely informational way.

The author finds that videos that rely on storytelling in conjunction with peers and medical experts being the transmitters, almost doubled self-reported HPV vaccination coverage from 12% to 22%. Hopfer (2012) used structural equation modelling to find that vaccination intention and self-efficacy – i.e. the own belief to execute vaccination behaviour – are heightened in the narrative treatments with peers and health experts. This approach combines factor analysis and multiple regression analysis, to understand the mediators in the

relationship between the treatments and reported HPV vaccination coverage. She finds that vaccination intention and self-efficacy are important mediators of vaccination after 2 months of the intervention.

While the post-question on HPV vaccination coverage is not derived from administrative data on vaccination coverage, we consider this variable of self-reported vaccination coverage to be more reliable than pure measures of vaccination intent. However, such a variable could potentially include experimenter demand or social desirability. Hence, we recommend obtaining vaccination coverage from health centres or general physicians.

White (2019) investigates the impact of vaccination on mortality and absenteeism in the United States using a natural experiment. He also examines the benefits when vaccination choice is reduced for a sub-group of the population: White examines vaccination mandates for healthcare professionals which have a large potential to increase externalities, i.e. provide herd immunity for patients close to the healthcare professionals.

The first part of his study borrows the identification from Ward (2014) by interacting state-level differences in vaccination rates with exogenous year-by-year variation in influenza vaccination effectiveness due to an unpredictable mismatch in influenza strains and the selected vaccination strains. Ward used a similar identification while leveraging a universal influenza vaccination campaign in Ontario, Canada. Ward finds that vaccination has externality benefits to the elderly of around 20 to 30 percentage points. In the United States, White (2019) finds mortality reductions of 795 fewer deaths through a one percentage point increase in the vaccination rate with externality effects of around 6-7 percentage points for individuals above the age of 75. Scaling his results, he also finds that the same one percentage point increase in the vaccination rate reduces work absenteeism due to sickness by 14.5 million hours per annum.

In the second part of the study, he focuses on vaccination mandates for healthcare professionals in California. In particular, he uses the roll-out of county-level mandates that apply to licensed health care facilities and interacts it with the average level of influenza activity by month. He finds that the health care worker vaccination mandates increase vaccination rates by 10.3 percentage points from a baseline of 74%. The mandates also reduce the number of inpatient visits diagnosed with influenza by 20.1% and the number of outpatient emergency department visits due to influenza diagnoses by 8.1%. He finds that the marginal benefit to vaccinating healthcare professionals is $131. White did not explicitly estimate the size of the externality from healthcare professionals but hypothesizes that it might be large since the unaffected group of children reveals the largest reductions in inpatients admissions and emergency department visits, albeit insignificantly.

Overall, he finds that one would need to vaccinate 313 individuals from the general population to achieve a one percentage point reduction in mortality and one would need only 32.8 healthcare worker vaccinations to obtain a one percentage point reduction in outpatient visits. Under the assumption of proportional effects, he claims that the benefits of vaccinating healthcare professionals are ten times higher than those of vaccinating members of the general population. This highlights the large benefits that stem from healthcare worker peer effects that are generated for society.

To conclude, we found only four studies with a convincing identification from the causal inference literature which can reveal unbiased estimates and are less likely to be affected by endogeneity concerns. There is substantial room for improvement to leverage individualized contracts and to leverage network effects from healthcare professionals, among others.

Table 5 Causal literature on verifiable vaccination coverage and healthcare professionals

Reference	Country	Mechanism	Method	Effect on Vaccination Demand
Andreoni et al. (2018)	Pakistan	Hyperbolic Discounting	RCT, Structural	Targeting vaccination contracts to individual discounting increases health professionals' efforts to increase vaccination coverage.
Brock et al. (2013)	Tanzania	Peer Effects	RCT	Peer observability does (not) increase questions from physicians about vaccination history by 27 pp. (patient's child vaccination).
Hopfer (2012)	US	Peer Effects	RCT	Narrative vaccination videos from peers and medical experts almost double self-reported HPV vaccination coverage from 12% to 22%.
White (2019)	US	(Health) Externalities	DiD	Vaccination of healthcare professionals results in substantial benefits to the whole population.

8 Applicability of the lessons learnt to the current crisis

The outbreak of COVID-19 pandemic gave new weight to the research on vaccine hesitancy and vaccine acceptance. Although in EU/EEA countries COVID-19 vaccines have been freely and easily available to the general public since 2021, the uptake is not universal. As of February 2023, 84.8% adults in the 30 countries completed the complete primary course but the figure it is still below or around 50% in countries such as Bulgaria and Romania. The uptake of the booster dose is 65.3% and has hardly changed since January 2022 (Vaccinetracker 2022).

Again, the quickly growing literature focused on the attitudes towards COVID-19 vaccine per se will be reviewed in a separate paper; however, it is also of great importance to be able to tell the scope of the applicability of the findings from earlier literature on vaccine hesitancy in the context of the current pandemic. This applicability cannot be taken for granted given all the idiosyncrasies of COVID-19.

