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Impact of Social Influence on Individuals' Vaccination Decision Making - A theoretical Approach

Abstract: Infectious diseases historically caused considerable losses to human societies, and they continue to do so today. Scientific developments allowed for individuals to get immunized from contracting vaccine-preventable infectious diseases, and the novelty is considered one of the greatest public health achievements of the last century. Due to COVID- 19 global health crisis, societies have witnessed an unprecedented disruption of the social and economic environment and experienced a new establishment of the habitat in which people interact. The actions made by governments and societal reactions raised concerns over the management of the ongoing crisis, and a general interest rose on the underlying intentions and behaviors to understand the developments of the State and populations responses. In the past few decades, research on vaccination behavior has been focused on a variety of factors, and the reasons for vaccination and most particularly COVID-19 vaccine hesitancy remain complex.

To address this issue, this paper presents a theoretical framework of the vaccination decision making process, taking into consideration the individual's perceived cost/benefit analysis, and social influences of their gourp of membership. Based on various policies utilized to encourage vaccination against COVID- 19, we look into the impact of those interventions on the defined framework of the decision making process.

The results show that understanding the perception of individuals on different components of their utility is key to implementing an effective policy, the process of imitation is impactful as well, and can create a shift from the cost minimizing decision. Conveying information sustainably around the share of the immune population and efficiency of the vaccine, can orientate individuals to re-examine their perceptions, and hinder free-riders from observing the opportunity to exploit herd immunization. Communicating on the length of the application of an intervention, and determining the appropriate fines on forged documents, can aid individuals in updating their believes and dissuading any potential divergence from the aims of the public regulator.

Introduction:

Through the history of humanity, contagious diseases have continuously been ominous to human societies all over the world (Fraser C. et al., 2009). The spread of those infections expanded further due to the globalization and the steady development of the cross border travels. In this context, preemptive vaccination has become the major strategy for intervention and control against infectious diseases (CDC 2009), and is considered as the most effective measure of modern times in reducing morbidity and mortality (Anderson RM, May RM., 1991). However, vaccination represents a long-standing social dilemma for public health regulators, and despite the scientific consensus that vaccines are safe and effective, unsubstantiated claims doubting their safety still occur to this day (Chen W, Landau S, Sham P, Fombonne E., 2004). After the outbreak of the COVID-19 pandemic, the debate was revived and the questions around regulations and human rights became the center of debates and concerns.

One of the main goals for studying infectious diseases is to improve the control over infections, and ultimately to reduce the contagion within a population. Models applied to epidemiology can be a powerful tool to approach an understanding of the individuals' behavior, and their reaction of policies that aim towards an expansion of the vaccinated share. Going back to the eighteenth century (Bacaër N., 2011), mathematical modelling in epidemiology has witnessed important conceptual and technical developments, those studies can offer an analysis of the repercussions of a mixture of control strategies, and the extent to which they can contribute in scaling down the infection (Xia S, Liu J., 2013; Arino et al., 2004; Buonomo and Lacitignola, 2011; Cai et al., 2009a,b; Eckalbar and Eckalbar, 2011). The ratio of the vaccinated host population determines the effectiveness of a vaccination program (Galvani AP, Reluga TC, Chapman GB, 2007; Wu B., Fu F., Wang L., 2011), the collective outcome of vaccination decisions dictates the level of population immunity, accordingly, controlling the spread on an infectious disease depends on individuals' decision to get vaccinated or not (Ferguson NM & al, 2006). This decision plays a focal role in reaching and sustaining an adequate vaccination level (Larson HJ & al, 2011; Black S., Rappuoli

R., 2010). In the case where the share of the immune host population surpasses the critical level of the herd immunity threshold (Fine P, Eames K, Heymann DL 2011), vaccination could be an effective tool to impede the widespread of the infection (John TJ, Samuel R. 2000).

To better understand the decision making process, the examination of individuals' optimized pay-offs based on the perceived risks and benefits of vaccination have been widely used, through game-theoretical analysis (Bauch CT, Galvani AP, Earn DJD. 2003). Some considering the issue of incomplete information by analyzing the personal believes on the various utility components (Coelho FC, Codeco CT. 2009), and the sources of information (d'Onofrio A, Manfredi P, Salinelli E. 2007). The focus in many of the previous studies was on several determinants that include the risks and costs of disease infection (Myers LB, Goodwin R. 2011), the safety and efficacy of vaccine (Streefland PH. 2001), in addition to the different costs associated with the taking the shot, such as time, productivity or any medical expenses that the action might necessitate (Bauch CT, Earn DJD. 2004), as components of the vaccination decision individuals have to make. The willingness to get vaccinated will reduce when the individuals will perceive potential risks due to the side effects of the shot (Roberts RJ & al, 1995). Other studies expanded on those elements to include social (Larson HJ & al, 2011) or financial costs (Streefland PH. 2001) in both cases of infection with and without being vaccinated.

