Modelling the use of Facemasks and Lock-Downs for the COVID-19 Pandemic

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Overview

- Paper: 'A modelling framework to assess the likely effectiveness of facemasks in combination with 'lock-down' in managing the COVID-19 pandemic' by Stutt et al.
- Authors use two different models:
  1. an agent-based branching process model (looks at mask wearing, lock-downs are not considered)
  2. A modified SIR model with 'free-living inoculum' (incorporates mask wearing and lock-downs)
- For both models, we assume 'facemask' to mean a protective covering for the nose and mouth designed to interfere with airborne pathogen.
- Important to note that this paper was accepted in May, so many parameters are based on best guesses and early data.

Model 1: The Agent-Based Branching Process Setup

- Question 1: What level of facemask adoption from the public in combination with facemask efficacy would be required to reduce $\mathcal{R}_e < 1$?

- Question 2: Does the time of facemask adoption make a difference in Question 1?

- First need to identify good control variables:

  i. p - proportion of population wearing facemasks
  ii. γ - effectiveness of mask in reducing transmission
  iii. $(1 - \gamma)$ - assumed reduction factor of relative infectiousness on days where individual wears a facemask

Interpretation of γ

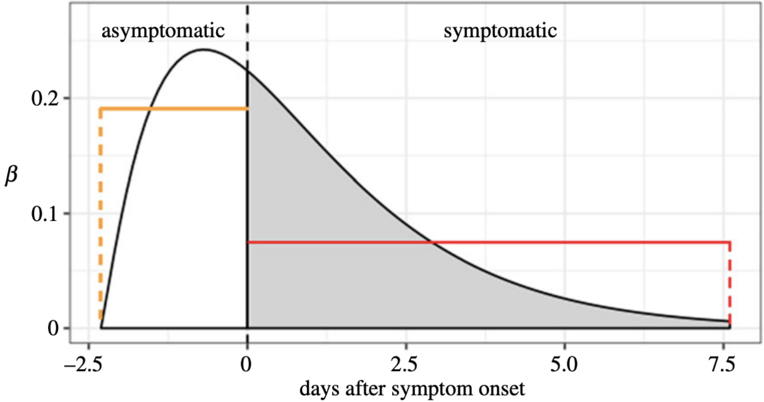
γ depends on porousness and face fit [2, 5]

- probably low γ for take-out bag
- high γ for full facemask.

The Agent-Based Branching Process

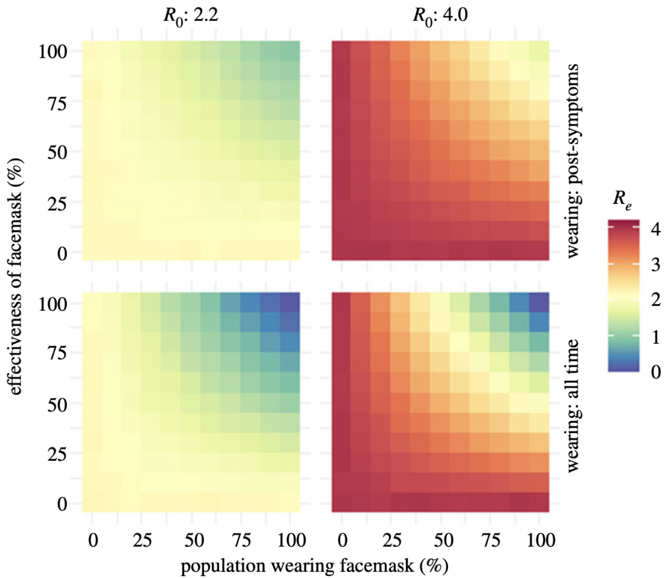
- # of secondary cases caused by one infective is pulled from a negative binomial distribution
  - mean $= \mathcal{R}_0 \times k \times t_\beta$
  - $k = 0.54$ is a dispersion parameter
  - t_β is the time of each new infection dependent on incubation period of 1st case and relative infectiousness $\beta(t)$
- This is done for $\mathcal{R}_0 = 2.2$ and $\mathcal{R}_0 = 4$
  ($\mathcal{R}_0 = 4$ based on estimates from European data of initial growth phase).
- Relative infectiousness $\beta(t)$ assumed to follow a shifted gamma distribution with peak occurring 1-2 days before onset of symptoms

