The effectiveness of extended social bubbles as a soft exit strategy from the COVID-19 lockdown

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Executive summary

- Clustering of additional contacts within social bubble is a highly effective means of controlling the increase in R while allowing more contacts.
- Allowing all households to expand their social bubble may increase R above 1
- Some targeted approaches only generate a marginally increase R, these include:
    - Paring of single or dual occupancy households
    - Pairing of households with primary school age children
- Young children are at least risk and likely to benefit most from allowing close contact with peers because of their ineffective communication digitally or with a 2m distance.

Summary

Methods: We used an individual based model where SARS-CoV-2 transmission is described by a Next Generation Matrix capturing the clustering contacts into households (according to the last census in E&W), social bubbles (according to the investigated strategy) and transmission in the general community. To parameterise to the current UK situation we assume a secondary household attack rate of 20% (10% and 40% alternatively) and that together with community transmission an average infected person infects 0.8 others (R~0.8). We make the conservative assumption that the attack rate within the bubble is the same as within the household (50% as an alternative). We assess the impact of different strategies on the net reproduction number in the population. Key strategies investigated include social bubbles for single or double occupancy households, households with primary school age children, and all households. We compare these with upholding current recommendations with either uninterrupted adherence or with 50% of households randomly choosing 3 additional contacts in the near future.

Conclusions:

For the same increase in the reproductive ratio, R, the clustering of additional contacts into social bubbles allows more than 50% more contacts compared to additional unclustered contacts. Under largely conservative assumptions (100% uptake, transmission with the bubble is the same as household, no reduced transmission to and from children) we find that there is likely minimal (<5%) increase in transmission from either pairing up single occupancy households or pairing households with single parents and a primary school age child with households that also have a primary school age child. While the associated increase in transmission is higher, we find that the net reproduction number would likely stay below 1 if dual occupancy households could pair up, or if households with primary school age children could form a social bubble. More substantial changes to the status quo, particularly allowing all households to extend their social bubbles may

risk increasing R above 1. Less conservative assumptions on uptake, child transmission and transmission risk within the social bubble can substantially reduce the amount of additional transmission.

Limitations:

- We only assessed the risk of extending social bubbles but not the benefits. Under current recommendation social contact beyond the household is restricted to digital contact or contact in open spaces with one individual while keeping 2 meters apart. In other words, one can have a conversation. While conversations are a large part of the social contacts of adults they have little role in social interactions of children. *Hence the benefit of extending bubbles for children is likely disproportionately higher*.
- We only consider the risks of easing the lockdown for the national mitigation strategy. Particularly this does not consider that strategies that include extension of contacts for elderly will see those at a disproportionately higher absolute increase in disease risk. *Similarly, the absolute increase in risk of disease for children by extending their social bubbles is likely small.*
- We also did not yet consider non-adherence to a social bubble strategy. Arguably though, this is equally a problem with the current household contacts only strategy, unless the social bubble strategy changes the risk perception in the population. In fact, the *social bubbles may be an opportunity to increase social contacts in a risk minimising way for those who would have increased their contacts sooner or later anyways*, though in that case not informed by risk minimisation strategies.

Background

In the UK, similar to many other countries, the so-called lockdown of the country in March in response to the Covid-19 pandemic has successfully reduced the spread of SARS-CoV-19 and prevented the healthcare system from being overwhelmed[1]. This success, however, comes at great economic and societal costs. With infection incidence on the decline countries are increasingly implementing strategies on how to effectively strike the balance between easing restrictions while making sure that infection rates do not increase again.

One potential part of a strategy on how to minimise social distress by allowing some direct interaction beyond the household while at the same time limiting the risk for increased transmission risk in the community as well as increased personal risk, has been deemed the social bubble strategy [2,3]. This has been implemented in some countries including New Zealand and Germany and is currently considered as part of the lockdown exit strategy in the UK[4].

We aim to assess the likely magnitude of increase in transmission owing to various plausible social bubble strategies in the UK.

Methods

Population

The model population was created by generating individuals who are residents of either of 3000 households. The size of the individual households was sampled from the most recent census in England and Wales in 2011 (Figure 1). The average household size was 2.4, while the average size of a household with at least one 5-9y old and <20y old child was 4.2 and 3.7 respectively. The proportion of households with at least one 5-9y old and <20y old child was 11% and 31% respectively. The proportion of the population who lives in households with at least one child and at least one primary school age child was 49% and 19%. The UK is therefore dominated by households of just 1 or 2 adults (Figure 1).

