# Public use of masks to control the coronavirus pandemic

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The US and UK governments, as well as the World Health Organization, currently advise against the use of masks by the public to fight the ongoing Coronavirus Disease 19 (COVID-19) pandemic (1). But could they be wrong?

The governments of China, South Korea, Hong Kong, Viet Nam, Czechia, Slovakia, Bosnia and Taiwan all recommend that the public wear masks to slow the spread of the coronavirus. In some countries, like Japan, masks aren't officially recommended, but are still widely used by the public. Many countries treat masks as a strategic resource. China has ramped up production of facemasks, converting Foxconn factories that once made iPhones to make face masks. Taiwan has also ramped up the production of facemasks, prohibited their export, and implemented price controls and rationing. It's hard to see how both approaches could be right. Increasingly, advice against the use of face masks has been questioned (1) (2) (3), including by the head of China's CDC (4). Austria has recently moved to make mask wearing in public obligatory, and in the United States, the CDC is now debating their use.

Common sense, scientific studies, but perhaps most of all the success of countries using masks to fight the coronavirus suggest that masks may make a difference. There are fewer scientific studies available to guide decision making than we might like, and the evidence is not always clear-cut. However, decision-making in a crisis requires that decisions be made in the absence of perfect clarity. What is clear is that the exponential mathematics of pandemics mean that even if masks are of limited benefit in reducing infection rates, masks could make a large difference over time, potentially slowing the pace of the pandemic, limiting its spread, saving lives, and finally, letting countries to restart the economies that their people depend on for their livelihoods.

**Masks protect you from others, others from you**

It seems sensible to assume that any barrier between two people's airways reduces the chance of an air-borne virus being transmitted between them. Masks worn by infected people catch some fraction of virus-laden respiratory droplets that are released by breathing and coughing. Perhaps just as important, breathing through a mask slows and deflects air as it is exhaled, potentially reducing the distance that viral droplets travel as aerosols. As a simple flow-visualization experiment, one can hold some flour in one's hand, then give it a hard puff of air, or a cough: it flies everywhere. When the same is done with a cotton T-shirt over the mouth, no matter how hard you try, it's difficult to move more than a tiny fraction of that flour. Particularly in light of the ability of coughs, sneezes, and breaths to expel jets of droplet-laden air (5), this implies that masks will limit the ability to spread particles by slowing the air released from the mouth.

Meanwhile, masks worn by uninfected people catch a fraction of the virus they'd otherwise inhale. If both infected and uninfected people wear masks, then these effects multiply. For example, hypothetically, if an infected person's mask reduces the amount of virus spread by 75%, and the uninfected person's mask reduces it by another 75%, then the total reduction of the virus spread is 94%.

It's still possible that this reduction isn't enough to prevent infection. However, masks could still protect people— because dosage matters. Lower dosing of virus means infection takes longer to build up, giving the immune system time to mount a response. Higher viral dosage gives the virus a head-start in its race against the immune system, leading to a more dangerous, rapid course of infection. We see this in laboratory studies of animals. For example, mice exposed to lower doses of influenza virus get less ill (6) than those exposed to high doses - which became more ill and suffered more lung damage. In chickens exposed to avian influenza, the higher the initial dose of virus, the faster the birds became sick and died (7).

The immune system fights viruses, like a farmer trying to remove weeds from his field. How difficult those weeds will be to control depends on how many seeds there are. 1000 seeds in a field might not be a challenge, but 1,000,000 or 100 million make weeding far more difficult. In the same way, even when masks fail to prevent infection, by lowering the initial dose of virus they could conceivably make the difference between mild symptoms and a severe illness requiring hospitalization, or even leading to death.

**Masks reduce viral spreading in laboratory and real world settings**

Experimental laboratory studies suggest that surgical masks can reduce inhalation of virus particles by an average of tenfold, with some masks providing less protection, but others providing more (8).

