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Lockdowns as options

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Abstract

I show that the irreversibility of dying coupled with gradual information acquisition over time on the likely arrival and eventual effectiveness of vaccines confers a real option value to lockdown strategies that delay the incidence of a pandemic.The case for lockdown strategies becomes stronger the more likely vaccine discovery is, and the less uncertainty exists about its effectiveness.

JEL codes: G12, G13, G18

Key Words: Pandemic Dynamics, Stochastic Vaccination arrival Information, irreversibility, Lockdowns, real options

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1 Introduction

Lockdowns are generally recommended by epidemiologists as a strategy to dampen down pandemic waves of contamination, yet their imposition has remained hugely controversial. A very rapidly growing body of economic research has resorted to coupled epidemiology/economic models to elaborate on whether there is a trade off between economic costs and health benefits of the various strategies and has also tended to come out in support of lockdowns as a containment strategy (cf Kaplan, Moll, and Violante (2020)) for a recent contribution that also contains a very extensive literature review).

The models used typically embed an extensive and complex variety of mechanisms linking the various model segments and policy actions. This has the obvious advantage of a high degree of power in outlining likely outcomes; but their very complexity may also mask the mechanisms at work. In this note we take the opposite tack: we focus strongly on one particular aspect of lockdowns that has not received attention in the literature, yet seems potentially important. To highlight the key issues we construct a very stylized model that abstracts from the arguments commonly made to defend lockdowns, not because we necessarily disagree with them but because we want to focus on an alternative line of reasoning.

Typically, lockdowns are defended as a strategy to avoid ICU overload and/or to slowdown the pandemic's escalating progress and in this way save life years. Delaying and spreading out the disease's incidence will lower the risk of ICU overlead and in fact also lead to life years saved even if the strategy would not lower cumulative mortality. In addition lockdowns also lead to a slightly lower overall mortality, although epidemiologists agree that absent a cure or effective vaccine, reaching herd immunity (HI) is the only way to ultimately contain the pandemic, and lockdowns may in fact delay rather than speed up the reaching of HI [1]. In this note we take these arguments into account but the main focus is elsewhere, on another advantage of lockdowns that to my knowledge has not been highlighted in the literature but, as we will show, makes up a substantial component of the total value of Lockdown strategies. With any new pandemic, there is uncertainty about whether a vaccine will become available, if so when, while its effectiveness given that it arrives is also uncertain. Lockdowns, by buying time, offer in effect a binary option to people who may gain access to a vaccine[2] once it arrives and proves effective. Dying before the vaccine becomes available clearly precludes access to that option. Dying before the vaccine arrives is the ultimate instance of irreversibility, and it is that combination of information acquisition and irreversibility that confers a real option characteristic to lockdowns. This line of thinking leads to a second message: the case for a lockdown strategy strengthens the more likely a vaccine discovery is, the less uncertainty persists about its effectiveness and the closer by its availability.

To highlight our option argument, there also is much we do not do. Contrary to the economic literature on Corona, we abstract from interactions with the economy, although our analysis does show features that are obviously relevant for such interactions but not always incorporated (in particular the importance of fear of contagion for labor supply). And although we stress the importance of the vaccine arrival process, we only consider uncertainty whether it shall arrive or not, and uncertainty about its effectiveness. We do not consider uncertainty about when it arrives if in fact it does. Both points a re remedied in Lin and van Wijnbergen (2021).

In the remainder of this note we first sketch a highly stylized model designed to bring out this real options aspect of lockdowns, to the exclusion of all other mechanisms; in the following section we then present a richer model of the pandemic coupled with a stochastic process representing vaccine arrival rates and their potential effectiveness to actually price the option value embedded in lockdowns. We incorporate uncertainty as to whether a vaccine will arrive and about its effectiveness. We abstract from timing uncertainty (i.e. given that an effective arrival is found, when will it reach the market?), although we do deal with that sort of delay in a highly stylized way at the end of Section 4. The final section concludes.

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[1] Moll (2020) gives s short introduction to the epidemiological literature.

[2] From now on we invariably use "vaccine" where we really want to say vaccine and/or effective medication.

