Luohan Academy

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NAVIGATING THE VACCINATION PHASE OF PANDEMIC ECONOMY

Implications for Adaptive and Robust Global Recovery

Navigating the Vaccination Phase of Pandemic Economy –

A Preliminary Evaluation and Implications for Adaptive and Robust Global Recovery

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Table of Contents

Navigating the Vaccination Phase of Pandemic Economy – 1
A Preliminary Evaluation and Implications for Adaptive and Robust Global Recovery 1
Summary 2
1. Background 2
2. Vaccine, as a game-changer, brings new opportunities and challenges 3
3. Build effective population immunity to recover step by step 6
4. Global vaccination landscape and immunity gap patterns 9
5. Roads to normalcy – what do we learn from the forerunners 11
6. Toward the end of the pandemic economy 16
7. References 20
8. Supplementary Information 20
8.1 Methods for calculating Effective Population Immunity Rates 20
8.2 Graphing the vaccination phase of representative countries in other regions 24
The Eastern Asia model face challenges 24
Western Europe slow in rolling out vaccination 25
Eastern Europe in turmoil 26
South and Southeast Asia longing for vaccines 27
Most of African countries waiting for help 28
Vaccination in Latin America kicks off while virus transmission still high 28

Summary

- Globally the vaccination phase of the pandemic economy commenced at the end of 2020.
- Vaccination offers a much-needed new tool that decision makers can use together social distancing and lockdowns as a two-pronged strategy to tame the pandemic.
- We developed a population-level effective immunity rate indicator and a four-stage scheme to help decision making by policy makers and general public.
- We applied the indicator system to evaluate the performance of forerunner countries in vaccination and synthesized three main lessons.
- Absolute herd immunity may not be achieved, and an economy with 50% effective immunity rate can fully re-open with the aid of digital tools such as vaccine passport, a quasi-normalcy.
- Substantial gaps exist across countries and regions in their vaccination and social distancing strategies and the regional immunity gap situation will hinder global recovery.

1. Background

The COVID-19 pandemic has resulted in 120 million infections and more than 2.6 million deaths officially recorded worldwide. The actual infected population is likely to be much higher at a minimum of 3-5 times of the official record[1] (Stout & Rigatti, 2021, p. 30). Classic public health measures, mainly social distancing and lockdown policies for disrupting the virus transmission network within population, are the cornerstones of pandemic mitigation and containment efforts. However, they would cause turbulence to normal social and economic activities of industrialized societies inevitably. This has negatively impacted the lives and livelihood of billions of people and caused trillions of dollars of economic losses. The social and economic turmoil is still evolving.

Herd immunity, a situation when a considerably large proportion of the population has developed **adaptive immunity (aka. acquired immunity)** to the virus so that transmission is contained, dictates the ultimate end of the pandemic economy. People can develop adaptive immunity from either getting vaccinated or being exposed to an infection. They help human body

[1] Based on statistical models developed by Imperial College London and the Institute for Health Metric Evaluation (IHME) at University of Washington, respectively.

learn to target specific pathogens in the future by making new antibodies that often last for a long time.

Initially, a small number of countries, such as the UK, Sweden and Brazil, designed their policy with the aim to achieve herd immunity through (controlled) mass infection. These attempts failed with high level of excessive deaths. By early March 2021, globally less than 10% of global population are likely to have attained COVID immunity, according to a synthesis on 500 seroepidemiological studies[2]. The indisputable consensus now is that **the only way to achieve herd immunity and end the pandemic is through fast and fair vaccination**.

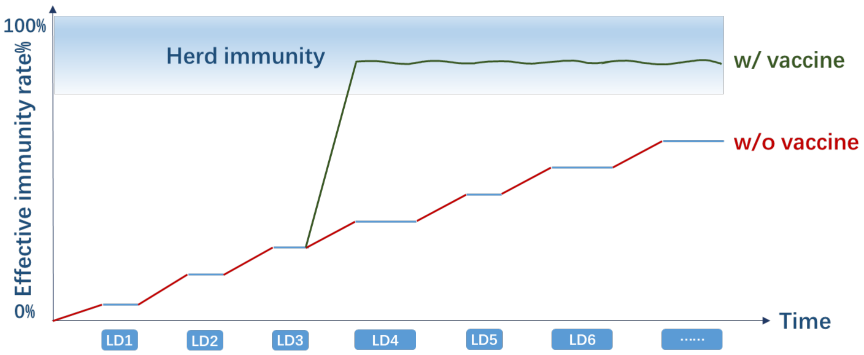


Fig. 1 A schematic depiction of acquired immunity via infection and vaccination. Blue boxes along the x axis indicate periods with mitigation measures such as lockdown (LD) and social distancing.

2. Vaccine, as a game-changer, brings new opportunities and challenges

Back in May 2020 when the pandemic was at its first peak, the Luohan Academy developed a five-phase pandemic economy framework (namely the Preparation, Response, Trough, Recovery, and Vaccination phases) to help understand the general co-evolutionary patterns of the pandemic and the economy. It defines that **the Vaccination phase would only commence with the successful development and approval of reliable COVID-19 vaccine(s). During the Vaccination phase, "mass vaccine production is made possible, followed by equitable and speedy deployment worldwide, then the economy decouples from the pandemic".**

Before reliable COVID vaccine is available, for most countries where early virus containment was not successful, there is a hard trade-off around the social distancing and lockdown policies. Such policies are good for public health but bad for economic and social stability; most countries, regardless of their income level, could not manage a delicate balance. As a result, many suffered

[2] From the comments of the WHO's chief scientist Soumya Swaminathan, shown on WHO's twitter account.

high death tolls and large economic losses simultaneously.

Taking a dynamical system view of this trade-off, the system is composed of a number of negative feedback loops coupled together (Fig. 2a). The only useable tool is social distancing and lockdown, a passive way to cope with the pandemic. The high fatality rate prohibited the option of achieving herd immunity through infection (dashed line in the diagram), as a result the system is trapped in sub-optimal conditions with back-and-forth lockdowns. What was especially worrying was the new virus variants. By the fourth quarter of 2020, a number of them emerged from multiple countries, including the UK, South Africa, and Brazil, and have been proven to cause higher transmission rate and death rate. Over the past winter season, they have become the dominant virus strains in many countries.

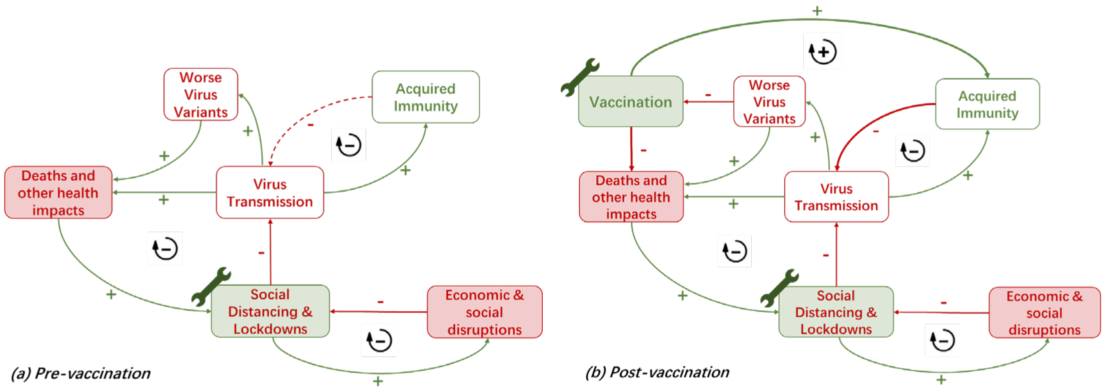


Fig. 2. Causal-loop diagrams on the potential of vaccination in changing the policy dilemma around social distancing and lockdowns in terms of the health and socioeconomic impacts.

The coming of mass vaccination can be a game changer (Fig. 2b), first by being able to substantially reduce death rate caused by virus infection, especially among vulnerable population. Second and equally important is that mass vaccination can help quickly build acquired immunity defense at population level. A number of studies have shown that once certain thresholds of population immunity (e.g., ~50% as shown in (Hogan, A. B. et al., 2020)), albeit below herd immunity level, is reached, virus transmission would slow down to an extent that some relaxation of social distancing and lockdown is feasible. This would give decision-makers precious space to alleviate the public health-economy trade-off when operating the social distancing and lockdown policies. Third, a critical side-effect of fast vaccination is the progressive reduction in the chance of having worse virus variants, or even variants that might make existing vaccine lose its function, a phenomenon called immune escape. Therefore, vaccination, as an active tool to deal with the pandemic, can substantially expand decision-makers' capacity in dealing with the pandemic and addressing the lockdown dilemma.