In the real world, several studies suggest masks provide at least some protection against spreading and catching airborne infections. A number of studies focus on influenza. A study of a hospital in Germany found that once staff began wearing masks continuously, the number of patients contracting influenza in the hospital declined by half (9). In a study of German households, use of masks and hand-washing reduced the spread of influenza between family members (10). Strikingly, a study of university students found that masks plus hand sanitizer could reduce spread of influenza by up to 75% (11). However a systematic review found that overall, evidence for the efficacy of facemasks in controlling influenza was surprisingly weak (12). They found evidence that face masks prevented influenza from spreading from infected people, but less evidence that they kept uninfected people from becoming infected (12).

COVID-19 does resemble influenza in being a respiratory virus, but isn't closely related to influenza. It's part of a distinct evolutionary family, the coronaviruses. This suggests we might need to be careful in extrapolating from influenza studies, and that studies of other coronaviruses may be more informative.

Studies of Severe Acute Respiratory Syndrome (SARS) are likely to help us understand COVID-19 because both are bat-derived coronaviruses (13) (14) (15), and share broadly similar epidemiology. Within a hospital setting, consistent and proper mask use was shown to prevent transmission of the SARS coronavirus to hospital personnel (16). Critically, two separate studies found that frequent mask use in public spaces during the SARS epidemic was associated with a lower risk of infection by the public (17), with one concluding that masks were "strongly protective." The authors said the finding that "mask use lowered the risk for disease supports the community's use of this strategy" (18). This study found that sometimes using a mask was associated with a 60% reduction in risk, while always wearing a mask was associated with a 70% reduction in risk of acquiring SARS (18). A systematic review of all retrospective studies of the SARS epidemic concluded masks were effective in preventing acquisition of SARS (19).

Perhaps most strikingly, when used in a hospital setting at Zhongnan Hospital in Wuhan University (20) a study found that N-95 respirators, combined with hand washing and disinfection, were 100% effective at preventing COVID-19 infection. Those using respirators were exposed to infected patients at a far higher rate than those not using protection, but failed

to catch the virus. Masks unquestionably work to protect people in a hospital setting: that's why doctors and nurses so desperately need them. There's little logical reason or evidence to think that they would not protect people in other settings.

The strong evidence that face masks work for SARS coronavirus and COVID-19, versus the more ambiguous evidence for effectiveness in controlling influenza is puzzling. One possible- and admittedly, hypothetical- explanation is that coronavirus is transmitted mostly by larger droplets (21) (22) which may be relatively easy to filter out. In the case of H1N1 influenza, about half of cases seem to come from aerosol transmission, i.e. fine droplets (23) which might be more likely to penetrate through masks or leak around the edges. This obviously is highly speculative, but suggests we should be careful about extrapolating from influenza studies to coronavirus in discussions of masks (or other aspects of epidemiology). One mistake we have made, over and over, dealing with COVID-19 is thinking it's "just like the flu". It's clearly not like the flu in terms of its ability to cause harm. It's reasonable to guess that it might not be "just like the flu" in how it spreads, either.

It is hard to overstate the implications of the findings for SARS coronavirus and COVID-19 for the current pandemic. The reproductive number of the virus, R, determines an epidemic's course. When R falls below 1, that is, each infected person passes the virus on to less than one other person on average, the epidemic slows, then dies out. Lots of estimates have been published for COVID-19s basic reproductive rate, R0, with a mean of 3.28 and a median of 2.79 (24). If its spread could be reduced by 70% (as found in one study of SARS) by universal use of masks, the reproductive rate would become 0.837-0.984. The effective reproductive rate would drop below zero, and the epidemic would cease. This is a simplistic scenario, but could actually underestimate the effectiveness of masks, because it assumes only reduction in the rate at which people catch the virus, not the rate of transmission. Interventions with small effects on transmission, especially if applied early, can have a large effect on total number of cases.

## Models suggest masks could work to control pandemics

Of course, it's possible that masks might have only limited benefit in stopping the spread of COVID-19— for any number of reasons. Masks might provide limited protection, because they are less effective than suggested by some studies, because people misuse them, because of shortages of effective masks like surgical masks and N-95s— or all of these.

