The European Journal of Comparative Economics
Vol. 21, no. 2, pp. 265-284
ISSN 1824-2979

Navigating the nexus of COVID-19 vaccination strategies: insights beyond the needle

Fayrouz Fliou*

Abstract:

The COVID-19 pandemic has wrought global disruptions, impacting societies and economies significantly, while vaccine hesitancy remains a pressing concern. This paper introduces a framework for analyzing vaccination decision-making, emphasizing the roles of perceived costs and social influences. To craft effective policies, comprehending individuals' cost perceptions is essential. Social imitation also plays a role in vaccination choices, as individuals often emulate their social circles, potentially altering the optimal decision. The established framework demonstrates that COVID-19 policies successfully encouraged vaccination through cost-related strategies. However, similar challenges may emerge in future crises. Therefore, establishing continual information dissemination and educational programs targeting vaccine hesitancy is critical. By consistently addressing this hesitancy, authorities can navigate potential obstacles and bolster their responses to future health emergencies.

Keywords: COVID-19 pandemic; Vaccine resistance; Vaccination decision-making; Social influences; Health policies

1. Introduction

The global impact of the COVID-19 pandemic has been nothing short of devastating, comparable to the magnitude of a September 11 attack unfolding every 1.5 days (Anderson et al., 2004). This unprecedented crisis has placed an overwhelming burden on healthcare systems worldwide, leading to a significant surge in cases and fatalities (Epidemiology Working Group for NCIP Epidemic Response, 2020). Beyond its immediate health impacts, COVID-19 has exposed vulnerabilities in public health systems and magnified existing economic challenges. Morganti (2023) highlighted the critical need for coordinated policy interventions, especially in times of heightened uncertainty and public health crises.

In the fight against the transmission of infectious diseases, vaccination has emerged as a critical and indispensable strategy for intervention and control. It is widely recognized as one of the most effective measures to mitigate the morbidity and mortality associated with such diseases (Lindstrand et al., 2021; Tillett, 1992). However, the issue of vaccination has long been a subject of social dilemma for public health authorities.

* University of Turin, department of economics and statistics "Cognetti de Martiis".

The authors would like to thank the editor and the anonymous reviewers for their comments and suggestions, which significantly improved the quality of this paper.

http://dx.doi.org/10.25428/1824-2979/033
First published online: 07/02/2025

Despite the overwhelming scientific consensus on the safety and efficacy of vaccines, persistent claims questioning their safety continue to circulate (Larson et al., 2021).

Furthermore, the outbreak of the COVID-19 pandemic has further intensified the ongoing debate surrounding vaccination regulations and has sparked concerns regarding individual rights. In addition, political fragmentation and health system capacity have been shown to significantly influence countries' responses to the COVID-19 pandemic (Brosio et al., 2022), shaping the speed and efficacy of policy implementation. These factors also intersect with public perception, as they affect trust in government and the healthcare system, both of which are critical determinants of vaccine uptake and broader public health compliance.

Throughout the course of several centuries, the field of epidemiological modeling has witnessed remarkable advancements, both in terms of conceptual understanding and technical capabilities. These developments have enabled researchers to analyze the impact of various control strategies on the transmission of diseases (Bacaër, 2011; Xia and Lui, 2013; Buonomo and Lacitignola, 2011; Cai et al., 2014; Eckalbar and Eckalbar, 2011). Mathematical modeling, in particular, has played a pivotal role in the realm of epidemiology, providing valuable insights into infectious diseases and facilitating the assessment of control measures. One crucial aspect of disease control revolves around achieving and sustaining adequate vaccination coverage (Ferguson et al., 2006; Larson et al., 2011; Black and Rappuoli, 2010). Therefore, the effectiveness of a vaccination program hinges upon the proportion of the population that receives the vaccine, as individual choices to either get vaccinated or not significantly influence the collective outcomes of vaccination endeavors (Galvani et al., 2007; Wu et al., 2011). By surpassing the critical threshold for herd immunity, wherein a substantial segment of the population becomes immune, vaccination emerges as a potent tool in thwarting the widespread transmission of the infection (Fine et al., 2011; John and Samuel, 2000).

In exploring the decision-making process surrounding vaccination, researchers have employed game-theoretical analyses, which take into account various factors such as perceived costs and benefits, infection risks, vaccine safety, and associated expenses (Bauch et al., 2003). Moreover, the role of social influence is recognized as pivotal, as individuals' decisions are influenced by their interactions with others. By incorporating social influence into vaccination models, researchers can gain valuable insights into the underlying mechanisms shaping vaccination choices and develop interventions to enhance vaccine uptake[19-21]. By adopting a dual-perspective approach that considers both costs and social influence, a comprehensive understanding of vaccination decision-making can be attained. Such understanding serves as a guide for formulating strategies aimed at improving vaccine acceptance and coverage (Xia and Liu, 2013; Jianwei et al., 2020; Bish et al., 2011).

This study is motivated by the recognition of the significant influence of human behavior in the intricate interplay between vaccination, social environments, and public policies. Our primary objective is to examine the repercussions of COVID-19 policies on individuals' decision-making processes regarding vaccination. To offer a comprehensive evaluation of these policies, we construct a theoretical model that incorporates two crucial elements: individuals' perceptions of vaccination costs and the impact of social factors. By taking these aspects into account, our aim is to enhance our understanding of how policies shape individuals' choices regarding vaccination and to generate insights into effective strategies for promoting vaccine acceptance.