We apply three main strategies:

1. We extrapolate findings from earlier literature considering the characteristics of COVID-19. For example, we know that being unfamiliar with something tends to evoke mistrust and that (mis)trust is a crucial factor in vaccine acceptance; consequently, unfamiliarity with the rapidly developed COVID-19 vaccinations is a major obstacle to its acceptance.
2. We review studies in which two types of measures were elicited in the same individuals:
    a. attitudes toward or intended/actual (self-reported) take up of COVID-19 vaccines and
    b. attitudes toward or intended/actual (self-reported) take up of other vaccines. If the two are highly correlated (and have similar determinants), there are reasons to believe that most of what we know about vaccine hesitancy in general is valid for COVID-19 hesitancy specifically as well.
3. We review studies in which two types of measures were elicited in the same individuals:
    a. attitudes toward or intended/actual (self-reported) take up of COVID-19 vaccines and
    b. vaccine hesitancy/confidence scales.

8.1 Extrapolating from pre-COVID literature

COVID-19 pandemic was a game-changer in many ways – attitudes towards vaccines are no exception. COVID-19 has often been compared to influenza. Indeed, this is a natural benchmark, as both are viral diseases with similar mechanisms of transmission and symptoms (ranging from none, through mild coughing and fatigue, fever, to death due to respiratory illness (Alimohamadi, 2020). Moreover, unlike childhood vaccinations, such as MMR, decisions about influenza and COVID-19 vaccines need to be taken repeatedly, over the course of a lifetime. Yet, COVID-19 differs from influenza in several ways that are highly important from the viewpoint of vaccine hesitancy considerations.

First, it is a completely new threat. Prior to late 2019, the pandemic could not have been predicted and the vast majority of the world population had not even been aware of the existence of coronaviruses. Second, in the early stages of the pandemic, the threat was largely unknown. While in the case of most public health threats of global potential, such as polio and measles, there is a wide scientific consensus, key information concerning transmission and morbidity of COVID-19 was not available or highly uncertain in the early stages of the pandemic. Third, in Europe COVID-19 was initially perceived as geographically distant. Fourth, morbidity and mortality for COVID-19 are far higher than influenza (Nersesjan et al., 2020). Fifth, there are differences in risk factors. Notably, unlike influenza, COVID-19 is i) less risky for females than for males (Conti and Younes, 2020) and ii) far less risky for small children than for adults (Zimmermann P, & Curtis, 2021).

These differences may have important consequences for the perception of the risk associated with the disease (which, as explored in Chapter 4 of this report, is a major factor in vaccine acceptance). It has been long established (Slovic, 1992) that risks which are new, unknown to science and “catastrophic” (suddenly affecting many people) are perceived as far larger. This consideration, in the face of the explosive nature of the COVID-19 pandemic and uncertainty surrounding the disease, along with its higher morbidity and mortality rates (compared to influenza) should, prima facie, lead to greater perceived risk.

The impact of perceiving COVID-19 as geographically distant and perhaps exotic is ambiguous. On the one hand, it contributes to uncertainty. On the other hand, distant risks are generally perceived as smaller (Spence et al., 2012). However, it only took a few months before cases of COVID-19 could be seen spreading worldwide. Relatively low risk for children (whom most parents and grandparents want to protect foremost) may also have been a factor lowering risk perception.

Empirically, most available studies indicate that COVID-19 is indeed perceived as a highly threatening disease Dryhurst et al., 2020; Faasse & Newby, 2020; Wise et al., 2020). For example, in the study by Dryhurst et al. (2020), it was universally perceived as highly threatening in ten countries studied, although substantial heterogeneity at individual level was observed, related inter alia to personal experiences.

However, studies trying to link risk perception to vaccine acceptance delivered mixed result. Malik et al. (2020) found a positive relationship in a US sample. On the other hand, in a study conducted in Australia at the beginning of the pandemics, perceived severity was not found to be a good predictor of intention to be vaccinated against COVID-19 (and neither was the perceived risk of infection). Similarly, Karlsson et al. (2021) observed a weak impact of perceived risk of COVID-19 disease on vaccination intentions.

Thus, applicability of findings on the impact of perceived severity of disease reported in pre-COVID vaccine hesitancy literature seems somewhat limited. First, although the disease is generally perceived as serious, a substantial fraction of the population chooses to remain unvaccinated. Second, such perception is a poor predictor of vaccination acceptance at the individual level.

Clearly, COVID-19 vaccine hesitancy can be associated with the other side of the novelty coin: the novelty of the vaccine itself, making patients uncertain about its efficacy, and, crucially, its safety. Indeed, concerns about side effects of the rapidly developed COVID-19 vaccine are a key explanation provided by hesitant respondents (see SteelFisher et al., 2021 for a review). This is in line with pre-COVID findings that people perceiving vaccines as safe accept them far more easily (e.g., Betsch et al, 2018) and that trust in science delivering the vaccines is crucial for their acceptance. It appears that the negative effect of the novelty of the vaccine is stronger than the positive effect of the novelty of the disease. On the net, COVID-19 vaccine acceptance is not universal and its further build-up is expected to be a very slow process.

