Thoughts from Work /

Simulating Pandemic Control as an ROI Model

#COVID #ROI #DataScience #Modeling

TL;DR

The spread and control of a pandemic can be modeled as a function of two key parameters:

- Initial number of cases (n_0)
- Basic reproduction number (R_0)

Addressing n_0 yields a **linear return on investment (ROI)**, while resolving R_0 leads to an **exponential ROI**.

- **Testing & isolation** strategies primarily affect n_0, slowing disease spread.
- **Vaccination & herd immunity** reduce R_0, exponentially decreasing transmission potential.

The model in this post provides a simplified quantitative framework for evaluating public health interventions.

Disclaimer

The model is very macroscopic, very naive, and simplistic. This short article is more to provide everyone with a qualitative analysis based on a small amount of quantitative simulation.

In simpler terms, you can understand this simulation as a mental model.

After all, this is a blog post, so the derivation of the R□ exponential return is simplified. You can click on this video to learn more about the visual derivation process and some extended reading [1][2] mentioned.

At the same time, when this article was published, the world had already experienced more than three years of the "pandemic." Therefore, some basic concepts such as nucleic acid and vaccines will not be introduced in detail.

Moreover, I am not a medical professional myself. I am more of an ordinary person doing some basic reasoning with a high school mathematics knowledge. Welcome everyone to point out any errors.

Understanding Disease Growth and Control

The pandemic response is essentially a race to **slow the growth rate of infections**. Let *n(t)* represent the total number of infections at time.

1. **If n(t) is increasing** □ More infections are occurring than recoveries.
2. **If n(t) is decreasing** □ Recoveries or immunity gains are outpacing new infections.
3. **If n(t) remains constant** □ The outbreak has stabilized, typically via herd immunity or sustained public health measures.

We can model the infection count as:

$n = f(n_0, R_0)$

where R_0 represents the **basic reproduction number** - the expected number of secondary infections caused by a single case in a fully susceptible population.

During the three years from 2019 to 2022, most people have had the experience of receiving a "nucleic acid test/COVID test" or "vaccination". Correspondingly, these are the solutions to the two variables n□ and R□ in the above function. To further illustrate:

- Through [nucleic acid □] testing, [we] continuously discover and monitor n, and then cooperate with medical measures and the process of natural recovery, of course, including death.
- Through [vaccine □] vaccination to reduce R□*, because a large number of people have acquired immunity, preventing or slowing down the spread of the virus, which leads to a slower increase in n.

> *$\boldsymbol{R_{actual}}$: By vaccinating and increasing the vaccination rate of the population to form an immune barrier, the actual R□ is reduced, resulting in a slower increase in the final n. In this way, with the addition of information and recovery, the final value of n can be reduced.

Assumption

In fact, nucleic acid testing itself does not directly treat infectious diseases. It is more about discovering positive cases, and then receiving targeted medical resources to slow down the growth rate of *n* and reduce the losses caused to the operation of society. Therefore, here, we do not set an upper limit for the medical resources invested after nucleic acid testing and vaccination, in order to simplify the discussion and reduce the number of parameters.

ROI Implications

□□Testing & Isolation: Managing

n_0

- **Reducing n_0 yields a linear return**: Identifying and isolating cases early prevents subsequent infections in a straightforward manner.

For example, if we want to give 10 people a nucleic acid test, it can be simply expressed as the following statement:

```
for i in [1, 2, 3, 4, ..., 10]:
Nucleic acid test i
Print nucleic acid test i result
```

This program will continue to print nucleic acid test results from 1 to 10.

As you can see from the example above, the idea reflected in this program is very intuitive and direct, that is, after determining [1, 2, 3, 4, ..., n], the execution can be repeated. Naturally, what can be thought of is that the resources for repeated execution are largely determined by {incremental iteration}, which is the size of n.

If the combined benefit after each positive patient is found by nucleic acid testing is r, then the final result is:

$$\mathbf{R_t = n * r - I_t}$$

This is a linear function, Where:

- R_t: Return nucleic acid testing
- n: Number of people tested
- r: Benefit per positive case found
- I_t: Initial investment of the test

Key Takeaway

- The impact of testing is **linearly proportional** to the number of infections detected.

- If R_0 **is high**, testing alone **loses effectiveness**—it must be complemented by **vaccination**.