Model

In our study, we direct our attention to a well-mixed population and delve into the context of a singular epidemic outbreak, such as the COVID-19 pandemic. Unlike seasonal diseases, where knowledge and experience can accumulate over time, in this pandemic scenario, vaccination becomes a one-time decision that individuals must make. We assume that costs and probabilities associated with vaccination can be estimated based on individual perceptions, which may vary from person to person. The initial phase of our investigation is centered on conducting a comprehensive cost analysis of vaccination decisions.

Divergent Choices, Shared Concerns: Understanding vaccination decision perspectives

On a first stage, facing an epidemic outbreak, an individual i initially perceives the costs associated with getting infected as C_i^{inf}, encompassing healthcare expenses, lost productivity, and potential pain or mortality. Additionally, they assess a probability of contracting the disease, denoted as $\hat{\beta}_i$. The individual's expected infection cost, based on their perception, can be calculated as $\hat{\beta}_i C_i^{inf}$. The second stage involves the introduction of the possibility to get vaccinated through a voluntary vaccination campaign, where individuals decide whether to get vaccinated or not. Given the available information, an individual, denoted as i, forms an estimation of the costs associated with vaccination, which includes perceived costs denoted as C_i^{Vac}. We define vaccine costs broadly, including both direct costs and anticipated risks. These costs include immediate monetary expenses, opportunity costs related to the time and inconvenience of vaccine administration, and potential adverse health effects as perceived by the individual. To account for the possibility of imperfect vaccination, individuals can still contract the disease after receiving the vaccine, with a probability denoted as β_i^{vac}. Taking all these factors into consideration, the total perceived costs of getting vaccinated for an individual i can be expressed as: $C_i^{Vac} + \beta_i^{vac} C_i^{inf}$.

When making the decision to get vaccinated or not, individuals weigh the relative costs of two options based on their perception. They can either bear the costs associated with refusing the vaccine, which can be represented as $\hat{\beta}_i C_i^{inf}$, or choose to get vaccinated, with total perceived costs given by: $C_i^{Vac} + \beta_i^{vac} C_i^{inf}$. Therefore, we express the perceived costs of the individual i's choice C_i as follows:

$$C_i = \begin{cases} C_i^{Vac} + \beta_i^{vac} C_i^{inf} & \text{acceptance of vaccination} \\ \hat{\beta}_i C_i^{inf} & \text{Rejection of vaccination} \end{cases}$$

To simplify the cost function without losing generality, we introduce the cost ratio between C_i^{inf} and C_i^{Vac}. This can be denoted as: $r_i^V = \frac{C_i^{Vac}}{C_i^{inf}}$. Thus, the decision to accept vaccination occurs when the cost of getting vaccinated is lower than the cost of not receiving the vaccine, or if the fixed cost ratio of vaccination is lower than the differential of the risk of infection without the vaccines: $r_i^V < \hat{\beta}_i - \beta_i^{vac}$. In this case, the costs of getting vaccinated can be expressed as: $C_i = C_i^{Vac} + \beta_i^{vac} C_i^{inf}$. The rejection of vaccination would translate to a cost of getting vaccinated that is higher than the cost of not getting the shot: $r_i^V > \hat{\beta}_i - \beta_i^{vac}$, and a cost of not getting vaccinated of $\hat{\beta}_i C_i^{inf}$.

In the case where the costs of both options are equal, an individual would be indifferent in choosing either to get vaccinated or not, and is more likely to not get vaccinated due to the omission bias. As a consequence, the decision of not getting vaccinated is taking under the condition: $r_i^V \geq \hat{\beta}_i - \beta_i^{vac}$.

$$C_i = \begin{cases} C_i^{Vac} + \beta_i^{vac} C_i^{inf} & if \;\; r_i^{Fix} < \hat{\beta}_i - \beta_i^{vac} \\ \hat{\beta}_i C_i^{inf} & if \;\; r_i^{Fix} \geq \hat{\beta}_i - \beta_i^{vac} \end{cases}$$

We introduce the variable γ_i to represent an individual's vaccination options. There are two possible decisions an individual can make: $\gamma_i = 1$ corresponds to accepting vaccination, while $\gamma_i = 0$ represents rejecting it. Taking into consideration this parameter, we can write the costs functions as follows: $C_i^{\gamma_i} = \gamma_i\left[C_i^{Vac} + \beta_i^{vac} C_i^{inf}\right] + (1 - \gamma_i)\hat{\beta}_i C_i^{inf}$, where: $C_i^1 = C_i^{Vac} + \beta_i^{vac} C_i^{inf}$ and $C_i^0 = \hat{\beta}_i C_i^{inf}$. Based on the perceived costs and probabilities associated with both choices for an individual i, we can express the cost-minimized choice in the following manner:

$$\gamma_i = \begin{cases} 1 & if \;\; r_i^{Fix} < \hat{\beta}_i - \beta_i^{vac} \; or \; acceptance \; of \; vaccination \\ 0 & if \;\; r_i^{Fix} \geq \hat{\beta}_i - \beta_i^{vac} \; or \; Rejection \; of \; vaccination \end{cases}$$