This is of particular importance in some vulnerable groups, notably migrants. Clearly, a detailed analysis of demographic determinants of vaccine attitudes is beyond the scope of this project. However, in view of the current unprecedented crisis involving millions of Ukrainians fleeing the Russian invasion, it may be worth noticing that several factors make refugees likely to be vaccine-hesitant. The trauma they have experienced and the experience of being forced to reside in a foreign country are likely to reduce trust and thus, vaccine acceptance. They may not be ready to face additional stress and risk (however small it may objectively be) of side effects. Depending on the migration wave in question, these mechanisms, associated with the fact of being a refugee, may be coupled with the effect of country of origin. For example, COVID-19 vaccine uptake in Ukraine was much lower than in the EU countries even before the current invasion (Coronavirus, 2022), partly due to exposure to Russian propaganda (Keegan, 2022). Overall, quickly growing empirical literature confirms that vaccination acceptance in refugees and, more broadly, migrant populations is particularly problematic, see the reviews by Tankwanchi et al. (2021), Belinda et al. (2021).

8.2 Correlating attitudes towards vaccines against influenza and COVID-19

Another approach to assessing applicability of pre-COVID findings to the current pandemic is to look at links between attitudes toward COVID-19 vs. other vaccines. Searching for relevant studies, we used a multi-channel approach. First, a Google Scholar search was conducted with keywords:

HPV OR influenza OR MMR COVID vaccination hesitancy.

As many as 13,000 papers were returned; however, a careful inspection of the top 100 showed that the remaining papers were highly unlikely to be relevant. Second, recent reviews of literature on vaccine hesitancy, namely Aw (2021), Biswas (2021), Sallam (2021), and Troiano (2021) were examined. Third, papers previously found to be relevant were screened for relevant citations. Likewise, papers citing sources found to be relevant were also inspected. This resulted in 47 relevant papers. They were all online surveys simply calculating measures of association between variables of interest (and thus not establishing causality). Below, we briefly report the best or most characteristic studies.

We focus on the papers investigating attitudes or behaviours associated with influenza vaccines which (perhaps due to the similarity of COVID-19 and influenza discussed before) represent the vast majority of this literature, references to other vaccines being much less common. Overall, these studies almost universally observed a positive, significant correlation of influenza measures with intention to vaccinate against COVID-19, also controlling for other variables. This is true for both approaches that may be distinguished here: asking about past influenza vaccine behaviour and asking about influenza vaccine intentions. We discuss some of the papers from each of both groups below.

Let us start with the papers eliciting, along with COVID-19 vaccine intentions, past influenza vaccine behaviours. Dror et al. (2020) collected 1941 anonymous responses to an online survey in healthcare workers and in the general population of Israel. They data was collected on March 19, 2020, just a week after the first wave of restrictions. Among others, the researchers asked if respondents would be willing to vaccinate themselves and their children against COVID-19, once such a vaccine becomes available. They also inquired about influenza vaccination behaviours. Dror et al. observed important differences between various categories of respondents. While among nurses and the general public about two in three reported having taken influenza vaccines, the number was as high as nine out of ten among doctors. In the case of what was back then a potential future COVID-19 vaccination, the acceptance among general public, at 75%, was on a par with the doctors (78%) while nurses were lagging behind (61%). Despite these diverging patterns, (self-reported) influenza vaccine behaviour was the most important predictor of COVID-19 vaccination intentions.

Shehkar et al. (2021) surveyed 3479 US-based healthcare workers in the autumn of 2020. Only one in three said they would take the COVID-19 vaccine as soon as it was available but further 56% were undecided and/or preferred to wait for more data with only 8% refusing explicitly. These distributions were strikingly different in the two groups split by the question "Did you get the influenza vaccine last year": as many as 43% of those saying "no" also refused future COVID-19 vaccines, whereas the number was only 6.8% among those saying they had not got the influenza vaccine last year.

Burke et al (2021) investigated antecedents of COVID-19 vaccine acceptance in 4303 individuals in five countries. Using factor analysis and structural equation modelling, the authors concluded that the key cognitive variables were trust in vaccines' approval, (a lack of) conspiracy beliefs, and perceived effectiveness of the vaccine in protecting others. Self-reported past influenza vaccination uptake was also a strong predictor of COVID-19 vaccination intentions.

As mentioned before, some studies looked at intentions to vaccinate against influenza (in the coming season), not only against COVID-19. Even in these studies these intentions are not directly comparable, as, again, they were predominantly run while COVID-19 vaccines were still hypothetical. Moreover, the question formats (notably, the menu of answers) were often different.

One of the few exceptions to this unfortunate pattern is Study 3 of Karlsson et al. (2021). The participants were 825 parents of small children surveyed in May 2020. They indicated how likely they would be to take a vaccine against COVID-19 if it was "available, free of charge, and recommended to everyone by the authorities". In a similar fashion, they reported the likelihood of taking an influenza vaccine. Interestingly, they were slightly more convinced in the case of COVID-19. While for either disease about half the sample said they would be "very likely" to get vaccinated, the fraction of those being only "likely" was more than one in five in the case of COVID-19 and less than one in ten in the case of flu.