2 A Skeleton Model

Avoiding ICU overload and gaining additional life years on the presumption that the strategy will be successful in delaying the incidence of the disease are the arguments commonly used when choosing for a lockdown (LD) strategy. In this note we introduce a third argument, arguing that in the presence of irreversibility and the slow acquisition of information, LD strategies can be looked at as real options. To sharpen focus on the real options perspective we set up a simple model abstracting from the conventional arguments for a LD strategy: the social objective is number of survivors, not life years, so postponing disease incidence without changing the final population outcome is not counted as socially beneficial. And we do not attach specific costs to a higher disease incidence in a given period, thereby ignoring the ICU overload problem. This is not to dismiss the traditional arguments for a lockdown strategy but simply for sharper focus on the option value line of reasoning.

The model represents extremely simple population dynamics under different containment scenarios, a Laissez-Faire (LF) approach versus a Lock Down (LD) strategy. The premise is that a lock down mostly postpones incidence of the virus infections but that in the end the pandemic will not die out before Herd Immunity levels of infection have been reached, unless a vaccine or effective cure is developed before that time.

In the simplest possible setup consider three points in time (i.e. a two period model, period 1 from t = 1 to t =2, and period 2 from t =2 to t = 3)): - time starts at t = 1, with population size normalized to Δ_1. - Under the Laissez Faire strategy (LF) a fraction ϕ_{LF} survives until t = 2, at which time a vaccine may or may not become available. The probability of the vaccine arriving at t = 2 is π. - If the vaccine is effective no further deaths will occur [3]. Call this realization V = 1. - If the vaccine is not effective (V = 0) a further fraction ϕ_{LF} dies, with the length of the second period (between t =m 2 and t =3) chosen such that the final population size at t = 3 is $Delta_{HI}$, after which the pandemic subsides[4]. - The dynamics under the lockdown strategy (LD) is slightly different, in that the disease incidence is shifted from period 1 to period 2 but eventually arrives at the same end point: in the absence of a vaccine, the LD strategy also arrives at a final Herd Immunity population Δ_{HI} at t =3.

This leads to the following dynamics at t = 1, population is Δ_1. Population at t = 2 depends on the containment strategy chosen: - $\Delta_2 = \Delta_1 * \phi_i$, with i = LF or i = LD, with $\phi_L F << \phi_L D$. Without vaccine or cure, herd immunity will be reached either way in the third period: $\Delta_3 = \Delta_{HI}$. So what the lock down does in the end is just postpone the infections, but without affecting eventual mortality if no vaccine is forthcoming or turns out to be ineffective if it does emerge (V = 0).

At t = 2, before the transition to t = 3 takes off, there may or may not emerge an effective vaccine. We introduce that possibility by declaring an index indicator V; for V =1 an effective vaccine emerges, and for V = 0 the efforts to develop a vaccine have failed. The probability that V = 1 equals π:

$$\begin{aligned} &\text{If} \quad V = 0: \quad \Delta_3 = \Delta_{HI} \\ &\text{If} \quad V = 1: \quad \Delta_3^{LF} = \Delta_1 \phi_{LF} \\ &\qquad\qquad\qquad \Delta_3^{LD} = \Delta_1 \phi_{LD} >> \Delta_1 \phi_{LF} \end{aligned} \tag{1}$$

We can now compare the two strategies in terms of their final outcome with and without the vaccine effort succeeding. We use the final number of survivors as our welfare criterion: $W_i = \Delta_3^i$. *Ex post* we get:

$$\begin{aligned} \text{V} = 0 &: W_{LD} - W_{LF} = \Delta_3^{LD} - \Delta_3^{LF} = 0 \\ \text{V} = 1 &: W_{LD} - W_{LF} = \Delta_1 * (\phi_{LD} - \phi_{LF}) > 0 \end{aligned} \tag{2}$$

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[3] in an extension we could also introduce effectiveness as a random variable

[4] in many SIR model simulations the Laissez Faire strategy actually leads to overshooting, which would obviously strengthen our argument