Behavioral aspects of the decision making have also been looked into, to comprehend the mechanisms of imitation (Bauch CT., 2005) and social learning (Bauch CT., Bhattacharyya S., 2012). As it has been shown that the individual cannot consider the options in actuality, but more so the perception about the disease and the vaccines, those dynamics have been explored to explain the impact of individuals' interactions in a social environment (Bish A & al, 2011). Friends or family members can influence the vaccination decision (Lau JTF & al, 2010), attitudes shared among parents more specifically would impact the vaccination decisions of their children (Eames KTD, 2009). Other social interactions might guide the individual's decision, through recommendations from health professionals (Zijtregtop E. & al, 2009) or colleagues as an example (Barriere J & al, 2010).

Time and experience are also crucial in assisting individuals to decide, therefore a concern has been raised over the set of information that is taken into account in the decision making process, especially for newly developed vaccines against emerging infectious diseases (SteelFisher GK & al 2010), due to the lack of such prior knowledge. As the believes regarding vaccinated share of the population get updated while it increases, the remaining individuals that choose not to get the shot observe that they are becoming progressively more protected, since it is less probable for them to get infected by the disease (Fine, P., Eames, K., Heymann, D. L., 2011). If herd immunity is attained by the host population, it creates a public good that is susceptible to free-riding. Acting on their own self-interest, it is theoretically predictable for individuals to weigh the pros and cons based on the available information (Hardin, G. 1968), and the state of a perceivably immune population might dissuade the newcomers from getting vaccinated. With increasing levels of vaccination coverage in the community, it would be less likely for an unvaccinated to become infected, and the incentive to get the short might be reduced, while still benefitting from the herd immunity. This equilibrium may lead to a low vaccination level, and a suboptimal coverage for the community (Galvani, A. P, Reluga, T. C. & Chapman, G. B. 2007), or even a reemergence of certain diseases that have been already under control. The dynamics of social versus self-interests generate a problematic instability in the vaccination uptake (Gordis, L. 2013), and this paradox is an inevitable problem in the vaccine market that makes it difficult to completely eradicate a disease (Bauch CT, Earn DJ, 2004).

To increase the immune share, voluntary programs have been shown to only partially incentivize the population to get the shot, and mounting evidence demonstrate that the level reached through the individuals' voluntary willingness to get the vaccine generally does not reach that of herd immunization (Reluga, T. C., Bauch, C. T. & Galvani, A. P. 2006; Bauch CT, Galvani AP, Earn DJD, 2003). Therefore, those programs often fail to protect populations from epidemics (Vardavas, R., Breban, R. & Blower, S. 2007). A recent example of this policy's shortcoming is the abrupt drop in of the combined measles-mumps-rubella vaccinations soon after administering it to children was made voluntary in Britain (Jansen, V. & al, 2003). In order to mitigate the repercussions of a disease spread, policy makers resort to other programs that would prompt a higher responsiveness from the population to increase the vaccination level, and some provoke vigorous debates about their civil liberties implications. A counter-policy would be the application of compulsory programs, which generate a serious concern over the possibility of infringement of individuals' rights (Colgrave J., 2006). Other strategies were established to avoid applying a mandatory program, and encourage the vaccination decision, especially during the Covid-19 pandemic. A strategy to increase vaccination up-take was the obligatory test-negative documents and health passports (Bamji A., 2019), as a requirement to access a wide range of activities. Though it might still be perceived unethical to restrict the individuals' movements (Persad G, Emanuel EJ., 2020), health certifications have been shown to encourage vaccination uptake (Wilf-Miron R, Myers V, Saban M., 2021).

This study is an analysis to describe the vaccination decision making process, through a theoretical model that considers the individuals believes on the costs engendered by both available options, either to get vaccinated or not. Based on social association, we also examine the possibility of an alteration of the individual decision to imitate that of their group of affiliation. Therefore, individuals are assumed to make their vaccination decisions by both minimizing the associated costs and examining their decision compared to that of others. In the next section, we evaluate various policies that aim to increase the vaccinated population, and their repercussions on the individuals' decision to get vaccinated or not.

Models and methods

Basic model:

In this section, we present the components of our model and discuss the assumptions.

We consider a given population and the case of a single epidemic outbreak. We assume that individuals can estimate the risk of disease infection based on their perceived disease severity, as reflected in the perceived disease transmission rate $\hat{\beta}_i$, as a consequence, an individual i can perceivably contract the disease with a probability $\hat{\beta}_i$. They also bear a cost of getting infected C_i^{inf} that includes any expenses related to healthcare, lost productivity, disease complications, or absence from work. The expected infection cost would be: $\hat{\beta}_i C_i^{inf}$. Under the assumption that individuals don't have the possibility to impact the perceived costs related to contracting the disease C_i^{inf}, the costs minimization would translate to the decrease of the probability of infection $\hat{\beta}_i$. In the case of unavailability of any pharmaceutical interventions, confinement measures, isolation, quarantine, could be solution to limiting the transmission rates (Lin TY & al, 2021).

Introduction vaccination under voluntary program:

In the stage of vaccination introduction, a public campaign to get the shot is initiated and individuals collect the available information to assist in forming their perception about the vaccines. In the case of Covid-19, and any other new disease outbreak, unlike other seasonal diseases, the accumulation of knowledge through experience is not a possibility, and getting vaccinated is a one-time decision that individuals have to make. During this stage, each individual decides whether or not to get the shot, based on their believes on the costs components.

