

The 'greed' and 'nationalism' in vaccination against Covid-19 lead to the Tragedy of the Commons, Nash equilibrium and Giffen's goods, giving SARS-CoV-2 more opportunities to escape mutants.

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Abstract

It is possible to follow an ideal vaccination global strategy, that will reduce to the minimum the number of infected and dead by COVID-19 as well as the likelihood of an escape mutant. This ideal vaccination strategy needs of a high degree of international cooperation among different countries. International initiatives as COVAX, advocated by the WHO, try to achieve such goal. However, in the present scenario with limited number of vaccine doses, Game Theory model also predicts that they are becoming goods subject to the Tragedy of the Commons. Countries with the capability to control vaccine dose distribution will desert from the international agreements, vaccinating first to their own nationals. If such behaviour is known by other countries (as is happening now) more countries will be tempted to desert as well. Eventually it will end in a Nash equilibrium, which stops the ideal vaccination strategy. Furthermore, in poorer countries, with great difficulties to get access to vaccine doses, these will be transformed into Giffen goods. Vaccination data available to date, show that we are in a scenario where vaccine doses have transformed into goods subject to the Tragedy of the Commons, countries desert from cooperation reaching a Nash equilibrium and vaccine doses are close to become a Giffen good for the poorer countries. This dynamic will not only rise the number of infected and dead by COVID-19, but also the likelihood of an escape mutant (in the SARS-CoV-2 populations) will be increased. If, eventually, this turns out to be the new scenario new vaccines could be developed for those new escape mutant strains, going back to a very similar setting as the starting one. Most likely, the world will reach a Pareto optimality (equilibrium between desertion and cooperation) due the pressure of those who seek high levels of cooperation to attain a global vaccination strategy.

Key words: escape mutant, COVID-19 vaccines, Tragedy of the Commons, Nash equilibrium, Giffen goods.

1. Introduction

Through mankind's evolutionary history many viruses managed to jump from animals to humans¹. Once they go through the animal-human barrier, these zoonotic viruses tend to wash mankind for centuries in successive waves². Fortunately, science development makes possible that we can, somehow, control these pandemics with antiviral drugs and vaccines.

In 2019 SARS-CoV-2 could trespass animal-human barrier causing a catastrophic pandemic, it has proven to be a quick evolving virus and the arising of an escape mutant is certainly a potential risk³. Since COVID-19 is a global pandemic, only a global adequate vaccination strategy can minimize the likelihood of an escape mutant³.

This is the reason why around 180 countries, with the support of the World Health Organisation, have signed the COVAX initiative to jointly negotiate the purchase and distribution of vaccine doses against SARS-CoV-2⁴. This initiative is an attempt to maximize the effectiveness of global vaccination⁴.

There is a risk that, despite these international cooperation efforts, some countries are tempted to desert from this initiative trying to accumulate vaccines. In this sense, the United Nations (UN) alerts that the *"progress in vaccination is wildly uneven and unfair"* pointing out that only ten countries have administered 75% of all COVID-19 vaccine doses while over 130 countries have not received a single dose⁵.

The risk of "vaccine nationalism" grows⁶. The WHO is pessimistic about the future of vaccination, stating that "the world is on the brink of a catastrophic moral failure - and the price of this failure will be paid with lives and livelihoods in the world's poorest countries"^{7,8}. A "me-first" approach would be self-defeating because it would push up prices and encourage hoarding. 'Greed' and 'capitalism' helped UK's vaccines success, says premier B. Johnson. "Ultimately, these actions will only prolong the pandemic, the restrictions needed to contain it, and human and economic suffering"^{7,8}. These concerns are shared by important economic agents that believe that without a global and complete control of COVID-19, economic recovery could be compromised⁹.

In this context we estimate the costs and benefits of the different vaccination strategies, using Game theory. This mathematical approach shows that it is possible to follow an ideal global vaccination strategy, that will reduce to the minimum the number of infected and dead by COVID-19 as well as the likelihood of an escape mutant. However, Game theory also predicts that the shortage of vaccine doses will make them a good subject to the tragedy of the commons^{10,11}.