$\beta(t)$ Profile

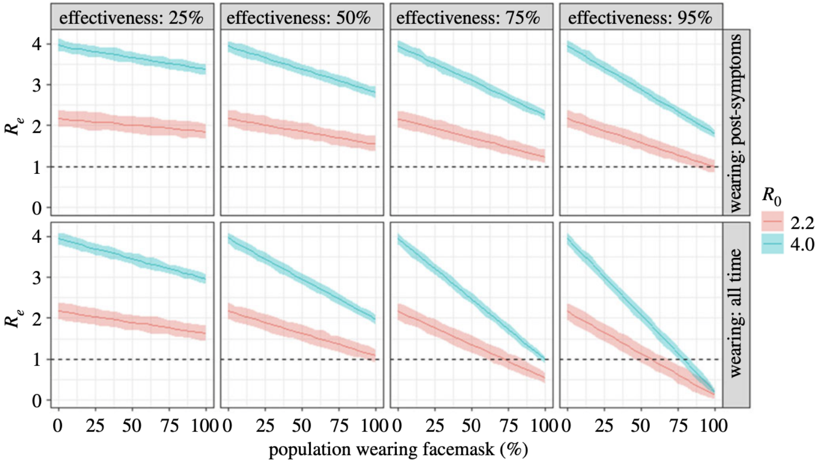


- Horizontal lines show average infectiousness per time unit

Model 1: Results ($\mathcal{R}_e$ Heat Maps)



Model 1: Results ($\mathcal{R}_e$ & Effectiveness View #2)



Big result: There exists parameter ranges (p, γ) for which $\mathcal{R}_e < 1$

Your Opinions So Far

- Anything here that you would have done differently? (Especially given that we know more about COVID-19 at this point)

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- Anything here that you would have done differently? (Especially given that we know more about COVID-19 at this point)
- How about more values for $\mathcal{R}_0$?
- Different population sizes?
- Is the parameter γ too strict/general? There is no way to properly weight face fit versus porousness

Before we move on to the second model, we should talk about how the virus can spread.

How Does COVID-19 Spread?

Two main ways:

1. Inhalation of transient loaded droplets D from the air
2. Hands pick up virus from surface reservoirs (called fomites F) and enter via mucous membranes of the head (eyes, mouth, nose) from face touching

Droplets → Fomites

- Air droplets quickly fall/decay and collect on surfaces to produce fomites
- Once formed, fomites decay much slower (assumed to live for roughly 48h in this paper)

What Are Facemasks Really Doing?

Masks serve two main purposes:

1. Primary goal is to catch and reduce air droplets loaded with the virus from exhalation
   - a droplet with $2\times$ the diameter has $8\times$ the weight in viral content
2. Aim to reduce intake of loaded external droplets
   - Most likely not as effective as catching during exhalation

Some Interesting Facemask Facts

- Inoculum is primarily released through the mouth, so estimating facemask efficacy at catching exhaled inoculum is important
- Filtration efficiency of different cotton-fabric facemasks varies between 43% and 94% in controlling the passage of bacteria, which travel in moisture droplets in the same way as viruses.
- Droplet-blocking efficiency of fabric samples was shown to be $90 - 98\%$ for 100% cotton T-shirt, dishcloth and silk shirt, which was as high as for fabric material used for the production of a three-layered commercial medical mask. [1]
- More recent research showed that surgical facemasks significantly reduced the detection of influenza virus RNA in respiratory droplets and coronavirus RNA in airborne droplets and it was concluded that surgical facemasks could prevent coronavirus transmission from symptomatic individuals.