Vaccination: Reducing

R_0 for Exponential Returns

However, when

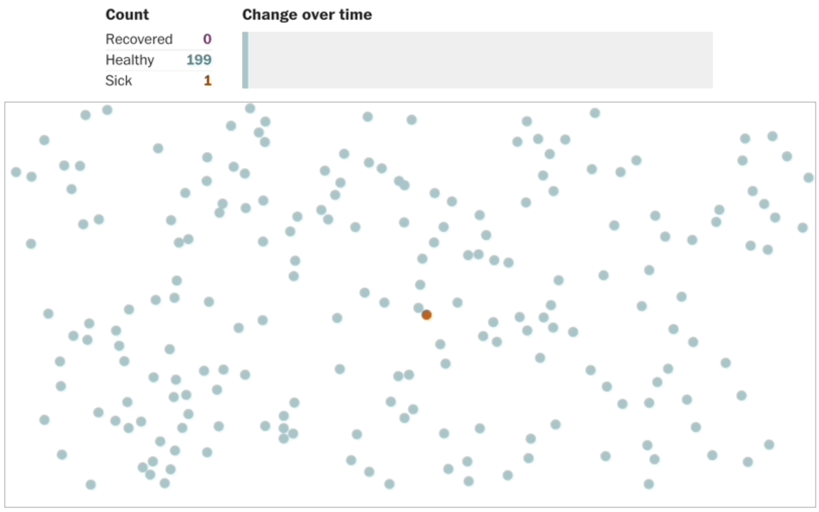
R_0

> 2, th

e spreading will

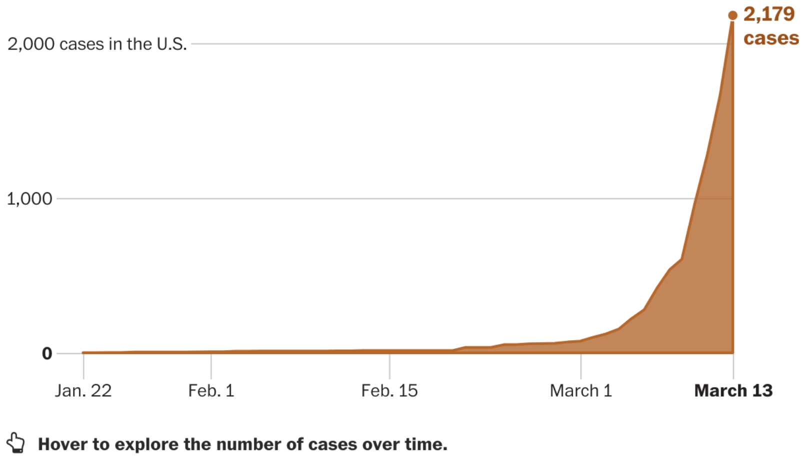
become exponential

:



Source: R0 virus spreading simulation from Washington Post[1]

When the spreading becomes exponential, the testing won't be able to catch up. Linear growth cannot keep up pace with exponential growth.



This so-called **exponential curve** has experts worried. If the

The **primary goal of vaccination** is to lower **R_0** by increasing **population immunity**, reducing transmission rates. Unlike testing, which provides **immediate but linear** benefits, vaccination follows an **exponential return curve**:

$$R_v = R_0^{f(n)} - I_v$$

This is an exponential function, where:

- **R_v** = ROI of vaccination,
- f(n) = a function representing vaccine coverage in the population

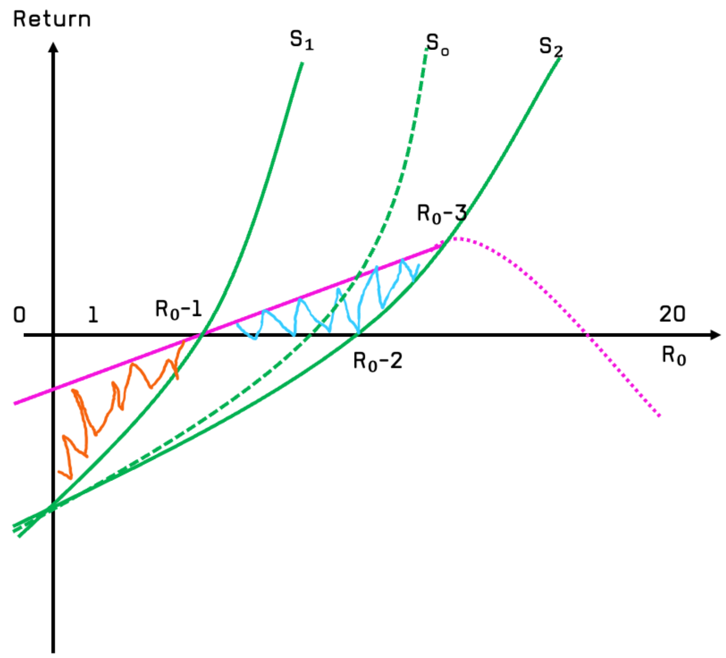
- $f(n)$ = a function representing vaccine coverage in the population;
- I_v = initial vaccine development and distribution investment.

