CONTACT-TRACING STRATEGIES FOR SARS-COV-2 ERADICATION **** UNFINISHED DRAFT ****

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ABSTRACT

As of 3rd April a large proportion of the global population are living under social distancing measures in order to control the spread of COVID-19. If these measures are successful, in a few months, prevalence will again be low in certain parts of the world. However, it is not clear what the best policy will be at that point. This paper investigates the feasibility of using contact tracing along with a combination of other measures in order to ease the social distancing measures while preventing a resurgence of the disease. We find that manual contact tracing will not achieve the speed or accuracy needed to contain the disease, and so suggest a technological solution based on tracing via mobile phone app. The proposed solution maintains user's privacy and conforms to European data protection laws.

**** THIS IS UNFINISHED RESEARCH WHICH MAY CONTAIN ERRORS AND IS SUBJECT TO CHANGE ****

Keywords COVID-19, SARS-CoV-2

1 Introduction

Many countries in the world are now committed to a surge in incidence of COVID-19 and are practising social distancing in order to suppress its spread. If successful, these countries will soon be in a situation where prevalence is reducing. Once this is achieved there are a number of strategies:

- lift the social distancing measures and allow a second (and subsequent) waves until herd immunity is achieved(Ferguson et al., 2020).

- maintain low levels until a vaccine is available

- eradicate the virus locally and impose strict border controls and containment strategies until the virus is contained globally

Here we investigate the feasibility of the third option by slowly lifting social distancing measures while maintaining self isolation of symptomatic individuals and implementing an extensive testing and contact-tracing capability.

2 Description of the Model

The model we use is based on the stochastic branching model described in (Hellewell et al., 2020) but implemented as an agent-based, discrete event simulation. This allows us to implement more complex containment strategies with less effort. It also allows us to correctly capture the tracing of infected agents via a previously untraced mutual infector, which is not properly captured in a stochastic branching model. In the presence of many asymptomatic carriers, and

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very fast and accurate tracing, this is expected to be important. It also allows us to capture the workload on a central testing facility and the feedback of delays as workload increases.[2]

The model consists of infected agents, each of which belongs to a household and a workplace/school. Once infected, an agent goes though an incubation period with duration drawn from a Weibull distribution with shape parameter 2.322737 and scale parameter 6.492272(Backer, Klinkenberg, & Wallinga, 2020). The transmission generation interval (i.e. time from exposure to transmission) is drawn from a skew normal distribution with location parameter equal to the clinical onset time (i.e. end of the incubation period), scale parameter of 2.0 and skew parameter of 1.95(Hellewell et al., 2020). This results in 15% of infections occurring before clinical onset(Hellewell et al., 2020). In order to avoid unrealistically early transmissions, the generation interval was bounded to a minimum of 1 day. At creation, 17.9% of agents are deemed to be asymptomatic(Mizumoto, Kagaya, Zarebski, & Chowell, 2020)[3]. Asymptomatic carriers are assumed to be $\frac{2}{3}$ as infectious as symptomatic carriers(Ferguson et al., 2020). The number of susceptible agents that an infected agent will infect if not isolated is drawn from a negative binomial distribution with overdispersion parameter 10.0(Zhuang et al., 2020)(Riou & Althaus, 2020) and mean of $\frac{3R_0}{3-\rho}$ for symptomatic agents and $\frac{2R_0}{3-\rho}$ for asymptomatic agents where $\rho = 0.179$ is the probability of being asymptomatic and R_0 is the basic reproductive number. At each transmission event a new infected agent is created, unless the agent is isolated, in which case the event has no effect.

Each transmission event occurs either in the household, at the workplace/school or in the community. This allows us to capture the differences in ease and speed of contact tracing in these three cases, as well as capturing the effect of closer and more frequent contact with household members compared to workplace and community. Distinguishing household contacts also allows us to simulate the effect of household-wide self-isolation policies such as those implemented in the UK. Finally, it allows us to capture any immunity in the population built up during a first wave of infections. After a first wave of infection we would expect there to be a correlation in immunity between members of the same household since during the peak, under "stay at home" rules, if one member of a household contracts the disease it is likely that all other members will also contract it, so we end up with immune and susceptible households. This means that only members of susceptible households can become infected during the contact-tracing stage. The relative probability of transmission in the three locations was calibrated in order to obtain equal aggregate numbers of transmission events in each location(Ferguson et al., 2020). The distribution of number of members in a household was calibrated against(Smith, 2014). A transmission event to an immune agent does not cause infection. Immunity is only applied to school/workplace and community transmissions for the reasons outlined above.