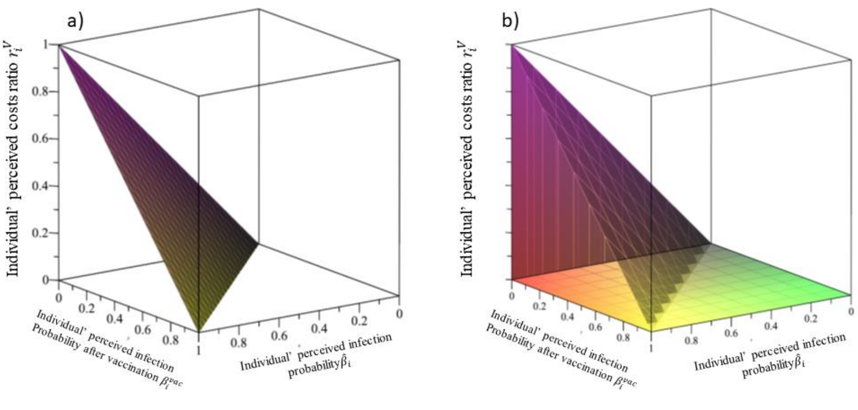

Figure 1: The vaccination behavior based on the combination of the perceived costs and probabilities of infection for an individual i. The graph a on the left depicts the indifference between the two options of

getting vaccinated or not. On the right, the graph b illustrates the air of vaccination acceptance: $r_i^V < \hat{\beta}_i - \beta_i^{vac}$

If all individuals adopt the same strategy of minimizing their cost functions, they will reach a steady state where no individual has an incentive to change their vaccination decision. The graphical representation in Figure-1-a, visually illustrates the highlighted surface where individuals are indifferent between getting vaccinated or not. The figure Figure-1-b depicts the region where the vaccination option becomes the less costly choice.

2. The Ripple Effect: Exploring social influences on vaccination choices

In the stage of a voluntary vaccination program, individually centered decisions are constructed through a perceived cost analysis as defined previously, those decisions are influenced by their social association. In fact, whether or not to opt for the vaccination decision depends not only on the individual costs assessment of each choice, but also on the perceived behavior of others (Ndeffo Mbah et al., 2012). In this section, social pressure among the population is considered to clarify its impact on the decision-making process of vaccination. We denote S_i the social group neighboring of individual i, every individual i find themselves neighboring a number of individuals N_i in various social settings. Each individual i has N_i neighbors $k \in N_i$ in their social group, whose vaccination decisions are represented by $\gamma_{i,k}$, where $\gamma_{i,k} = 1$ indicates i observes vaccination of member k and $\gamma_{i,k} = 0$ indicates i observes refusal of member k.

The average vaccination uptake in i's neighborhood, as perceived by the individual i, is:

$$\bar{\gamma}_i = \frac{\sum_{k=1}^{N_i} \gamma_{i,k}}{N_i}$$

To assess the probability of an individual shifting their decision to that of the majority, we use the Fermi function (Fu et al., 2011). It is a sigmoid function that has been widely used for describing how individuals' behavioral changes as a response to the discrepancy between two different choices. The parameter ϕ_i illustrates the sensitivity of individuals to the choice difference from their social neighborhood; therefore, a higher ϕ_i translates to a higher responsiveness, and an individual being more sensitive to the difference. In this case, a shift of the initial optimal decision $\tilde{\gamma}_i$ is more likely to occur, to approach that of majority of the group members. The probability $p_i(i \leftarrow S_i)$ of copying the group's strategy is given by:

$$p_i(i \leftarrow S_i) = \frac{1}{1 + \exp\{-\phi_i |\gamma_i - \bar{\gamma}_i|\}}$$

Hence, we define $p_i(i \leftarrow S_i)$ as the probability of an individual switching their decision to copy that of the majority made by their neighbors. There will be a shift of the individual optimal decision γ_i with a probability $p_i(i \leftarrow S_i)$, and with a probability $\big(1 - p_i(i \leftarrow S_i)\big)$, the individual is going to keep the less costly decision $\tilde{\gamma}_i$. $p_i(i \leftarrow S_i) = 0$ corresponds to the case of a cost-based decision maker, whereas $p_i(i \leftarrow S_i) = 1$ indicates that the individual is an absolute social follower. Consequently, the costs function would be as follows:

$$C_i^{\gamma_i} = p_i(i \leftarrow S_i) C_i^{Social} + \big(1 - p_i(i \leftarrow S_i)\big) C_i^{Individual}$$

where:

$C_i^{Social} = |\gamma_i - \bar{\gamma}_i|$ represents the implicit cost of deviating from the group norm.

$C_i^{Individual}$ is the individual's cost based on their personal decision (as derived in the previous section).

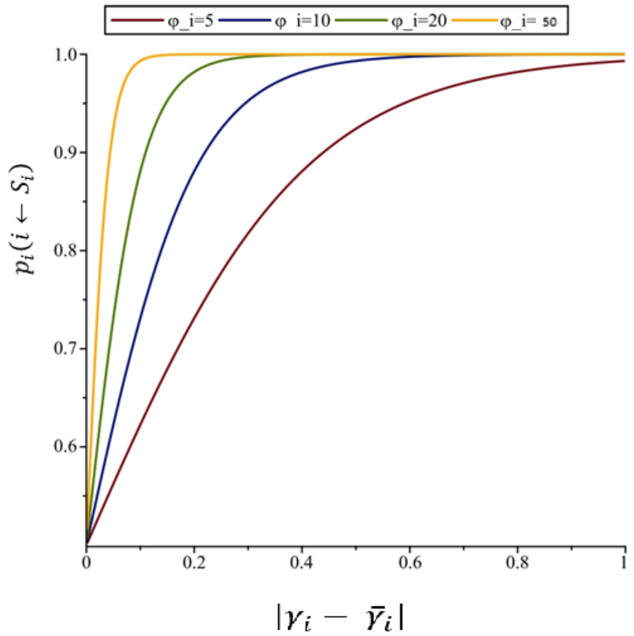

Figure 2: The graph depicts the perceived gap between the average social choice of the group and the individual's optimal choice, and the probability of the individual to shift their decision to that of the majority of their social group. The impact is also influenced by the responsiveness to the choice discrepancy, here we illustrate different levels of ϕ_i.

