Agent Based Modelling and Epidemiology: Once Upon a Time in England

Luka Milić and Vladimir Nosov

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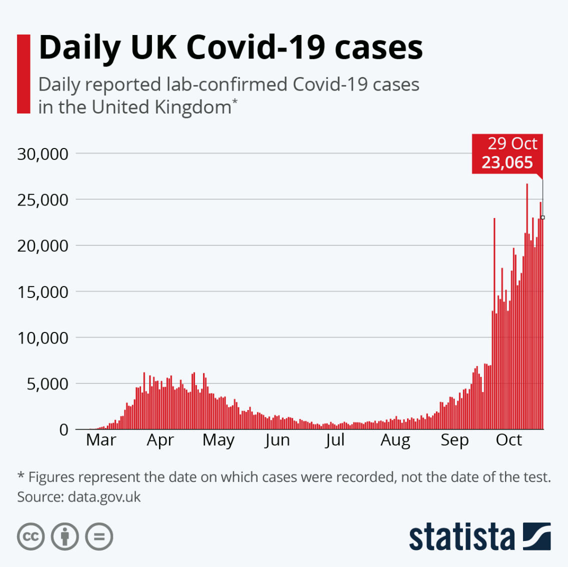
Background: A Convoluted Controversy

- In the early stages of the COVID-19 pandemic, the U.K governments' approach to limiting the spread of the novel coronavirus was in stark contrast to their European counterparts.
- Throughout January and February, Prime Minister Boris Johnson continuously delegated the pandemic efforts to his health secretary.
  - This resulted in delays with ordering essential equipment, such as testing kits, and caused mixed messaging about the public health practices needed to slow the spread (social distancing measures).
- "The government placed too much confidence in Britain's scientists and doctors, without doing enough to obtain the scarce equipment they required to do their jobs" - Dr. Liam Payne *(epidemiologist at the London School of Hygiene and Tropical Medicine)*

Background: A Convoluted Controversy

- Despite this laissez-faire approach, during the month of February, Britain appeared to be coping well with identifying the infected and contact tracing.
- It was not until cases began to increase exponentially in early March, that the failure to move fast on obtaining testing kits would come back to haunt the United Kingdom.
- Prime Minister Boris Johnson took the reigns and announced on March 12^{th}, that the U.K government would cease tracing and testing contacts of coronavirus patients.
    - Effectively accepting that a full-scale outbreak was inevitable in the country.
- The federal government shifted focus to "delaying" the spread of the virus.
    - It took four more days before Boris Johnson formally advised the public to begin socially distancing.

Background: A Convoluted Controversy



Background: A Convoluted Controversy

- There were whispers inside the government that the long-term goal was for Britain to develop "some kind of herd immunity" against the diseases, however, this was never an official policy.
- Messaging changed abruptly when on March 16^{th}, Neil Ferguson, delivered a bombshell 20-page paper to the Prime Minster where the messaging was clear: 510,000 people could die if the government didn't abandon its current strategy of allowing the disease to spread.
    - This now famous report is tittled *"Report 9: Impact of non-pharmaceutical interventions (NPIs) to reduce COVID-19 mortality and healthcare"*
- On March 23, the British government shifted its stance once again, now in favor of a suppression strategy, as the country made preparations for weeks of lockdown.

Controversy

- Both the original code and the modified code used to create report 9 were never released as well as the data used in report 9.
- The code of the model that led to the lockdown was criticized as "totally unreliable", "buggy mess" and "something you wouldn't put your life on.".
- Initially, researchers were unable to reproduce the results.
- After the government initiated a lockdown, that Neil Ferguson himself advised, he was caught violating it to meet with his married lover. As a result, he resigned from his position as a government advisor on the Scientific Advisory Group for Emergencies (SAGE) committee.
- Ferguson contracted COVID19, and was showing symptoms two days after meeting with PM Boris Johnson. Although it is virtually impossible to prove, it is feasible that Ferguson is the one who infected the PM.

Neil Ferguson: A Man Looking for Forbidden Love and COVID?