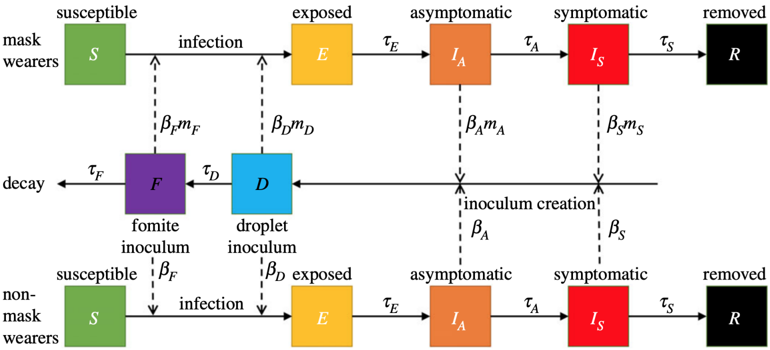
Model 2: Modified SIR with 'Free-living Inoculum'

- Authors use compartmental model with the goal of showing potential COVID-19 dynamics with mask wearing and lock-downs.
- Begin by breaking susceptible population into two categories: facemask wearers and non-facemask wearers.
- Assume that susceptible individuals become infected by coming into contact with inoculum generated by infectives (which in turn are separated into asymptomatic and symptomatic classes)
- The model also separates the process of inoculum creation by infectives from inoculum uptake by suceptibles.
- Thus, there are two pairs of transmission rates:
  - β_A, β_S - inoculum creation rate by asymptomatic and symptomatic infectives
  - β_D, β_F - uptake and infection of susceptible individuals from droplet and fomite inoculum

For Reference

Description	Param.	Default Value
inoculum release rate of asymptomatic infectious individuals	β_A	2.71 unit inoculum per day per capita relative to β_s [3]
inoculum release rate of symptomatic infectious individuals	β_S	1 unit inoculum per day per capita
infection rate due to droplet inoculum	β_D	4.46×10^{-5} per unit inoculum per day
infection rate due to fomite inoculum	β_F	2.58×10^{-9} per unit inoculum per day

Model Flow-Chart & Facemask Friction



- m_A, m_S - measures droplet capture from mask wearers (so they spread less inoculum per unit time, $m_A, m_S < 1$)
- m_D, m_F - viral uptake reduction factor from droplets and fomite. Assumed $m_D < 1$ and initially, $m_F = 1$
- τ_i - mean time spent in class i.

τ_i Values Used In Paper

Description	Param.	Default Value
average duration between infection and onset of asymptomatic infectiousness	τ_E	3.8 days
average duration between onset of asymptomatic infectiousness and first symptoms	τ_A	1.2 days
average duration between first symptoms and end of infectiousness	τ_S	3.2 days
average lifespan of droplet inoculum before deposition	τ_D	10 seconds
average lifespan of fomite inoculum before loss of viability	τ_F	48 hours

ODE Model & $\mathcal{R}_0$

$$\frac{dS}{dt} = -(\beta_F m_F F + \beta_D m_D D)S,$$

$$\frac{dE}{dt} = (\beta_F m_F F + \beta_D m_D D)S - \frac{E}{\tau_E}$$

$$\frac{dI_A}{dt} = \frac{E}{\tau_E} - \frac{I_A}{\tau_A}$$

$$\frac{dI_S}{dt} = \frac{I_A}{\tau_A} - \frac{I_S}{\tau_S}$$

$$\frac{dR}{dt} = \frac{I_S}{\tau_S}$$

$$\frac{dD}{dt} = \beta_A m_A I_A + \beta_S m_S I_S - \frac{D}{\tau_D}$$

$$\frac{dF}{dt} = \frac{D}{\tau_D} - \frac{F}{\tau_F}$$

$$\mathcal{R}_0 = (\beta_D \tau_D + \beta_F \tau_F)(\beta_A \tau_A + \beta_S \tau_S)N$$

A Note On m_F

The paper makes a note of saying that one can also assume $m_F > 1$. What do you think this means and why do you think it is necessary to consider?