In figure 2, the graph illustrates the relationship between the difference $|\gamma_i - \bar{\gamma}_i|$ and the probability of individuals contemplating a change in their strategy by adopting the option closest to the group's average. As this difference increases, the likelihood of an individual reconsidering their optimal choice $\tilde{\gamma}_i$ and opting for a strategy closer to the average of the group also rises. The existence of such a discrepancy acts as a catalyst, prompting individuals to reassess their decisions and contemplate adopting an alternative that brings them in line with the collective. Moreover, the probability of individuals opting for the option closest to the group average is additionally influenced by ϕ_i, their level of responsiveness. Individuals with higher responsiveness exhibit a greater inclination to adjust their decisions and align them with the choices made by the group. This means that individuals who are more responsive to the actions and preferences of the group are more likely to adopt strategies that mirror the collective decision-making process. It is clear that plugging into the social pressure works as a "double-edged sword", which, on the one hand, promotes vaccine uptake in the population when it's the uptake of taking a shot is the majority, but, on the other hand, it may also impede it if the majority are refusing the vaccines. Consequently, the presence of social-pressure can facilitate cluster formation among the individuals whose behaviors are inclined to conform to the majority of their neighbors.

3. Results: Vaccination policies and implications on individuals' decision making process

The interplay between vaccination policies and decision-making is of paramount importance in devising and executing strategies that foster vaccine acceptance and achieve widespread coverage, thereby playing a vital role in controlling and managing the ongoing pandemic. The effectiveness of vaccination policies hinges not only on individual decision-making but also on the broader socio-political frameworks influencing these choices. As highlighted by Garzarelli et al. (2022), government policies like lockdowns involve a trade-off between health and liberty. In this section, our primary goal is to investigate the influence of vaccination policies on the decision-making process. We place particular emphasis on examining how alterations in the costs associated with vaccination affect individuals' choices. By gaining a deeper understanding of this relationship, we can effectively evaluate the implications of COVID-19 policies implemented by regulatory authorities. These insights will enable us to make informed assessments and recommendations regarding policy strategies that can enhance vaccine acceptance and coverage.

Mandatory program of Vaccination:

The debate over mandatory vaccination raises concerns about personal autonomy and the justification for such policies. While some argue that mandatory vaccination infringes on individual freedom, some ethical arguments support these policies (Colgrove et al., 2022). One argument is based on the moral obligation not to harm others, as unvaccinated individuals can potentially harm those more susceptible to infection (Yeh, 2022). Another argument that is in favor of a compulsory vaccination is that of the free-rider problem (Stiglitz, 1988), and left to make a decision based on their own self-interests, individuals might choose not to get vaccinated even if they believe that vaccines can lower the infection rate. As seen in the previous sections, a voluntary program have proven to have a limited effect in encouraging vaccination, and are not sufficient for the population to reach herd immunity.

In the figure-1-b, the graph illustrates the combination of probabilities and costs that individuals would perceive as less costly to get vaccinated under a voluntary program. If the authorities would introduce a mandatory policy, for the share of the population that would choose not to get vaccinated, they will bear higher costs depending on how they compare the outcome of getting the shot or not. Regulators could justify the application of the policy by communicating the considerable risks that might be inflected to others or to a specific share of the population, and emphasize on the benefits of vaccination by conveying that it would significantly reduce the contagion. Depending on the arguments made to the public, authorities should legitimize the necessity of a compulsory vaccinated based on individuals' duty and the evidence on risks, and the policy should be portrayed as a non-negotiable legal obligation towards a more vulnerable share of the population.

Passport to Health: Green-Pass as a substitute to a mandatory vaccination policy

Governments have introduced the green pass as a means to incentivize vaccination among the population (Wilf-Miron et al., 2021). This document allows individuals who have been vaccinated to access public services and engage in recreational activities. However, similar to compulsory vaccination policies, the green pass has faced challenges in terms of its constitutionality and perceived usefulness. The unique aspect of the green pass is that, unlike a mandatory vaccination policy, it imposes restrictions on access to various activities gradually at different time intervals, targeting different social groups at each phase of application.

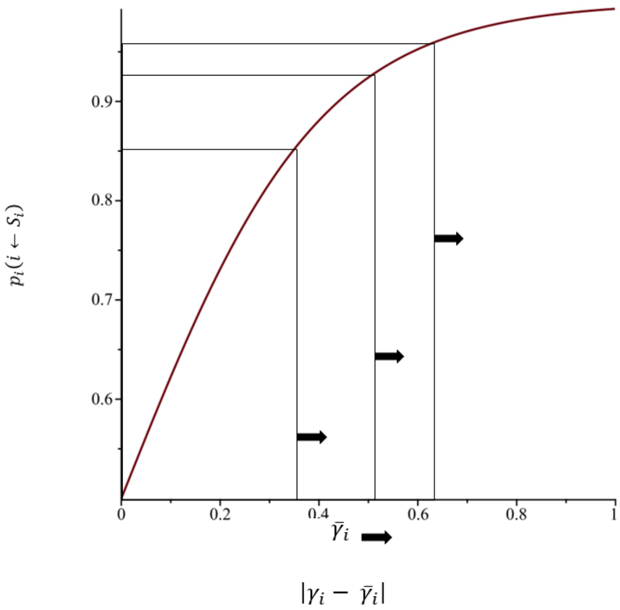

Figure 3: The figure depicts the probabilities of imitation of an individual i that perceives not getting vaccinated as the less costly option, in a group that initially has a low vaccination rate. It shows the progression of the vaccination decision average following the application phases of the Green-pass, shifting the average to be closer to that of an acceptance.