The source code of the model is available at https://github.com/danftang/Covid19

2.1 Contact tracing and isolation policy

3 Policy Scenarios

Various policy scenarios were simulated to find the probability that an initial population of 100 infected agents could be eradicated. Eradication was deemed to have been achieved if the cumulative number of cases remained below 5000 and there was no untraced infected population at 15 weeks into the simulation. It was assumed that 5% of the population was immune. The probability of eradication was estimated by performing a monte-carlo run of 300 simulations and counting the proportion that achieved eradication.

3.1 No contact tracing, self isolation

Ordering people to self-isolate upon becoming symptomatic is unlikely to work on its own. The only chance of containment is if isolation occurs immediately on symptom onset. Figure 1 shows the case when 15% of transmission is pre-symptomatic and there is 90% compliance. This kind of compliance so quickly after symptom onset would only be practical under legal enforcement and close monitoring (e.g. thermal cameras, social stigma, fines etc.) and would only work if R0 is on the low side of the feasible range.

3.2 Whole household isolation

Ordering a whole household to self-isolate upon any member becoming symptomatic is more effective (Figure 2) but still not probable enough to be a good strategy.

3.3 Isolation of whole household and work-colleagues

Ordering both the household and close contacts at work to be isolated could work under some parameter values. In this scenario, close contacts of a symptomatic at home and work would immediately be asked to self-isolate and take a swab test. Swab tests take 24 hours to process and come back positive if the agent's infectiousness is above 2% per day.

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[2] Although a discrete-event simulation takes longer to execute than a branching model, execution time is not a bottleneck so it is worthwhile in order to capture these dynamics.

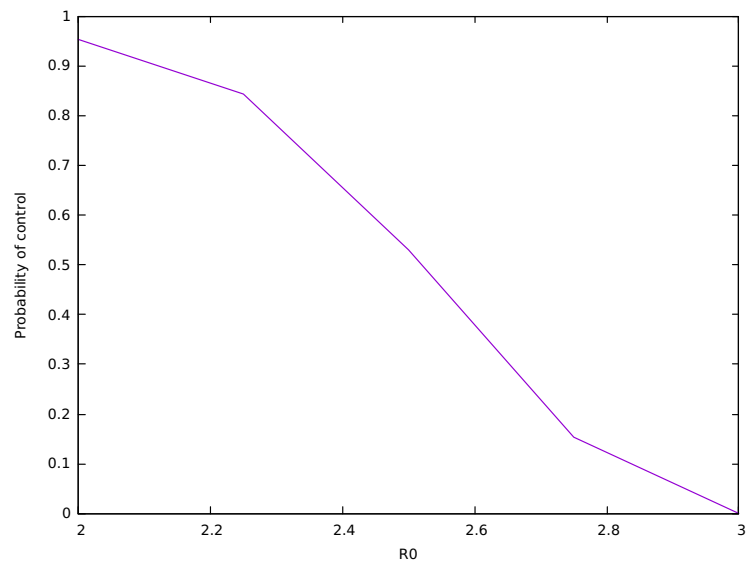[3] [TODO: Age weight this figure]

Figure 1: Probability of eradication under self-isolation only assuming 90% compliance and 15% pre-symptomatic transmission.
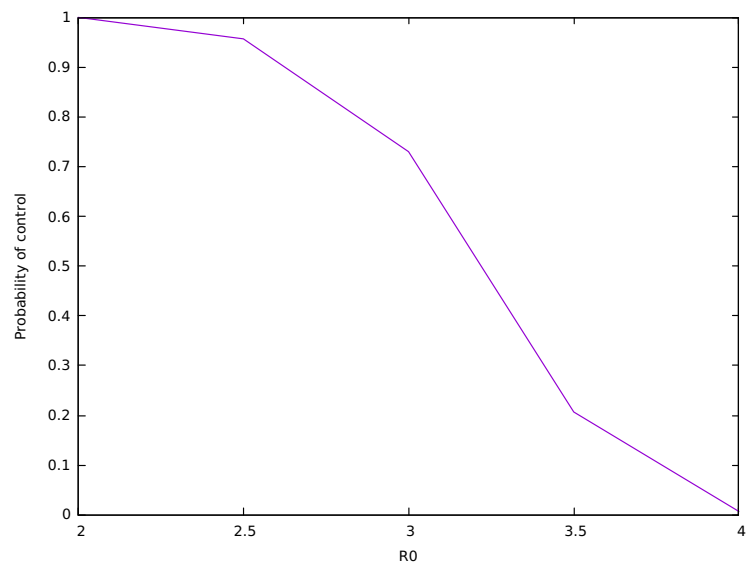