In *ex ante* terms we get:

$$E(W_{LD} - W_{LF}|t = 0) = \pi * \Delta_1 * (\phi_{LD} - \phi_{LF}) \tag{3}$$

The expression for the *ex ante* welfare difference given in Equation 3 clearly shows what is going on: a fraction $(\phi_{LD} - \phi_{LF})$ of the original population Δ_1 receives as it where a binary option on the vaccine being a success [5]. the lockdown strategy delays the pandemic's incidence of the disease; if there is no vaccine, i.e. the option is out-of-the-money, that makes no difference under our final survivor criterium; but if the vaccine development strategy is successful, the option is in-the-money, the lockdown allows a fraction $(\phi_{LD} - \phi_{LF})$ of the original population to profit from the vaccine availablity and survive, an option that is not available to them under the Laissez Faire strategy. The valuation is straightforward: the number of people getting access to the binary option times the value of the binary option itself.

3 Moving beyond the skelton model: the SIR model

Of course the stylized model of Section 2 is designed to bring out the basic option characteristic that is the subject of this note and it does so by eliminating almost all other aspects of pandemic-fighting strategies. In this section we add a more realistic epidemiology model. Lin and van Wijnbergen (2021) model the vaccin discovery process as a Poisson arrival process.

3.1 A more realistic epidemiological model: the SIR model

In this secton, we bring in another advantage of Lockdown strategies, that they will actually reduce the overall burden of disease by lowering the overall loss of life years even if the vaccin turns out not to be effective, i.e. when the vaccin binary option ends up being out of the money. Introducing this additional benefit allows for some indication of the relwevance of the option value element by ontroducing other benefits too.

From an epidemiological point of view the main shortcoming of the very stylized model from section 2 is that we equate the herd immunity threshold with the final burden of the disease. But the HI threshold is the threshold after which infections start to decline; the burden of the disease is the cumulative incidence including the "ramp down" phase after HI has been reached. In this note I do not incorporate the costs of ICU overload or other economic costs but focus on refining the concept of Herd Immunity in line with the epidemiology literature[6].

The simplest SIR model defines three categories, Susceptibles S_t, Infectuous I_t and recovered or death R_t where we assume, like **?**, that a constant fraction π of the change in the R category, $\dot{R}$, dies, so the forth category, cumulative death $D_t = \pi R_t$. We assume simple linear dynamics, ignoring any more realistic delays or stochastics in the various processes:

$$\begin{aligned} \dot{S} &= -\beta SI \\ \dot{I} &= \beta SI - \gamma I \\ \dot{R} &= \gamma I \\ \dot{D} &= \eta \dot{R} \end{aligned} \tag{4}$$

The rate of increase in infections obviously depends both on how many are already infected and can therefore spread the virus, and on how many people are yet to be infected. We model this simply by letting the change in infections depend on the product SI. The number of infected

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[5] note the similarity to what Hull (2009) calls a binary cash-or-nothing call, with similar valuation formula. In a complete market setting, π would correspond to the risk neutral exercise probability evaluated using the risk neutral distribution. In our unhedgeable risk environment, pricing is not preference-independent.

[6] But see the extensive list of references in Kaplan et al. (2020) or for an analysis incorporating the real options approach in a truly integrated Integrated assessment Model combining epidemiology and economics, Lin and van Wijnbergen (2021)

increase in line with the number of newly infected βSI and declines with the number of infected who either die or survive ($\dot{R}$). And with a constant death rate, we always get $D_t = \eta R_t$.

Clearly we also get:

$$S_t + I_t + R_t = 1 \tag{5}$$

since R_t includes the number of people who have succumbed to the disease. We ignore autonomous population growth. Since we assume immunity for survivors, we do not need to keep track of mortality for tracing the development of I: somewhat morbidly for the progress of the disease it does not matter whether you are immune or dead, either way you do not contribute to further infections anymore.

Following **?** we define the basic reproduction number $R_0 = \beta/\eta$ and the implied Herd Immunity threshold $S^* = 1/R_0$ or, more usefully defined in terms of the cumulative number of people infected (or equivalently, the number of people who recovered from the disease or are dead after having caught it), $R^* = 1 - \beta/\eta$. Similarly total incidence is defined as R^∞. A lockdown is simulated by assuming a β low enough to push the normalized reproduction rate β_t/η below one.