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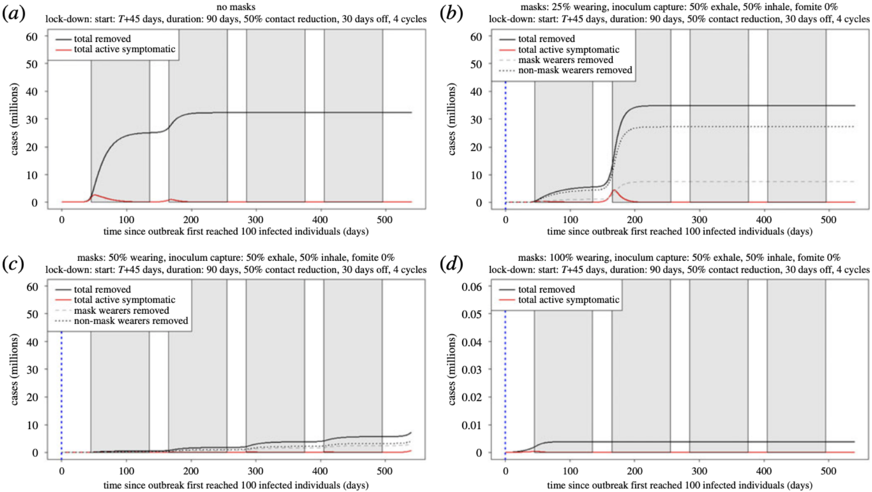
FACE TOUCHING FROM MASK ADJUSTMENT!

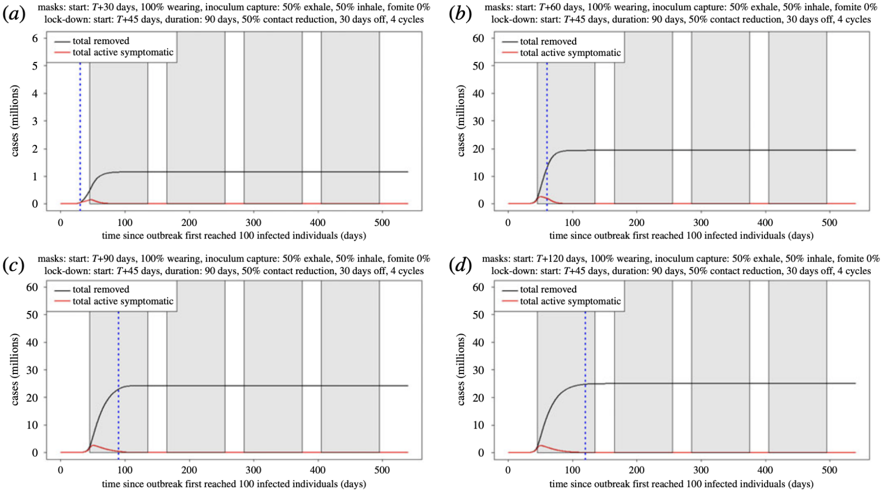
How Do We Add In Lock-Downs?

- Assume lock-down reduces β_i $(i = A, S, D, F)$ by a fixed proportion q
- lock-down reduces inoculum produced in public AND reduces time susceptibles spend with inoculum $\implies$ overall reduction factor by q^2