Fortunately, in the past year, we have witnessed truly unprecedented progress in COVID vaccine research and development, in which about a dozen types of COVID vaccines have been approved by different nations, while many more candidates are still being developed and tested. It was estimated that 12 billion vaccines from a range of producers, in both developed and developing countries, will be produced in 2021 (Lancet, 2021). Since the third quarter of 2020, several vaccines have been approved for emergency uses. The approval of the BioNTech/Pfizer mRNA vaccine by the WHO on Dec. 31st 2020[3] signified a pivotal moment in our Vaccination Phase globally. By the mid-March 2021, almost 400 million doses of vaccines have been administered in 100+ countries.

About three months have passed since early approval of vaccines for emergency uses in major advanced economies. Countries vary significantly in their capability to development, produce, access, afford, and implement COVID-19 vaccinations, and strong differentiations have been witnessed in the progress of vaccination around the world. Globally reported cases began to decline from the highest point since January, 2021, and has rebounded since mid-February, 2021., largely in Europe where vaccine availability is among the highest (Fig. 3a). In the meantime death rate is maintained at a high level of 8,000-9,000/day (Fig. 3b).

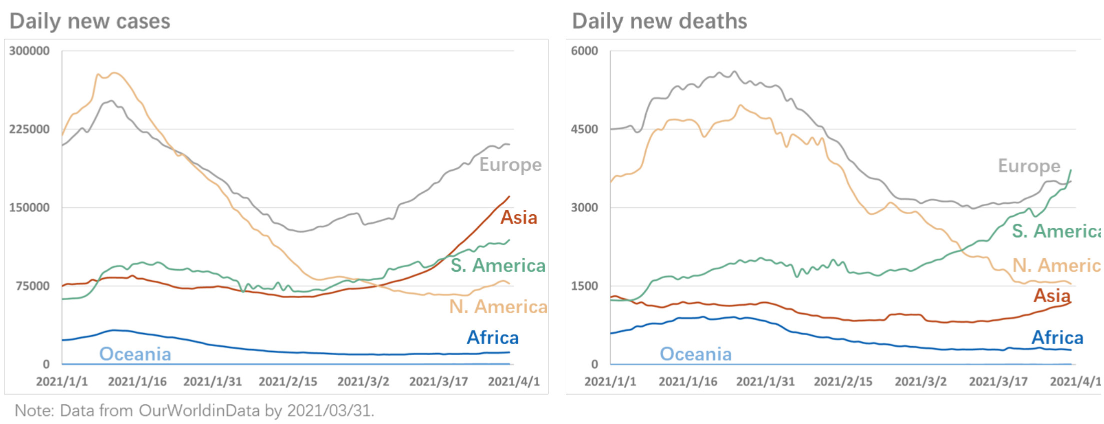


Fig. 3. Daily reported cases and deaths worldwide in regions Jan. 1st 2021.

Obviously, vaccination is not a magic bullet, and we should not expect that substantial

[3] https://www.who.int/news/item/31-12-2020-who-issues-its-first-emergency-use-validation-for-a-covid-19-vaccine-and-emphasizes-need-for-equitable-global-access

improvement of the pandemic situation may happen at large scale in merely three months of its initial implementation of mass vaccination. But the three months of operation, in various ways and paces across countries, gives us an opportunity to conduct an evaluation of the efforts by far. The Vaccination phase globally is expected to be at least two years long, and it's impossible and unnecessary to wait until herd immunity is reached before we let lockdown policies to relax and re-introduce normal social and economic activities to societies. Therefore, learnings from recent efforts are of great value in tackling the major challenge now - **how to simultaneously implement vaccination and practice social distancing and lockdown policies effectively and adaptively so that deaths and socioeconomic losses can be minimized** in this last part of the journey.

3. Build effective population immunity to recover step by step

For countries that have suffered great economic and social impacts from lockdowns, the challenge above basically boils down to the question of when such policies can be relaxed, at what level and for how long. The key indicator here is the level of acquired immunity at population level in a certain area.

Since the roll-out of vaccines, a number of global vaccine trackers (Bloomberg, NYTimes, OurWorldinData, etc.) have been developed and updated on a daily basis for most countries and regions. They provide detailed data on several metrics of vaccination and the most commonly used indicators include:

- Total doses administered per hundred people
- Percentage of people that have taken at least one dose of vaccine
- Percentage of people that have been fully vaccinated

Bloomberg also calculates an index of the remaining time to reach herd immunity based on projection of the full vaccination percentage data of each country. These indicators, while useful, are only indirect proxies of immunity gained from vaccination. These indicators are also merely partial, especially for countries with severe outbreak in the past year, as they do not consider immunity attained from past infection.

Thus, what matters is the **Total Effective Immunity Rate (TEIR)** of the whole population, which comes from **Effective Immunity Rate from Infection (EIRi)** and **Effective Immunity Rate**

from Vaccine (EIRv). Population level's EIRi and EIRv each can be calculated as a proportion of the infected and vaccinated population, respectively.

The current vaccination policy does not exclude people with past infections (red color in Fig. 4). As more people are vaccinated (green color in Fig. 4), it will include a certain proportion of previously infected individuals (overlapping area in Fig. 4). Therefore, we have

TEIR = EIRv-x + EIRx + EIRi-x = EIRv + EIRi – EIRx

in which, EIRx is the level of effective immunity from vaccinated individuals with past infection, EIRv-x is the effective immunity from vaccination only, and EIRi-x is the immunity from past infection only. For detailed information on how these EIR metrics are calculated, all based on publicly available information and knowledge, please check the Supplementary Information Section 8.1.

Based on state-of-art knowledge on the epidemiology of COVID-19 and making use of to the EIR metrics, we propose a general sub-phase scheme of the vaccination phase as rule-of-thumb principles to –

a) understand the status of the pandemic vaccination phase in a country;

b) to track the effective contribution of vaccination to population immunity;

c) to inform decisions on operating the various social distancing and lockdown policies; and

d) to position a country in a global ladder of COVID immunity levels, hence the roll of economic recovery and re-integration into the post-COVID global economic system.

The rules for sub-phase classification is as follows (see Fig. 4 for a visual guide) –

- Pre-vaccination phase EIRv = 0
- Early-vaccination (sub)phase 0 < EIRv < 20%
- Mid-vaccination (sub)phase 20% <= EIRv AND 20% < TEIR < 50%
- Late-vaccination (sub)phase 20% <= EIRv AND 50% < TEIR < 75%
- Normalcy phase 75% <= TEIR

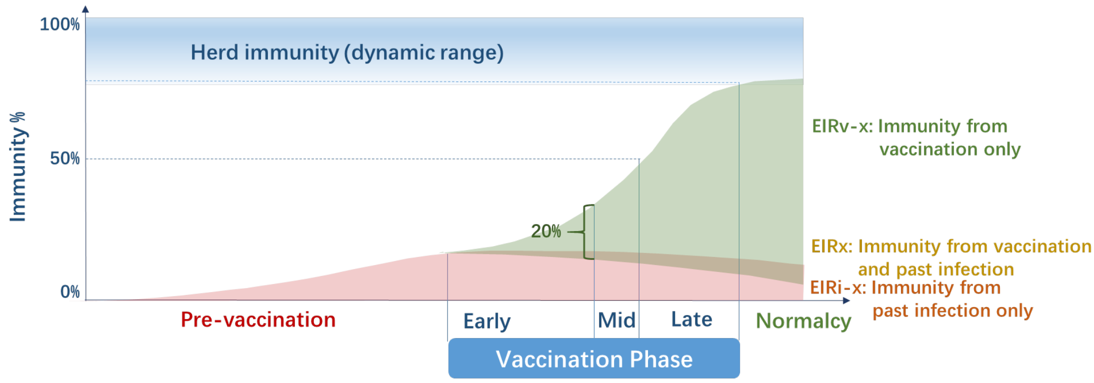


Fig. 4 Schematic depiction of the sub-phases of the vaccination phase of pandemic economy.

An EIRv, effective immunity from vaccination, of 20% is used as the first threshold here that divides the Early and Middle vaccination stages. This is what WHO, GAVI - the Vaccine Alliance, and other partners proposed as an initial target of vaccination in the COVAX facility program. Countries usually prioritize to first vaccinate critical workers, followed by the vulnerable population especially the elderlies. Such immunity level from vaccination, plus some level of immunity from past infection, provides a basic defense level at which severe fatality rate can be prevented and most strict lockdown may not be necessary any more. At this level, essential services can be fully functional without causing substantial additional virus transmission.

The next threshold is 50% of TEIR - total effective immunity rate, around which ICL study suggested more relaxation of social distancing rules can be practiced. The 20% EIRv requirement is retained, as this marks a critical threshold at which large outbreaks and high fatality rate can be avoided. Only when both conditions are met a country can be considered to be in the Late vaccination stage. During this stage, many non-essential businesses and activities can be reopened, likely with some restrictions.