3.2 Simulation results using the SIR model: impact of the no-lockdown and the lockdown strategies

In the simulations we have set $R_0 = 3$ and β and γ commensurately. The no-lockdown Laissez-Faire scenario (cf Panel A in Figure 1), show the familiar outcome, a sharp single peak of infections, a slow decline in the susceptible population share S_t, with R rising until the herd immunity level R^* is reached (yellow dotted lines), after which the decline in the infections starts and the eventual incidence level settles at a higher value R^infty than the Herd Immunity level R^*. Equivalently, the susceptibles share S settles at less than the Herd Immunity level. And the effective reproduction rate R_t falls below one once the Herd Immunity level is passed.

Contrast this result with a repeated-roll-over lockdown strategy (cf panel B in Figure 1), as followed in most affected countries. The by now familiar wave pattern of infections emerges, as the effective reproduction number R_t switches between values above and below 1. Eventually the herd Immunity level is reached too, but considerably later and since the decline at the last peak starts from a much lower level than in the no-lockdown case, the final total incidence settles at a substantially lower level.

From our options theory perspective what matters is the value of S_t at the vaccine discovery date, which we set at 320 days, the time between the first infections in 19 November 2019 and the approval date of the first vaccine (Pfizer-Biontech, 11 December 2020 by the FDA) in the US[7]. Under the no-lockdown scenario, by the time the first vaccine had been approved the final disease incidence level would already have been reached, with some 97% of the population having contracted the disease, and a total mortality of almost 3% of the total population. At 320 days, the S_t value was and 60% under the lockdown scenario. This means that no less than an additional 53% of the population received the binary vaccine option because of the lockdown strategy. This corresponds to the expression $(\phi_{LD} - \phi_{LF})$ in 2.

4 Using the SIR simulations in valuing the Vaccine option

The simulations run in the previous section clearly suggest that the lockdown strategy contributes to welfare in several ways: (A) even without vaccine discovery (i.e. the binary option ends up out-of-the-money), overall less people get sick and less people die. (B) even those who do get sick and eventually die, do so later than would have occurred under the no-lockdown scenario, which implies additional life years saved for given cumulative mortality. And (C), the third component, corresponds to the impact of a vaccine discovery (i.e. the binary option ends up in-the-money):

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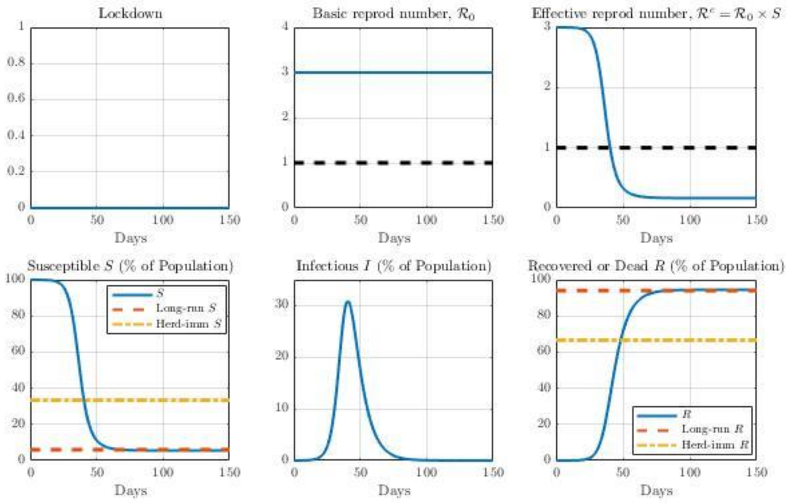
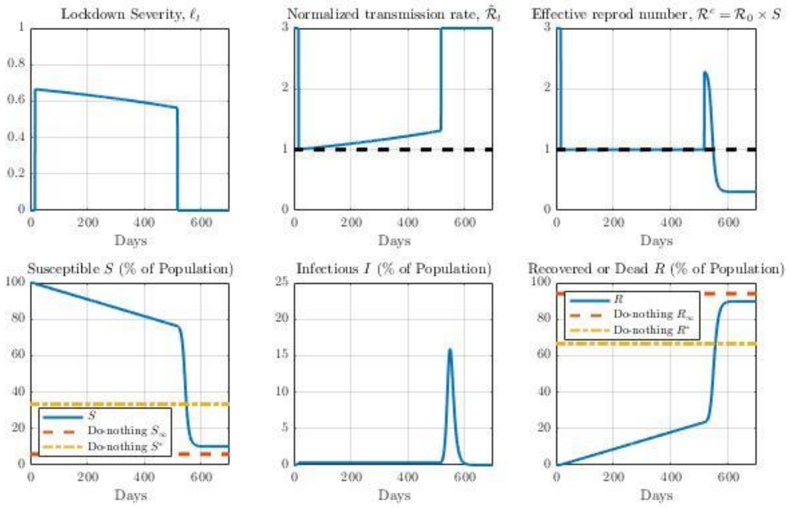
[7] In a more complete analysis the timing of the arrival should be stochastic too of course. See Lin and van Wijnbergen (2021))