It is highly probable that the different vaccination strategies reach a Nash equilibrium^{12,13}. The best general outcome would be that every country cooperated in a global vaccination strategy, but each country knows what strategy the others are following, so with that information he adapts its own strategy to what believes is best for its own interests and doing so deserts from the cooperative strategy. Finally, there is a great added risk that vaccines end up as Giffen goods for the poorer countries¹⁴

These will significantly reduce the effectiveness of the vaccination programs, what could allow natural selection to favour an escape mutant.

2. Theoretical background

2.1. Conditions for the COVID-19 vaccines to become a good subject to the Tragedy of the Commons.

Since Game Theory, Tragedy of the Commons^{10,11} can be explained as a non-cooperative game in which all players share a common good^{14–18}.

James G. Hardin (1968), in one of his most influential papers, showed that when several individuals act upon: i) a limited resource, ii) irrationally, iii) driven only by personal interests and iv) independently from one another, in a long term, they end by destroying the shared common good, even though is not advisable for none of them (nor individually nor collectively) the destruction of that limited common good¹¹

In its classical example, a group of cattle breeders share common pastures. Each farmer tries to maximize its profit and wonders: What benefit do I get by adding one animal more to my cattle that I keep in the common pasture? The benefit is having one extra animal because the owner gets all the production of that added one. The cost of adding one more animal is a function of the common pasture destruction due to that one animal overuse. Because the effects of the overuse are shared by all cattle breeders that exploit the common pasture, its cost is significantly lesser than the benefit. Adding costs and benefits, a rational farmer concludes that it is in his interest to add another animal to his cattle, and why not another? and one more? and another?...

Each and every one of the “rational” cattle breeders that share the common pasture come to the same conclusion. In the end all of them participate in a game that makes them increase their herd unlimitedly. But because the pasture is limited, they end destroying the common good. It was no one’s intention, each of them was freely managing a common good pursuing their best interests but is precisely that freedom what is unfavourable to all of them.

In a classic payoff matrix (Table 1) when all players (cattle farmers) cooperate and use fairly the common good (only one animal per farmer) all get the same reward (+1).

If player One decides to increase his reward (adding one more animal) he gets a reward of nearly 2 ($2 - e$) because adding that new animal generates some costs that are shared by all players including himself. The other players will receive a reward slightly below 1 ($1 - e$) because they also assume part of the added animal cost but get no reward. In the end all players will desert although the final result is a zero reward for everyone.

Table 1. Classic payoff matrix in Game theory for the Tragedy of the Commons.

One player	All the other players	
	Cooperate	Defect
	Cooperate	Defect
Cooperate	1 , 1	$(1 - e), (2 - e)$
Defect	$(1 - e), (2 - e)$	0 , 0

In COVID-19 pandemic, the limited resource is the vaccine.

There is an ideal vaccines distribution among the different countries, that would maximize the global benefit minimizing the total number of infected and dead by SARS-CoV-2. At the same time, it would minimize the likelihood of a new mutant strain emerging that could evade vaccines and spread around the globe causing a new wave within the already vaccinated. This ideal distribution can be designed using minimax strategies developed in Game theory, but countries must cooperate.

However, some of the countries that control vaccine production and distribution could be tempted to desert from this common vaccination strategy, increasing the number of doses they reserve for their own nationals. As this position wide spreads vaccine doses could become a good subject to the tragedy of the commons.

2.2. Scenario in which the different countries, with their COVID-19 vaccination strategy, could reach a Nash equilibrium

In Game Theory, Nash equilibrium gives the best outcome when: i) all players know each other's strategy; ii) each player knows his best strategy; and iii) each player is following his best strategy. At this point they reach equilibrium because each individual player is playing with his best possible strategy, knowing what the others do¹⁹⁻²¹. Furthermore, each individual player cannot increase his winnings changing his strategy if the others do not modify their own. Consequently, players do not have incentives to change strategy. But in a Nash equilibrium the outcome is not the best group result, is only the best possible result for each of them individually. The outcome could be better for everyone if all players coordinated a common strategy.