Figure 2: Probability of eradication under whole household quarantine assuming 90% compliance and 15% pre-symptomatic transmission.
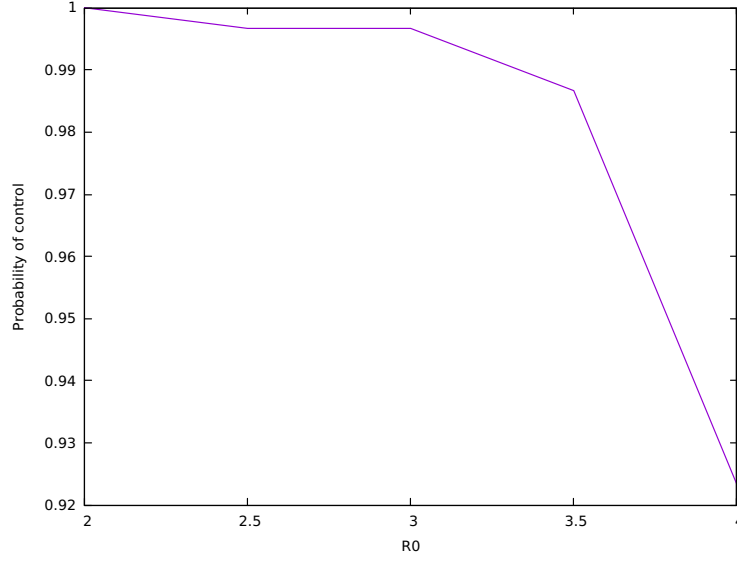
Figure 3: Probability of eradication under quarantine of whole household and workplace contacts assuming 90% compliance and 15% pre-symptomatic transmission.
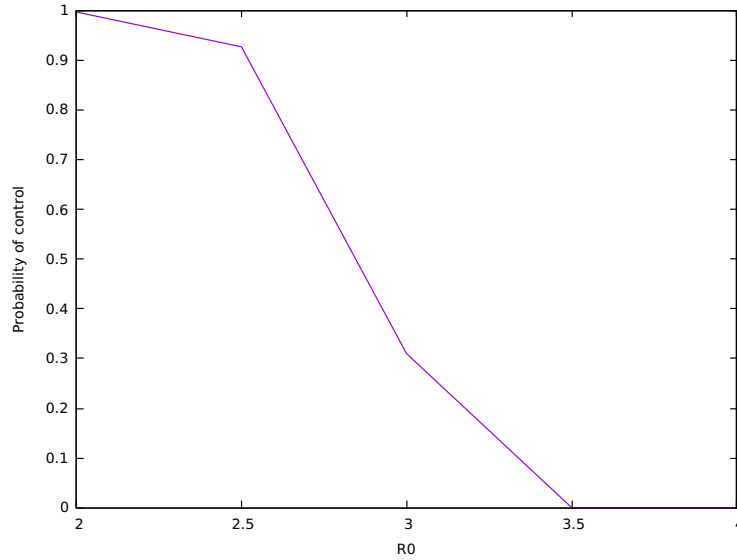

Figure 4: Probability of eradication under quarantine of whole household and workplace contacts assuming 90% compliance and 50% pre-symptomatic transmission.

This captures the vast majority of the time the agent is infectious but excludes the latent phase. Those that test positive require their whole household and close work contacts to also isolate and take a swab test and so on. By instating a legal requirement for companies to force traced contacts to stay at home and by making it a duty for companies to report symptomatic employees it is feasible that the time from onset to isolation can be made small while making compliance high. Figure 3 shows that with $R0 \leq 3$ and 15% pre-symptomatic transmission then this strategy would have a high chance of success given 90% compliance. However, at a pre-symptomatic transmission of 50% this strategy looks less feasible (figure 4).