Figure 1: Laissez-Faire versus Lockdown Scenario's



A: Laissez Faire scenario



B: Lockdown scenario

53% of the population does receive the vaccine option under de lockdown strategy and will not get it under the Laissez Faire strategy [8].

Consider first the various elements of the vaccine discovery/effectiveness probabilities. The medical literature (MacPherson (2021)) reports that the probability for a vaccine making it from the very fist testing phase (Phase 1) to the next stage (Phase 2), based on a large number of vaccines developed for a variety of infection diseases, is 38.2%, while the probability of making it from Phase 2 to licensure is a lower 10%. Combining the vaccine discoveries reported in the medical literature with effectiveness of the discovered vaccines gives us an estimate for the overall probability of the vaccine option ending up ”in-the-money”. We explore two effectiveness numbers: a midrange value of 70%, in between the minimum level of effectiveness required for approval (50%) and the maximum of 100%; and that maximum level of 100%, which is the reported effectiveness in preventing serious illness of the Pfizer-BionTech vaccine. This yields two values for the binary option ending up ”in the money”, 2.% and 3.8%.

We still need the epidemiological consequences of the two policies considered before we can proceed to the option value calculations. We use the model runs to quantify the epidemiological effects of the two policies considered, cf Table 1 below.

Table 1: Pandemic incidence of different policies

	Lockdown	Laissez Faire
Total (cumulative) number of infections at V-date (perc of population)	0,40	0,97
Total death at V-date (perc of population)	0,008	0,019
Total (cumulative) nr of infections at F-date (perc of population)	0,82	0,97
Total death at F-date (no Vaccine) (perc of population)	0,016	0,019
Expected nr of days until R** reached	50	300

The Table uses the results from the model runs from the previous section to calculate total infections and corresponding deaths both at the vaccine discovery date and the same once the final incidence level $R^{*}*$ has been reached (labeled ”F-date”, i.e. the final overall cumulative infection- and corresponding death rates) under both the lockdown and a Laissez Faire strategy. We now have the building blocks necessary to quantify the various effects under Lockdown and Laissez Faire strategies.

In Table 2 we use the numbers derived sofar to build up our estimates of option values based on the values for the Value of a Statistical Life VSL and the related concept Value of a Statistical Life Year VLSY reported in Kniesner and Viscusi (2019): for non-US median estimates VSL = \$ 7 million. If we assume the average expected life time remaining is 40 years for the samples they base their estimates on, the corresponding figure for the Value of a Statistical Life year VSLY = \$ 0.3 million. These estimates of VSL and VSLY allow us to quantify the various effects listed under (A), (B) and (C) in the opening paragraph of this section. We first report the results for the mid-range vaccine effectiveness of 70% and a maximum effectiveness 0f 100 %.

Table 2: Components of Lockdown strategy value (perc GDP)

Value of life years saved if Vaccine does NOT arrive/is ineffective (A)	0,078
Value of lives saved if V=0, because of difference in F-mortality (B)	0,394
Value of Vaccine option (C)	0.040
effectiveness/arrival probability	0.027 - 0.038
Total Value Lockdown Strategy	0,514 - 0.528

The results in Table2 already show that a higher effectiveness percentage (or higher arrival rate probability) will lead to a higher probability of the option ending up ”in the money” and

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[8] We now know the Corona vaccine option did end up ”in the money”, i.e. various effective vaccines have been developed with infections reduced by 70% 95% depending on the vaccine used, and risk of death practically eliminated.