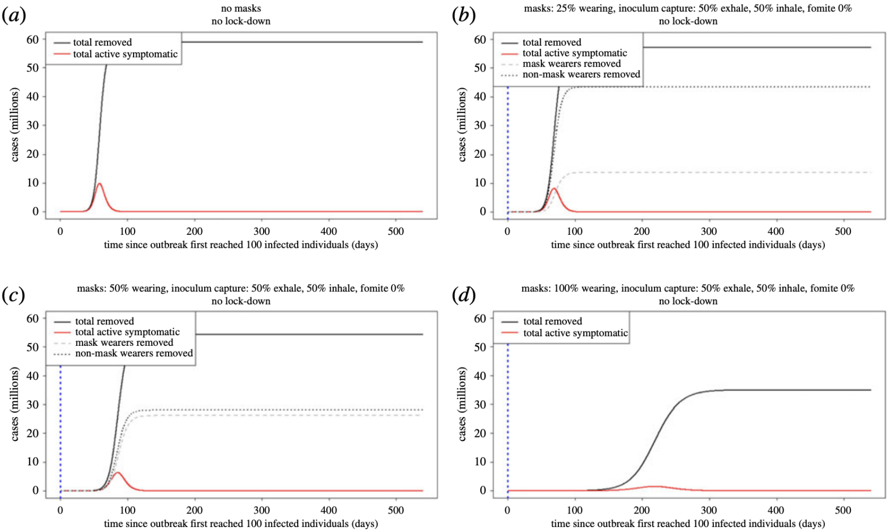
Main Results: Mask Wearers & Lock-Downs



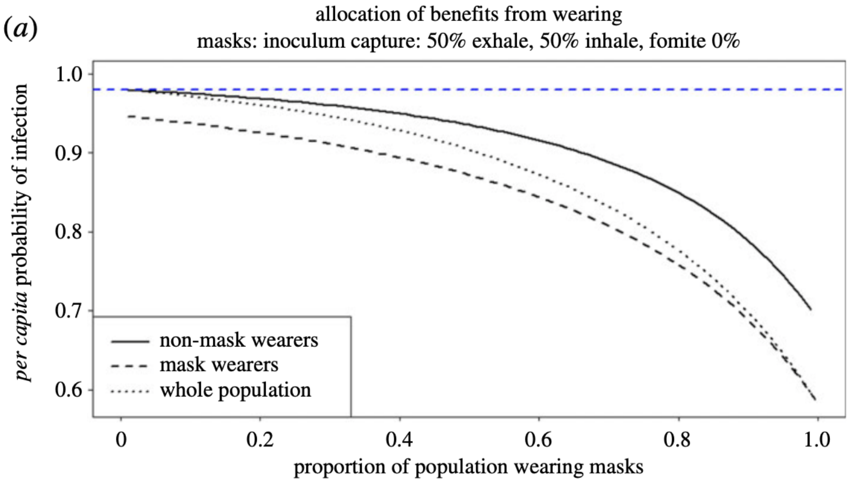
Main Results: Time of Mask Adoption & Lock-Downs



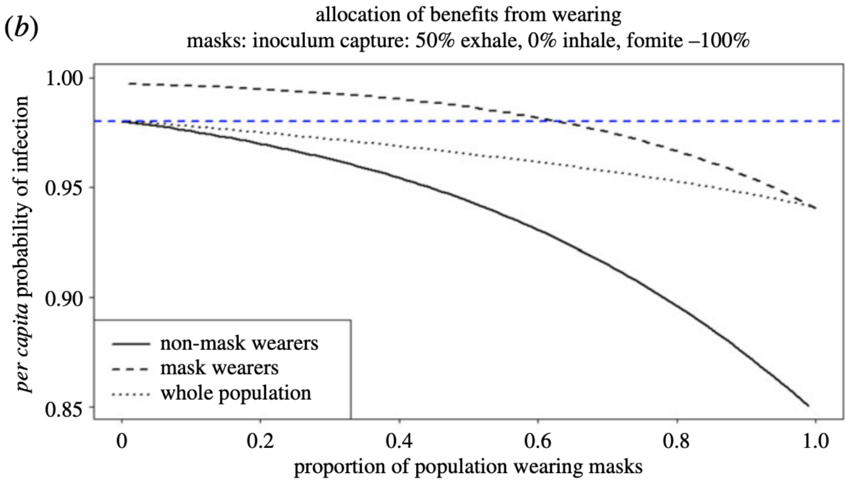
Main Results: Mask Wearers & No Lock-Downs



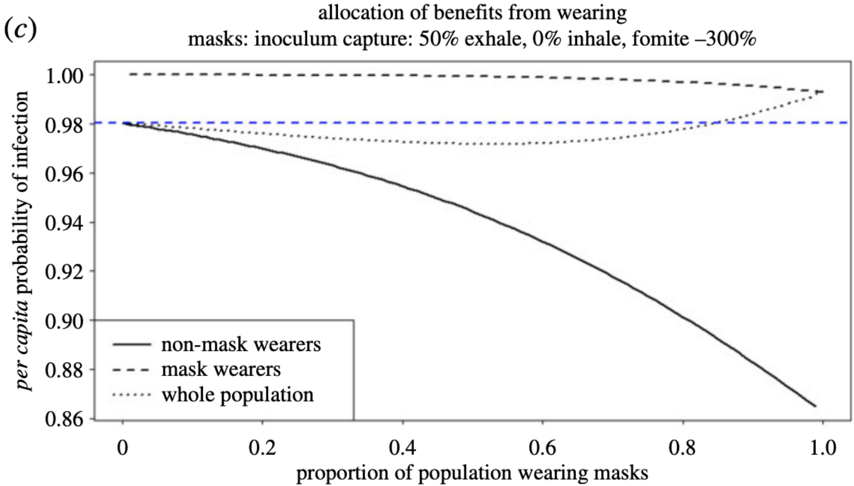
Main Results: Allocation of Benefits (1/3)



Main Results: Allocation of Benefits (2/3)



Main Results: Allocation of Benefits (3/3)



Anyone want to guess a reason for this counter-intuitive result?