Daily Mail
WEDNESDAY, MAY 6, 2020
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Expert who convinced ministers to take drastic measures broke rules for affair
THE VIRUS TSAR

The Daily Telegraph
Lockdown professor steps down after breaking rules to meet married lover
Government adviser behind social distancing measures allowed woman to visit him despite telling the nation to stay at home
Scottish blow to NHS contact tracing app
Furlough could be cut back as costs soar

THE Sun
30p
Wednesday, May 6, 2020
THE PEOPLE'S PAPER
WIN! BUMPER TECH BUNDLE
SHOWBIZ EXCLUSIVE
COWELL'S MEL HELL
LAUREN'S FURY: SEE PAGE 13
BORIS BOFFIN & MARRIED BLONDE
Prof Lockdown broke lockdown to get his trousers down

Report 9, IBMIC and CovidSim

- Report 9 results were created using IBMIC (Individual Based Model from Imperial College London), an agent based model.
- The original code for Report 9 has not been released.
- CovidSim was developed by a team at Imperial College London led by Neil Ferguson with industry collaborators to recreate the model in Report 9.
- Unlike Report 9, CovidSim has been externally validated.
- Both IBMIC and CovidSim are derived from an agent based model developed to model influenza pandemic, published by Neil Ferguson in 2005.

Agent Based Models (ABM)

- A microscale model that allow us to monitor the state of agents (individuals) and their interaction with each other.
- Agents make their own decision.
- Unlike compartmental models, we do not have to assume all agents have an equal probability to meet each other.
- Allows us to simulate real world locations.
- Each agent can have their own set of characteristics and behaviour.
- Additional behavioural rules and characteristics can be added without too much trouble.

CovidSim

- Divide any region into *cells*, each cell consists of 81 (9x9) *microcells*.
- Individuals have characteristics such as age.
- People are allocated based on population density data.
- Once an individual is assigned a residence, we assume he does not move.
- Individuals interact with each other in other cells defined as places and through random social interactions.

CovidSim

- Individuals are assigned to *places* such as households, office, school etc. that have a precise location.
- Within a place, individuals form *place groups*, e.g., departments, workers on the same floor and classmates.
- Individuals do not move between cells, instead, spatial mixing probability distributions are used to evaluate the probability a person in cell X interacts with a person from cell Y.

CovidSim

- Initial seed could be implemented randomly or assigned by the user.
- Transmission is done by sweeping over all contacts and calculating *FOI*, Force Of Infection. There are 3 transmission mechanisms:
    1. Household infections (e.g. between family members)
    2. Place infections (e.g. at work)
    3. Spatial infections (e.g. when travelling around)
- Other parameters include compliance of individuals to policies, infection threshold before closure of places and many more.

Non-Pharmaceutical Intervention (NPI) Scenarios

Table 2 | Definition of interventions from Report 9 considered in CovidSim

Label	Policy	Description
CI	Case isolation in the home	Symptomatic cases stay at home for seven days, reducing non-household contacts by 75% for this period. Household contacts remain unchanged. Assume 70% of households comply with the policy
HQ	Voluntary home quarantine	Following identification of a symptomatic case in the household, all household members remain at home for 14 days. Household contact rates double during this quarantine period, contacts in the community reduce by 75%. Assume 50% of households comply with the policy
SDOL70	Social distancing of those over 70 years of age	Reduce contacts by 50% in workplaces, increase household contacts by 25%, and reduce other contacts by 75%. Assume 75% compliance with policy
SD	Social distancing of entire population	All households reduce contact outside household, school, or workplace by 75%. School contact rates unchanged, workplace contact rates reduced by 25%. Household contact rates assumed to increase by 25%
PC	Closure of schools and universities	Closure of all schools, 25% of universities remain open. Household contact rates for student families increased by 50% during closure. Contacts in the community increase by 25% during closure

Results: The Goal

- The objective of this paper is threefold:
  1. The reproduce the results from Report 9 (using covidSim)
  2. To analyze the effect of school closures on mortality from COVID-19
  3. To investigate a second wave using covidSim

Results: The Setup

- An average of 10 simulation runs with the same random number seeds are used.
- Each simulation is run for 800 days, with each simulated intervention period lasting for three months (91 days), with some interventions extending for an additional 30 days.
- Each NPI scenario is considered using reproduction numbers of $R_0 = 2.2$ and $R_0 = 2.4$.
- Each mitigation scenario is considered using a range of ICU triggers.