Considering the concept of imitation tendencies, let's examine the scenario involving an individual i, who views not getting vaccinated as the optimal option $(\gamma_i = 0)$, and belongs to a group characterized by a low average vaccination rate. The introduction of the green pass policy facilitates a gradual vaccination process, targeting a portion of the group during each stage. At each phase of application, as illustrated in the graph on in figure 3, the average of vaccination uptake depending in the social group $\frac{\sum_{k=1}^{N_i} \gamma_{i_{i,k}}}{N_i}$ increases and approaches 1. Hence, the probability of imitation of an individual i that refuses to take a shot as the optimal decision, increases due to the progressive expansion of the vaccinated share in the socially neighboring group S_i.

Consequently, the green pass incentivizes vaccination through accentuating the social compliance to getting vaccinated, and serves as an alternative to mandatory vaccination, gradually targeting a larger population while avoiding potential adverse social consequences. It allows for flexible regulations and adaptability based on risks and objectives and its application can assist in avoiding adverse social repercussions a mandatory vaccination might provoke. The possibilities the tool offers regulators to adapt and target specific populations makes it a valuable strategy to encourage vaccination and control the spread of infectious diseases.

4. Extending the Analysis to Empirical Evaluation: A Focused Methodology

To empirically validate the theoretical insights presented in this study, we propose a difference-in-differences (DiD) methodology. This approach capitalizes on the phased introduction of the Green Pass policy as a natural experiment to measure its causal impact on vaccination rates. By comparing regions or population groups that were exposed to the policy at different times (treatment groups) with those that were not yet exposed or less affected (control groups), this method isolates the effects of the Green Pass on vaccination behavior.

The Green Pass, which restricted access to public spaces and services for unvaccinated individuals, offers a structured opportunity to analyze behavior under incentivized policy enforcement. The primary outcome variable for this analysis would be the vaccination rate, tracked over time and across regions. Key independent variables include the timing and intensity of Green Pass implementation, as well as demographic and socio-economic factors such as age, gender, education, and income levels. These controls ensure that observed effects are attributable to the policy rather than other time-dependent factors.

The required data include vaccination records (e.g., weekly vaccination rates by region and dose type), policy implementation timelines detailing when and how the Green Pass was enforced, and demographic data to capture regional heterogeneity. Additionally, mobility and social interaction metrics, sourced from platforms like Google Mobility Reports, can provide insights into social influence mechanisms. The temporal scope of the dataset should cover periods before, during, and after the policy's introduction to capture dynamic effects.

The DiD approach compares trends in vaccination rates between treatment and control groups, focusing on the interaction between the time of policy implementation and the regions affected. The core analysis would quantify the incremental increase in vaccination uptake attributable to the Green Pass. This model also allows for examining variations in policy effectiveness across regions and demographics, as well as testing the role of social clustering in amplifying vaccination behavior.

This methodology offers a rigorous empirical framework to extend the theoretical work presented. By leveraging Green Pass data, it becomes possible to validate the proposed mechanisms of cost influence and social imitation, providing actionable insights for future policy design. This transition from theory to data-driven analysis not only substantiates the study's conclusions but also enriches the discourse on effective public health interventions.

5. Individual's perceptions and COVID-19 certifications

During the COVID-19 pandemic, health certifications were proposed as a means to facilitate safer access to various activities. These certifications took different forms, such as QR codes (Liang, 2020) or paper certificates (Pavelka et al., 2021), and granted individuals permission to return to workplaces and non-essential establishments. They served as an incentive for vaccination, resulting in increased vaccination rates, particularly among the younger population (Mills and Rüttenauer, 2022). In order to examine the impact of health certificates, we focus on the proportion of the population that remains unvaccinated due to refusal or hesitancy. It is important to note that only those who are willing to access establishments that require presenting a certification are concerned by the application of the policy.

In our model, individuals engage in a decision-making process where they weigh the benefits and costs associated with vaccination. Those who refuse vaccination are presented with two alternatives: obtaining periodic test-negative certificates or acquiring documentation illicitly. We also consider the limited perspective individuals have regarding the duration for which negative certificates remain applicable.

The decision-making process is driven by the evaluation of benefits and costs associated with each choice. Consequently, an individual i will choose to get vaccinated if the total costs associated with obtaining the certification are both higher than the costs of vaccination and lower than the costs of acquiring counterfeit certificates.