Key Takeaway

- When R_0 **>1**, reducing R_0 through vaccination leads to **exponential reductions** in cases.
- **ROI increases significantly** as more of the population is immunized, leading to **herd immunity effects**.

Comparing ROI of Testing vs. Vaccination

1. Massive Test: $R_t = n * r - I_t$; R_t **is the ROI of covid test**
2. Massive Vaccination: $R_v = R_0^{f(n)} - I_v$



- **X-axis:** R0 values from 0 to 20
- **Y-axis:** ROI (return on intervention)
- **S green lines** are difference scenarios
- **Purple solid line**   **Linear ROI** from testing
- **Purple dashed line**   **Testing effectiveness declines** beyond a threshold R0
- **Green solid line** **Exponential ROI from vaccination**

S1 Scenario

At a certain R value, nucleic acid tests and vaccines are used simultaneously.

Then the difference in overall benefit between the two ΔR = Rv - Rt is:

> ***The area under the green curve of S on the X and Y axes minus the area under the purple solid line on the X and Y axes, which is the orange shaded area since both are negative values.***

In the S scenario, the benefit of using nucleic acid testing as the main means is greater than the benefit of using vaccination as the main means.

The actual situation is that the huge upfront cost of vaccine development and time often lag behind the application of nucleic acid testing technology. This is determined by the inherent clinical research and development cycle to market.

S2 Scenario

When R□ reaches a critical value, the benefit curve of nucleic acid testing will drop rapidly, especially when the growth rate of the number of positive cases *n* becomes larger and larger due to R□. Doing nucleic acid tests will become a negative return. That is to say, after R□□ in the figure, in order to ensure comprehensive benefits, vaccines must be used as the main solution. The comprehensive benefit difference ΔR > 0

Moving from S1 to S2 Scenario

> This is what we essentially experiencing that the COVID's R0 is increase from initial around 5 to now 10+ of variants.

When R□□ < R□ < R□□, for the green solid line with S□ vaccine as the main focus, the benefit of the nucleic acid-based solution is still greater than that of the vaccine. This is the area of the blue □ shadow in the figure. Of course, if the vaccine-based approach can be introduced earlier after R□□, there will actually be an optimal vaccination benefit curve S optimal between S□ and S□. The comprehensive benefit difference of this curve ΔR = 0, which is:
The comprehensive benefit of nucleic acid testing is equal to the comprehensive benefit of vaccination, Rv = Rt

Key Observations

- **Testing provides strong early ROI** when cases are manageable (R0 is low).
- **Vaccination dominates as R_0 increases**, preventing rapid outbreaks.
- **There exists an optimal switch point** $R_{optimal}$, where public health measures should shift from testing to vaccination.

Policy Implications

1. **Early Phase of an Outbreak**:
   - **Testing and isolation** are cost-effective as **R_0 is low** and cases are trackable.

1. **Mid-Pandemic Response**:
   - As **R_0 increases**, testing loses cost-effectiveness, and **mass vaccination must take over**.

1. **Long-Term Strategy**:
   - If **vaccination is deployed early**, the **exponential benefits outweigh** short-term testing strategies.

Final Takeaways

- **Mitigation measures** (e.g., lockdowns, testing) are effective when transmission is low.
- **Vaccination** is the most scalable long-term solution, offering **exponential benefits**.
- **A data-driven, adaptive policy** should **switch strategies** based on the **real-time growth rate of infections**.

> ***I believe this model effectively explains China's successful containment of the pandemic from 2019 to 2021, but unfortunately, the zero-COVID policy is now***

> ***pandemic from 2019 to 2021, but unfortunately, the zero-COVID policy is now facing challenges and has had a significant impact on the lives and economy of its people, especially in 2022 when COVID virus become extremely contagious while isn't that fatal given now vaccination is available.***

Further Reading

The idea for this article was conceived around April or May of 2022. Then, on November 21, 2022, New York City published an article[3] detailing the benefit calculation of New York City's vaccine rollout campaign. It was very detailed and calculated that every $1 spent brought $10.19 in return (through reduced infection rates, mortality rates, decreased loss of efficiency, and optimized use of medical resources). That's almost a 10x return, which is an exponential return.

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1. https://www.facebook.com/washpostvisuals (2020). Why outbreaks like coronavirus spread exponentially, and how to 'flatten the curve'. [online] Washington Post. Available at: https://www.washingtonpost.com/graphics/2020/world/corona-simulator/ [Accessed 17 Dec. 2022].
2. Meltingasphalt.com. (2022). Outbreak. [online] Available at: https://meltingasphalt.com/interactive/outbreak/[Accessed 17 Dec. 2022].
3. Return on Investment of the COVID-19 Vaccination Campaign in New York City | Public Health | JAMA Network Open | JAMA Network

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