Initially, an individual i forms an estimation on the vaccination costs that would include fixed costs $C_i^{Vac,Fix}$, related to any immediate monetary cost, the opportunity cost of time spent to get the vaccine and any perceived adverse health effects that the individual would endure if vaccinated. As well as the expected costs of getting infected after vaccination to account for imperfect vaccination $C_i^{Vac,Var}$ (Sudfeld CR, Navar AM, Halsey NA, 2010), that would depend on the risk β_i^{vac} of individuals contracting the disease after vaccination:

$$C_i^{Vac,Var} = \beta_i^{vac} C_i^{inf}$$

There are two possible decisions that an individual can make, and we denote γ_i representing the individual's vaccination decision:

$$\gamma_i = \begin{cases} 1 & acceptance\ of\ vaccination \\ 0 & Rejection\ of\ vaccination \end{cases}$$

Then, we can introduce a cost function for individual i with a decision γ_i, as follows:

$$C_i(\gamma_i) = \gamma_i\left[\, C_i^{Vac,Fix} + \beta_i^{vac} C_i^{inf}\right] + (1-\gamma_i)\hat{\beta}_i C_i^{inf}$$

We simplify the cost function without loss of generality by setting the parameter r_i that would describe the fixed cost ratio of C_i^{inf} and $C_i^{Vac,Fix}$, we denote $r_i^{Fix} = \frac{C_i^{Vac,Fix}}{C_i^{inf}}$.

$$c_i(\gamma_i) = \gamma_i\left[r_i^{Fix} + \beta_i^{vac}\right] + (1-\gamma_i)\hat{\beta}_i$$

Table 1. Parameters used for modeling the costs in the vaccination decision making

Symbol	**Meaning**
i	Individual indicator
$\hat{\beta}_i$	Perceived disease transmission rate for an individual i
C_i^{inf}	Perceived costs of infection of the individual i
$C_i^{Vac,Fix}$	Perceived fixed costs of vaccination for the individual i
$C_i^{Vac,Var}$	Perceived variable costs of vaccination for the individual i
β_i^{vac}	Perceived risk of contracting the disease after vaccination for the individual i
γ_i	The vaccination decision of the individual i
$C_i(\gamma_i)$	Cost function for individual i with a decision γ_i
r_i^{Fix}	Perceived fixed cost ratio
$c_i(\gamma_i)$	Relative cost function for individual i with a decision γ_i
$\tilde{\gamma}_j$	The vaccination decision of the individual i that minimizes the costs

Cost minimization. The acceptance of vaccination would translate to a cost of getting vaccinated that is lower than the cost of not getting the shot:

$$r_i^{Fix} + \beta_i^{vac} < \hat{\beta}_i$$

$$r_i^{Fix} < \hat{\beta}_i - \beta_i^{vac}$$

Or fixed cost ratio of vaccination being lower than the differential of the risk of infection without the vaccines, relatively to the state of being vaccinated. The costs of getting vaccinated would be:

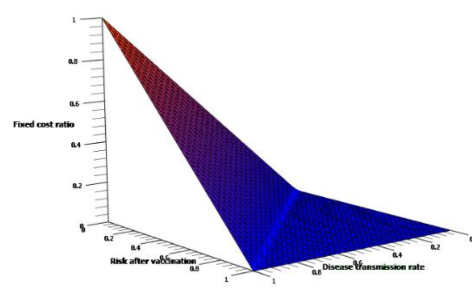
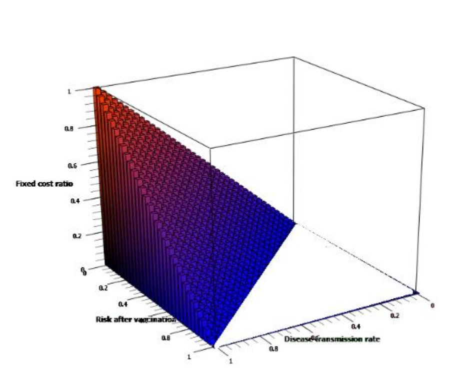
$$c_i(\gamma_i = 1) = r_i^{Fix} + \beta_i^{vac}$$

The rejection of vaccination would translate to a cost of getting vaccinated that is higher than the cost of not getting the shot:

$$r_i^{Fix} > \hat{\beta}_i - \beta_i^{vac}$$

In the case where both options would yield to the same costs, an individual would be indifferent in choosing either to get vaccinated or not, and is more likely not get vaccinated as this option would require an action, compared to the decision of not getting vaccinated that maintains the same state. As a consequence, the decision of not getting vaccinated is taking under the condition:

$$r_i^{Fix} \geq \hat{\beta}_i - \beta_i^{vac}$$

$r_i^{Fix} = \hat{\beta}_i - \beta_i^{vac}$	
$r_i^{Fix} < \hat{\beta}_i - \beta_i^{vac}$	