6. Choosing testing: the dynamic duo of negative tests and vaccination

Opting for periodic negative tests involves obtaining regular testing to demonstrate a lack of infection. Individuals perceive a fixed extent of application when deciding to get the shot or not, represented as T_i. Additionally, we incorporate the associated cost of obtaining a negative test that we assume to be fix and only incorporates a known monetary cost of the test, denoted as C^{Test}, Costs of acquiring the tests occur at different points in time, and the value attached to them may differ because of various sources of time preference[33]. The standard technique to enable comparison is by calculating present values, with future costs receiving less weight than present ones. For this, a discount rate is used and the present value of a stream of costs can be defined as: $\left\{\sum_{t=1}^{T_i} \frac{C^{Test}}{t}\right\}$, which is a partial sum of harmonic series. To approximate the sum[34], we denote γ the constant that is defined as the limit of the sequence:

$$\gamma = \sum_{t=1}^{T_i} \frac{1}{t} - ln(T_i)$$

Here γ represents the Euler–Mascheroni constant (γ = 0.577). Consequently, we can write the estimated future costs of acquiring a test as: $C^{Test}[ln(T_i) + \gamma]$
By weighing the costs of different options, an individual i will choose to get vaccinated under the following constraint:

$$C_i^{Vac} + \beta_i^{vac} C_i^{inf} < \hat{\beta}_i C_i^{inf} + C^{Test}[ln(T_i) + \gamma]$$

$$C^{Test} > \frac{C_i^{Vac} + (\beta_i^{vac} - \hat{\beta}_i) C_i^{inf}}{[ln(T_i) + \gamma]}$$

Individuals might perceive differently the same policy, depending on the length of application T_i. Considering the costs of the negative test, a higher iteration number T_i naturally corresponds to an increased probability of individuals perceiving vaccination as the less costly option. For the vaccination option to be the optimal one, the applied test's costs should cover the perceived costs of vaccination relatively to the option of not getting the shot, while taking into account how the information is translated from individual to another, and the possibilities of the costs discount during the period of application.

These findings emphasize the significance of clear and effective communication from authorities regarding the duration of mandatory testing requirements. It is crucial to provide transparent information about the timeframe during which testing will be necessary. This transparency is vital as if individuals perceive the testing period to be shorter, they may be more inclined to consider frequent testing as a viable alternative to vaccination. This perception can subsequently reduce their willingness to get vaccinated.

By ensuring that individuals have a clear understanding of the testing requirements and the potential duration, authorities can assist individuals in more accurately weighing the costs and benefits of vaccination versus testing.

Tackling forgery, illicit activities, and vaccination:

Another option that we assumed to be available is that of forged documents. The counterfeit certificates have a fixed cost C^{Fake}, and a fine f^{Fake} is applicable depending on the probability of detection p_i^{Fake}: $C^{Fake} + p_i^{Fake} f^{Fake}$. We express the costs comparison in terms of ratio relatively to the fine of the test:

$$\hat{\beta}_i C_i^{inf} + C^{Test}[ln(T_i) + \gamma] < \hat{\beta}_i C_i^{inf} + C^{Fake} + p_i^{Fake} f^{Fake}$$

Or: $r^{Fake} > r^{Test/Fine}[ln(T_i) + \gamma] - p_i^{Fake}$ where: $r^{Fake} = \frac{C^{Fake}}{f^{Fake}}$ and $r_i^{Test} = \frac{C^{Test}}{f^{Fake}}$

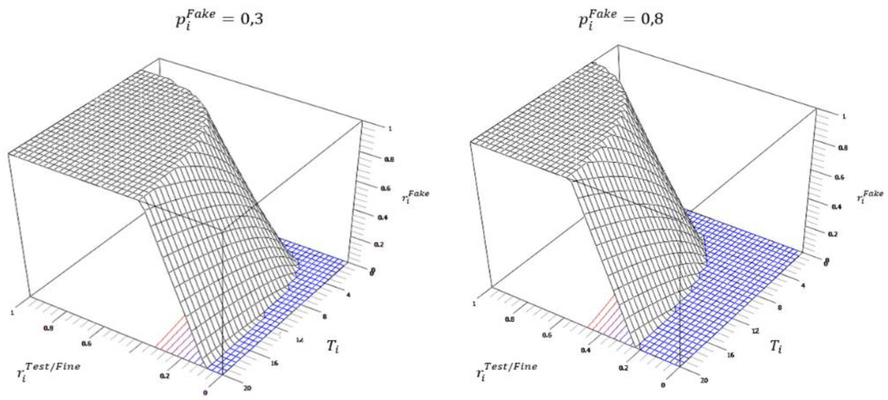

Figure 4: the area depicted in the graphs is $r^{Fake} = r^{Test/Fine}[ln(T_i) + \gamma] - p_i^{Fake}$*. For any combination of costs and probabilities that is higher than the threshold, the individual i will find it less costly to acquire a negative test. It depict the changes that occur if the individual perceived different negative test period from 0 to 20, and three levels of probability of detection of the illicit activity.*

The presented graphs in Figure 4 illustrate how a change in perception regarding the probability of detection can significantly influence the outcome of the vaccination decision-making process. This emphasizes the crucial role of effective communication regarding measures aimed at curbing the use of forged documents. To address this issue, it is essential to communicate the potential ramifications of acquiring illegal documents, while also considering individuals' tendencies to discount future consequences and their varying perceptions of the timeframe during which negative test results remain valid.

Regulators should implement fines that appropriately reflect the different levels of iterations and probabilities perceived by individuals. Furthermore, broadcasting information about the potential legal consequences of utilizing counterfeit certificates can serve as a deterrent to those who might contemplate engaging in such activities. By taking these steps, authorities can work towards mitigating the problem and discouraging individuals from participating in fraudulent practices.