We use a herd immunity level of 75%, corresponding to a reproductive number (R0) of 4, to take the spread of the new, more transmissible, variants into account. Any country with a total effective immunity rate of 75% or more, together with further vaccination capacity, should be able to get back to (new) normal social and economic lives.

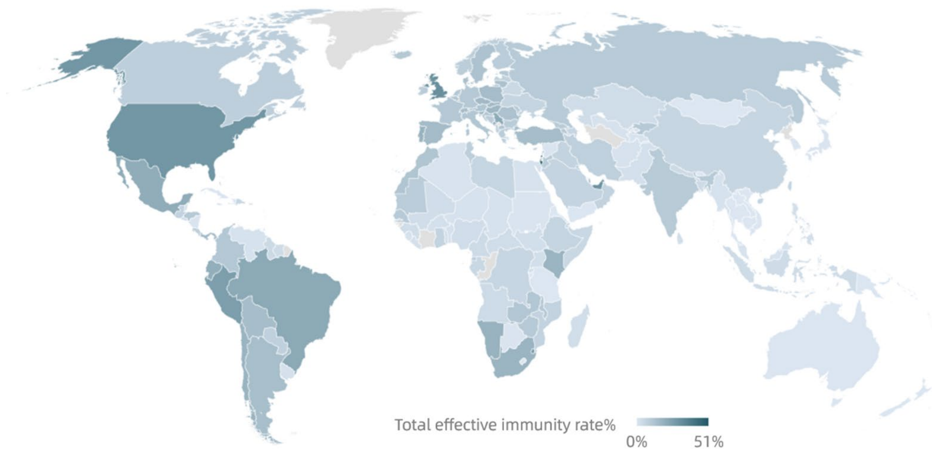
We apply the effective immunity rate calculation methods and the vaccination subphase scheme to 185 countries as an evaluation of the first three months of the Vaccination Phase of the COVID pandemic economy, and hope to bring the learnings and lessons to the ongoing and later efforts to help speed up the vaccine rollout in order to help countries achieve a robust recovery.

4. Global vaccination landscape and immunity gap patterns

Despite the extremely unequal level of vaccine availability and affordability across countries, which has been reported extensively in Jan. and Feb. 2021, the mid-to-long term prospect of vaccination seems to be slightly more promising. More vaccines are produced and approved, new channels, many through bilateral agreements with Chinese and Russian vaccine makers, are made available, and the COVAX facility has successfully secured sufficient funding for its 2021 target thanks to G7's recent financial commitments. However, the current progress of vaccination and effective population immunity varies vastly between income groups and regions. On average the effective immunity rate from vaccination is 6 and 25 times higher in high-income countries than that in upper-middle and lower-middle income countries respectively.

As of the total effective immunity rate, the global average is 3.4% by March 16th, 2021, ranging from 0-51% (Fig. 5). Israel, Bharain, UAE, Seychells, the UK, and the USA are the leading countries

Fig. 5. Total effective immunity rates vary substantially across countries (by March 16th, 2021).



The total effective immunity rate shows a strong cross-regional variation (Fig. 6). Generally, countries that have been hit harder by the pandemic (i.e., higher death rates) have higher immunity rates, mainly from past infections (e.g., Africa and Latin America), and richer countries who have better access and implementation capacity to vaccination tend to have higher immunity rates from vaccination plans (e.g., US, UK, and West Asia). By far, in European countries the two sources contributed roughly equal to its total effective immunity (Fig. 7), while East Asian and Oceanian countries generally have low immunity rates from both sources, except China and Singapore.

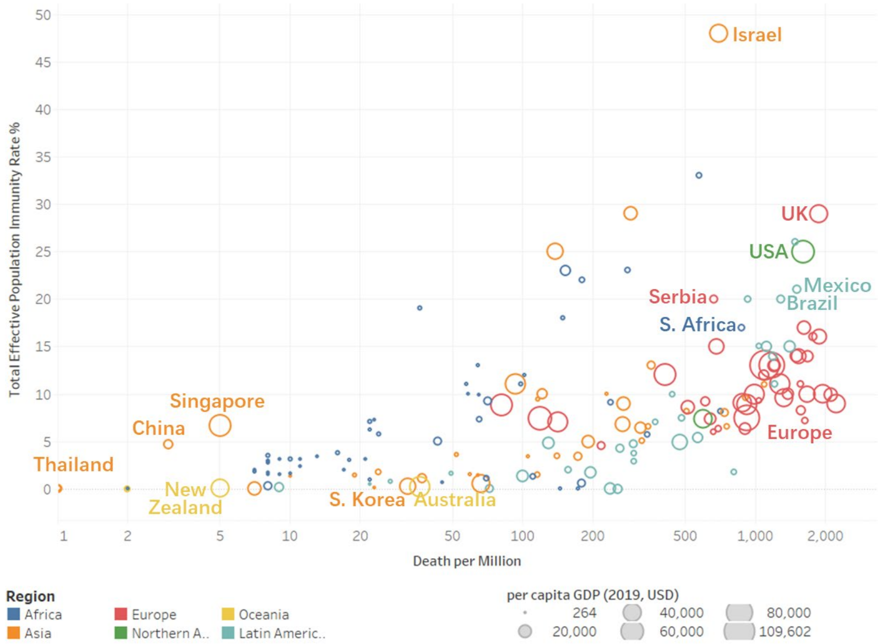


Fig. 6 Effective immunity rates of countries from different regions and income groups.

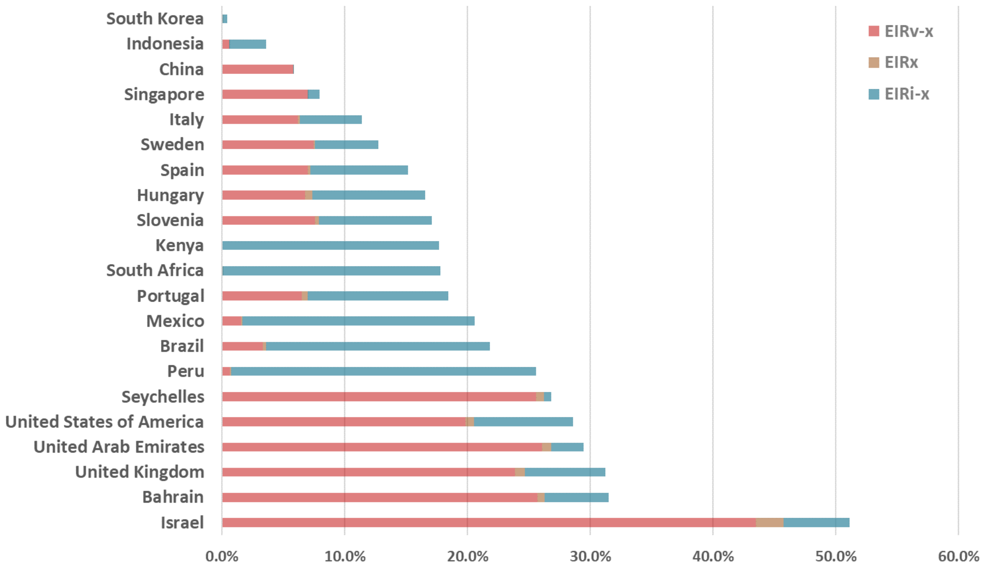
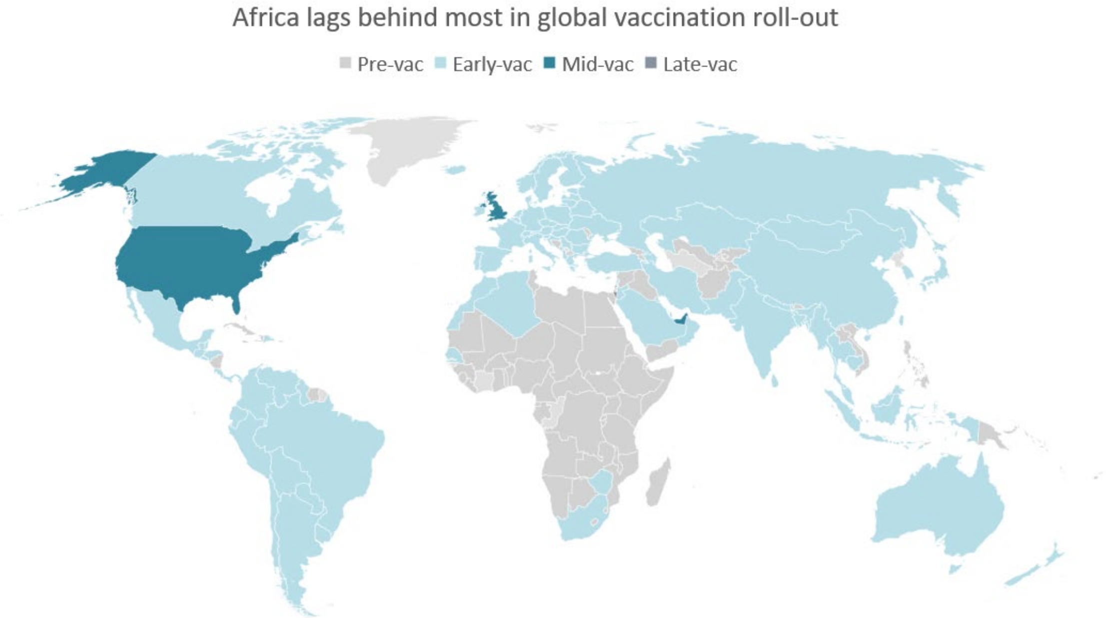


Fig. 7 Contribution of vaccination & past infection to total effective immunity in selected countries (EIRv-x, EIRx, and EIRi-x correspond to immunity from vaccination only, from both vaccination and past infection, and from past infection only, respectively.