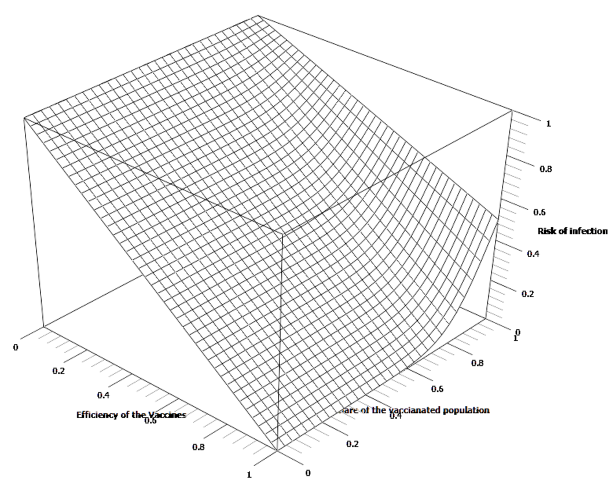
For each individual i, depending on their perception on the various components of the costs associated to each of the options, a choice will be made based on the decision that would minimize the costs, we denote this optimal choice $\tilde{\gamma}_j$

$$\min_{\gamma_i} c_i(\gamma_i) = c_i(\tilde{\gamma}_j)$$

Possibility of Free-riding:

In this section, we take into account the possibility of individuals updating their believes on the risk of infection, based on the perceived level of the vaccinated population. We denote ρ_i as the believes around the proportion of vaccinated population, the higher the immune share the closer the population is going to reach herd immunity and the lower the probability is going to be for an individual to be affected by the disease. Though the efficiency of the vaccine is not going to change from the individual's point of view, the more this share increases to reach a certain threshold, the less incentivized individuals will be to get the shot. As an assumption, we assume that the efficiency of the vaccines to be perceivably reducing starting from a share of the vaccinated population of 50%, and to reach half if the totality of the population is vaccinated:

$$\beta_i^{vac} = \left[1 - \frac{\varepsilon_i}{(1+{\rho_i}^{10})}\right]$$

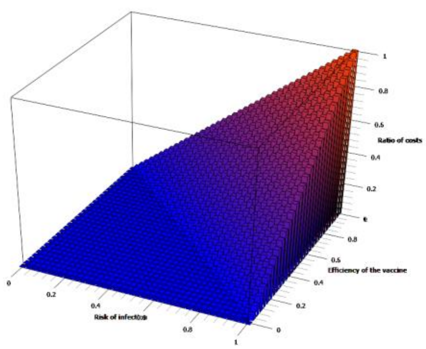
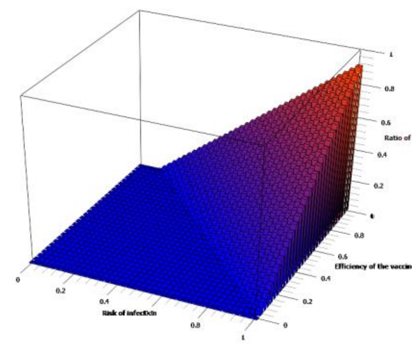
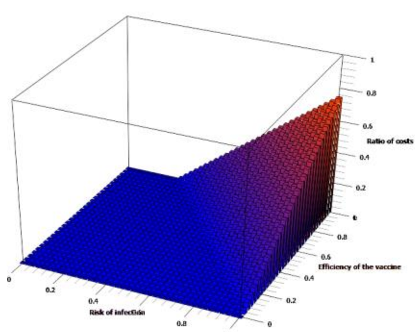
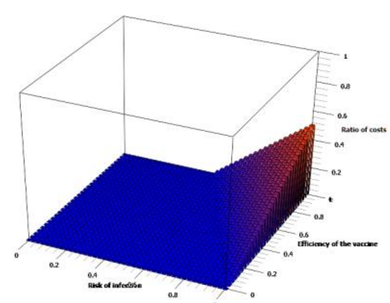


At the stage when the vaccinated share is going to be low, the risk of infection will change proportionately to the efficiency of the vaccines. The slope is going to get steeper until reaching $-\frac{1}{2}$. As shown in the graphs below, for individuals that might initially find the option of getting vaccinated less costly, if they update their believes around the immune proportion, a share might perceive the option of not getting vaccinated as less costly, and observe an opportunity to free-ride.

$$r_i^{Fix} = \hat{\beta}_i - \left[1 - \frac{\varepsilon_i}{(1+\rho_i{}^{10})}\right]$$

Vaccination option less costly if:

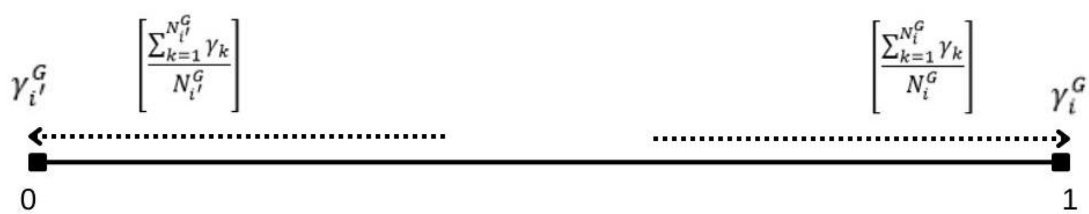
$$r_i^{Fix} < \hat{\beta}_i - \left[1 - \frac{\varepsilon_i}{(1+\rho_i{}^{10})}\right]$$

$\rho_i = 0$	$\rho_i = 0,8$
	
$\rho_i = 0,9$	$\rho_i = 1$
	

Social Influence:

In the stage of a voluntary vaccination program, individually centered decisions are constructed through a perceived cost analysis as defined in the previous section, as well as an additional cost related to their social association. For every individual i, they find themselves in a group that we consider not be changeable before and after the decision is made. Depending on the individual and the society and its characteristics, those groups might represent family, friends, workplace, or any social group that might have an influence on the decision making process, and that is unchangeable during the stage of opting for the option to take a shot or not.