Households were joined into social bubbles in accordance with the respective policy strategy under consideration (see Scenarios).

Transmission model

The model stochastically simulates an epidemic in a population of individuals who are connected via a transmission probability matrix $\mathbf{A} = \mathbf{H} + \mathbf{B}$. $\mathbf{A}_{i,j} > 0$ indicates that individuals *i* and *j* are in potentially transmission relevant contact. We define H as the matrix of within household connections, where non-zero entries reflect the probability of transmission as a Poisson process with rate τ_H, $1\text{-}e^{-T_H}$. Similarly, non-zero entries in B hold the probability of transmission for contacts within the social bubble and outside the household, $1\text{-}e^{-T_B}$. For a random draw **A**' of **A**, the population vector indicating whether an individual in infected in generation *g*, $I(g)$, is given by multiplication of the previous generation with **A**': $I(g) = \mathbf{A}'*I(g\text{-}1)$. Infected individuals are assumed to develop protective immunity at the end of the generation time.

To simulate ongoing spread in the community beyond the household and the social bubble, at each generation we also randomly infect individuals with probability $1\text{-}e^{-\Delta I\ \varepsilon/Nh\ S/N}$, where ε is the

infection rate for a household from the community, *N*h is the household size, ΔI the number of new infections in that generation and *S/N* the proportion of susceptibles in the population.

The net reproduction number was calculated as the ratio of the number of new infections in the fifth vs the fourth model generation, by which time the estimates had stabilised and in the non-epidemic scenarios a total of 3 to 4% of the model population had been infected.

Parameterisation

To infer parameters of the Covid-19 transmission dynamics in the model we need to define the infection pressure within a household, within a bubble and from the community. To parameterise the within household transmission we assume that, in line with observations from contact tracing[5], the secondary household attack rate is 20% and hence $\tau_H = 0.22\ (1-exp(-T_H)=0.2)$. We assume that community transmission is at a level that, in combination with household transmission, generates anet reproduction number of about 0.8, similar to current estimates in the UK[6]. Accordingly, we calibrate ε using a parameter sweep. Further, as a base-case, we make the conservative assumption that transmission within the bubble is the same as within the household, i.e. $\tau_H = \tau_B$.

To assess the sensitivity of our results to a reasonable range for the input parameters we alternatively assume that the secondary household attack rate is 10% or 40% (e.g. good within household isolation on symptom onset or missing a substantial proportion of subclinical infections with PCR in studies that have estimated the SAR[7]) and that the transmission rate within the social bubble is half of that within the household (e.g. reflecting that adults can keep a 2m distance while their children, who are potentially less transmissible[8] and/or susceptible[9], play).

We assess the impact of social bubbles on the reproduction number (calculated as average secondary number of infections per case in generation 3), assuming that all eligible households would indeed take up the opportunity to expand their social bubble and that they would comply with the exclusivity of the bubble.

All analyses were done in Matlab[10] and R[11] and are available via github.