The authors also investigated the role of beliefs and emotions (triggered by the disease but also by the vaccine itself) in COVID-19 vaccination acceptance and confirmed that COVID-19 is perceived as more threatening than influenza. Moreover, comparing the predictors of vaccination intentions, they found different patterns for COVID-19 and influenza. For the latter, several factors, including perceived vaccine safety, perceived likelihood of infection, concerns about transmitting the disease, and perceived severity of the disease were all important predictors; for COVID-19, perceived vaccine safety had a sweeping effect, dwarfing other influences.

Gerusi et al. (2021) investigated a group of 509 Italian patients who had recovered from COVID-19 in March-May 2020. They asked them about their intention to vaccinate against influenza and COVID-19. Demographic determinants of these two decisions were similar, with older patients being much more vaccine-acceptant. However, clinical characteristics were predictive of preference for influenza vaccine only. Individuals with hypertension and chronic diseases as well as those undergoing chronic therapy were much more likely to be willing to get vaccinated against influenza than their healthier counterparts. There was no such pattern for COVID-19. Similarly (and paradoxically!), those who needed hospitalization during their COVID-19 spell,

compared to those who did not, were more likely to be willing to vaccinate against influenza - but not against COVID-19 - compared to those who did not.

Johnson et al. (2021) interviewed 248 adult patients of the Internal Medicine Clinic in Louisiana. As many as 67% of them were unsure or did not intend to get vaccinated against COVID-19, compared to 19.3% for influenza. Still, the two variables were highly correlated. Of those willing to get a COVID-19 vaccine, 97.5% also opted for a flu shot, compared to just 72.7% among those unwilling or unsure about COVID-19 vaccine.

Grüner and Krüger (2021) conducted a survey with German 1249 students, including 208 healthcare students as well as 213 healthcare professionals and 367 other professionals. The fraction declaring willingness to be vaccinated against COVID-19 was close to 80% in all groups. The fraction willing to vaccinate against flu was much higher among healthcare professionals (67%) compared to the other groups (around 40%). Other than that, the attitudes toward the two kinds of vaccination tended to correlate with the same factors. Reflective (as opposed to intuitive) thinking style, as measured by the Cognitive Reflection Test (Frederick, 2005), was associated with greater willingness to be vaccinated; so was the trust in the government, the media, and the healthcare system. Those believing in homeopathy were less willing to be vaccinated.

Graupensperger et al. (2021) ran an online survey with 647 US undergraduates. As the study was conducted at the beginning of the (2020/2021) influenza season, they asked the responders whether they "got or were planning to get" a flu shot. In this sense, the study lies in the grey area between the two groups we defined. In either case, the correlation between the responses to the influenza vaccine question and the COVID-19 vaccine intentions question was just .17. This is partly because there was very little variance in the COVID-19 declarations: as many as 92% endorsed the vaccine, a clearly unrealistically high number. Interestingly, the patterns of correlations with perceived social norms were also markedly different for the two types of vaccination. Specifically, the authors measured norms by asking the following questions: ''Considering typical young adults in America, what percentage [0-100%] do you think will get a [COVID]/[flu] vaccination/shot?" (Descriptive norm) and ''in your estimation, how important do typical young adults think it is to get a [COVID]/[flu] vaccination shot? [1-7]" (injunctive norm). Both norm variables correlated at around .3 with the (previously) reported own willingness to be vaccinated against COVID-19, whereas analogous associations were very weak in the case of flu shots.

To conclude, there is by now some literature correlating COVID-19 vaccine intentions with influenza vaccine behaviours or intentions. This field of research is growing quickly and now that COVID-19 vaccination is widely available, numerous studies linking COVID-19 vaccine self-reported behaviours with influenza variables will certainly be appearing as well. Moreover, with regular mutations of the COVID-19 virus, seasonal waves, and time-restricted efficacy of the vaccine triggering up-take of boosters, decisions about COVID-19 vaccinations may soon resemble annual decisions about influenza vaccines. These developments will help address the methodological limitations in this literature, namely that the influenza questions and the COVID-19 questions are not comparable.

So far, the main findings are as follows. First, influenza variables (both those concerning past behaviour and intentions) are good predictors of COVID-19 vaccine intentions. Second, the strength of correlation between COVID-19 and influenza variables depend strongly on the sample and specific questions asked. Third, the antecedents of COVID-19 and influenza vaccine choices tend to show important differences. Notably, trust in vaccines' safety plays a much greater role in the case of COVID-19 than in the case of influenza. Again (while there is mixed and limited empirical evidence to prove it so far, Beleche et al. 2021), one would hope that this key obstacle in COVID-19 vaccine take-up will slowly be dismantled as the vaccine ceases to be perceived as a novelty.

8.3 Linking attitudes towards COVID-19 vaccines with vaccine hesitancy/confidence scales

Another approach, a road much less travelled by, involves investigating concurrent validity of vaccine hesitancy scales. As in the case of linking of the previous approach, this exercise allows telling if the willingness to accept COVID-19 vaccines is idiosyncratic or whether it reflects the general attitude towards vaccines. To identify relevant publications, we searched google scholar for items containing "COVID" and "vaccine hesitancy scale", "vaccination acceptance scale". We also scrolled through the bibliography of found items and the papers that cited them. This procedure yielded 12 relevant papers, again, all being online surveys.