Applying our vaccination subphase scheme, by March 16th, 2021, out of 185 countries and regions evaluated, there are 98 countries in early-vac subphase and 5 in mid-vac subphase (Bahrain, Seychelles, UAE, UK and USA) (Fig. 8). Israel is the only country in the late-vac subphase with a total effective immunity rate of 51%, the majority of which came from recent vaccination.

Fig. 8 World map of countries various subphases of the vaccination phase of pandemic economy. By March 16th, 2021, Bahrain, Seychelles, UAE, UK and USA are the five countries in Mid-vac



subphase, while Israel, with the highest TEIR of 51%, has reached late-Vac subphase.

5. Roads to normalcy – what do we learn from the forerunners

After the first three months of mass vaccination, six countries have emerged as the forerunner in this race to herd immunity and to normalcy, led by Israel in the late-vac stage. Fig. 9 shows the changes of key pandemic economy indicators along with effective immunity rates in these countries from Jan. 1st to mid-March. Although a small number of countries might not be representative enough in many regards, it is still highly useful to examine their different patterns and learn from them.

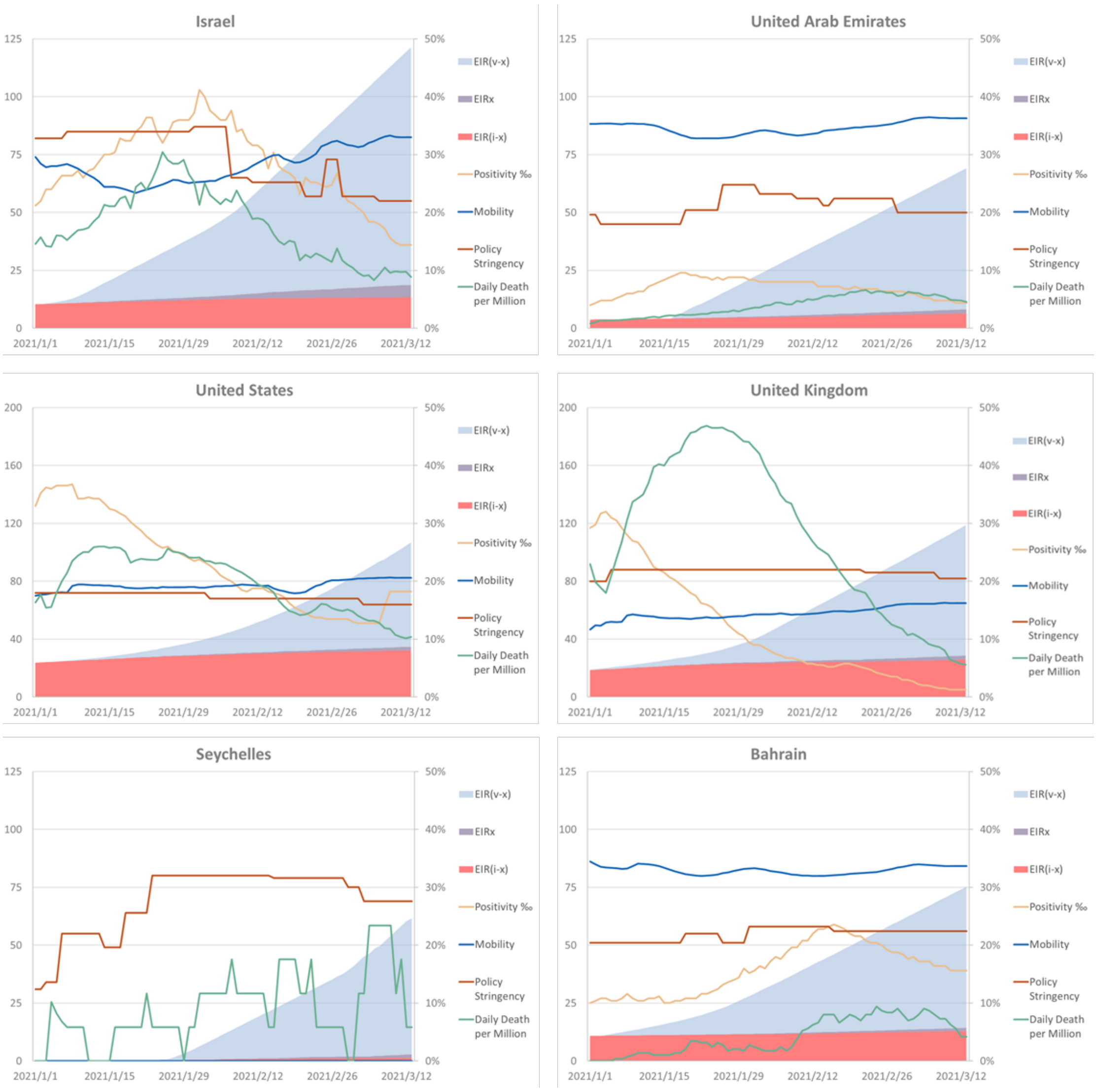


Fig. 9 Dynamics of key pandemic economy indicators along with effective immunity rates in the forerunner countries during the vaccination phase by March 13th. Note that Israel reached 50% on March 16th, which is not reflected in this figure.

Israel provides the world with the most compelling evidence of the effectiveness of a combination of fast vaccination and strict social distancing policies, behind which there is strong financial capacity and political will. Stringent policies (e.g., a policy stringency score of 80+) during the early days of vaccination helped limit further virus transmission within the population, especially when the new virus variants were spreading. As more of the priority population (i.e., key workers and vulnerable elderlies) were vaccinated, both fatality rate and test positivity rate started to decline from early February (Fig. 9). This trend is steady even after some relaxation of the early social distancing and lockdown rules and increasing mobility of population. By the time Israel enters the late-vac subphase, its fatality rate and positivity rate have both dropped to the level before this past winter wave of the outbreak.

Israel's strategy also includes large-scale social campaign to motivate all people above 16 years old to get vaccinated, as well as the use of a new Green Pass System with QR code, enabled by digital technology, to let fully vaccinated people to travel freely and attend events with limited mass gatherings. People without the green pass cannot attend events, but are still allowed to use the essential services, to avoid inequity that might be caused by a two-speed system between early and late vaccinated people. Israel might be the first medium-size economy to fully re-open its economy, but its final step toward heard immunity and normalcy still faces uncertainties, especially as 25% of its people reported to be unwilling to take vaccines despite a strong social campaign for the individual and collective benefit of vaccination. Overall, it's a living model of how a relatively small population can re-gain normalcy by exploiting synergy between social distancing and vaccination.

UAE and Bahrain, two countries also in Western Asia, were the second and third countries entering the mid-vac subphase. Despite relatively lower social distancing policy stringency (both at 50-60), they both employed additional test requirement as well as digital vaccine passport system similar to Israel's. Declining in positivity and fatality rates have been observed in both countries recently, after they reach the mid-vac subphase in early March.

Seychelles, an even smaller economy, is the first in the world to announce the acceptance of vaccine passport to help revitalize tourism, its main economic income source. However, its vaccine rollout offered a perfect counter-example. Despite the economic shock, the country remains to be almost virus free for a long period until the end of 2020, with only around 200 cases and zero death. Policy stringency was low at around 30 when the vaccination started. However, as soon as the news of the arrival of initial batch of vaccines was released and before the first dose of vaccine was given in mid-Jan. 2021, people increased their activity level and optimism was around that the country would reach herd immunity by mid-March. However, what followed was an immediate surge of the cases not seen before. More than 3,000 cases have been reported out of a small population of 100,000, and 16 died in 2021. The adjustment of policy stringency first to 60 and later to 80 was not able to stem this trend that could have been avoided, resulting in an awkward parallel increasing trend of both infection and vaccination in the country.