Results: Reproduction of Report 9

- The results obtained from covidSim are not precisely identical to Report 9 for a number of reasons:
  - The results are an average of 10 stochastic realizations.
  - The population dataset has changed
  - The algorithm used to assign individuals from households to other places (school, universities and workplaces) has been modified to be deterministic.

Results: ICU Demand for Different NPI Scenarios

Table 1 | Peak demand for UK-wide intensive care unit beds (in 000s) for different intervention scenarios and different intensive care unit (ICU) triggers during the coronavirus disease 2019 epidemic

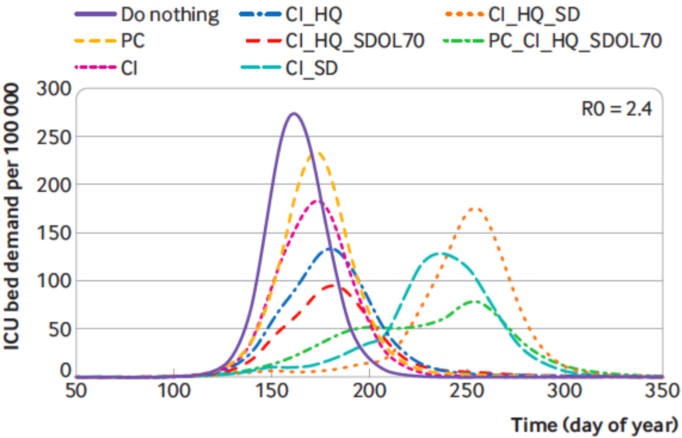
Trigger*	Time	PC	CI	CI_HQ	CI_HQ_SD	CI_SD	CI_HQ_SDOL70	PC_CI_HQ_SDOL70
0.1	1st wave	152	119	87	8†	20	62	33
0.1	Total	152	119	87	115	84	62	51†
0.3	1st wave	153	119	87	10†	22	62	34
0.3	Total	153	119	87	115	73	62	48†
1	1st wave	154	119	87	11†	22	62	35
1	Total	154	119	87	104	59	62	37†
3	1st wave	159	119	87	13†	22	62	37
3	Total	159	119	87	82	40	62	37†

CI=case isolation (home isolation of suspect cases), HQ=household quarantine of family members; SD=general social distancing; SDOL70=social distancing of over 70s; PC=place closures, specifically schools and universities.

*For each trigger value of cumulative intensive care unit (ICU) cases (in 000s), the peak demand for ICU beds, and the peak during the first wave when the interventions were in place are shown.

†Optimal strategy for minimising peak demand.

Results: ICU Demand for Different NPI Scenarios



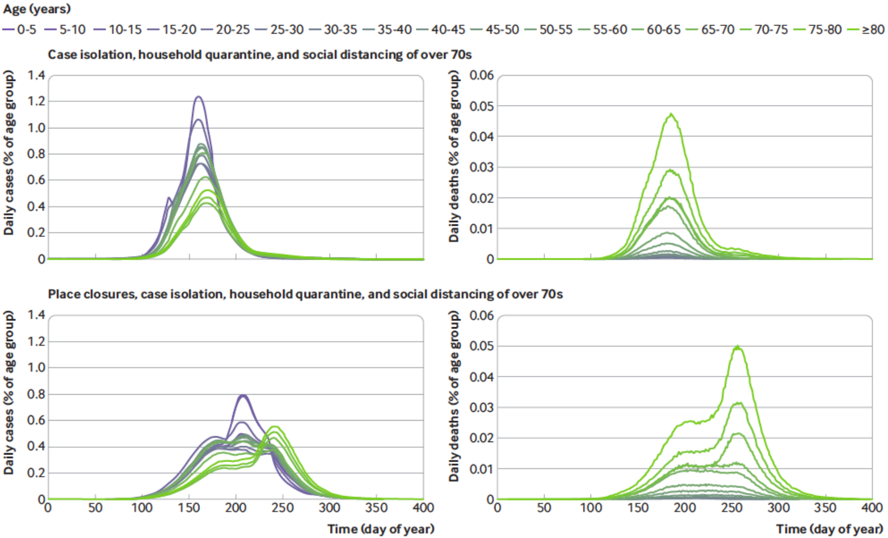
Results: Total Number of Deaths for Different NPI Scenarios