7. Discussion

A thorough comprehension of individuals' behavior when it comes to making health decisions plays a pivotal role in anticipating the potential consequences of policies aimed at improving vaccination acceptance rates. The process of decision making in this context relies on individuals' personal beliefs, which shape their perceived parameters. Consequently, policymakers should effectively communicate the pertinent details that enable individuals to update their information regarding associated costs and timeframes. By doing so, policymakers can facilitate a more informed decision-making process, ultimately fostering greater acceptability of vaccination and enhancing public health outcomes. To prevent divergence that might occur after the application of any policy, the interventions that would encourage vaccination should be communicated clearly to prevent possible temporal discounting, as well as the consequences of any illegal activities discouraged through conveying the appropriate fines.

Strengths and Limitations

Various mathematical models have employed payoff-based approaches to understand individuals' vaccination decisions, considering perceived costs and benefits (Chen, 2006; Codeço et al., 2007; Vardavas et al., 2007). As an advancement over existing models, we propose considering an individual's vaccination decision as a hybrid process that incorporates both self-initiated cost minimization and the influence of social group's average decision. Our study introduces a comprehensive modeling framework that incorporates social factors into individuals' decision-making processes, specifically focusing on understanding vaccination policies and their underlying mechanisms of influence. However, it is crucial to acknowledge that the findings of this study may be influenced by the particular social network considered. Like any model, our approach also necessitated making certain simplifying assumptions. Furthermore, it is important to acknowledge that our research assumes individuals to be passive recipients of social influence, and we have not explicitly considered their active behaviors in our analysis. These assumptions provide a foundation for our model but should be recognized as potential limitations in understanding the full complexity of individuals' decision-making processes.

8. Conclusions

The policies employed in inciting individuals to getting vaccinated during the COVID-19 pandemic were primarily strategies that impacted the costs. Even though increasing the costs of the refusal or reluctance in getting vaccinated might encourage individuals to get the shot, those policies do not aim in changing the perceptions around the rates of infection or the costs of any of the decisions of getting vaccinated or not. The intervention might be effective in reaching head immunity, and stopping the spread of the disease, however, authorities might face the same social reactions in case another health crises might hit in the future. A long-term remedy to vaccination hesitancy might be an establishment of channels of information transmission, that would continuously advise and clarify misconceptions and doubts around vaccines in particular, and health related questions in general. Educational programs might also contribute in the increase of individuals' confidence in public health management, improve the relationship between policymakers and scientific and technical bodies, and increase transparency over the use of medical data collected within the population.

References

Anderson R.N. et al. (2004), 'Deaths: injuries, 2001' in Natl Vital Stat Rep., 52(21), 1-86.

Bacaër N., Bernoulli D. (2011), 'D'Alembert and the inoculation of smallpox (1760)' in A Short History of Mathematical Population Dynamics. Springer. DOI: 10.1007/978-0-85729-115-8_4

Bauch C.T., Galvani A.P., Earn D.J. (2003), 'Group interest versus self-interest in smallpox vaccination policy', in Proc Natl Acad Sci, 100(18), 10564-10567. DOI: 10.1073/pnas.1731324100

Bish A., et al. (2011), 'Factors associated with uptake of vaccination against pandemic influenza: a systematic review. Vaccine.', 29(38), 6472-6484. DOI: 10.1016/j.vaccine.2011.06.107

Black S., Rappuoli R. (2010), 'A crisis of public confidence in vaccines.' in Sci Transl Med, 2(61). DOI: 10.1126/scitranslmed.3001738

Brosio, G., Pelosi, R., Zanola, R. (2022), 'Short-term exit from pandemic restrictions: Did European countries' speed converge?' in The European Journal of Comparative Economics, 19(2), 145–159. DOI: 10.25428/1824-2979/015

Buonomo B., Lacitignola D. (2011), 'On the Backward Bifurcation of a Vaccination Model with Nonlinear Incidence.' in Nonlinear Analysis: Modelling and Control, 16, 30-46.

Cai C.R., Wu Z.X., Guan J.Y. (2014), 'Effect of vaccination strategies on the dynamic behavior of epidemic spreading and vaccine coverage.' in Chaos Solitons Fractals, 62, 36-43. DOI: 10.1016/j.chaos.2014.04.005

Chen F.H. (2006), 'A susceptible-infected epidemic model with voluntary vaccinations.' in Journal Math Biol, 53(2), 253-272. DOI: 10.1007/s00285-006-0006-1

Codeço C.T., et al. (2007), 'Vaccinating in disease-free regions: a vaccine model with application to yellow fever.' in Journal Royal Soc Interface, 4(17), 1119-1125. DOI: 10.1098/rsif.2007.0234

Colgrove J., Samuel S.J. Freedom (2022), 'Rights, and Vaccine Refusal: the History of an Idea.' in Am Journal Public Health, 112(2), 234-241. DOI: 10.2105/AJPH.2021.306504

Eckalbar J.C., Eckalbar W.L. (2011), 'Dynamics of an epidemic model with quadratic treatment.' in Nonlinear Analysis Real World Applications, 12(1), 320-332

Ferguson N.M. et al. (2006), 'Strategies for mitigating an influenza pandemic.' in Nature, 442(7101), 448-452. DOI: 10.1038/nature04795

Fine P., Eames K., Heymann D.L.(2011),' "Herd immunity": a rough guide.' in Clin Infect Dis., 52(7), 911-916. DOI: 10.1093/cid/cir007

Fu F. et al. (2011), 'Imitation dynamics of vaccination behaviour on social networks.' in Proc Biol Sci., 278(1702), 42-49. DOI: 10.1098/rspb.2010.1107