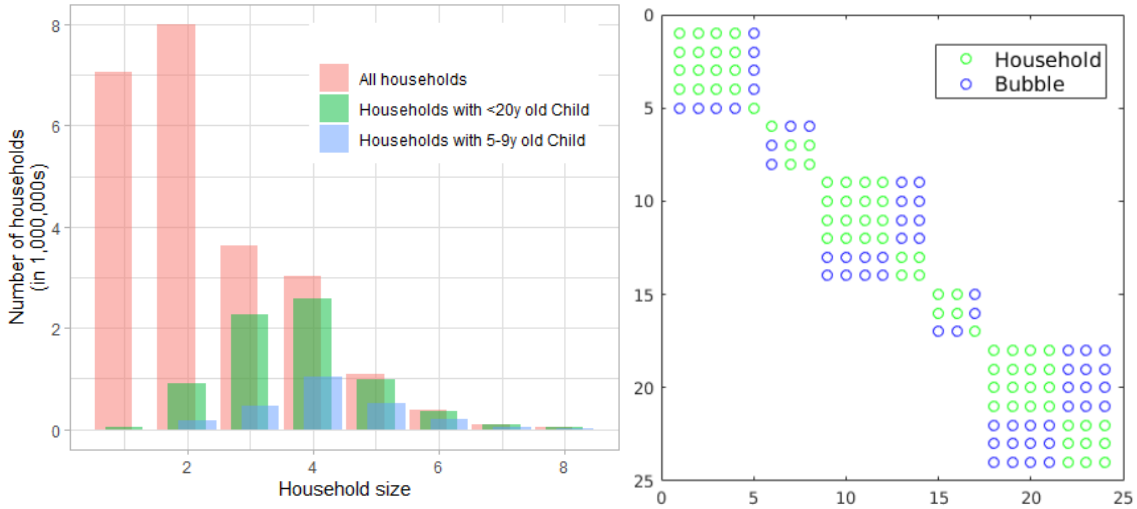

Figure 1: left panel: household size distribution for all households in England and Wales, for those households with at least one child younger than 20 years old and for those with at least one child between 5-9 years olds (roughly primary school age). Data are from the census in 2011. Right panel: illustrative transmission probability matrix showing the pairing of households of various sizes.

Scenarios

We considered a number of strategies how to relax the current lockdown:

1) Allow households with primary school age children to pair up
2) Allow households of size 2 with primary school age children to pair up with another household with primary school age children
3) Allow households with children of any age to pair up
4) Allow single occupancy households to pair up
5) Allow single occupancy households to pair up with another household of any size
6) Allow households of size 2 or less to pair up
7) Allow households of size 2 or less to pair up with another household of any size
8) A combination of scenarios 1 & 3
9) Allow all households to pair up

We compare the above scenarios against the reproduction numbers in two simple counterfactual without social bubbles:

C1) Perfect adherence to the current household-only contact strategy (other than the background transmission risk from the community)

C2) Assume that 50% of households do not adhere to C1 and have 3 contacts chosen at random among the general population.

Results

Assuming a current net reproduction number of 0.8, perfect adherence to the recommended social bubble strategy and that all eligible households indeed pair up, we find that strategies that exclusively target small households or households with young primary school age children are unlikely to increase the net reproduction number above 1. While allowing all households to form pairs is estimated to increase the reproduction number to 1.21 (range for alternative assumptions

on the SAR: 1.01 - 1.40), a similar reproduction number would be reached if only 50% of households made the same number of additional contacts per household but have those randomly distributed across all other households instead of clustered (Figure 2).