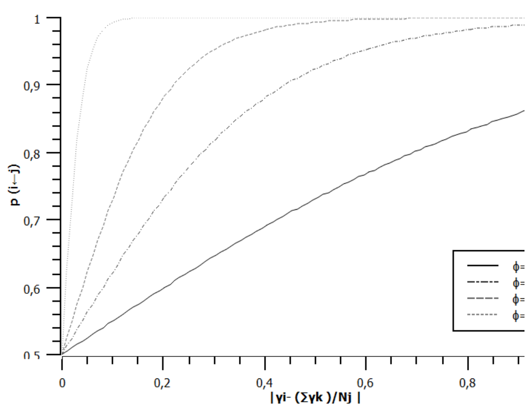
We consider that for each individual i, there is a group G_i of size N_i^G that they are affiliated in. The average $\frac{\sum_{k=1}^{N_i^G} \gamma_k}{N_i^G}$ represents the mean of the strategies taken by the members k of the group G_i. Initially, the average decision of the all group members $k \in N_i^G$ would be closer to γ_i^G compared to $(1-\gamma_i^G)$: $\left[\frac{\sum_{k=1}^{N_i^G} \gamma_k}{N_i^G}\right] = \gamma_i^G$, where $\left[\frac{\sum_{k=1}^{N_i^G} \gamma_k}{N_i^G}\right]$ is the closest integer to the average. As an example, for i and i' that finds themselves in groups that have a high and a low number of vaccinated members respectively, the average of the decisions of their group under voluntary vaccination program would be closer to $\left[\frac{\sum_{k=1}^{N_i^G} \gamma_k}{N_i^G}\right] = \gamma_i^G = 1$ and $\left[\frac{\sum_{k=1}^{N_{i'}^G} \gamma_k}{N_{i'}^G}\right] = \gamma_{i'}^G = 0$:

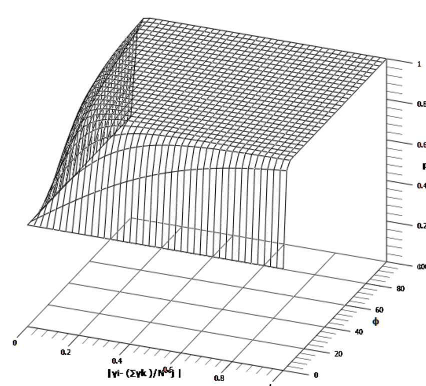


The Fermi function (Fu F & al, 2011) is a sigmoid function that has been widely used for describing individuals behavioral changes as a response to the payoff discrepancy of two different choices. We use the concept in this section to describe the probability of an individual to be influenced in their decision making by the average collective decision of their group. The parameter $\phi_i \in [0; 100]$ illustrates the sensitivity of individuals to the payoff difference from their group of membership; therefore, a higher ϕ_i translates to a higher responsiveness, and an individual being more sensitive to a payoff difference, and more inclined to adopt the strategy that would approach that of the collective of the group members. The probability $p_i^j(i \leftarrow j)$ of copying the group's j strategy by individual is given by:

$$p_i^{G_i}(i \leftarrow G_i) = \frac{1}{1 + \exp\left\{-\phi_i \left|\gamma_i - \frac{\sum_{k=1}^{N_i^G} \gamma_k}{N_i^G}\right|\right\}}$$

Therefore, $p_i^{G_i}(i \leftarrow G_i)$ would be the probability of the individual conforming to the option of the group, and $\left(1 - p_i^{G_i}(i \leftarrow G_i)\right)$ the probability of the individual choosing a different option than that of the group.





The new costs minimizing function would describe a probable shift in the decision $\tilde{\gamma}_i$ that minimizes the costs of both options of vaccination for the individual. There will be a shift of the decision to imitate that of the group with a probability $p_i^{G_i}(i \leftarrow G_i)$, and with a probability $\left(1 - p_i^{G_i}(i \leftarrow G_i)\right)$, the individual is going to keep the costs minimizing decision $\tilde{\gamma}_i$.

$$c_i^G(\gamma_i) = p_i^{G_i}(i \leftarrow G_i)c_i(\gamma_i = \gamma_i^G) + \left(1 - p_i^{G_i}(i \leftarrow G_i)\right)c_i(\gamma_i = \tilde{\gamma}_i)$$

As shown in the graph, the higher the difference $\gamma_i - \frac{\sum_{k=1}^{N^j} \gamma_k}{N^j}$, the higher the probability of individuals considering a change in their strategy and adopting the closest one to the average of the group. This probability is intensified by the level of responsiveness ϕ_i. For a responsiveness that would equal 0, the individual is not sensitive to the group's choice, and the associated probability is 50%, which brings the problem back to the costs minimization of both decisions to get vaccinated or not.