The easiest example of the Nash equilibrium is in a modification of the prisoner's dilemma, when both know what the other is going to do. In the classic prisoner's dilemma police arrest two suspects from a recent robbery. Without solid evidence against them they decide to interrogate the suspects separately. The robbers have three options: a) if both suspects cooperate and none of them confesses, police cannot put charges against them and both have to be released; b) If one of them deserts from the cooperative strategy and confesses that it was his partner who did the robbery, he will be released and the other will go to jail; c) finally, if both confess, both will go to jail but with a reduction in the sentence for cooperating with the police. It would be best for both if they cooperate and none confesses, but if they only seek personal interest and do not trust each other both should adopt the desert strategy, which will end in an equilibrium in which losses are minimized for each of them.

Applying complex prisoner's dilemma models that allow multiple players or repeating the game numerous times, cooperative strategy always maximizes gains for everyone, and desert strategy minimizes individual losses when players do not know what others will do.

It is a well-known fact that several countries that control vaccine production and distribution have already deserted from a common vaccination strategy. Once these desertions are known by everyone, to those other countries that have access to a great number of doses the temptation to

desert increases. In doing so, the real global vaccine dose distribution could reach a Nash equilibrium, with a very different outcome than with the ideal one that could minimize the number of infected and dead and reduce the likelihood of an escape mutant.

2.3. Conditions for the COVID-19 vaccine doses become Giffen goods in the poorer countries

In a market economy, the normal thing is that as the price of a certain good increases, its demand by consumers decreases, this is the Law of Demand. The opposite situation, in which consumers respond to an increase in price of a certain good by demanding more of it is known as Giffen behaviour and the good is known as a Giffen good²²

In the following equation,

$$\Phi = \Phi^h - b\Phi_r \quad (\text{Eq. 1})$$

where:

Φ is the total effect = price elasticity of demand

Φ^h is the Hicksian demand = substitution effect or price elasticity compensated (i.e., elasticity of demand due to variation on the price, excluding the income effect and maintaining the utility function constant)

b is the budget allocated for the good

and Φ_r the elasticity of the resources (being $b\Phi_r$ the income effect).

Developing the equation:

$$(\delta x / \delta p_1) = (\delta h_1 / \delta p_1) - x(\delta x / \delta I) \quad (\text{Eq. 2})$$

$$(\delta x / \delta p_2) = (\delta h_2 / \delta p_2) - y(\delta y / \delta I) \quad (\text{Eq. 3})$$

Eq. 2 represents the direct effect (due to the change in the price of x)

Eq. 3 represents the crossover effect (due to change in the price of y)

where:

x = good representing the demand of the basic good.

y = good representing the demand of the wealthy good

p_1 = price of x

p_2 = price of y

h_1 = Hicksian demand of x

h_2 = Hicksian demand of y

I = income = $p_1x_1 + p_2x_2$

Then:

Total effect (TE) represents the global variation of the demand in such circumstances.

Substitution effect (SE) is the effect derived from the variance of the price of a good that conducts to a decrease of the demand of that good and increase of other, change the interchange rate.

Always acts in opposite direction of the energetic price.

Income effect (IE) is the effect derived from the variance in purchasing potential, the real income.

It acts in opposite direction of the energetic price for common goods and in the same direction of the energetic price for inferior goods.

The conditions for a Giffen good are:

$$SE \leq 0 \text{ and } IE > 0$$

with

$$(b\phi_r > \phi^h); \phi > 0$$

(Eq. 4)

3. Practical application

In order to verify if Covid-19 vaccines could become a good subject to the Tragedy of the commons we used the number of vaccines produced to date by the pharmaceutical companies as well as with an estimate of the future production^{23,24}. We compare these data with the estimated need²⁵ and from these figures we estimate most likely values for the payoff matrix.

To verify if the vaccination strategies countries follow could reach a Nash equilibrium we use in our calculations, the number of vaccine doses countries have allocated to vaccinate its nationals^{24,26} and the number of doses that have reached COVAX initiative²³. We also examined to what extent this information is of public domain²⁷.

To verify if vaccines could be Giffen goods for poorer countries we check differences in vaccine doses price for different countries^{23,24,26}.

4. Results

4.1. Why COVID-19 have already become a good subject to the Tragedy of the common

Worlds demand greatly exceeds actual production²³. In a very optimistic scenario at least 5,400 million people should be vaccinated, some of the current vaccines need two doses for immunization. But these figures can be greater if people have to be revaccinated after a period of time or if SARS-CoV-2 variants arise that escape the current vaccines and new ones have to be produced.