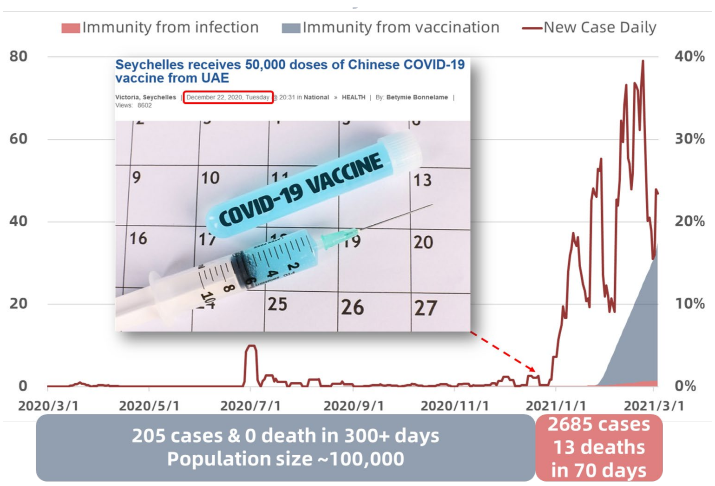


Fig. 10 (OPTIONAL)

Larger economies face more complex situations and require more delicate design of their vaccination and social distancing/lockdown strategies.

The UK, despite its mistaken early policy choices a year ago, has been rather determinant in implementing the best scientifically informed policy arrangement since the past winter, especially when it was confirmed that a new variant originated in the UK were causing higher transmissibility and potentially also higher deaths. In early Dec. 2020, the UK approved the emergency use of BioNTech/Pfizer vaccine, earlier than the US and EU. It has since then implemented the most stringent and longest lockdown policies (scoring 90+, note that the Y axis on the left is scaled twice as much for the US and the UK in Fig. 9). The arresting of the increasing fatality rate from the new variant was impressive, likely due to the effective targeting and participation of vulnerable elderlies in the initial round of vaccination program. To maximize vaccine coverage, the UK government decided to abandon manufacturer's suggestion of a two-dose vaccination scheme with a two-week interval, instead they extended the interval to as much as three weeks. This was considered to also help increasing population immunity in a faster way.

The UK reached a 20% effective immunity rate from vaccination on March 6th in our calculation. Two days later the government kicked off the initial step of a comprehensive 4-month long unlocking program by first reopening schools and allowing people to leave home for recreation and exercise outdoors. The next steps will be to reopen outdoor sport facilities and relax "stay at home" rule on March 29th, when we expect the UK will approach ~40% total effective immunity rate, and to reopen non-essential businesses and allow for small size gathering and events by April 12th, when its total effective immunity rate may reach more than 45%, close to the threshold of late-vac subphase. According to the ***Roadmap out of lockdown*** the UK expects to get back to normalcy by late June. The plan seems quite attainable, as the UK may approach an effective population immunity level of 70% or higher, considering that the country has secured more than enough vaccines and vaccine hesitancy in the UK is among the lowest in advanced economies. The coming of a new vaccine passport system will also help the UK to reopen robustly even if the immunity level is a bit lower than herd immunity threshold, making the UK the first major economy to regain normalcy by summer 2021.

The situation in **the US** has substantially improved since Biden took the presidency on Jan. 20th. They reached the 20% threshold of effective immunity rate from vaccination on March 15th, and Biden's commitment of administering 100 million doses in the first 100 days of his presidency will be realized at least 40 days earlier. However, there exist vast heterogeneity across the states and municipalities in the US in terms of their social distancing and lockdown policy stringency, and at a national level the stringency is only at 70, much lower than that of the UK and Israel. There also is debates around vaccine hesitancy as well as privacy issue related to vaccine passport. Therefore, we expect that the US overall may enter the late-vac stage in summer with large variation among states. Nevertheless, the chance is high that the US will be back to the new normalcy in the third quarter of 2021.

To summarize, some key learnings from these forerunners are –

a. Vaccination should absolutely be preceded and full accompanied by (during the early-vac period) strict social distancing and lockdown to quickly build a double-shield system for key workers and vulnerable population.
b. Relaxation of social distancing and lockdown can take place from around the mid-vac period but need be step-by-step, matching with the level of effective population immunity, in an adaptive way.
c. Digital technology can be an important assurance in implementing both vaccination and lockdown with precision, for example through an APP-based vaccine registration system. Testing and contact tracing, including vaccine passport, are necessary part of the relaxation process and may stay with us for a long while even during the new normalcy period.

6. Toward the end of the pandemic economy

While the messages from the forerunners are encouraging and the light at the end of the COVID-19 tunnel seems more visible, for the whole world the final part of the journey will not be smooth.

Careful examination of the situations in the other regions (for detailed graphing of representative countries in other regions, please check Supplementary Information 8.2) showed a variety of challenges faced by different countries.

The European Union countries have also secured plenty of vaccines, but have been stuck in a mixture of bureaucracy, vaccine hesitancy, and dispute over vaccine efficacy between the governments and large vaccine provider AstraZeneca, among other reasons. As a result, the EU countries have an average of only 5% effective immunity rate from vaccination after 2.5 months of deployment, much slower than the UK and the US, but generally most Western European Countries were able to control their positivity and fatality rates to a low level, which provides a good foundation for the later speeding up of vaccination once the barriers are cleared. Some of Eastern European countries, however, have observed a new outbreak as vaccination took place, likely in a similar situation as what happened in Seychelles. Several countries, such as Hungary and Czech, are experiencing their highest ever daily cases and deaths, despite increasing vaccine rollout. But overall these countries have reasonable affordability and accessibility, thus will be able to reach late-vac subphase, or even close to normalcy period before the end of 2021.

In Eastern Asia and Oceania, the countries with the early successes, such as China, South Korea, Vietnam, Singapore, Australia and New Zealand, suddenly found that they are in an disadvantaged position in terms of the total effective population immunity, thanks to their effective protection of the population from infections. Except China and Singapore who have been deploying fast mass vaccination program, the other countries have been waiting for more robust vaccine result data. **This may cost these early winners a late recovery due to their immunity gap with the majority of the advanced economies toward the second half of 2021. Vaccine passport is likely to help alleviate the impacts to some extent.**

Vaccine rollout in the Global South across Africa, South and Southeast Asia and Latin America is generally much slower, except in a few countries such as Chile and Morocco. Different from the high-income forerunners, most of these lower-middle income and low-income countries have very limited or delayed access to the vaccination as well as vials, syringes and even other vaccine-related staff, and many of which also face substantial logistic challenges. It is rather certain that most of them will not be able to achieve high population immunity until 2022 or even later.

In Jan. 2021, the WHO Director-General called this extremely inequitable global vaccine allocation a “catastrophic moral failure”, and pushed the rich countries to release some of their vaccines in the stockpile and share them with the developing countries. While later, the G7 committed to providing more financial support to ensure sufficient funding for the implementation of COVID-19 Vaccines Global Access (Covax) facility in 2021, very few have committed to spare a major part of their existing vaccine orders to developing countries. So far, high-income countries have secured enough doses of vaccines that could vaccinate their population 2.5 times, while low-income countries have access to vaccines that could only cover around 20% of its population, mainly through Covax.

Recent research shows that these short-sighted decisions will have severe health and economic consequences in both developing and developed countries.

Equitable vaccine distribution will save more lives

To assess the health consequences of varying vaccine allocation strategies, network scientists at Northwestern University in the US modelled the potential losses of lives in two scenarios. They assumed that three billion doses of vaccine had been available in the early stage of the pandemic. In the uncooperative scenario, high-income countries monopolize and stockpile the first 2 billion doses of a vaccine, and in the cooperative allocation scenario, vaccines are equally distributed according to population size instead of income-level and/or R&D capacity. The model results showed that, assuming an 80% efficacy level of the vaccine (similar to what we have now), equitable global distribution of vaccines would save almost twice as many lives than in the uncooperative scenario. When compared with the cooperative allocation scenario, the high-income countries gain modestly in the uncooperative scenario, while the losses for low-income countries will be devastating .

Given the urgent situation that new, more transmissible and deadly, virus variants are emerging and spreading to new territories and have largely caused the most recent wave of the pandemic rebound since Feb. 2021, the potential health benefits of equitable vaccination become more critical. Delaying distribution of surplus vaccines to low-income countries will inevitably extend the length of the pandemic. The longer the virus persists somewhere around the world, the more likely a new vaccine-resistant variant will emerge. This is agreed by the overwhelming majority (88%) of 77 epidemiologists from 28 countries in a recent survey conducted by the People's Vaccine Alliance. Two-thirds of them thought that we have at most one year before the virus mutates to the extent that most first-generation vaccines are rendered ineffective, and new or modified vaccines are required.