But to understand how they could still make a difference, we have to consider masks in the context of small reductions in viral transmission rates. Consider how epidemics grow— exponentially. Allowed to spread unchecked, one case of Covid-19 becomes 2.5 (assuming for this model an R0 of 2.5), each case causing 2.5 more, and so on. Over the course of 15 reproductive cycles, each taking 7 days, or about 3 months in total, one case becomes 2.5 x 2.5 x 25… or $2.5^{15} = 931{,}323$ cases (Fig. 1).
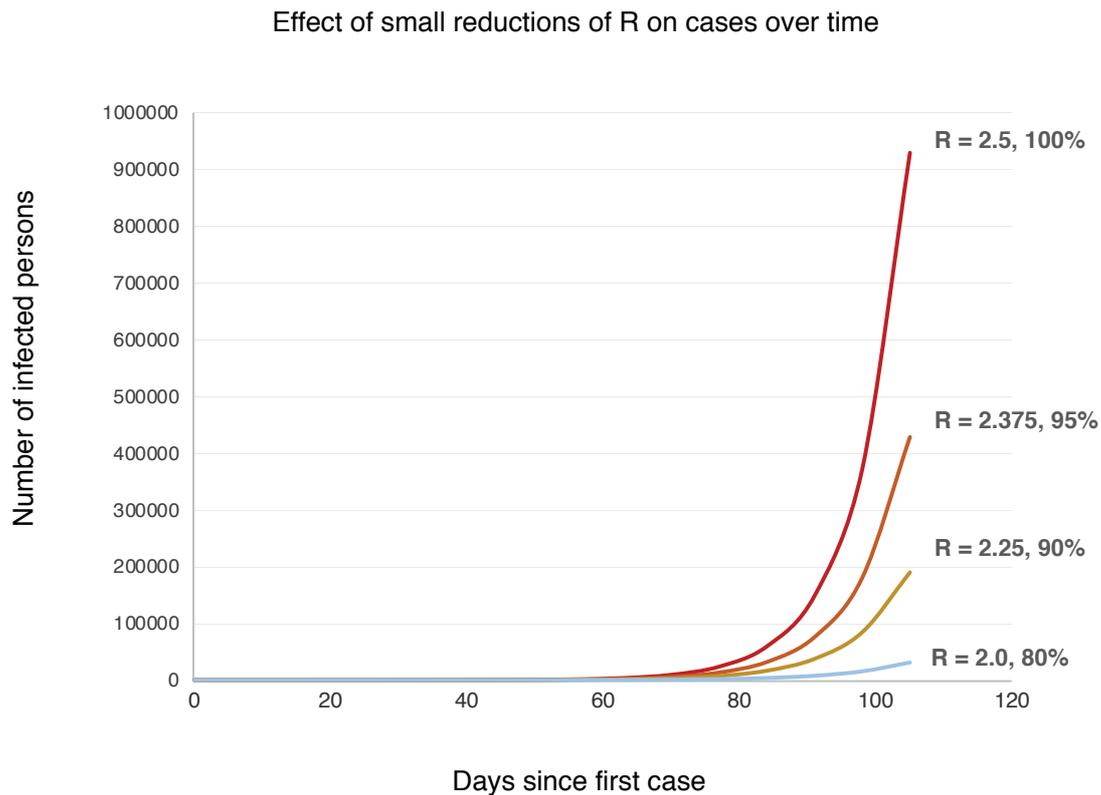
**Figure 1.** A simple model showing exponential growth in an uncontained outbreak over time (generation time = 7 days, R0 = 2.5) and with small reductions in the reproductive rate R.

Now, let's suppose widespread use of masks cuts the growth rate by just 10%. Each person now infects 2.25 others, who infect 2.25 others, and so on. Over 15 cycles, 2.25^15 = 191,751 cases. An 80% reduction. Understanding this exponential growth explains how the virus caught the world by surprise even as the pandemic was monitored in real time. Exponential growth just doesn't make sense, until you do the numbers, and even, they're still hard to believe. But another counterintuitive aspect of exponential growth is that small decreases in the exponent greatly slow growth. A 10% increase in the exponent can have a massive effect, but even a limited intervention, with a 10% decrease over time, pays large dividends (Fig. 1).