Akel et al. (2021) focused on the adult Vaccine Hesitancy Scale (aVHS) consisting of ten items (reflecting general attitude toward vaccines) such as “I am concerned about serious adverse effects of vaccines.” and "Vaccines are important for my health” (reverse-coded). The scale was investigated as a predictor of COVID-19 vaccine acceptance. The authors ran a survey with ca. 2300 individuals from the US and China in the March-June of 2020. The (dichotomized) scale had some predictive power in the US. Conducting a Poisson regression with COVID-19 vaccine acceptance as dependent variable, they estimated that this acceptance among those scoring high on the aVHS was almost 30% lower than among those scoring low. However, in China, the relationship was much weaker. Moreover, when the original (not dichotomized) aVHS was investigated, its link with COVID-19 vaccine acceptance appeared non-monotonic. Moreover, for the past and planned influenza vaccination (which was only elicited in one of the waves in the US), aVHS was a better predictor than it was for the COVID-19 vaccine acceptance.

Breslin et al. (2021) surveyed 400 individuals from Ireland and Northern Ireland in February 2021. They correlated i.e. the following measures: i) the Vaccination Confidence Scale (VCS), consisting of items assessing benefits and harms of vaccines in general and trust in health care providers, ii) the Vaccine Attitudes Examination Scale, consisting of items assessing vaccine mistrust, future worries, profiteering, and preference for natural immunity and iii) COVID-19 vaccination intentions (measured with three, highly intercorrelated items). The correlation between i) and iii), and that between ii) and iii) were high and very similar (both above 0.7). A very similar correlation between the VCS and COVID-19 vaccination intentions was found in a survey of 217 young Austrians (Knobel et al., 2021).

Thus, the evidence is limited in number but rather consistent: vaccination hesitancy/consistency scales are good predictors of COVID-19 vaccination intentions. This strongly suggests that building up trust in vaccinations in general, their safety and efficacy, will have a sizable impact on COVID-19 vaccination take-up. It would be an attractive opportunity given the evidence of overload and active avoidance of messages related to COVID-19 (de Bruin et al., 2021; Buneviciene et al., 2021; Mannell and Meese, 2022). The major practical difficulty is, naturally, that it is very hard to foster trust in vaccinations in general, which is also why the association discussed in this subsection has not been confirmed in experimental studies.

9 Conclusions

Vaccination choice is a complex topic and while the supply-side has received attention from an economic perspective, a systematic investigation of the demand-side factors from a behavioural economics viewpoint is still underdeveloped. In this review, we investigate the current state of the literature by focusing on a non-exhaustive list of four factors: vaccination involvement, vaccination decisions under uncertainty, over time, and the impact of peers on the propensity to get vaccinated. We mainly focus on behavioural aspects in contrast to health outcomes. Throughout the literature review, three groups received more attention: children, parents and healthcare professionals. In particular, for healthcare professionals, we dedicated one separate chapter, to highlight research where behavioural factors may matter on the supply side.

Involvement of individuals who make decisions for themselves, but also others (such as parents for their children), implies a state of motivation and information to make educated vaccination decisions. The topic is quite complex and may cover information overload, choice overload, information avoidance, risk and benefit perceptions, psychic costs, salience and proxy vaccinations. A large amount of the literature is on childhood vaccination, albeit not necessarily with an explicit focus on proxy vaccinations. We recommend investigating further the distinction between vaccination choices for oneself and for others. We also see large scope to investigate psychic costs across different types of individuals, such as infants, children, and mothers.

Vaccination decisions are made under uncertainty with small propensity risks of side-effects being traded off against probabilities of getting sick. Therefore, risk aversion may play a central role in making vaccination decisions. However, only few studies have investigated risk preferences from an economic perspective to begin with. The role of ambiguity, i.e., not even knowing whether a state can occur with a certain probability, is another avenue that has barely been covered. Regret aversion and overweighting of small probability events in the spirit of prospect theory deserves more systematic attention for side-effects with small propensities. Once vaccination decisions have been made under uncertainty, individuals might trade off perceived benefits of being vaccinated against their other actions. This phenomenon is known as moral hazard and more research can illuminate how information should be provided to subjects to reduce such unintended consequences of vaccination. Overall, the domain of uncertainty leaves large scope to combine theoretical and empirical research but also push the boundaries of quasi-experimental and experimental research to understand the special choice situation that vaccination is.

Vaccination decisions are made over time and can be delayed. One category of vaccine-hesitancy is an explicit delay of vaccination. From an economic perspective delay can occur either rationally, or due to procrastination of a present-biased individual who intends to engage in vaccination tomorrow, but when tomorrow comes, the costs are perceived higher than the benefits, and he will alter his plan and not vaccinate. Imperfect memory might be another driver of vaccination inaction. While such choices over time can lower vaccination coverage, only very few papers explicitly study vaccination decisions over time. Low hanging fruits in the domain of vaccination choices over time are likely to be found easily with some ex-ante experimental design effort. Research in this domain has the potential to increase coverage substantially.