Equitable vaccine distribution makes better economic cases

Besides health benefits, sharing vaccines with developing countries will also benefit the rich countries economically. The Eurasia Group, a global political risk research and consulting firm, studied ten advanced economies (Canada, France, Germany, Japan, Qatar, South Korea, Sweden, United Arab Emirates, United Kingdom and the United States). They assessed the economic benefits to these countries by contributing to WHO's Access to COVID-19 Tools (ACT) Accelerator program, in particular for securing Covid-19 vaccines for the Low and Lower-middle Income countries through the Covax Facility. They found that an equitable vaccine solution will bring at least US$ 153 billion in 2020-21 alone for the ten countries, and this benefit will increase to US$ 466 billion by 2025. This makes up more than 12 times the US$ 38 billion estimated total cost of the ACT Accelerator.

On a global scale, the short-term economic impact may be even more significant. Economists from Turkey and the US constructed an economic-epidemiological framework that combines a Susceptible-Infected-Recovered (SIR) model with international production and trade network to estimate the potential economic cost for 65 major economies and 35 sectors under three global vaccine distribution scenarios.

In the worst scenario – with wealthy nations fully vaccinated by the middle of 2021 whilst leaving poor countries largely behind in COVID vaccination – the study estimates that the global economy would suffer losses exceeding $9 trillion. Unexpectedly, wealthy countries such as the United States, Canada, and Britain will likely absorb nearly half of those losses. In a more modest scenario, in which rich countries manage to vaccinate all their susceptible population by early summer while emerging and developing economies vaccinate half of their susceptible population by the end of 2021, the world economy will lose a sum of somewhere between $1.8 trillion and $3.8 trillion.

No country is an island in the network of virus transmission, and no one is an island in the

network of global economy either.

The world will experience a couple of waves of recovery, like how the world experienced the initial waves of the pandemic. The advanced economies and some emerging economies will lead in the pandemic economy recovery, starting from summer 2021, while most others will lag behind. While this big trend seems unavoidable, minimizing this gap by getting people in all countries vaccinated as soon and as widely as possible is not only ethically important, but also brings a strong economic case. The interdependencies among countries imply that the health and economic drag in one country has short- and long-term consequences for the others. Under the continuing threat of new vaccine-evading variants, the need for innovation and global cooperation to ensure the equitable access of vaccines, tests, therapeutics, and other key resources are more urgent and undeniable than ever.

Similar to the need for a globally concerted effort to contain the virus in the early phases, especially the Preparation and Response Phases, which did not happen, global coordination in the Vaccination Phase is even more critical. Humanity may not be able to afford another misstep like what we had in the pandemics 'early wave a year ago. Closely monitoring and analyzing population level effective immunity rate, besides other vaccination, epidemiological and economic indicators, and actively communicate

7. References

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8. Supplementary Information

8.1 Methods for calculating Effective Population Immunity Rates

What matters for achieving herd immunity is the **total effective immunity rate** of the whole population, which is the sum of **Effective Immunity from Infection (EII)** and **Effective Immunity from Vaccine (EIV)**. Population level EII and EIV each can be calculated as a proportion of the infected and vaccinated population, respectively.

$$\mathbf{EII = \alpha * Pi}$$

&

$$\mathbf{EIV = \beta * Pv}$$

α - percentage of infected population (Pi) that actually develop a high-enough level of immunity and maintain it over time. α may vary due to changes in virus variants composition and various population characteristics. Recent research has shown that the immune systems most people who recovered from COVID-19 had durable memories of the virus up to eight months after infection, but this acquired immunity may be significantly lower for those with mild and asymptotic infection.

β – percentage of vaccinated population (Pv) that achieve a high-enough level of immunity and maintain it over time. β varies across different vaccines, as well as changes in virus variants composition and population characteristics. Max β of a specific vaccine is usually achieved several weeks after the initiation of vaccination (often a 2-dose procedure with 1-4 weeks in between the two vaccinations).

At individual level the biology of vaccine, as demonstrated by Fig. S1, is that human body develops the first adaptive immune response after initial vaccination, then exposure to antigen following this initial vaccination, be it a booster or infection, stimulates an elevated immune response, which hopefully will last for a long time, if not lifetime.

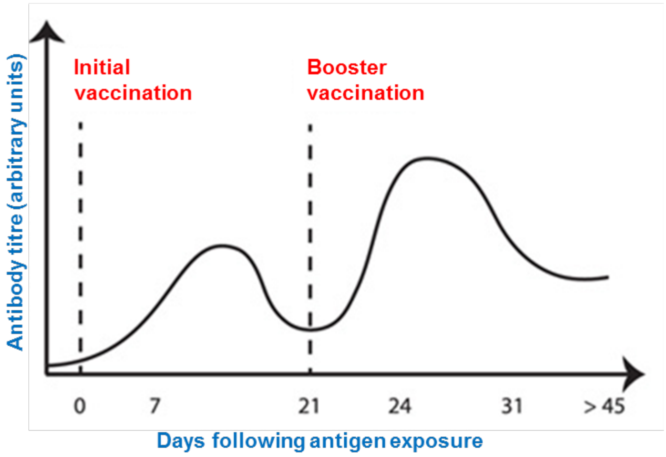

Fig. S1 Demonstration of change dynamics of the level of acquired immunity following initial and booster vaccination.

At population level, the acquired immunity from a two-dose vaccination follow about the same trajectory, though sometime substantial variation exists across individuals. Published results from vaccine developers, such as BioNTech/Pfizer, suggests that a protection rate of ~50% is reached ~21 days after initial vaccination and >90% of protection rate is achieved within 1-2 weeks of the second vaccination[4].

We define partial vaccination rate as the proportion of the population receiving only one dose of vaccine in a two-dose regime, and full vaccination rate as the proportion of the population receiving two doses. For vaccines with a one-dose regime, only full vaccination rate will be calculated.

The effective immunity rate from vaccination in a country or a region is an average rate value weighted by its partial vaccination rate and full vaccination rate. The partial vaccination rate indicates the share of the population that have received at least one dose of COVID-19 vaccine, while the full vaccination rate indicates the share of the population fully vaccinated against COVID-19. Effective vaccination rate can be a more desirable index than any other to evaluate how well

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[4] "Reg 174 Information for UK Recipients". In Section 3. How COVID-19mRNA Vaccine BNT162b2 is given, it stated: "If you receive one dose of COVID-19 mRNA Vaccine BNT162b2, you should receive a second dose of the same vaccine 21 days later to complete the vaccination series. *Protection against COVID-19 may not be effective until at least 7 days after the second dose*." – (https://www.bmj.com/content/372/bmj.n217/rapid-responses)

different types of vaccine can protect people in a wide range of countries and regions against the virus, which can make sense for medical researchers to assess the fluctuations of the pandemic, for clinical experimenters to improve the development of vaccines, for policy makers to arrange the order contracts and distribution of the vaccines and also for the public to determine whether and which kind of vaccines to administrate. The effectiveness of the vaccine could vary due to the vaccinated people, including the characteristics of the individuals such as their age and health and the similarity between the virus and the vaccines. Even when the vaccine is well matched to the circulating virus, the benefits of vaccination would change depending on a wide range of determinants such as the type of the up-to-date circulating virus and the regular protection measures taken in the community. Based on the data regarding the protection rate of each vaccine and the share of population being vaccinated in each stage, it would be feasible for us to substantially measure the benefits brought by the vaccination in terms of preventing the infection and its complications, and even forecast the development of the ongoing pandemic in the near future.

Based on published information we set up the parameters such that: (1) the first dose of vaccination would typically take effect after 12 days from its injection, (2) the daily protection rate of the first dose of vaccination would be 5%, (3) the accumulative protection rate of the first dose of vaccination would be up to 45%, (4) the daily protection rate would increase to 4% in case that all vaccines have been fully administrated, and (5) the accumulative protection rate of the additional dose of vaccination would be up to 40%. The estimated vaccination protection rate is calculated in a linear formula as follows:[5]

$$\text{The Effective Immunity Rate from Vaccination}_{c,d} = \sum_{i}^{i+D_1+D_2} \text{Partial Vaccination Rate}_c \times \mathrm{e}_1\% + \sum_{i+D_1+1}^{i+D_1+1+D_2} \text{Full Vaccination Rate}_c \times \mathrm{e}_2\%$$

[5] The vaccine panel data available at Our World in Data website is collected and used to calculate the rate. The data also show that the share of people that have received at least one dose of COVID-19 vaccine include the share of those who have been fully vaccinated against COVID-19, so their difference is actually equal to the partial vaccination rate.

where i indicates the sequence of the date when the first dose of vaccination takes effect, D_1 and D_2 respectively indicates the days that the effect of only the first dose of vaccination and all the doses last for, and c indicates country and d indicates day. Fig. S3 shows the difference between EIR and several vaccination indicators, using Israel and the UK as examples. Note that the two have very different strategy in the interval between first and second doses.