These are very, very simple models. But sophisticated modeling also shows large scale use of masks could slow, even stop pandemics. A 2010 study found that above a certain threshold, widespread use of effective masks can reduce the reproductive number (R) of an influenza virus below 1, and the pandemic stops (25). If face masks were highly effective (well-designed, used properly and consistently), then public use of masks could stop a flu pandemic if used by just 50% of people. If masks were less effective, more than half the population would have to wear them to stop the pandemic. If masks were highly ineffective, they could flatten the curve of the epidemic, but wouldn't stop it (25). We don't know which model is most accurate. But does it even matter? In the context of the current pandemic, any of these scenarios would be a huge win.

A second study (26) got similar results modeling pandemic influenza. The model found that the pandemic was highly sensitive to the number of people wearing masks. Even if 25% or

50% of people wore masks, the number of cases drops drastically (26), flattening the curve. Critically, masks are far more effective implemented *early*, than implemented late in the course of an epidemic (26). This study also found it was important for both infected and uninfected people to wear masks (26). These studies support the results of simple calculations: use of masks can make a major difference.

Production of masks costs money. While discussions need to focus first on human life, which has a value that can't be put in terms of economic costs, we also need to think rationally about strategic use of resources to combat COVID-19. One modeling study found that depending on the coverage of masks, the use of masks in the US might save almost $600 billion (27). Given the unprecedented economic disruption caused by the pandemic, which has caused record number of jobless claims and declines in purchasing (28), it is entirely possible that this is an underestimate. Again, it seems that under a wide range of different pandemic and economic scenarios, masks are an economic win.

Finally, a review paper offers a note of caution for anyone advocating for public use of masks. A systematic review of pandemic modeling studies looked at different studies, which included a variety of pandemic responses- including social distancing, quarantines, air travel restrictions, case isolation, antiviral drugs, vaccination- and masks (29). They found that strategies using a combination of different interventions were far more effective than those that used a single approach to fighting the pandemic.

The implications are clear- even assuming (for the sake of argument) that masks were the single most effective intervention we have, the current pandemic will be brought under control more quickly, with less damage by employing a wide range of interventions (29). There is probably no magic bullet against coronavirus, a single tool that will stop the pandemic, not even vaccination (29). Battling coronavirus will require many different tools, each of which cut down on transmission to some degree, a death by a thousand cuts, to stop the pandemic. Obviously these are models, and what works in theory needs to be tested in the real world. But the remarkable success of China in suppressing a large outbreak, using a multi-faceted approach, suggests that in this respect, the computer models are broadly correct.