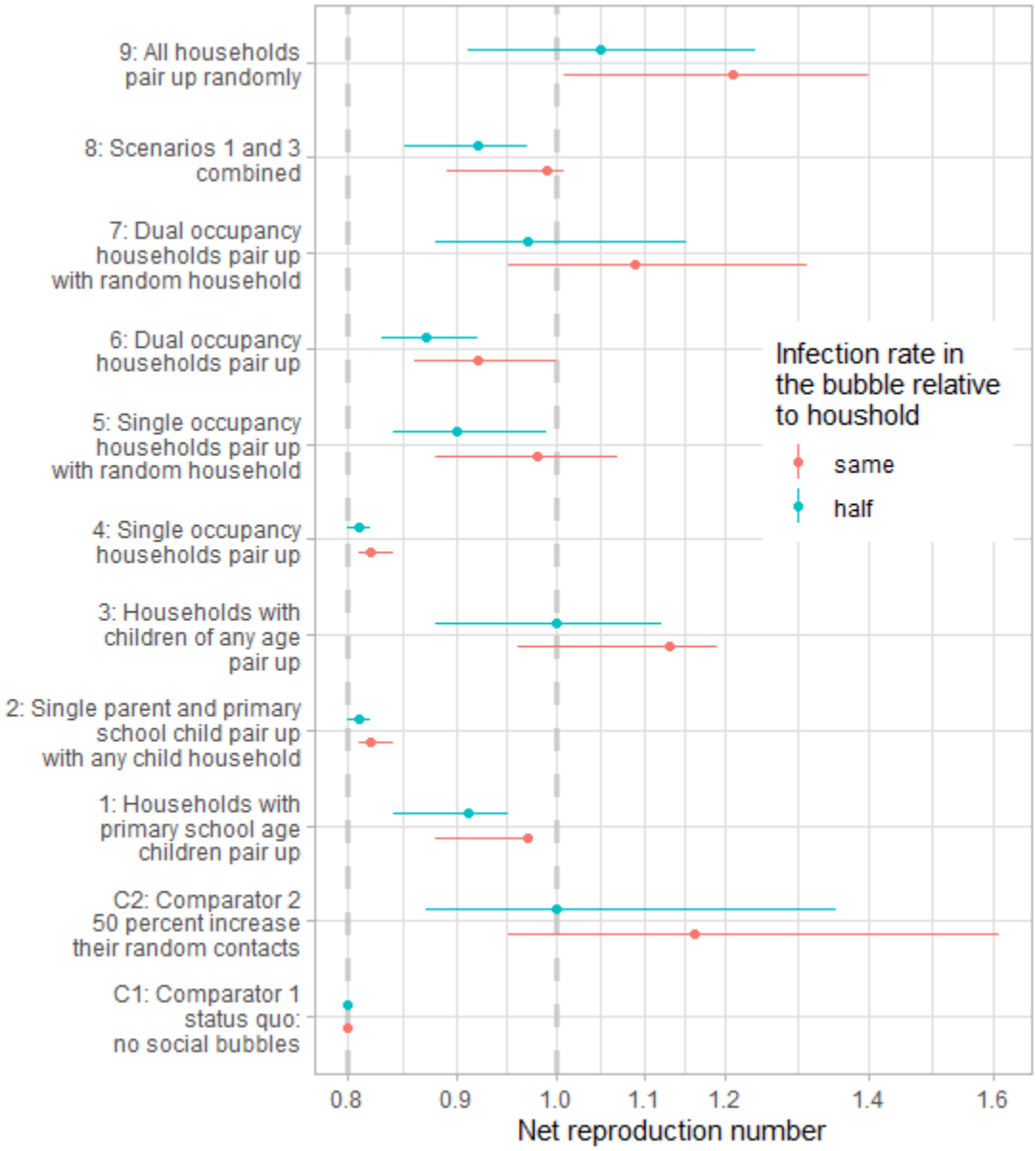

Figure 2: Estimated reproduction number for the considered scenarios under the assumption that all eligible households pair up and thereby form exclusive social bubbles and that transmission rates within a social bubble are the same as within the household. Central estimates are assuming SAR_{HH}=20% and the upper and lower limits represent the respective 10% and 40% assumption.

Generally, the fewer households that were deemed eligible for expanding their social bubble under a specific strategy and the smaller the average household size of those, the smaller the increase in transmission as a result. Among the strategies tested we estimate that the pairing up of single occupancy households (scenario 4) and allowing households with a single parent and a

primary school age child to pair up with another household with a primary school age child (scenario 2) each results in less than a 5% increase in transmission (Figure 2). Allowing dual occupancy households (scenario 6) or households with primary school age children to join up (scenario 1) would likely increase the net reproduction number by more than 10% but probably keep it below 1.

If assuming that transmission within the bubble is less effective than within the household all strategies will increase transmission substantially less than in the base case (*cf* Tables 1 and 2); although the same relative relationships between the scenarios is maintained.

Conclusion & limitations

We find that contact clustering, or the forming of social bubbles that effectively join two households, can be an efficient way to allow social contacts while limiting additional risk for transmission. While allowing all households in the UK to pair up and thereby effectively double their current amount of close contact interactions may increase the reproduction number above one, a more targeted approach could improve the *quality* of life for those most in need while only marginally increasing the risk for transmission in the community. We estimate that either allowing single person households to pair up with other households, or households with single parents and a primary school age child to pair up, or any subset of those strategies would increase the net reproduction number in the population by less than 5%. Also, the extension of the social bubble of households with primary school age children is unlikely to push the reproduction number above 1. If the risk for infection in the social bubble can be kept below that within the household the magnitude of additional transmission from the extension of the social bubble can be further minimised.

A recent survey in New Zealand highlights the extension of one's social bubble beyond the household as one of the major improvements in quality of life during the lockdown. Currently allowed forms of social interactions beyond households in the UK include digital communication and, since a few days ago, meeting of one person at a time in open spaces while upholding a 2m distance. While these forms of interaction allow conversational contact among adults, for young children these restrictions basically mean no meaningful interaction with their peers at all. The plan to have young children go back to school as early as June is predicated on evidence suggesting that children are less susceptible to disease and infection and potentially less likely to effectively transmit Covid-19. Hence an extension of their social bubble while recommending adults to adhere to the social distancing rules should further minimise the risk compared to what we have considered here.