Peers generally can influence behaviour either through beliefs about the actions of others, i.e. via nonconformity, or by following one's peers through conformity. The literature points to a consensus direction that free-riding only plays a minor role and that peers such as friends or co-workers can have a large impact on the own propensity to get vaccinated. While there seems to be some divergence on whether peers are improving coverage or reducing coverage, it is not clear by how much free riding might offset conformity. Further investigations into the mechanisms, such as learning from peers or information spillover are crucial to understand which policies to recommend.

On the supply-side topic of healthcare professionals, there are many studies that investigate this special sub-group. However, only few studies provide credible causal interventions that can address behavioural factors to encourage trust, to improve information, education of healthcare professionals, to ultimately increase vaccination coverage of patients through the individuals who recommend and provide vaccinations. Especially leveraging networks and contracts may allow a reduction in behavioural biases which can improve overall vaccination coverage.

This work provides a quite comprehensive state-of-the-art on the behavioural determinants of vaccination. However, across numerous behavioural factors, with the majority from the demand-side, but also healthcare professionals from the supply side, we find that there are large gaps in the literature. A substantial amount of work would still need to be done to improve our understanding of vaccination behaviour and to recommend policies that allow improving overall societal welfare in a world where coverage from each individual is important in itself and generates positive externalities.

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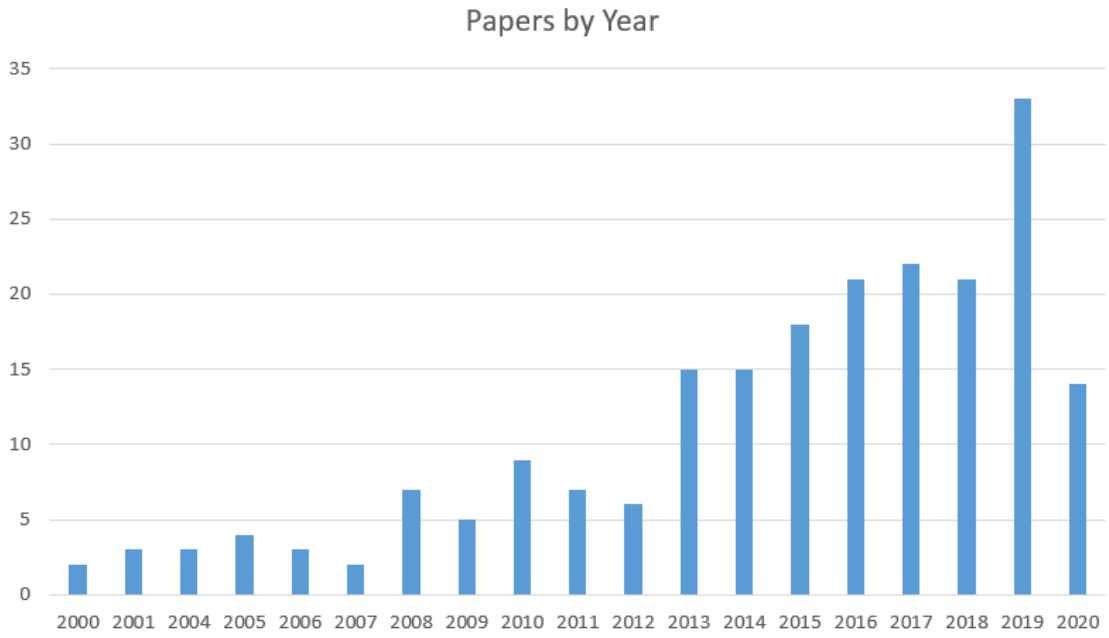
List of abbreviations and definitions

AIDS	Acquired Immunodeficiency Syndrome
CCT	Conditional cash transfer
CDC	Centre for Disease Control and Prevention
DiD	Difference-in-Difference
DiDiD	Difference-in-Difference-in-Difference
DOI	Digital Object Identifier
DTP	Diphtheria, tetanus, and pertussis (vaccine)
EC	European Commission
EU	European Union
HCP	Health Care Professionals
HB	Hepatitis B (vaccine)
HH	Household
HIV	Human Immunodeficiency Virus
HPV	Human Papilloma Virus
IV	Independent Variable
MMR	Mumps, Measles, Rubella (vaccine)
RCT	Randomized Control Trials
RDD	Regression discontinuity design
SAGE	Strategic Advisory Group of Experts on Immunization
SHARE	Survey of Health, Ageing and Retirement in Europe
SMS	Short Message Service
TB	Tuberculosis (vaccine)
US	United States
USD	Unites States Dollar
VH	Vaccine hesitant
VHP	Vaccine hesitant parent
WHO	World Health Organization