Nowadays, the vaccine production capability is limited, but companies expect to meet demand, with production estimates for 2021. Pfizer expects to produce 1.3 billion doses²⁸, Moderna hopes for a number of doses in the range between 700 million and 1 billion²⁹, while AstraZeneca anticipates they can produce 3 billion Covid-19 vaccine doses³⁰.

Under these circumstances, a country with the opportunity to decide over the destination of the vaccines (whether because it produces them or because has a great purchase capability) will be tempted to increase its benefit by keeping more vaccines than the ones he is entitled to according to the ideal global distribution. If a country keeps one million more vaccine doses, many of its citizens will sooner return to a normal life, but why not keeping another million, and one more, and another, ...? And if one country does it, why not another country, and another, and one more, ...? In the end, every country capable of deciding over the vaccines will stockpile much more doses than the ones entitled to, following the ideal distribution. The consequence is that the ideal distribution will not happen and the minimizing effect of infected and dead will not be, and the likelihood of a new SARS-CoV-2 strain more dangerous will not be reduced.

Countries less influential will not have enough vaccine doses to follow an adequate vaccination strategy and will be forced to make decisions that could favour natural selection of mutants that evade the vaccine protection (e.g., one dose vaccination, vaccinating during a high prevalence wave, slow vaccination programs, ...). If a mutant that evades vaccines emerges, the common good (the vaccines) would be destroyed (they would be useless for that escape mutant). The payoff matrix for the COVID-19 vaccines (common good) is resumed in Table 2. This table 2 also shows an attempt figure of the number of years it will take (with the different strategies) to control the COVID-19 pandemic in the best and worst scenario. It is assumed that in the event of countries that can decide upon vaccines they desert, then the likelihood of an escape mutant increases.

Table 2. Payoff matrix in a Tragedy of the commons setting applied to the vaccine distribution strategy. t : time the pandemic could be defeated; c_o : cost for a country to cooperate; b_o : deserting benefit for a country; b_a : deserting benefit for the other countries. In brackets, number of years COVID-19 pandemic could be under control.

Countries that cannot decide on vaccines		
Countries that can decide on vaccines	Cooperate	Defect
	$t - c_o, t - c_a$ Best scenario (2, 2) Worst scenario (2, 2)	$t - c_o, t + b_a$ Best scenario (2, 2) Worst scenario (2, 3)
Defect	$t + b_o, t - c_a$ Best scenario (1, 3) Worst scenario (escape mutant)	$t + b_o, t + b_a$ Best scenario (1, 3) Worst scenario (escape mutant)

Is in the power of those countries that can decide the destination of the vaccine doses that vaccination becomes or not a scenario of the tragedy of the commons. If these countries cooperate, they will overcome COVID-19 pandemic later but the risk of emergence of a new mutant that evades vaccination will be low. If they desert, they will be over the pandemic sooner than if they cooperate, but the likelihood of an escape mutant increases significantly.

4.2. Why Vaccine doses global distribution is reaching a Nash equilibrium

Vaccine dose distribution is variable, while Israel has received 8,731,727 doses and has vaccinated to a 100,9% of its population, some countries have not yet received a single dose³¹. Table 3 shows a list of those countries that have already gone beyond the 10% mark of its population with at least one dose of a vaccine.

Table 3. *List of countries that have administered more doses, in total and per 100 population (as off 19-03-2021)*³¹

Country	Total doses administered	Total doses administered per 100 population
Israel	8.731.727	100,90
United Arab Emirates	6.830.369	69,06
UK	26.063.501	38,40
Chile	6.134.402	32,09
U.S.	98.081.045	29,63
Serbia	2.040.313	29,50
Malta	111.240	21,60
Hungary	1.586.105	16,20
Morocco	5.682.508	15,39
Turkey	11.261.612	13,40
Estonia	172.725	13,00
Cyprus	115.482	13,00
Ireland	612.783	12,30
Switzerland	1.035.004	12,00
Poland	4.508.646	11,90
Finland	650.937	11,80
Lithuania	328.510	11,80
Austria	1.053.635	11,80
Greece	1.218.668	11,40
Italy	6.634.450	11,10
Slovakia	597.924	11,00
Norway	584.212	10,90
Spain	5.181.446	10,90
Portugal	1.113.673	10,80
Sweden	1.093.127	10,60
Germany	8.553.350	10,30
Netherlands	1.784.484	10,30
Canada	3.885.270	10,29

In this setting, when a country (with the possibility to control production and distribution of vaccine doses) knows that others desert, his best strategy will be to desert as well, securing enough vaccine doses supply for his nationals.