Limitations:

- We only assessed the risk of extending social bubbles but not the benefits. Under current recommendation social contact is restricted to digital contact or contact in open spaces with 1 individual while keeping 2 meters apart. In other words, one can have a conversation. While conversations are a large part of the social contacts of adults they

have little role in social interactions of children. Hence the benefit of extending bubbles for children is likely disproportionately higher.

- We only consider the risks of easing the lockdown for the national mitigation strategy rather than an individual's additional risk for severe disease. However, in the model an individual's risk for infection can be approximated by $1-(1-e^{-\varepsilon})(1-e^{-\varepsilon/Nh\ \tau H})^{Nh}(1-e^{-\varepsilon/Nb\ \tau B})^{Nb}$, where Nh is the number of additional household members and Nb is the number of bubble members. Hence, for our baseline model parameters an elderly person living on their own would increase their risk for Covid infection by 9% if extending their social bubble to include a 3 person household. However, we would argue that shielding of vulnerable individuals should continue due to their greater risk.
- We assumed that all eligible households would indeed make use of the opportunity to pair up with others. In NZ the uptake, however, was only about 50% which would further reduce the impact transmission of the social bubble strategy
- We did not yet include the possibility to form bigger social bubbles that would cluster together 3 or more households. While this has been implemented in other countries the complexity of creating an exclusive cluster of three or more households could lead to a loss of adherence.
- We also did not yet consider non-adherence to a social bubble strategy. Arguably though, this is equally a problem with the current household contacts only strategy unless the social bubble strategy is communicated in a way that may change the risk perception in the population. In fact, the social bubbles may be an opportunity to increase social contacts in a risk minimising way for those who would have increased their contacts sooner or later anyways, though in a way not informed by risk minimisation.

Conflicts of interest

SF has a 5y old daughter.

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Supplement

Table 1: Estimated reproduction number for the considered scenarios under the assumption that all eligible households pair up and thereby form exclusive social bubbles and that transmission rates within a social bubble are the same as within the household.

TB=TH, equal transmission within household and within bubble				
#	Scenario description	Reproduction number, assuming SAR_{HH} =		
		10%	**20%**	40%
C1	Comparator 1 (Baseline): Current lockdown with all households adhering to the lockdown rules	0.8	0.8	0.8
C2	Comparator 2: Current lockdown with 50% of households having 3 extra random contacts	0.95	1.16	1.61
1	Allowing all households with primary school age children to pair up	0.88	0.97	0.97
2	Allow households of size 2 with primary school age children to pair up with another household with primary age children	0.81	0.82	0.84
3	Allowing all households with children of any age to pair up	0.96	1.13	1.19
4	All single occupancy households to link up with other single occupancy households	0.81	0.82	0.84
5	All single occupancy households to link up with any other household	0.88	0.98	1.07
6	All households of size 2 or less to link up with other households of size 2 or less	0.86	0.92	1.00
7	All households of size 2 or less to link up with any other household	0.95	1.09	1.31
8	Scenarios 1 and 4	0.89	0.99	1.01

9	All households pair up	1.01	1.21	1.40

Table 2: Estimated reproduction number for the considered scenarios under the assumption that all eligible households pair up and thereby form exclusive social bubbles and that transmission rates within a social bubble are a half of those within the household.

TB= TH/2 reduced transmission in bubble compared to household				
#	Scenario description	Reproduction number, assuming SAR_{HH} =		
		10%	**20%**	40%
C1	Baseline 1: Current lockdown with all households adhering to the lockdown rules	0.8	0.8	0.8
C2	Baseline 2: Current lockdown with 50% of households having 3 extra random contacts	0.87	1.00	1.35
1	Allowing all households with primary school age children to pair up	0.84	0.91	0.95
2	Allow households of size 2 with primary school age children to pair up with another household with primary age children	0.8	0.81	0.82
3	Allowing all households with children of any age to pair up	0.88	1.00	1.12
4	All single occupancy households to link up with other single occupancy households	0.8	0.81	0.82
5	All single occupancy households to link up with any other household	0.84	0.9	0.99
6	All households of size 2 or less to link up with other households of size 2 or less	0.83	0.87	0.92

7	All households of size 2 or less to link up with any other household	0.88	0.97	1.15
8	Scenarios 1 and 4	0.85	0.92	0.97
9	All households pair up	0.91	1.05	1.24