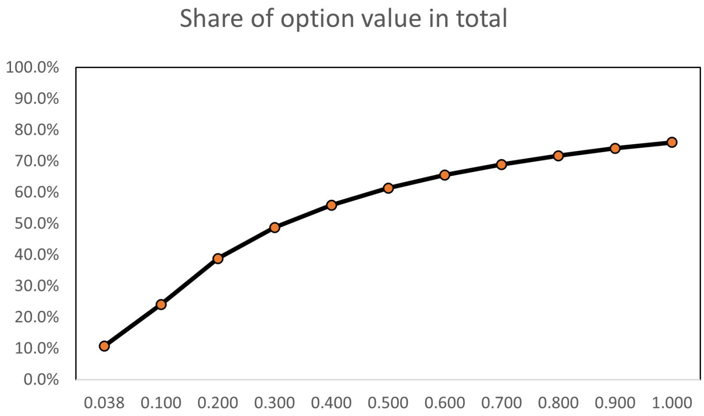
correspondingly to a higher value of the Lockdown strategy compared to the Laissez-Faire policies. We further elaborate on this relation in Table 3 below:

Table 3: Total value of the Lockdown strategy as a function of arrival/effectiveness probabilities (perc GDP)

Total value of Lockdown Strategy	0.514	0.528	0.621	0.770	0.920	1.07	1.219	1.97
effectiveness/arrival probability	0.027	0.038	0.10	0.20	0.30	0.40	0.50	1.00

Finally, at higher "in the money" probabilities the option element (C) contributes more to the total valuation of the Lockdown strategy. In 2 we plot the option value component as a share of the total valuation of the lockdowen strategy, which demonstrates this (cf Figure 2).

Figure 2: Option Value as a share of total value Lockdown strategy



Calculating this graph and Table 3 all the way through to probability 1 (100%) is not done just for completeness sake: We can look at the case of a combined arrival/effectiveness probability close to 1 (100%) as the situation where we know the vaccine works, trials have indicated its very high effectiveness, but production delays imply that it is not available until some time in the future. The three hundred days arrival delay that we assume throughout this paper is not unrealistic for many countries outside the EU/US at the time of writing this note. An interesting consequence of these resutls is that the closer a vaccine solution is, the stronger the case for continuing a Lockdown strategy.

5 Conclusions

Avoiding ICU overload by delaying and spreading out the pandemic's incidence is the argument most commonly used to defend a lockdown strategy over the Laissez Faire approach of just letting the pandemic escalate until herd immunity is reached, the so-called Swedish approach. In addition, several authors have shown that a lockdown will actually lead to lower cumulative mortality because herd immunity will be reached at lower rates of infection which causes a shorter tapering-down time (Moll (2020)). In this note we show that this argument for a lockdown strategy underestimates the value of a lockdown strategy for two reasons. First, even if the Lockdown strategy only delays the pandemic's incidence without affecting cumulative mortality, that would still imply additional life years saved. Second, and more importantly, delaying the disease's incidence has the additional benefit of giving a larger segment of the population access to a vaccine, if and when it is discovered and turns out to be effective. We show that this can be interpreted as a larger segment of the population receiving a *binary option* on the vaccine, with the in-the-money state corresponding to the discovery and roll-out of an effective vaccine, an option that they do not receive under the Laissez-Faire strategy. In an economist's language: lockdowns have a real option value in addition to their traditionally recognized advantages in terms of avoiding ICU overloads and leading to less overall loss of life. We show that this option value component can range from aboute 10% to close to 80 % of the overall value of the lockdown strategy depending on the specifics of the stochastic process driving Vaccine discovery. The option value emerges because of the stochastic nature of vaccine arrival and effectiveness combined with the unfortunate fact that death is irreversible. Dying prematurely blocks access to options that only become available after once's death. This line of thinking also leads to a second message: the case for a lockdown strategy strengthens the more likely a vaccine discovery is, the less uncertainty persists about its effectiveness and the closer by its availability.

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