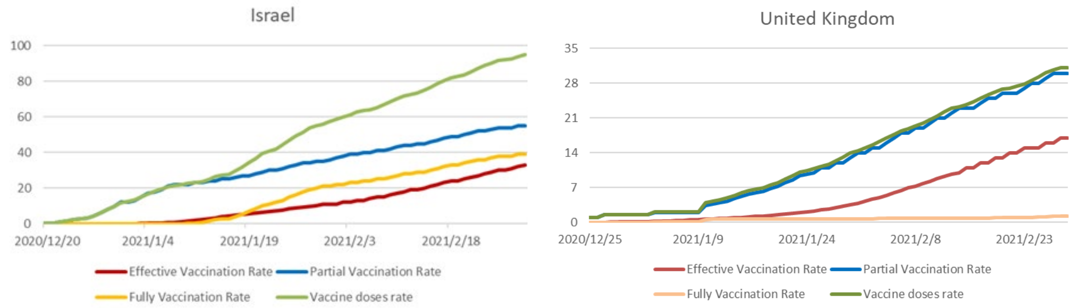
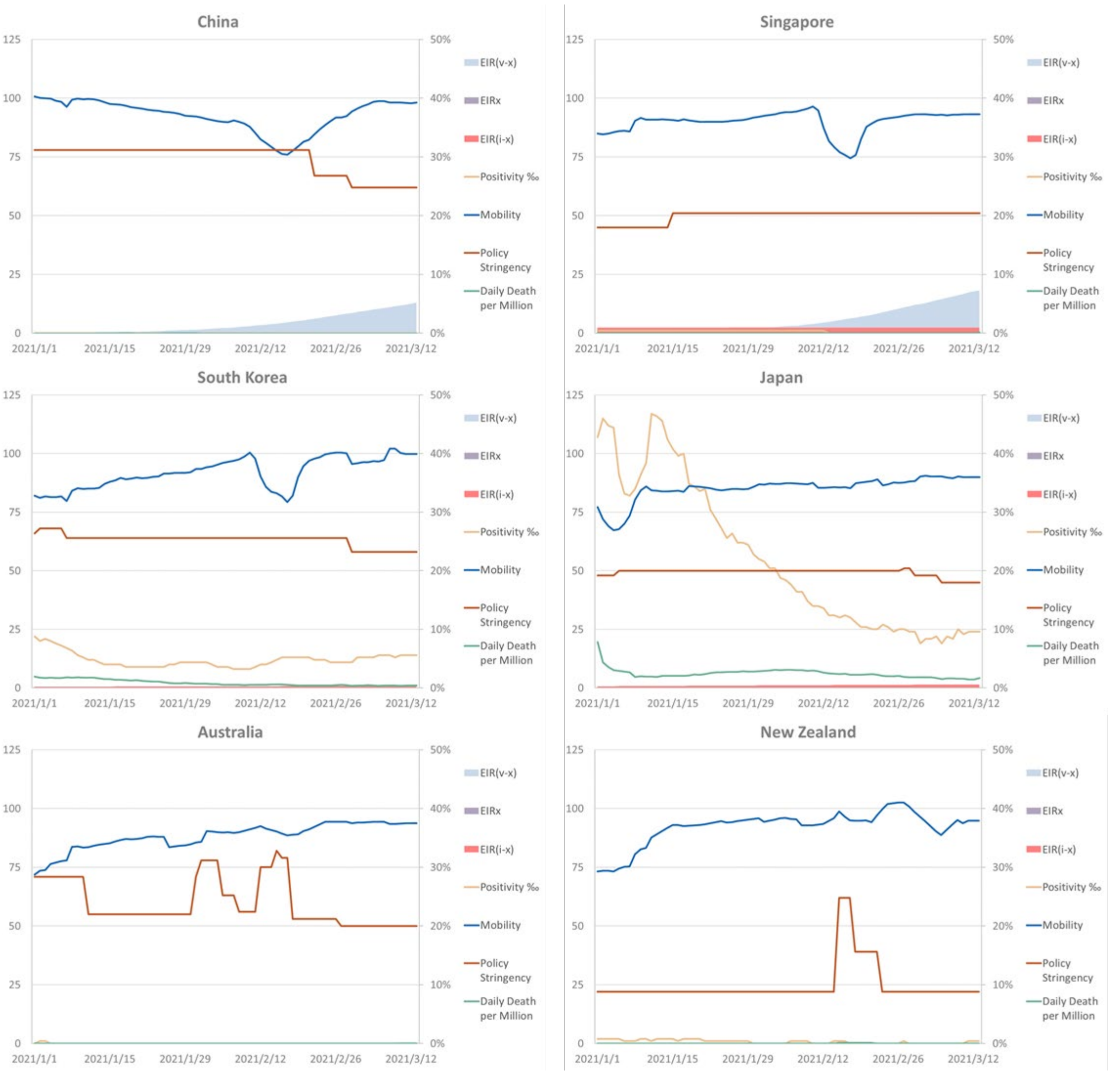


Fig. S2. Comparison of effective immunity rate from vaccination to other vaccination level indicators.

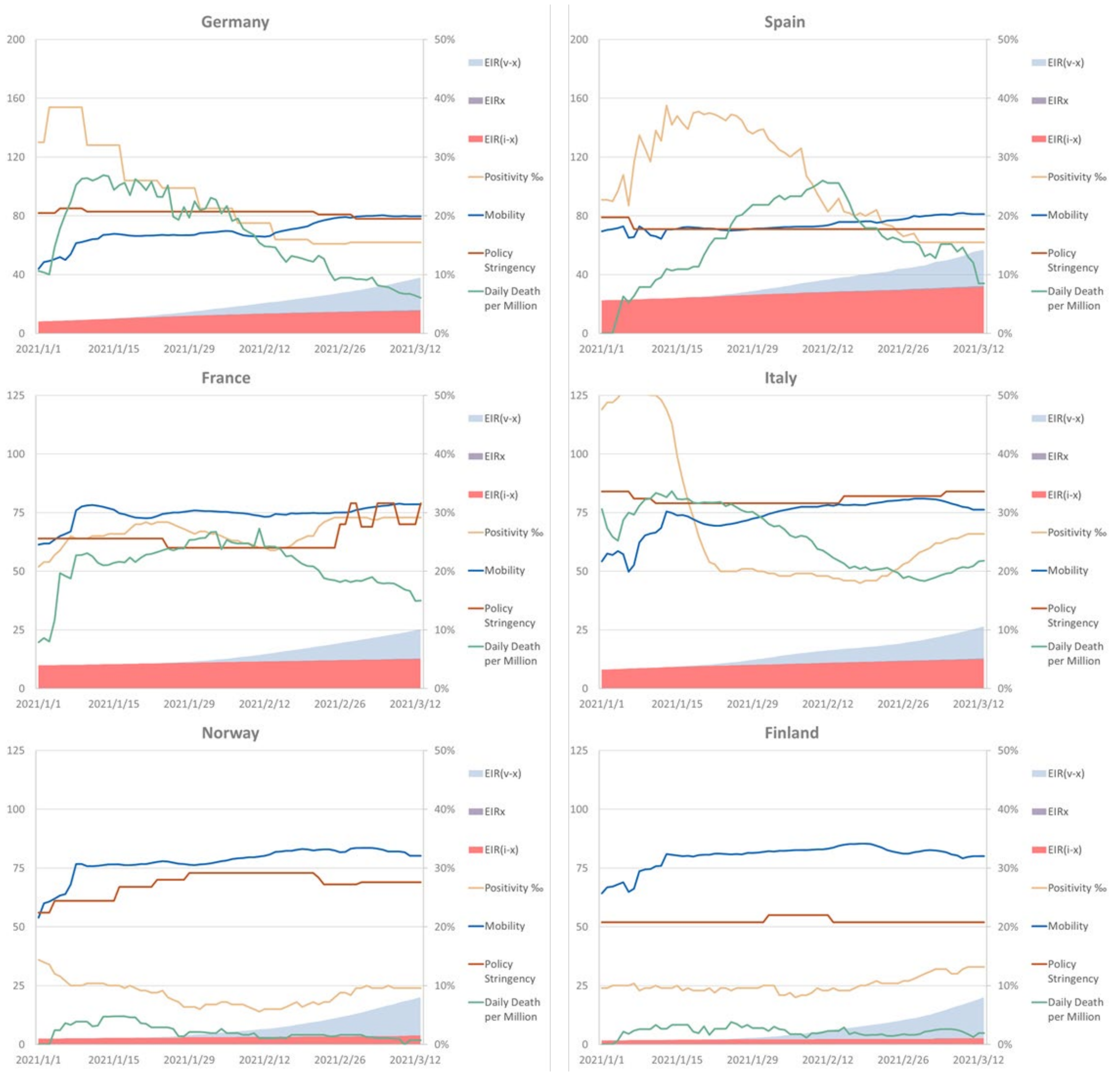
Overall, our estimate is more toward a conservative end, which is consistent with a more precautious principle in decision-making during pandemic economy. For example, some new evidence suggests that an initial vaccination can trigger substantial immunity response in previously infected people, which was not considered in the current computation. But this will only cause a slight delay in such immunity to emerge at population level, as long as the same person will be fully vaccinated later. The thresholds for the subphases are meant to be used as rule-of-thumb principles, accompanying information from other sources in order to help inform robust decision making in the Vaccination Phase.