Every country knows that this strategy is worst from a global perspective, because it gives the virus a greater chance of producing an escape mutant but known what others have done is his best option.

Table 4 shows a payoff matrix of different cooperation and desert settings for COVID-19 pandemic ideal vaccine dose distribution, that would minimize total number of infected and dead and the likelihood of emergence of an escape mutant strain. In it we can analyse conditions for a Nash equilibrium.

The key that some of the strategies reach a Nash equilibrium solely depends on those countries with decision capability over vaccine doses destination. If these countries desert from the common strategy they will overcome the COVID-19 pandemic sooner, temptation is too big. If one deserts and others know, then temptation for these ones is too big as well. If all of them desert, the world will reach a Nash equilibrium and in return mankind takes the risk of the emergence (in one of those countries with no decision power) of a new mutant that evades vaccines and spreads around the world, going back to starting point.

Table 4. *Game theory payoff matrix for different cooperative and desert scenarios for COVID-19 pandemic ideal vaccine dose distribution. Last two could lead to a Nash equilibrium*

Strategy	Strategy	Payoff	Payoff	Consequences
Countries that can decide on vaccines	Countries that cannot decide on vaccines	Countries that can decide on vaccines	Countries that cannot decide on vaccines	World
Cooperate	Cooperate	$t - c_o (2)$	$t - c_a (2)$	Selection against the escape mutant
Cooperate	Defect	$t - c_o (2)$	$t + b_a (2.5)$	Selection against the escape mutant
Defect	Cooperate	$t + b_o (1)$	$t - c_a$	Selection in favour of an escape mutant
Defect	Defect	$t + b_o (1)$	$t + b_a$	Selection in favour of an escape mutant

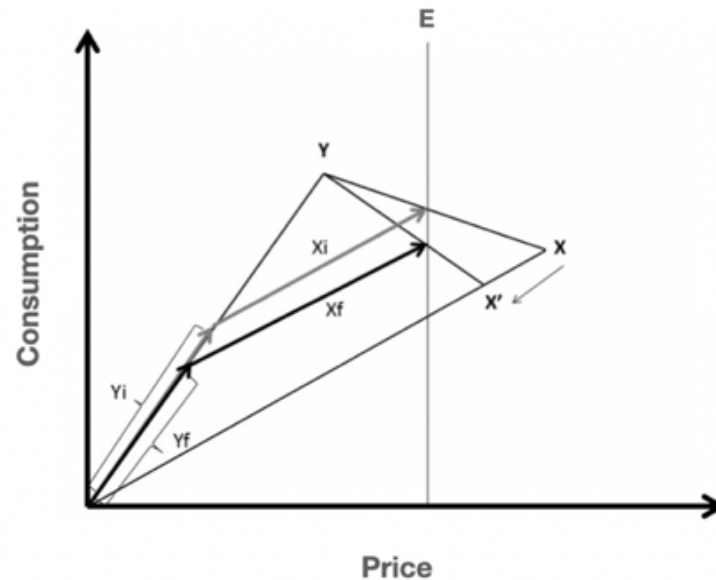
4.3. Why COVID-19 vaccine will be a Giffen good for the poorer countries

Countries are paying different price for the same vaccine, some poor countries are paying even more than many richer countries^{23,24}

The response of the demand to a change in vaccines' price considering the staple good (x) as a Giffen good is summarized in Figure 1. As shown in the figure, vaccine doses will become a Giffen

good for the poorer countries when there is a supply of 2 or more vaccines with different price, and none of them alone will be enough to satisfy total demand.