**Real world experience suggests masks work in pandemics**

And perhaps the most compelling evidence of the potential effectiveness of masks in the fight against COVID-19 comes from their use in the real world. Places that have controlled their coronavirus epidemics most effectively - China, South Korea, Hong Kong, Taiwan, Vietnam, Singapore, Kuwait, Czechia, Slovakia, Japan- use masks (Fig. 2). Aside from China, which was the epicenter of the pandemic and so played catchup in developing and implementing its strategy, virtually all of the worst outbreaks are in Western countries that officially advise against mask use, and where there is little culture or practice of mask wearing.
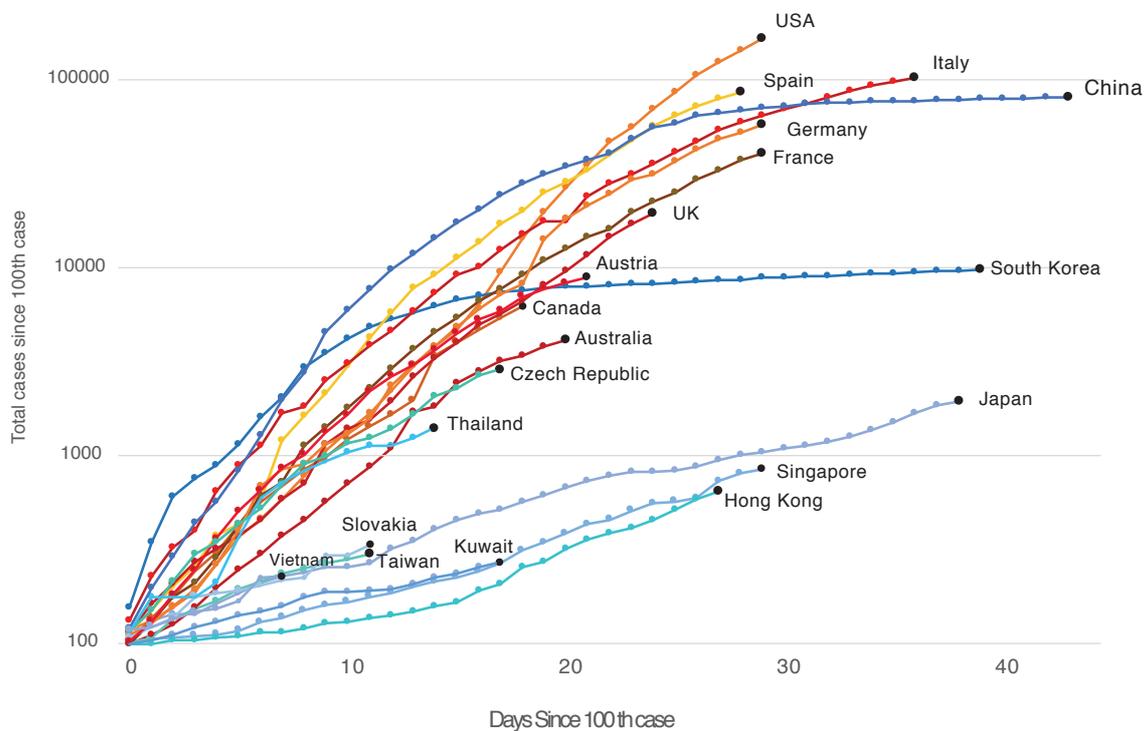
**Figure 2.** Western countries (US, Canada, Australia, UK, Western Europe) versus countries and territories using masks as part of official government or in practice policy (China, South Korea, Japan, Hong Kong, Taiwan, Vietnam, Thailand, Kuwait, Slovakia, Czech Republic, in blues and greens). Countries with official or unofficial policies of mask usage have controlled the outbreak far better than those without. Note that Austria currently uses masks but has only revised its official policy recently.

Correlation is not causation. In theory, masks could be a signal of an effective pandemic response- an aggressive willingness by the government and public to do everything possible to control the outbreak- rather than a direct cause of suppression, much like the number of luxury cars on the road is a signal of economic prosperity, rather than a direct cause of it.

But the diversity of these countries, and their responses, argues against this interpretation. Places like China, South Korea, Taiwan, Vietnam, Kuwait, Czechia and Singapore differ greatly in political organization, ranging from communism to democracies, and also in their level of economic development and population density. And strikingly, these countries also differ in their suppression strategies. China implemented a lockdown of Wuhan, shut down industry nationwide, implemented temperature checks and social distancing, tested extensively— and employed masks. Korea responded with an aggressive testing and contact tracing—and masks. Japan has done far less extensive testing than Korea, but shut down schools and large gatherings— and used masks. The pandemic management strategies used by these countries far more diverse than has been appreciated. Arguably one of the few things all these successes share is widespread wearing of masks. And on the other hand, one common factor shared by the pandemic suppression strategies of the US, Canada, the UK and Europe is the decision to discourage the use of masks by the public. This evidence doesn't prove, but it does very strongly hint that masks are a critical part of these country's suppression strategies.

And by watching countries like Austria that have recently revised their policies, we can test this idea.