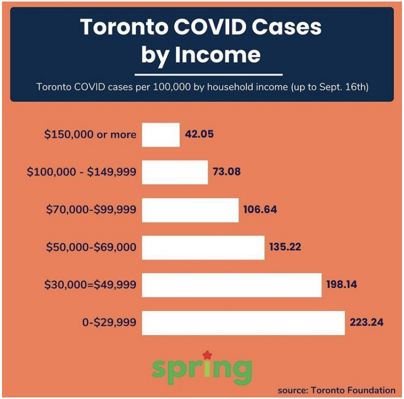
Does this Paper Make Sense Today?

- The Institute for Health Metrics and Evaluation recently released a COVID-19 forecasting paper (using COVID-19 data from February 1 – September 21) with findings [6]:

  "...achieving universal mask use (95% mask use in public) could be sufficient to ameliorate the worst effects of epidemic resurgences in many states."

Other Variables That Can Be Added To The Model

- Additional cleaning of surfaces/self-sterilizing can modelled via reducing the lifespan of fomite inoculum τ_F.
- Can easily add compartments to include age structure, geographic location, income, etc.



- What would you add to this?

Model Issues

- Arbitrarily set $m_a, m_s = 0.5$ in the absence of detailed data on individual-based transmission. Consistent with lower ranges quoted by Furuhashi, van der Sandeet al. and a recent article [4]
- Assumes fixed periodic lock-down scheme
  - Although authors admit that this choice was not intended to model any particular scenario
- Assumes fomite creation is final stage
- Model assumes that once infected, you are immune. This might not be the case! [7]
  - The Netherlands 50 cases of reinfection
  - Brazil has 95 cases of reinfection
  - Sweden has 150 cases of reinfection
  - Mexico has 285 cases of reinfection
  - Qatar has at least 243 cases of reinfection

References I

- Onur Aydin, Md Abul Bashar Emon, and M Taher A Saif. "Performance of fabrics for home-made masks against spread of respiratory infection through droplets: a quantitative mechanistic study". In: *medRxiv* (2020).
- Centers for Disease Control, Prevention, et al. "Use of cloth face coverings to help slow the spread of COVID-19". In: *See https://www. cdc. gov/coronavirus/2019-ncov/prevent-getting-sick/diy-cloth-face-coverings. html* (2020).
- Xi He et al. "Temporal dynamics in viral shedding and transmissibility of COVID-19". In: *Nature medicine* 26.5 (2020), pp. 672–675.

References II

- William G. Lindsley et al. "Efficacy of face masks, neck gaiters and face shields for reducing the expulsion of simulated cough-generated aerosols". In: *medRxiv* (2020).
- Marianne van der Sande, Peter Teunis, and Rob Sabel. "Professional and home-made face masks reduce exposure to respiratory infections among the general population". In: *PloS one* 3.7 (2008), e2618.
- IHME COVID-19 Forecasting Team. "Modeling COVID-19 scenarios for the United States". In: *Nature Medicine* (2020).
- Jop de Vrieze. *More people are getting COVID-19 twice, suggesting immunity wanes quickly in some*. 2020. URL: https://www.sciencemag.org/news/2020/11/more-people-are-getting-covid-19-twice-suggesting-immunity-wanes-quickly-some.

Stock Photo Links

Take-out bag mask & Hand Rail - Photos by RF.studio from Pexels

N95 Mask - Photo by CDC by Pexels

Coughing - Photo by cottonbro from Pexels

Mask Fiddler - Photo by Polina Tankilevitch from Pexels

Lonley Lock-Down - Photo by Nandhu Kumar from Pexels