Figure 1. Response of the demand to a change in the price of vaccines. Y represents the demand of vaccines (Y_i at the initial moment and Y_f after the change in the prices), X represents the demand staple good (X_i at the initial moment and X_f after the change in the



5. Discussion

Countries as different as New Zealand, Taiwan, Australia or Vietnam showed that COVID-19 pandemic could have been controlled with classic epidemiological strategies (mobility restrictions, tracking contacts, infected isolation, quarantines, facemasks, hygiene, ...). Unfortunately, majority of countries failed to implement adequate strategies and SARS-CoV-2 became a global pandemic. At present times, most countries base all their hopes to control the pandemic in the effectiveness of vaccines and vaccination.

We need to follow a good vaccination strategy if we want to minimize the number of infected and dead, avoid the likelihood of escaping mutants, overcome the COVID-19 pandemic as soon as possible and prevent that SARS-CoV-2 stays among us for decades³². This ideal vaccination strategy exists^{33,34}. Several mathematical models and recursive algorithms, including classic minimax strategies from Game theory, would allow fully optimize the vaccination strategy^{35–37}.

International cooperation is needed, in order to really implement this ideal vaccination strategy, between those countries with the capability to control vaccine doses (either because they produce them or because they have enough money to buy them) and those other countries incapable to do so. With this idea in mind the COVAX initiative was born, advocated by the World

Health Organisation, to achieve an effective distribution of COVID-19 vaccine doses among the poorer countries, trying to maximize the effectiveness of a global vaccination⁴. A great degree of international cooperation is needed for this global vaccination strategy to be successful, minimizing the number of infected and dead and reducing the likelihood of a mutant strain arising that could evade the vaccine.

However, while COVID-19 vaccine doses continue to be a scarce good, a global vaccination strategy will face many hurdles. It is not easy that a rich country shares millions of vaccine doses with poorer countries, especially if many of its inhabitants are yet to be vaccinated, the temptation to desert from this international cooperation initiative is considerable. Although UN is warning that we are witnessing a worrisome “vaccine nationalism” that will be counterproductive to all, the “*me first*” temptation is substantial.

In that respect, COVID-19 vaccines can be considered as a common good and subsequently be subject to the Tragedy of the Commons¹¹. Temptation to desert is significant and Game theory predicts that it is most likely it will happen³⁸. In fact such desertion has already happened, a number of organizations are warning that richer countries are hoarding more than 99% of the vaccine doses^{39,40}. Given that the decision of some countries to desert from cooperating and follow a “*me first*” strategy is well known, temptation for the remaining ones increases. Given that many others have deserted, the best individual strategy for those countries that can obtain vaccine doses is to desert too.

In line with afore mentioned, the ideal conditions to reach a Nash equilibrium are met. Every player knows each other’s strategy and in that generalized desertion setting, their best strategy is to desert as well. Obviously, every country (if capable) end following the best single strategy for him. No country can increase its gains changing strategy while the other countries abide to their own. Alas, with this Nash equilibrium the number of infected and dead is not minimized, nor is the likelihood of an escape mutant arising.

In this “*every man for himself*” setting there is an added problem: As prices different countries are paying for the vaccine doses against SARS-CoV-2 are known, it becomes clear that the pharmaceutical industry is charging differently, to different clients, for the same product²⁷. For example, US pays for the Moderna’s vaccine doses 15 US dollars, Europe \$18 and Israel \$23.50²⁷. Although it may seem a contradiction, commonly, poorer countries pay higher prices than richer ones for the same product (e.g., South Africa pays \$5,25 for Astra Zeneca’s vaccine doses while Europe buys it for \$2,15)²⁷. We are at risk that vaccines end being Giffen goods for poorer countries.

The conditions under which Giffen behaviours can occur have been a subject of debate in economics^{41–44}. The consensus is, that only subsistence goods as basic food or drugs that people in extreme poverty and with a very limited budget need, can become Giffen goods that their demand increases as the price goes up^{45–48}. After all, the poorer consumers only have access to a very small number of goods with a limited supply. Giffen behaviour generally takes place locally, rather than globally⁴⁷. For example, Jensen and Mille^{45–47} describe the generation of Giffen behaviour among people in extreme poverty from the province of Hunan (China), regarding

the acquisition of rice and noodles. Giffen behaviour not only affects humans. This same conduct has been demonstrated in animals, rigorous experimental studies have shown it in rats and pigeons^{48,49}. The same behaviour has been observed in the wild in conditions of food scarcity with the sardines and is favoured by the action of natural selection³².