### What kind of mask? Surgical masks as good as N95s; are improvised masks better than nothing?

If face masks can help control the spread of respiratory disease, then which work best? Surprisingly, surgical masks seem just as effective as N95 respirators. One study randomly assigned surgical masks or N95 respirators to nurses (30), they got influenza at about the same rate. Study of a hospital in Singapore during the 2009 H1N1 influenza outbreak showed the same thing (31). Another study tried to isolate influenza virus from infected patients wearing a surgical mask or N95. Both were equally good at stopping viruses (32). One recent study assigned health care personnel to wear respirators or surgical masks. Those using respirators fell ill at about the same rate as those using surgical masks (33). A systematic review of the available studies, synthesizing these and other results, confirmed that surgical masks were comparable to respirators in effectiveness (12). Similarly, a systematic review found "limited evidence" that respirators were superior to surgical masks during the SARS epidemic (19).

This has important implications given current shortages. Respirators and surgical masks are both in short supply. But surgical masks are cheaper and simpler, making it easier to accelerate production. Surgical masks are easier to use and more people might wear them (12).

If simpler masks are effective, this raises the possibility of using improvised masks, made in factories, or even homemade. Would cloth masks work? Research into the effectiveness of cloth masks is limited  (34). Existing research shows homemade masks are-unsurprisingly- inferior to surgical masks. However, they appear to be better than nothing. One laboratory study found homemade masks were half as effective as surgical masks in filtering particles (35). Another study found homemade masks made from various materials stopped virus aerosols, but less well than surgical masks (36). A surgical mask stopped 90% of viral aerosol particles, a dish towel, 72%, linen, 62%, and a cotton T-shirt, 51% (36).

Improvised masks made from cotton fabric might perform similar to a T-shirt or linen, letting through about 3-5 times as many viral aerosol particles as a surgical mask. The only real-world study of cloth masks found they were less effective than medical masks, consistent with laboratory studies  (37). Unfortunately, this study lacked a proper control - a no-mask group - and so can't be used to argue that cloth masks don't work, because the alternative - no masks - wasn't evaluated.

Finally, non-medical face masks and respirators offer another alternative. Although not specifically studied for their ability to stop viruses, studies of non-medical masks showed that dust respirators were better than surgical masks in filtering fine airborne particles, and two of the three cycling masks studies compared well to surgical masks in performance (38).

Clearly, improvised or non-medical masks should only be used when access medical masks is impossible. However, the speed and spread of the current pandemic have created a widespread shortage of medical masks. This creates a need to find innovative solutions to such shortages, and specifically value engineering (39) of the sort that dealt with materials shortages in World War II to identify ways to produce filtration comparable to medical masks with cheaper, more easily sourced materials and production techniques, and also to find new ways to sterilize, reuse, and/or recycle masks  (40).

### Arguments against masks don't hold up

*The public doesn't need them because doctors and nurses do.*

The argument that the public doesn't need masks because doctors and nurses do is logically inconsistent (41). Both can't be true: masks cannot work for doctors and nurses and be vital to protect them inside a hospital, but fail to work to protect the public elsewhere. A more reasonable argument is that doctors and nurses need masks more than the public. This may be true, and it is of upmost importance to protect frontline health care workers. However, this argument isn't backed up by scientific studies or real-world experience. It also assumes that wearing masks is a purely defensive act. In fact, wearing a mask not only protects the wearer against infection, but reduces potential for onward spread from infected people. A single mask worn by an average person could stop a chain of infection or a super-spreading event, could save many lives— members of the public but also doctors and nurses, as well as the heart attack victims and cancer patients they care for, who might die if health care systems become overwhelmed.

Particularly if worn by people who are likely to either catch or spread the virus, public use of masks is likely to reduce the number of people from coming into hospitals, protecting health care workers. Clearly, ensuring access to masks by health care workers must remain a top priority, but it makes sense to issue them to others as well. In practice, widespread use of masks of the sort seen in Asia may have saved the lives of countless doctors and nurses by preventing hospital systems from becoming overwhelmed. Models could be developed to provide an evidence-based rationale for a distribution of masks that would minimize worldwide loss of life, human suffering, and economic damage, in that order.