Galvani A.P., Reluga T.C., Chapman G.B. (2007), 'Long-standing influenza vaccination policy is in accord with individual self-interest but not with the utilitarian optimum.' in Proc Natl Acad Sci U S A, 104(13), 5692-5697. DOI: 10.1073/pnas.0606774104

Gaygısız Ü. et al. (2010), 'Why were Turks unwilling to accept the A/H1N1 influenza-pandemic vaccination? People's beliefs and perceptions about the swine flu outbreak and vaccine in the later stage of the epidemic.' in Vaccine, 29(2), 329-333. DOI: 10.1016/j.vaccine.2010.10.030

Garzarelli G., Keeton L., Sitoe A.A. (2022), 'Rights redistribution and COVID-19 lockdown policy.' in European Journal of Law and Economics, 54(1), 5-36. DOI: 10.1007/s10657-022-09732-x

Hothersall E.J., de Bellis-Ayres S., Jordan R. (2012), 'Factors associated with uptake of pandemic influenza vaccine among general practitioners and practice nurses in Shropshire' in UK Prim Care Respir Journal, 21(3):302-307. DOI: 10.4104/pcrj.2012.00056

Jianwei W. et al. (2020), 'Realistic decision-making process with memory and adaptability in evolutionary vaccination game' in Chaos, Solitons & Fractals, 132(109582). DOI: 10.1016/j.chaos.2019.109582.

John T.J., Samuel R. (2000), 'Herd immunity and herd effect: new insights and definitions.' in Eur Journal Epidemiol, 16(7), 601-606. DOI: 10.1023/a:1007626510002

Larson H.J., Broniatowski D.A. (2021), 'Why Debunking Misinformation Is Not Enough to Change People's Minds About Vaccines.' in American Journal Public Health, 111(6), 1058-1060. DOI: 10.2105/AJPH.2021.306293

Larson H.J. et al. (2011), 'Addressing the vaccine confidence gap.' in Lancet, 378(9790), 526-535. DOI: 10.1016/S0140-6736(11)60678-8

Liang F. (2020), 'COVID-19 and Health Code: How Digital Platforms Tackle the Pandemic in China. ' in Social Media and Society, 6(3), 2056305120947657. DOI: 10.1177/2056305120947657

Lindstrand A. et al. (2021), 'The World of Immunization: Achievements, Challenges, and Strategic Vision for the Next Decade.' in Journal Infect Dis, 224(12 Suppl 2), S452-S467. DOI: 10.1093/infdis/jiab284

Mills M.C., Rüttenauer T. (2022), 'The effect of mandatory COVID-19 certificates on vaccine uptake: synthetic-control modelling of six countries.' in Lancet Public Health, 7(1), e15-e22. DOI: 10.1016/S2468-2667(21)00273-5

Morganti, P. (2023), 'Indebtedness and growth in the EMU before the Covid-19 pandemic shock.' in The European Journal of Comparative Economics, 20(1), 39-70. DOI: 10.25428/1824-2979/018

Ndeffo Mbah, M. L. et al. (2012), 'The impact of imitation on vaccination behavior in social contact networks. ' in PLoS computational biology, 8(4), e1002469. DOI: 10.1371/journal.pcbi.1002469

Pavelka, M. et al. (2021), 'The impact of population-wide rapid antigen testing on SARS-CoV-2 prevalence in Slovakia.' in Science, 372(6542), 635-641. DOI: 10.1126/science.abf9648

Stiglitz J.E. (1988), Economics of the public sector, 2nd ed., New York.

Tillett H.E. (1992), 'Infectious Diseases of Humans; Dynamics and Control.' in Epidemiol Infect, 108(1), 211.

Vardavas R., Breban R., Blower S. (2007), 'Can influenza epidemics be prevented by voluntary vaccination?' in PLoS Comput Biol, 3(5), e85. DOI: 10.1371/journal.pcbi.0030085

Wilf-Miron R., Myers V., Saban M. (2021), 'Incentivizing Vaccination Uptake: the "Green Pass" Proposal in Israel.' in JAMA, 325(15), 1503-1504. DOI: 10.1001/jama.2021.4300

Wu B., Fu F., Wang L. (2021), 'Imperfect vaccine aggravates the long-standing dilemma of voluntary vaccination.' in PLoS One, 6(6), e20577. DOI: 10.1371/journal.pone.0020577

Xia S., Liu J. (2013), 'A computational approach to characterizing the impact of social influence on individuals' vaccination decision making' in PLoS One, 8(4), e60373. DOI: 10.1371/journal.pone.0060373

Yeh M.J. (2022), 'Solidarity in Pandemics, Mandatory Vaccination, and Public Health Ethics.' in American Journal Public Health, 112(2), 255-261. DOI: 10.2105/AJPH.2021.306578

Yi, R., Gatchalian, K. M., Bickel, W. K. (2006), 'Discounting of past outcomes.' in Experimental and clinical psychopharmacology, 14(3), 311-317. DOI: 10.1037/1064-1297.14.3.311

Zhonghua L. Z. (2020), 'Epidemiology Working Group for NCIP Epidemic Response, Chinese Center for Disease Control and Prevention.' in Chinese journal of epidemiology, 41(2), 145-151. DOI: 10.3760/cma.j.issn.0254-6450.2020.02.003

Zijtregtop E.A. et al. (2009), 'Which factors are important in adults' uptake of a (pre)pandemic influenza vaccine?' in Vaccine, 28(1), 207-227. DOI: 10.1016/j.vaccine.2009.09.099