Table 2. Parameters used for modeling Social Influence: pro and anti-vaccination groups

Symbol	**Meaning**
G_i	Group's indicator for an individual i
N_i^G	Size of the group G_i
γ_i^G	Nearest integer to the average of the group's decisions
ϕ_i	Sensitivity of individuals to the payoff difference from their group of membership
$p_i^j(i \leftarrow j)$	Probability $p_i^j(i \leftarrow j)$ of copying the group's j strategy by individual i

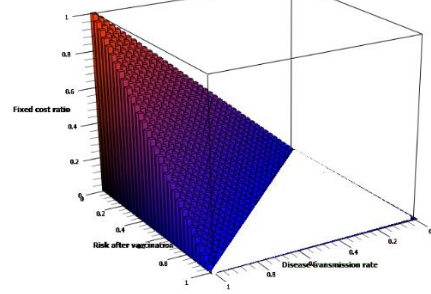
Discussion: Vaccination policies and implications on individuals' decision making process:

The next steps are to identify how the costs are going to change and thus impact the individual's choice following a policy that the public regulator is going to adopt. Consequently, what would be the impact of each of the policies on the social aggregate of the population. When it comes to the analysis of each of these cases, the assumption from a policy maker's point of view, is to enforce a policy that will increase the share of the vaccinated population, taking into consideration the impact of those policies on the individual' decision process.

Mandatory program of Vaccination:

Although it is debatable if the policy is an infringement of one's autonomy, compulsory vaccination could be justifiable by the fact that individuals have to follow a moral code that incentivizes them not to harm others. Indeed, for a preventable disease, being at a higher risk of transmitting it to other could be considered as inflicting harm on the contaminated person (Harris J, Holm S., 1995). Another argument that is in favor of a compulsory vaccination is that of the free-rider problem (Stiglitz JE., 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 fail to encourage a higher acceptance of vaccination, and are not sufficient for the population to reach herd immunity. In a study that was conducted on a sample of German residents (Graeber D, Schmidt-Petri C, Schröder C., 2021), examined the willingness to get the shot and the reasons for an acceptance (or rejection) of a mandatory policy of vaccination against COVID-19. The results showed that 70% of adults in Germany would voluntarily get vaccinated, and for the share of individuals would get vaccinated voluntarily, the proportion of acceptance of the mandatory policy was 60%. For those that would not get vaccinated under the voluntary program, the acceptance of a mandatory policy was 27%.

$$r_i^{Fix} < \hat{\beta}_i - \beta_i^{vac}$$



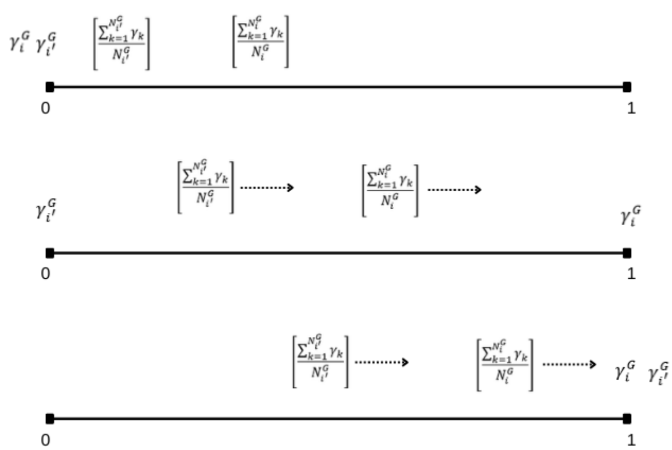
The graph shows the combination of risk and costs that individuals would perceive as less costly to get vaccinated under a voluntary program. If the authorities would introduce a mandatory policy, for the share of the population that would choose not to get vaccinated, they will bear higher costs depending 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.

Green-pass:

Governments have provided the green-pass as a measure for incentivizing vaccination by population (Wilf-Miron R, Myers V, Saban M, 2021). Individuals that acquire the document can access public services as well as recreational activities. Similarly to the compulsory policy of vaccination, the green-pass was contested in many parts of the world due to the constitutionality exceptions that it raises. A survey showed that most unvaccinated participants believed that the green-pass is a form of discrimination and that it is not useful (De Giorgio A & al, 2022). The particularity about this document is that contrary to a mandatory policy, it restricts access to different activities increasingly and on different periods of time. Taking the example of Italy, the document was first required to travel starting august 2021, then it was extended in September 2021 to access transportation, universities and schools. On

October 2021, the Green pass was compulsory to enter any workplace, and on December 2021 the super green pass was introduced, with which only vaccinated or people recovered from the virus can participate in social life.