*Masks are only needed to prevent infected people from spreading*. Another argument is that masks are only needed by infected people. The CDC officially recommends using masks by infected persons to prevent influenza and made the same recommendation for coronavirus. As discussed above, studies suggest masks can be effective to prevent people from catching, not just from spreading, coronaviruses. The other problem with COVID-19 is that it is difficult to know who is infected. Around half the people spreading show no symptoms, and do not know they are infected (42). This is the point of a lockdown; if it was known who was infected, these individuals could be isolated and society could function normally. Because we don't, we must act as if everyone is. The same logic should apply to masks. In a rapidly spreading pandemic, with limited access to testing, it is logical to act as if everyone is infected: everyone wears a mask.

*Masks could increase the risk of infection if used improperly*. No scientific evidence was found that improper mask use would increase the risk of infection. This argument employs something of a double standard- we need more scientific evidence for effectiveness of masks, but arguments about the risk of masks have been made without any strong scientific research to back them up. Logically, even improper mask use- improper fitting masks, failure to sterilize a mask properly, or touching the infected outer surface- seems likely to be a less efficient means of transmission than inhaling virus without any protection. By analogy, a bulletproof vest worn improperly may be less effective, and won't protect you from shooting yourself in the foot, but gives better protection against bullets than nothing at all. In practice, public education campaigns could quickly educate people on the proper use of masks to minimize improper use and maximize effectiveness; there's little reason to think that wearing masks is a skill that only doctors and nurses can master.

*We know too little to risk acting.* There are many unanswered questions about COVID-19 and more scientific studies are clearly needed. But it's been argued that we can't really do anything because we know so little. This isn't logical. If one wakes up in the middle of the night to find the house burning down, one quickly faces lots of unknowns. How did it start?

What's on fire? How fast is it spreading? Where is the family? Despite these uncertainties, one immediately takes action. The same applies in a pandemic. Public health workers must act with incomplete data with gaps and inaccuracies in their intelligence, but never the less must make difficult, life-or-death decisions, because failure to make a decision is often fatal. In a crisis situation, we can't wait for studies.

Furthermore, masks are an asymmetrical gamble. There is a potential upside, with little or no downside. Widespread mask use might help a little, or a lot, and the cost might not be trivial, but they come with little if any real risk. The real risks lie largely or entirely in not acting. Fears that masks inspire 'false confidence' in their protection are exaggerated. People wearing masks now tend to be those most proactive in protecting themselves, their families, and society. Far from inspiring risk-taking, masks send a powerful social signal that the threat is real, and we need to rapidly, collectively change our behaviors.

Masks provide a high potential for an upside with no risk, and produced on a large scale, they come with limited cost. Even assuming they are a gamble, it is arguably a rational gamble to take. The situation is much like Pascal's Wager. Pascal argued that we should believe in God because if He existed, we'd go to heaven, and if not, one had nothing to lose by believing. Similarly, almost any strategy with uncertain upsides and no downside is worth pursuing, particularly if there is a real, and relatively inexpensive chance to help reduce the spread of COVID-19. The alternative, which is to wait for absolute certainty, would seem a poor strategy for facing an existential pandemic threat. That being said, the scientific evidence in favor of mask use appears to be stronger than has been made out.

## Conclusions

Strong scientific evidence and rational arguments exist for the widespread, public use of facemasks. The principle behind facemasks- they reduce the amount of virus exhaled by infected people, and inhaled by uninfected- suggest they should be a primary tool in combating any respiratory virus. Scientific research, including experimental studies, retrospective studies of the SARS epidemic, hospital studies of COVID-19, and modeling studies, all suggests masks are likely to be effective in controlling the pandemic. Most importantly, the experience of countries using masks against SARS and the current coronavirus pandemic imply that they are effective when used by the public. However, modeling studies and the real-world experience of countries like China and South Korea suggests that neither masks, nor anything else, provides a magic bullet against a pandemic. So strategies should not rely on any single intervention, but rather a wide range of interventions, potentially including masks. Further research and open debate on the effectiveness of masks and other strategies are urgently needed.

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