List of tables

Annexes

Annex 1. Methodology



Annex 2. Behavioural Factors – Suggestive Evidence

Table A1 – Suggestive Involvement Literature

x out of 51 report	References
Suboptimal Decision-Making	
5 … the vaccination problem is difficult to comprehend for subjects leading to suboptimal decisions	Binder and Nuscheler (2017) Buttenheim and Asch (2016) Le Marechal et al. (2018) Omer et al. (2017) Opel and Omer (2015)
Parents and HCP	
6 … mistrust of medical professionals and the government is correlated with parental vaccine hesitancy for their children	Benin et al. (2006) Deml et al. (2019) Holte et al. (2012) Gust et al. (2008) Raude et al. (2016) Salmon et al. (2005)
4 … vaccine hesitant parents are more likely to trust providers of alternative medicine professionals	Benin et al. (2006) Hadjipanayis et al. (2020) Repalust et al. (2017) Salmon et al. (2005)
8 … personal interactions with non-vaccine hesitant healthcare providers correlate with vaccination intentions of parents for their children	Adeyinka et al. (2009) Collange et al. (2016) Karafillakis et al. (2016) Napolitano et al. (2018) Petts and Niemeyer (2004) Verger et al. (2015) Verger et al. (2016) Wilson et al. (2020)
1 … Participator provider-parent interaction reduces vaccination intention	Opel et al (2015)
(Parental) Perceptions, Beliefs, Attitudes	
1 … there is no large difference between parental vaccination intention for children or own	Verelst et al. (2018)

vaccination intention	
10 … the perception of a larger disease severity and vaccine efficacy is positively correlated with parental vaccination intention	Abhyankar et al. (2008) Bauch and Earn (2004) Benin et al. (2006): infants Cox et al. (2010) Guo et al. (2017) Marti et al. (2017) Reluga and Galvani (2011) Sadique et al. (2013) Tsutsui et al. (2012) Zimet (2005)
8 … the perception of side-effect severity is negatively correlated with vaccination intention	De Bekker-Grob et al. (2010) Guo et al. (2017) Gust et al. (2008) Napolitano et al. (2018) Nuscheler and Roeder (2016) Rey et al. (2018) Sadique et al. (2013) Salmon et al. (2005)
1 … Oscillations of vaccination take up are more likely when the perceived risk of vaccines is high	Bauch (2005)
1 … individual world-views impact risk-and-benefit perceptions of vaccines	Kahan et al. (2010)
1 … incorrect beliefs can increase vaccine-hesitancy	Funk et al. (2010)
1 … positive parental attitude towards vaccination increases vaccination intention for children	Hofman et al. (2014)
Awareness, Information, and Knowledge	
2 … increasing awareness can increase vaccination coverage	Catalan-Matamoros and Peñafiel-Saiz (2020) Kreidl et al. (2017)
1 … vaccination knowledge of school children spreads through informal networks	Mascia et al. (2020)
6 … lack of parental information is correlated with lower vaccination coverage for children	Catalan-Matamoros and Peñafiel-Saiz (2020) Downs et al. (2008) Funk et al. (2010)

	Marti et al. (2017) Phukan et al. (2008) Vikram et al. (2012)
1 … providing information to parents is not helpful in reducing confusion	Downs et al. (2008)
2 … vaccine critical information increases risk perceptions and reduces vaccination intention	Betsch et al. (2010) Jolley and Douglas (2017)
(Parental) Fear and Anticipated Regret	
3 … anticipated regret positively correlates with low vaccination intention and coverage	Hofman et al. (2014) Sadique et al. (2013) Sato and Fintan (2020)
1 … fear positively correlates with low vaccination knowledge	Sato and Fintan (2020)
(Parental) Skills, and CCT	
1 … mothers' cultural capital (communication skills) can increase vaccination propensities of children	Vikram et al. (2012)
1 … conditional cash transfers can increase immunization rates	Medlin and de Walque (2008)

Note: Those categories here are broad, based on the main take-away and not necessarily with the authors' intention of what aspect should receive the largest weight.

Table A2 – Suggestive Uncertainty Literature

x out of 54 report	References
1 … the vaccination problem is difficult to comprehend for subjects leading to suboptimal decisions	Binder and Nuscheler (2017)
Risk Perceptions	
21 … the perception of a larger disease severity and vaccine efficacy is positively correlated with vaccination intention	Abhyankar et al. (2008 Bauch and Earn (2004) Benin et al. (2006) Boehm et al. (2016) Brewer et al. (2017) Cox et al. (2010) Damnjanović et al. (2018) Deml et al. (2019) Determann et al. (2016) Fournet et al. (2018) Guo et al. (2017) Jarmolowicz et al. (2018) Karafillakis et al. (2017) Killian et al. (2016) Marti et al. (2017) Rossen et al. (2016) Sandhofer et al. (2017) Sundaram et al. (2015 Tsutsui et al. (2012) Wheelock (2015) Ozawa and Stack (2013)
20 … the perception of side-effect severity is negatively correlated with vaccination intention	Boehm et al. (2016) Brewer et al. (2017) Damnjanović et al. (2018) De Bekker-Grob et al. (2010) Deml et al. (2019) Determann et al. (2016) Fournet et al. (2018) Guo et al. (2017)