In those countries that vaccines can turn into Giffen goods, the efficacy of vaccination will be reduced because they will be forced to follow deficient vaccination strategies that could lead to selection of escape mutants that can put at risk the effectiveness of current vaccines. Developed countries will answer to that new scenario developing new vaccines for those new mutant escape strains.

We would go back to a similar situation as before, there could be an ideal vaccination strategy (that could minimize the number of infected and dead caused by these new SARS-CoV-2 escape variants) but for that it would be necessary an international cooperation between those countries that control the new vaccines and those that do not. Once again, vaccine doses could be common goods subject to the Tragedy of the Commons, temptation to desert from a cooperative strategy will increase, those who desert would be known, a Nash equilibrium would be reached and for poorer countries vaccine doses would turn into Giffen goods. We could enter an infinite circle that would assure that SARS-CoV-2 would stay for decades.

What is the likelihood? We need to look into the dynamics of the occurrence of the mutation process. Luria & Delbruck (1943)⁵⁰ in his work -worthy of a noble prize- proved that mutations happen pre-selectively, pre-adaptatively and in a general way. Mutants arise randomly as simple natural stochastic mistakes during the genome replication. They happen before natural selection acts and not as a consequence of it, mutations have no purpose. Numerous early researchers' work confirmed Luria & Delbruck's work (i.e., Newcombe, 1949; Novick & Szilard, 1950; Lederberg & Lederberg, 1952)⁵¹⁻⁵³, others more recently have also proved them right. For example, in microorganism populations spontaneously and recurrently arise new mutant strains, resistant to substances of late synthesis even before industry used them^{54,55,64,56-63} or of military use never seen in nature before⁶⁵ or radioisotopes of nuclear industry⁶⁶⁻⁶⁹.

These mutants can increase their frequency or be removed from the populations by the effect of natural selection and genetic drift⁷⁰⁻⁷⁴. Frequently these mutants are deleterious and will be removed by natural selection, but because of mutation being a recurrent process they will constantly emerge, remaining at a low frequencies thanks to mutation-selection equilibrium^{38,73}. For those selectively neutral mutants is mutation-drift what maintains the balance^{38,75}. If suddenly there is a drastic change in the environmental conditions (e.g., volcanic eruptions, industrial catastrophes, ...) some of these resistant strains can find the right conditions to become dominant in the population^{71,72,74-78}.

Something similar can happen with the escape mutants. If random mutations can produce them, it is certain then (since the mighty size of SARS-CoV-2 population) that they have already happened. However, considering the specific characteristics of the SARS-CoV-2 population genetics, for these escape mutants to have a high likelihood of fixing within the population they need a tremendous selective advantage (close to 50%)³. Most likely, before massive vaccination

takes place, these escape mutants will have less fitness and will be at very low numbers due to mutation-selection equilibrium.

The problem will come when poorer countries do not vaccinate extensively their people because they do not have enough doses. In this setting, those low frequency escape mutants will have a chance. Predictions about COVID-19 pandemic duration show that it may be enough time for an escape mutant to spread^{79,80}. The vaccination strategy followed in poorer countries will determine if the likelihood of escape mutants spreading is minimized or not.

Most likely, vaccine dose distribution will follow a mixed model, not a complete cooperation nor a total desertion setting. Most countries that control vaccine doses will solve primarily their own situation (as Israel or United Arab Emirates are doing) but will also allocate part of those doses for countries in need. As it happens with a number of human economic activities, it is probable that vaccine dose distribution follows a power law like Pareto distribution, with a 80:20 ratio cooperation-desertion^{81–86}. This is obviously not an ideal vaccine dose distribution but somehow reduces the likelihood of an escape mutant.

Despite everything, face to face with the deserting temptation we must not forget that SARS-CoV-2 escape mutants could already be within the population. If richer countries do not cooperate the virus will have the opportunity to stay with us for a long time.

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