Table 3 | Predicted total number of UK-wide deaths (in 000s) from coronavirus disease 2019 for different intervention scenarios and different triggers for the interventions based on ICU admissions during the coronavirus disease 2019 epidemic

Trigger*	Time	PC	CI	CI_HQ	CI_HQ_SD	CI_SD	CI_HQ_SDOL70	PC_CI_HQ_SDOL70
0.1	1st wave	418	354	252	21†	39	177	75
0.1	Total	496	416	355	440	402	262†	357
0.3	1st wave	456	378	281	32†	58	200	104
0.3	Total	495	416	355	437	390	261†	356
1	1st wave	479	398	310	48†	86	223	139
1	Total	494	416	355	428	370	261†	351
3	1st wave	490	407	325	70†	114	237	172
3	Total	495	416	355	411	347	262†	342

PC=place closures; CI=case isolation; HQ=household quarantine; SD=social distancing; SDOL70=social distancing of over 70s only.
*For each trigger value of cumulative ICU cases (000s), the total deaths across the full simulation and during the first wave are shown.
†Optimal strategies for minimising short term and long term deaths.

Results: Understanding the Effects of School Closures



A Second Wave in CovidSim: The Setup

- The NPI considered for the second wave analysis were the actual policy implementations enacted by the British Government on March 23rd, which include:
  - Place closures (PC), case isolation (CI), household quarantine (HQ) and general social distancing (SD)
- Each intervention begins in late March (day 83) and lasts for three months (91 days).
- The simulation is initialized such that roughly 15,600 deaths occur by day 100 in all of the scenarios.
- For best fit purposes, a wide range of reproduction numbers, R_0, are considered ranging from 2.5 and 4.0.

A Second Wave in CovidSim: Results

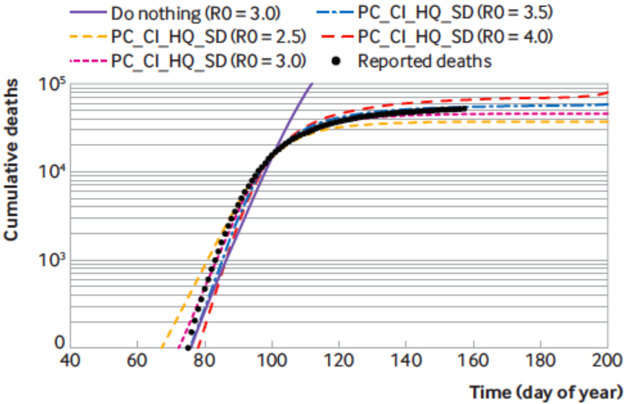


Figure: Refit of the IBMIC March parameterisation based on death data through to June. The black dots denote the cumulative deaths in the first wave, using data from National Records of Scotland11 and Connors and Fordham.

A Second Wave in CovidSim: Results

- Following the first wave, only 5-10% immunity throughout the general population is achieved. As a result, once restrictions are lifted and the second wave arrives, it has many similarities as the first wave from an epidemiological standpoint. However, the death rate is slightly lower.

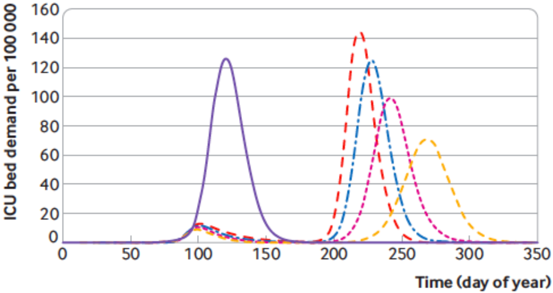


Figure: ICU Bed Demand per 100,000 People During the Second Wave

Discussion

- CovidSim models the geography of all towns, but only the simulated people are representative of the true population. This uncertainty means that the model cannot reliably predict which town will experience an outbreak. Specifically, whereas the timing of the national outbreak is uncertain by days, the timing of an outbreak in a town is uncertain by months.
- The stochasticity gives a variance of around 5% in total number of deaths and ICU bed demand between different realisations. More important is the uncertainty of the timing of the peak of the infections between realisations, which is around five days. These predictions were compared to the actual death rates from COVID-19.

References

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