8.2 Graphing the vaccination phase of representative countries in other regions

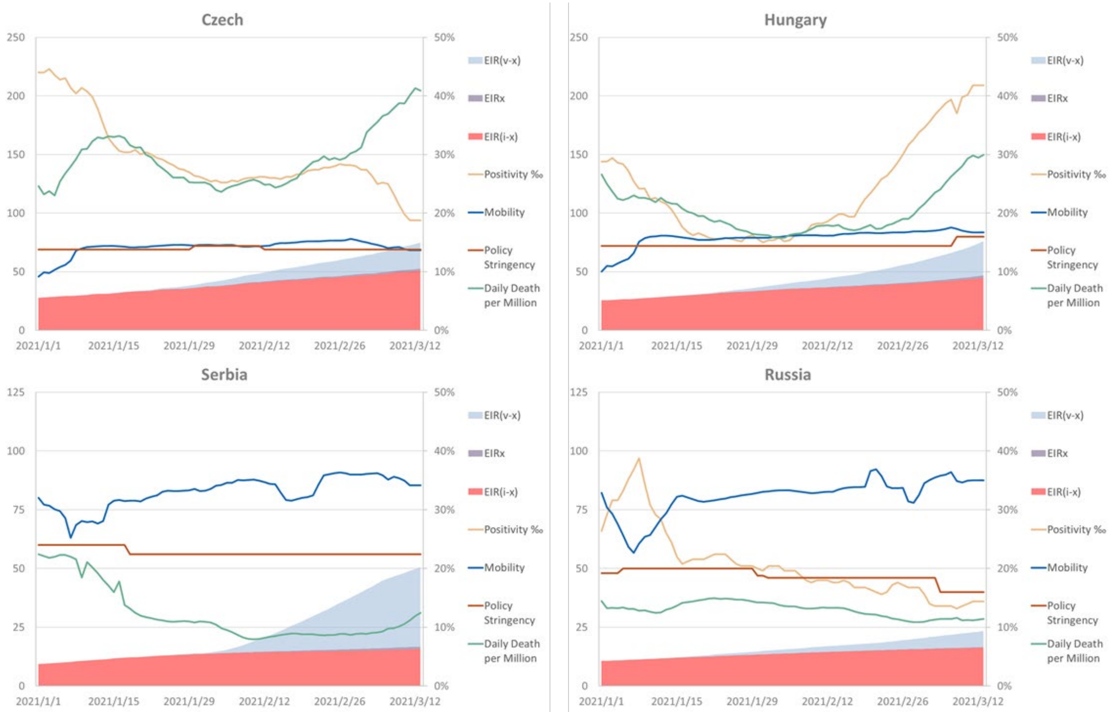
The Eastern Asia model face challenges



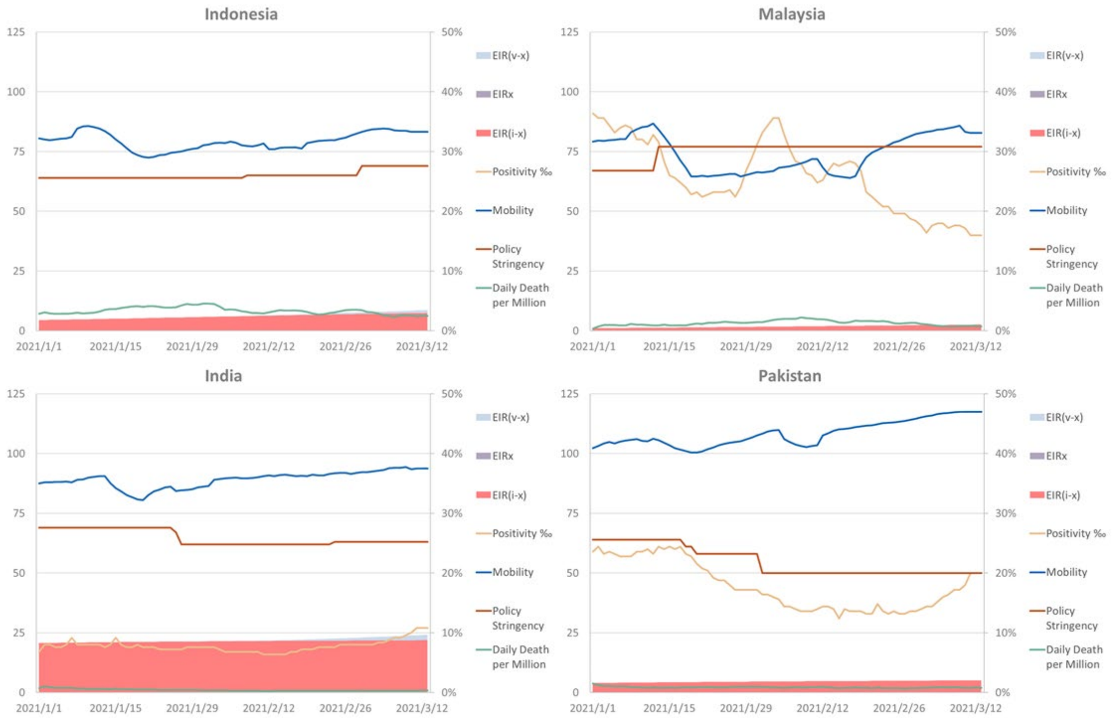
Western Europe slow in rolling out vaccination



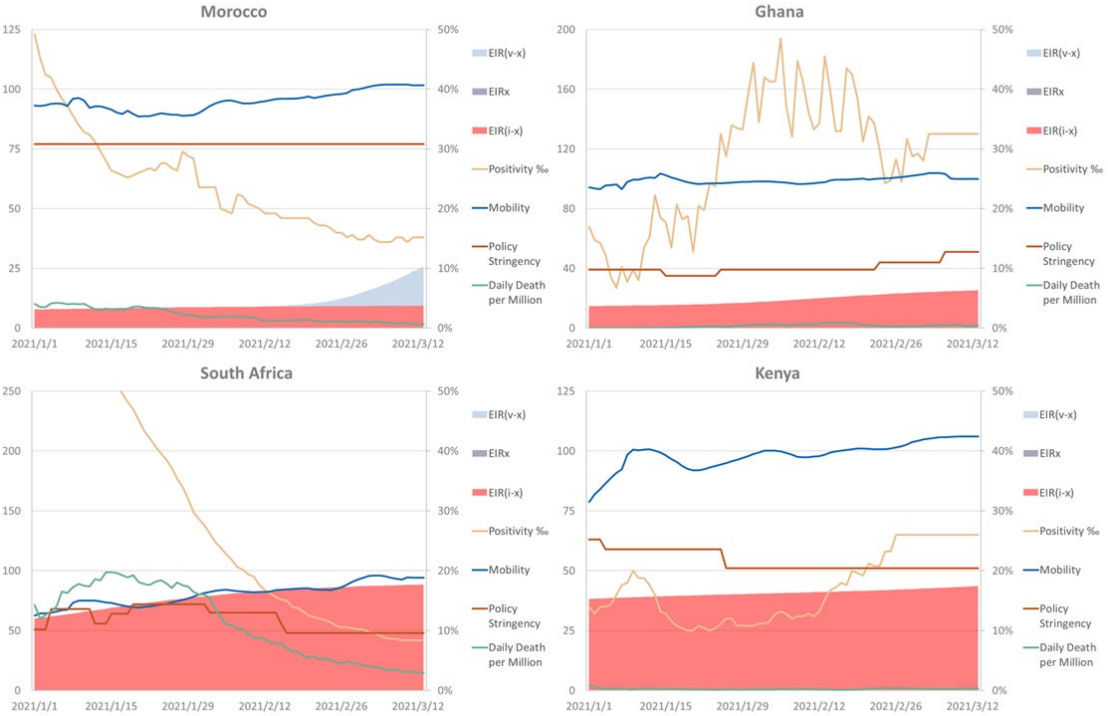
Eastern Europe in turmoil



South and Southeast Asia longing for vaccines



Most of African countries waiting for help



Vaccination in Latin America kicks off while virus transmission still high