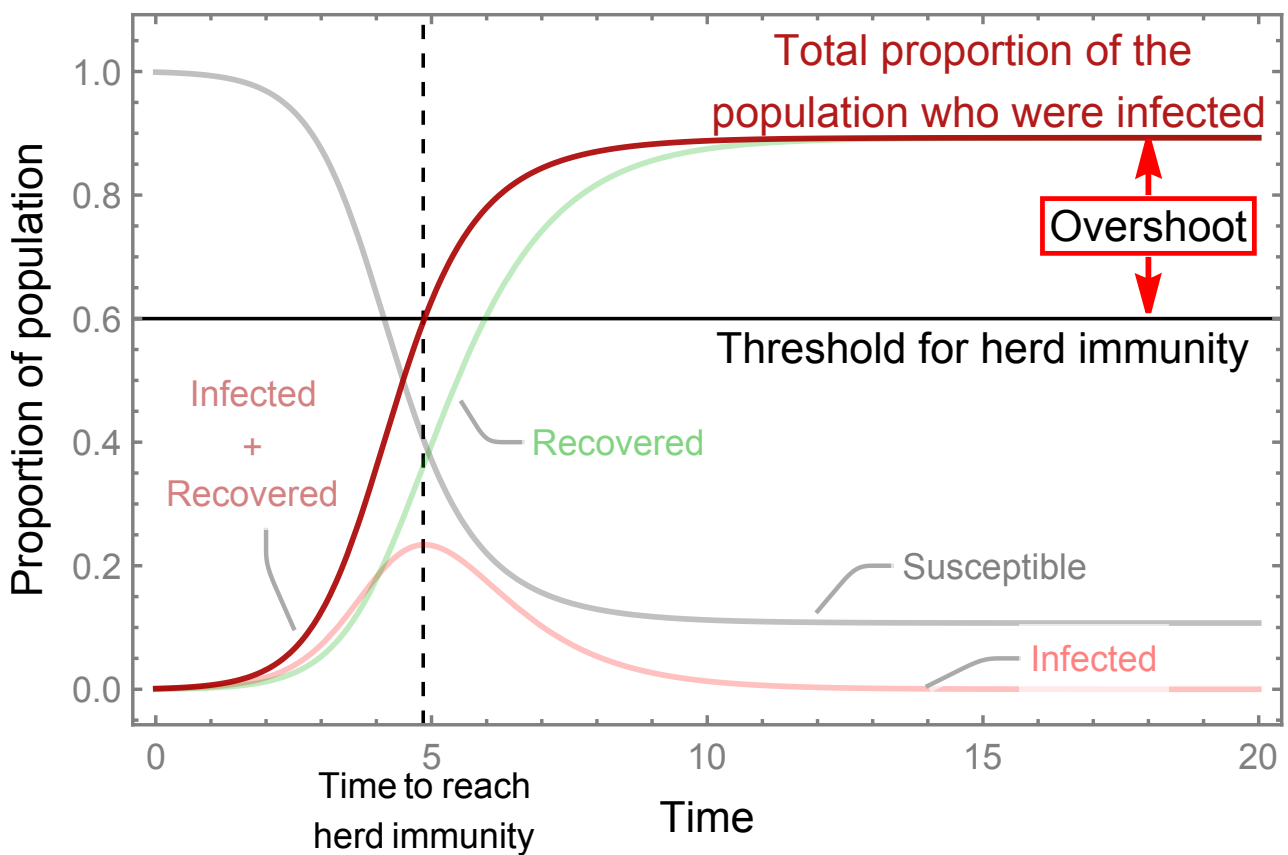# Herd immunity:
Letting the pandemic run?

The graph shows the proportion of susceptible, infected, and recovered individuals over time. When the number of individuals who are either recovered or currently infected ('infected + recovered') hits the herd immunity threshold, the epidemic does not come to a sudden halt. It has a momentum. Until the virus dies out, many more people get infected than required for herd immunity.

First of all, what is herd immunity? To make this clear, we need to look at the so-called reproductive number R of the virus. The reproductive number is the number of people to whom a single infected individual transmits the disease on average. If this number is larger than one, the virus can spread, and more and more people become infected. If it is smaller than one, the number of infected people declines. We can reduce this number, for example, through physical distancing or contact tracing and isolation of contacts. However, this requires ongoing action. As soon as we stop, the reproductive number goes up again.

A permanent solution is immunisation of a large part of the population. If many people are immune, it is likely that an infected person does not meet a susceptible person who could catch the disease, and the reproduction number of the virus is below one. In that case, we speak of herd immunity. The population as a whole is immune even though some individuals may not be immune. We can reach this through vaccination if we have an effective vaccine. However, immunity also builds up in the population over time as more and more people become infected, develop an immune response, and recover. This requires, of course, that individuals remain immune for an extended period of time after recovery (see below).

The buildup of immunity is why some people argue we should just let the pandemic run, taking no control measures. However, achieving herd immunity through infection of large parts of the population is not the same as achieving herd immunity through vaccination, and it doesn't work the way many people think. Let's have a look at that!