Demographic characteristics have been shown to be a key factors driving people's behaviors to receive the COVID-19 vaccine (Wang C. & al, 2021). Accordingly, restrictions related to the Green-pass widened gradually based on aspects that differentiate individuals within a nuclear family, and by the use of the document, regulators delegated the burden of control to businesses and institutions as a perquisite for their functionality in a normal environment. Taking back the characterization of the imitation tendencies, we consider two individuals i and i' that being in groups with low vaccination average amongst the members. The application of the green-pass is going to permit a progressive transmission where only a share of the group is concerned by the policy at each stage.



The green-pass can be an alternative to a compulsory policy of vaccination, and by increasingly targeting a larger share of the population, it can avoid adverse social repercussions a direct enforcement of a mandatory vaccination might provoke. Due to its flexibility in regulations and implementation (Waitzberg R & al, 2021), the document can change according to the epidemiological risks, and regulators objectives.

Compulsory COVID-19 certifications:

In the midst of the Covid-19 pandemic, regulators suggested the requirement of health certifications to enable a safer access to a range of activities. In certain parts of the world, those certifications took the form of QR codes allowing entry into public spaces (Liang F., 2020), or paper certificates (Pavelka M & al, 2020). Those certifications have created an incentive by allowing return to all workplaces and visits to non-essential facilities, and led to increased vaccinations before implementation in anticipation, and after their application especially for the younger generation (Mills M., Rüttenauer T., 2022). On the other hand, a negative-test can give an erroneous sense of risk, resulting in lowering precaution, such as a lower intention to wash hands (Waller J & al, 2020). The nature of acquiring an official documentation is expectedly susceptible to forgery and an emergence of a counterfeit certificates' black market, those illicit activities led to more outbreaks in some parts of the world (Adepoju P., 2019).

To elaborate on the effects of those certificates, we look into the share of the population that is not vaccinated, due to a vaccine refusal or hesitancy. We assume that individuals weigh the benefits and costs any time they need to make a decision of getting vaccinated or not. The refusal of vaccination signify a choice between acquiring a test-negative certificate, or obtaining the documentation illicitly. We take account of the myopic perceptions of individuals regarding the period of application of those documents, for each t they would need to provide a negative test, and we fix the perceived extent of application to T_i^t, and the associated cost C^{Test} that is discounted in future iterations: $\left\{\sum_{t=0}^{T_i} \frac{C^{Test}}{t+1}\right\} = C^{Test}[ln(T_i) + \gamma]$, where γ is the Euler–Mascheroni constant ($\gamma = 0{,}577$).

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}: $C^{Fake} + p_i^{Fake} F^{Fake}$

At each stage t, an individual i has the option of:

Option	**Costs**
Getting vaccinated	$C_i^{Vac,Fix} + \beta_i^{vac} C_i^{inf}$
Acquiring a test	$\hat{\beta}_i C_i^{inf} + C^{Test}[ln(T_i) + \gamma]$

Counterfeit certificates	$\hat{\beta}_i C_i^{inf} + C^{Fake} + p_i^{Fake} f^{Fake}$

$$C_i(\gamma_i) = \gamma_i\left[\, C_i^{Vac,Fix} + \beta_i^{vac} C_i^{inf}\right] + (1-\gamma_i)\left[\hat{\beta}_i C_i^{inf} + C^{Test}[ln(T_i) + \gamma]\right]$$

$$C_i(\gamma_i) = \gamma_i\left[\, C_i^{Vac,Fix} + \beta_i^{vac} C_i^{inf}\right] + (1-\gamma_i)\left[\hat{\beta}_i C_i^{inf} + C^{Fake} + p_i^{Fake} F^{Fake}\right]$$

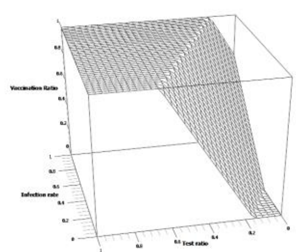
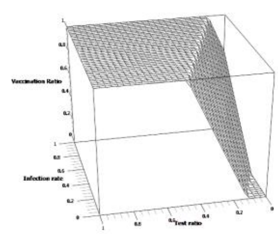
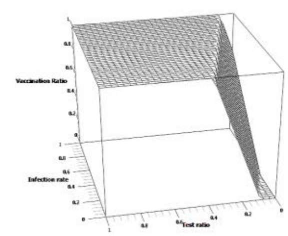
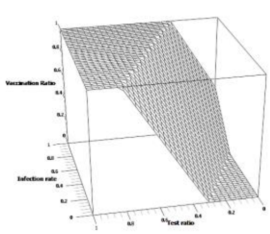
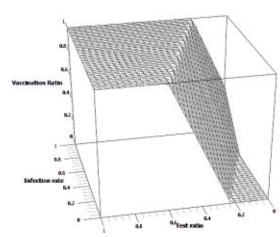
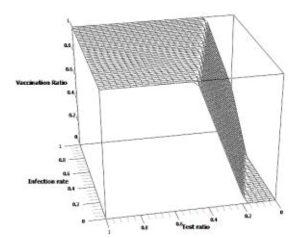
<u>Negative-Tests:</u>