3.4 Community contact tracing

If, in addition to household and workplace tracing, contacts could also be traced in the community, and told to isolate and take a swab test if they had been in close contact with a person who has tested positive, then there is a good chance of success even in the case of $R0 = 3.5$ and 50% pre-symptomatic transmission, see figures 5 and 6.
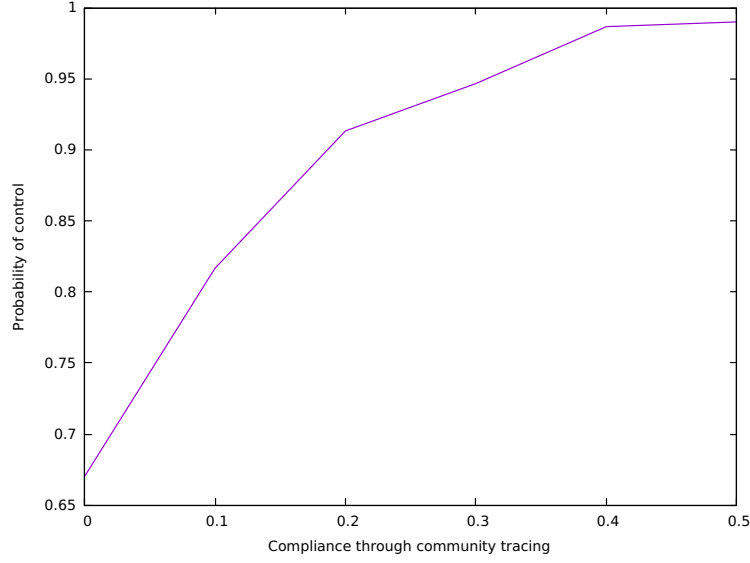
Figure 5: Probability of eradication under community tracing assuming 90% self-report compliance, 50% pre-symptomatic transmission and $R0 = 2.5$.
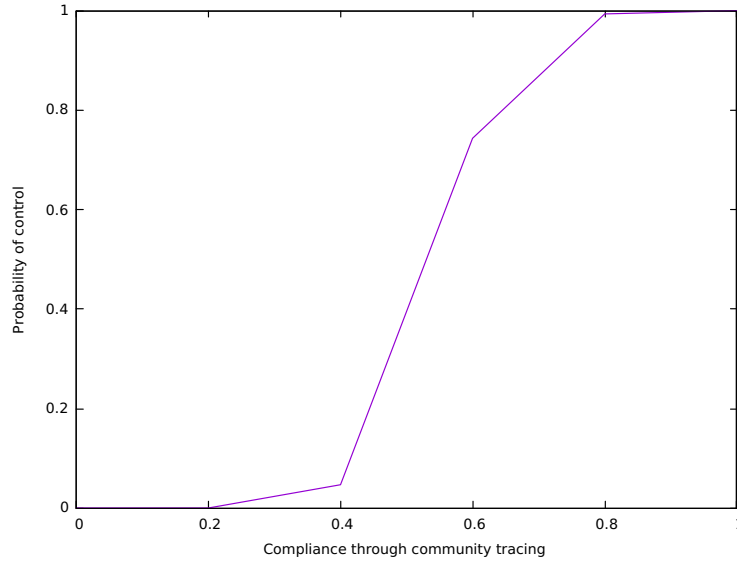

Figure 6: Probability of eradication under community tracing assuming 90% self-report compliance, 50% pre-symptomatic transmission and $R0 = 3.5$.

However, even under this scenario, we need 80% compliance in the community, in addition to enforcement at work, to have a good chance of success. In order to minimise risk, then, it would be advisable to maintain some social distancing measures in addition to the contact tracing, in order to bring down the effective R value.

[People who do not install the phone app are more likely to also not report symptoms or self isolate. However, non-compliants more likely to be immune (size of this effect?)]

4   Contact tracing in the community while maintaining privacy

Achieving contact tracing that is fast and efficient enough to make the above strategy feasible will require a technological solution, probably by leveraging mobile phones. For any such contact-tracing strategy to be acceptable in the context of a western democracy, the privacy of the participants is of paramount importance. For that reason we suggest the following technological solution to contact tracing:

Each participant must have a mobile phone equipped with Bluetooth and an Internet connection. An app will be installed which turns on the phone's Bluetooth connection. To maintain anonymity, the Bluetooth MAC address will be

spoofed to a randomly chosen 48-bit number[4]. The chosen number will be locally stored in the app. If another phone with the app installed comes close for more than a fixed amount of time, then the two will be classed as a "close contact" and each phone will store the MAC address of the other's along with it's own MAC address. At intervals of, say, 2 minutes, the MAC address will be changed to a new, randomly chosen number.

As a person travels through the community, the app will collect the temporary MAC addresses of all close contacts, along with the MAC addresses that it spoofed. Because these are randomly generated numbers there is no way to identify anyone or track their movements from the temporary MAC addresses.

If a person tests positive, all the MAC addresses on that person's phone will be made public on the Internet. Since these are just random numbers, no sensitive information is disclosed. Periodically, all apps will check the published numbers against it's own locally stored record of the MAC addresses that it has spoofed. If there is a match, the user can be notified that they are at risk and should self-isolate and be tested.

In this way, all close contacts of a newly confirmed case (as long as they are using the app) can immediately be informed that they are at risk. The only limitation being the uptake of the app and the compliance of the user with advice to self isolate.

In order to encourage people to install the app public shops and buildings could require the app to be installed in order to gain entry[?].

5 Discussion

These early results are subject to further calibration of the model and are likely to change as our understanding of the dynamics of SARS-CoV-2 develops. It also remains to do a proper sensitivity analysis of the model (particularly sensitivity to the proportion of asymptomatics), and to properly treat uncertainty, which is large.

However, the results indicate that contact tracing in the community will be necessary to have a good chance of eradication. We have presented a technological solution to achieve the speed and accuracy needed to make this possible, while maintaining the privacy of users.

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[4]Is this possible?