For the reproduction number to be smaller than one, a large enough fraction of the population needs to be immune. This fraction depends on the reproduction number of the virus in a population where no one is immune and where no control measures are in place (this is called the basic reproductive number,

which is a characteristic property of the virus). Mathematicians have derived a formula to obtain an estimate for the required fraction. For SARS-CoV-2, for which every patient infects around 2.5 other patients during the early phase of the epidemic, this fraction is 60%. Hence, if we had a vaccine and gave it to 60% of the population[1], the virus could not spread in the population (there could still be small outbreaks though).

The herd immunity threshold

Let R_0 be the basic reproductive number of the virus. I.e. every infected person infects R_0 other people on average in a fully susceptible population. If we take out a fraction x of the susceptible population (e.g. through vaccination), the reproductive number drops to $R_0(1-x)$. How large does x need to be to achieve herd immunity? Well, the reproductive number needs to be smaller than one. Hence:

$$R_0(1-x) < 1,$$

which solves to

$$x > 1 - \frac{1}{R_0}.$$

However, what does it look like if we let the pandemic spread to reach the required fraction of 60% immune people? By the time that 60% of the population is infected or recovered, the reproductive number drops below one and the number of infected individuals starts declining. This is hence the peak of the epidemic. However, at the peak of the epidemic, a lot of people are infected. Even though each of them now only infects less than one other person, this is still a very large number of new infections. And these newly infected patients can again infect new individuals. In that way, although the threshold for herd immunity has been reached, a lot of infections still occur until the virus finally goes extinct. Again, mathematicians have developed a model to grasp the size of this 'over-

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[1]In reality, we need to give it to some more, since even the best vaccine is not perfect and some people may not become immune.

shoot'. The following figure shows how many people will get infected until the epidemic dies out and the herd immunity threshold, depending on the basic reproductive number of the virus.
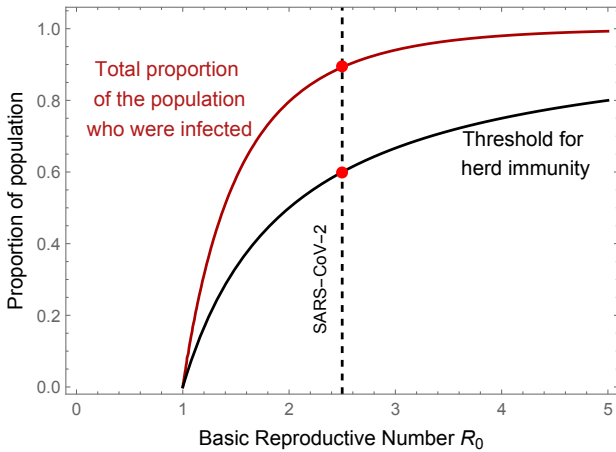

We can read from this graph that for SARS-CoV-2 ($R_0 \approx 2.5$), almost 90% of the population will become infected, as can also be seen in the figure on the first page. This is much more than the 60% required for herd immunity! This does, of course, not happen if we achieve herd immunity through vaccination, since vaccinated people cannot infect others such that we are fully in control. We could try to reach the herd immunity threshold of 60% more slowly, with considerable control measures in place. This would reduce the overshoot (the extra 30%) but it would take a very long time.

Importantly, unlike with vaccines, which are very safe, from these 90% that would become infected in an uncontrolled epidemic, many will develop severe symptoms, many will require hospitalisation, leading to overburdening of the health care system, and part of them will die.

There is yet another problem with this approach to herd immunity. We do not know for how long immunity to SARS-CoV-2 lasts. If it wanes too quickly, herd immunity cannot build up, and the virus will keep circulating in the population, reinfecting people over and over again. So far, we don't know for how long people remain immune following an infection with SARS-CoV-2.

Controlling close to the peak?
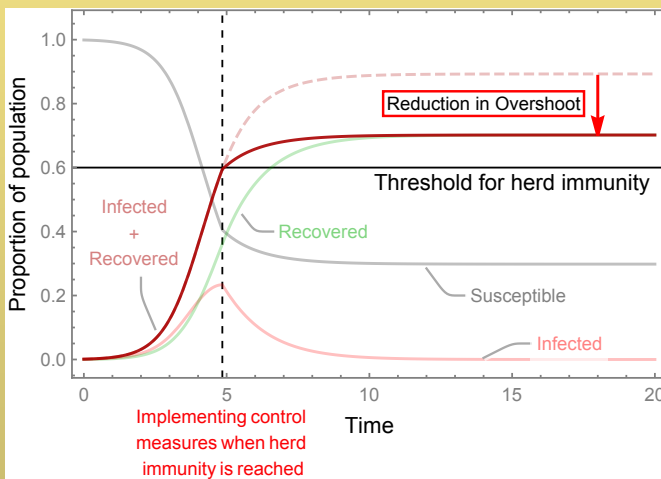
We can reduce the overshoot if we implement strict control measures once the herd immunity threshold has been reached (or even a bit before). However, in reality, it is difficult to make a full stop at the right time, and it is a risky strategy.

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