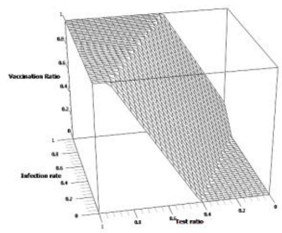
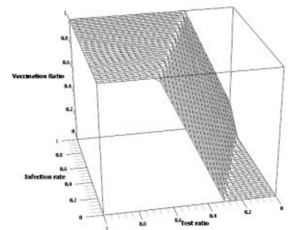
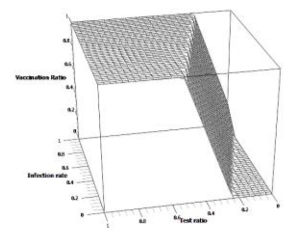
To incite individuals to get the vaccines, the additional costs of acquiring the certification should exceed the costs associated with the vaccination, and we express the costs in relative terms:

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

$$r_i^{Fix/Inf} + \beta_i^{vac} < \hat{\beta}_i + \; r_i^{Test/Inf}[ln(T_i) + \gamma]$$

$r_i^{Fix} = \frac{C_i^{Vac,Fix}}{C_i^{inf}}$ and $r_i^{Test} = \frac{C^{Test}}{C_i^{inf}}$

	$r_i^{Fix} = \hat{\beta}_i + \; r_i^{Test}[ln(T_i) + \gamma] - \beta_i^{vac}$		
	$T_i = 4$	$T_i = 8$	$T_i = 16$
$\beta_i^{vac} = 0{,}3$			
$\beta_i^{vac} = 0{,}6$			

$\beta_i^{vac} = 0,8$			

We can observe from the graphs that a higher iteration number T would increase the probability of an individual finding the option of getting vaccinated less costly. For the example of $T_i^t = 16$, the changes were not pronounces in terms of the volume of individuals that find the costs of getting vaccinated to be lower than the costs of a recurrent negative-test, compared to that of $T_i^t = 4$. The results indicate that authorities need to communicate clearly the period in which the compulsory tests are going to be required, and as demonstrated in the different graphs, the longer the period, the less sensitive individuals are going to be towards their perception on the efficiency of the vaccines.

Deterring forgery and illicite activities:

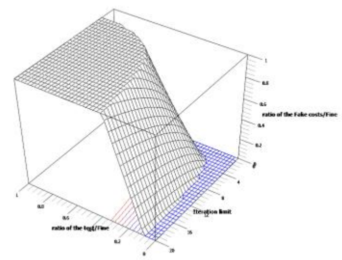
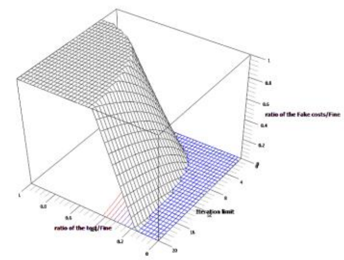
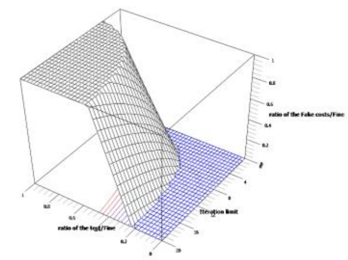
Curbing the possibilities of forgery is strengthened through an investment in enhancing the probability of detection, and/or an increase in the fine in case of detection of counterfeit certificates. We express the costs in terms of ratio relatively to the fine of the test:

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

$$C^{Test}[ln(T_i) + \gamma] < C^{Fake} + p_i^{Fake} F^{Fake}$$

$$r^{Test/Fine} < \frac{r^{Fake} + p_i^{Fake}}{[ln(T_i) + \gamma]}$$

$$r^{Fake} > r^{Test/Fine}[ln(T_i) + \gamma] - p_i^{Fake}$$

$r^{Fake} = r^{Test/Fine}[ln(T_i) + \gamma] - p_i^{Fake}$		
$p_i^{Fake} = 0,3$	$p_i^{Fake} = 0,6$	$p_i^{Fake} = 0,8$
		

The graphs depict the changes that occur if the individual perceived different iterations from 0 to 20. At a low ratio of the test and the fake certificate costs relative to the fine applied, no matter what number of iterations are taken into account, it is not going to be optimal for the individual to divert from acquiring the test, and recurring to a forged vaccination document. As a consequence, regulators should communicate the repercussions of such acts and implement fines that would compensate its devaluation due to the probability of detection, and the cumulative costs of a negative-test even at a low iterations. On the other hand, this process can be costly as the authorities should invest in mechanisms of inspection and conduits of communication to the individuals and the professionals that might contemplate the possibility of engaging in criminal activities.

Conclusion:

Understanding individuals' behavior regarding health decisions is key to predicting the repercussions of policies aimed at enhancing the vaccination acceptability. The costs of choosing any action should be considered in the societal environment they are taken in, and the mechanism of imitation and shift of decisions are determinants of the efficacy of any public intervention. The decision making process is based on perceived parameters built on individuals' personal believes. Therefore, policy makers should communicate the information that would permit an updating of the information related to the efficiency of the vaccine and the share of the immune population. 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, and consequences of any illegal activities discouraged through appropriate fines.

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