	Hansen and Schmidtblaicher (2019) Jarmolowicz et al. (2018) Karafillakis et al. (2017) Killian et al. (2016) Koç (2015) Ozawa and Stack (2013) Rey et al. (2018) Sandhofer et al. (2017) Seanehia et al. (2017) Verelst et al. (2018) Wheelock (2015) Wilson et al. (2020)
1 … vaccine critical information increases risk perceptions and reduces vaccination intention	Betsch et al. (2010)
1 … messaging that there is no risk, increases risk perceptions	Betsch and Sachse (2012)
1 … Oscillations of vaccination take up are more likely when the perceived risk of vaccines is high	Bauch (2005)
1 … individual world-views impact risk-and-benefit perceptions of vaccines	Kahan et al. (2010)
1 … Parents do not act upon risk messages from the media	Petts and Niemeyer (2004)
1 … Even doctors who are not vaccine-hesitant fear vaccination risks	Verger et al. (2016)
3 … Unfavourable perceptions about risks reduces likelihood of doctors to recommend vaccination	Collange et al. (2016) Corace et al. (2016) Verger et al. (2015)
2 … Vaccine scare can lead to low vaccine coverage even after risk perceptions return to baseline	Oraby et al. (2014) Chen and Fu (2019)
1 … individuals are more likely to follow social norms to vaccinate others in contrast to vaccinate oneself, especially when risk preference is contrary to social norm	Petrova et al. (2016)
At-Risk-Patients	
1 … Universal recommendation for HPV but no mandatory vaccination due to different risk-profiles	Zimmerman (2006)

1 … improving vaccination coverage for children may improve health outcomes for the elderly	Galvani et al. (2007)
1 … evidence-based behavioural kernels can reduce vaccination risk-factors	Embry (2004)
1 … complacency is lowering coverage for high-risk groups	Schmid et al. (2017)
1 … machine learning can be used to predict vaccine hesitancy as a warning system for at risk groups	Bell et al. (2019)
1 … nurses are more likely to have vaccination doubts	Picchio et al. (2019)
Risks-Incentives	
2 … Vaccination risks may encourage free-riding	Betsch et al. (2013) Romley et al. (2016)
1 … economic incentives may compete against risk perceptions for sex workers, increasing risky behaviour where no vaccine is available	Operario et al. (2013)
2 … conditional cash transfer to compete against low risk perceptions does not change immunization coverage	Bassani et al. (2013) Wigham et al. (2014)
1 … conditional cash transfers can increase immunization rates	Medlin and de Walque (2008)
Ambiguity Aversion	
1 … ambiguity aversion may reduce vaccination coverage	Dubov and Phung (2015):

Table A3 – Suggestive Peer Effects

x out of 25 report	References
3 … free riding (negative correlate)	Attari et al. (2014) Betsch et al. (2013) Ibuka et al. (2014)
2 … prosocial behaviour (positive correlate)	Attari et al. (2014) Betsch et al. (2013)
10 … social norms (positive correlate)	Allen et al. (2009) Determann et al. (2016) Lehmann et al. (2015) Liao et al. (2016) Ng et al. (2020) Petrova et al. (2016) Picchio et al. (2019) Quinn et al. (2017) Romley et al. (2016)
7 … peer influence (positive correlate)	Cao et al. (2019) Cocchio et al. (2020) McKillop et al. (2019) Salathé et al. (2013) Saran et al. (2018) Seanehia et al. (2017) Sundaram et al. (2015)
2 … peer messaging (positive and zero correlate)	Hopfer (2012) Langley et al. (2015)
1 … peer influence (negative disease correlate)	Curtis et al. (2013)
2 … positive peer influence on antibodies	Gallagher et al. (2008) Pressman (2005)

Table A4 – Suggestive Health Care Professionals Literature

x out of 24 report	References
Patients	
2 … prosocial behaviour	Boehm et al. (2016) Lehmann et al. (2015)
4 … trust in healthcare professionals and healthcare system	Karafillakis et al. (2016) Napolitano et al. (2018) Ozawa ad Stack (2013) Repalust etal. (2017)
HCP	
3 … vaccines are safe and effective	Corace et al. (2016) Lim et al. (2019) Raude et al. (2016)
4 … vaccines have large side-effects	Collange et al. (2016) Karafillakis et al. (2016) Lim et al. (2019) Verger et al. (2016)
3 … peer effects (positive correlate)	Killian et al. (2016) Paterson et al. (2016) Lehmann et al. (2015)
2 … HCP are trusted influencer	Cocchio et al. (2020) Paterson et al. (2016)
3 … trust in health authorities reduces vaccine hesitancy (negative correlate)	Karafillakis et al. (2016) Raude et al. (2016) Verger et al. (2016)
5 … knowledge about increases vaccination recommendation (positive correlate)	Collange et al. (2016) Corace et al. (2016) Kassianos et al. (2018) Paterson et al. (2016) Verger et al. (2016)
2 … differential vaccination hesitancy by vaccine	Kuhn et al. (2019) Genovese et al. (2019)

1 … perception not based on scientific evidence	Le Marechal et al. (2018)
1 … specialists are vaccine hesitant (correlate)	Kassianos et al. (2018)
1 … physician quality affects vaccination propensity (correlate)	Schmitz and Wuebker (2011)
1 …mobile vaccination worker vaccination protects patients	Curtis et al. (2013)

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