Modelling COVID-19 – what have we learned?

Matt Fletcher, Matthew Edwards, Louis Rossouw, Stuart McDonald

26 November 2020
Structure of today’s presentation

• **Data**, *Matt Fletcher*

• **Model parameters**, *Matthew Edwards*

• **International perspectives**, *Louis Rossouw*

• **Communicating model results**, *Stuart McDonald*

• **Discussion**

*Future sessions with other speakers are planned on other aspects of the pandemic*
COVID-19 data – what have we learned?

Matt Fletcher
COVID-19 simplified lifecycle

Healthy → Infection → Hospitalisation → Death

Recovery
Infections and cases

- **Infection**: an individual who is or has been infected with SARS-CoV-2
- **Case**: an individual who is infected **and has received a positive test**
- Cases in many countries are much higher than in the first wave – but there is much more testing.
  - UK – initially the only tests were in hospital

Source: gov.uk
Infections and cases

• The proportions infected can be estimated in various ways
  • Surveillance testing – estimates proportion currently infected
  • Serology testing – estimates proportion ever infected
  • Community testing – estimates proportion infected of those requesting a test

• Considerations
  • Date of test vs date of report
  • Single vs multiple tests
  • False positives and negatives
  • Biases in the tested population

Source: ONS COVID-19 Infection Survey
Hospitalisations

• Individuals will typically be tested for infection on admission
• Was the hospitalisation “with” or “because of” COVID-19?
• What level of care are the individuals receiving?
• What are the admission criteria?

Source: gov.uk
Deaths

• What exactly does a “COVID-19 death” mean?
  • Location (hospital, care home)
  • Positive test needed? (cases vs infections)
  • Time after positive test?

• Other considerations
  • Date recorded vs date of occurrence
    • Recording protocols
    • Weekend / bank holiday effects

Deaths within 28 days of positive test

Source: gov.uk
Excess Deaths in England & Wales

Week by week deaths
England & Wales 2015-2020

Week by week standardised death rates
England & Wales 2015-2020

Source: ONS data
Standardised using CMI approach
Google Average Mobility

Canada

South Africa

https://www.google.com/covid19/mobility/
Model parameters – what have we learned?

Matthew Edwards
Infection Fatality Rate
Risk of death among all infected individuals including asymptomatic / mild infections

- **Issues**
  - How many infected people?
  - How many deaths?
    - Outside hospitals
    - Inside hospitals (other causes?)
  - Time lag?

- **Cambridge MRC Biostatistics Unit**

- **New York study**

- **Imperial College UK – Report 34**

<table>
<thead>
<tr>
<th>Age band</th>
<th>Cambridge</th>
<th>New York</th>
<th>Imperial</th>
</tr>
</thead>
<tbody>
<tr>
<td>All ages</td>
<td>0.7%</td>
<td>1.4%</td>
<td>0.5-1.1%</td>
</tr>
<tr>
<td>45-64</td>
<td>0.3%</td>
<td>0.9%</td>
<td>0.2-0.9%</td>
</tr>
<tr>
<td>65-74</td>
<td>2.2%</td>
<td>4.9%</td>
<td>1.4-2.2%</td>
</tr>
<tr>
<td>75+</td>
<td>11%</td>
<td>14%</td>
<td>3.4-16%</td>
</tr>
</tbody>
</table>
Multi-factorial perspectives on risk factors

• Petrilli study of New York hospitalisation

- Diabetes: 2.8
- Male sex: 2.8
- Hypertension: [1.2]
- Obesity: 4.3
- Ethnicity: 1.4 (Asian) – 2.0 (other)
- Tobacco use: 0.7

• UK study of 130k cases with 28,246 deaths

- Ethnicity (BAME): 1.1-1.35
- Ethnicity (Indian/Chinese): 1.2-1.3
- Regional: 0.8-1.2


• Other studies looking more at medical history find morbidity risk factors of order of 1.2-1.5


Multi-factorial perspectives (2)

- OpenSafely study in UK covers whole healthy to death transition, by cross-indexing 17.3m EHRs with details of 11k COVID-19 deaths.

<table>
<thead>
<tr>
<th>Factor</th>
<th>Mortality Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Obesity</td>
<td>125-225% (per severity)</td>
</tr>
<tr>
<td>SE Class (IMD quintile)</td>
<td>Top quintile 80% of mid, Lowest quintile 140% of mid</td>
</tr>
<tr>
<td>Ethnicity</td>
<td>Asian, Black, Mixed – 160-170%</td>
</tr>
<tr>
<td>CHD, Cancer (1-5 yrs past)</td>
<td>120-130%</td>
</tr>
<tr>
<td>Diabetes</td>
<td>150-250% (per severity)</td>
</tr>
<tr>
<td>Hypertension</td>
<td>[No effect]</td>
</tr>
<tr>
<td>Smoking</td>
<td>[Mixed effects]</td>
</tr>
</tbody>
</table>

Socio-economic and ethnicity effects – other studies

**Morbidity**

*Socio-economic*
- Batty et al. (UK Biobank)  
  ‘High’ (RR=1.8), ‘Mid’ (RR=1.25)

**Ethnicity**
- Lassale et al. (UK Biobank)  
  Black (RR=2.7) / Asian (RR=1.4)
- Price-Haywood et al. (Louisiana)  
  Black (RR=2.0) vs White

**Mortality**

*Socio-economic*
- ICNARC (eg 26 June 2020 report,  
  7k patients)
  - No difference groups 1-4, circa 1.2  
    for 5th quintile (most deprived)

**Ethnicity**
- ICNARC study as above  
  - Asians circa 1.3, Black circa 1.1  
    (but CI includes 1.0)
Non-COVID-19 parameters?
Some international* perspectives

Louis Rossouw
Disclaimer

This is work in progress, and may be subject to significant change as new information becomes available.

[Comic strip]

**HI.**
HELLO. YOU LOOK... FINE.

I HAVE NOW READ VIRTUALLY EVERY AVAILABLE SCIENTIFIC PAPER ON COVID-19.
COOL, WHAT'D YOU LEARN?

WELL, IT SEEMS THIS VIRUS WANTS TO GET INSIDE YOUR CELLS.
MHMM...

BUT IT'S A TRAP! YOU SHOULDN'T LET IT!
I THINK WE KNEW THAT.
BUT NOW I KNOW IT WITH ERROR BARS!

https://xkcd.com/2281/
Different angles

As a South African

• Part of the Global South
• Lower Middle Income Country
• Economically Struggling
• Also advanced
  • Death registry
  • Great researchers
  • Data (but less than developed world)
• Keen to help!

Experience

• Actuarial Society of South Africa HIV/AIDS Committee
  • Actuarial involvement
  • Model building
• Analytics/modelling experience
• International exposure
  • South Africa
  • Canada
  • UK
  • Australia
Estimating R

• New infections generation function:
  \[ i_t = R_t \sum_{\tau=0}^{t-1} i_\tau g_{t-\tau} \]

• Infections today \( i_t \) is a function of
  • Reproductive number \( R_t \)
  • Infections in the past \( i_\tau \)
  • And how infectious those past cases are over time \( g_{t-\tau} \)

• Reverse that process to estimate \( R_{t,m} \)

• Can also use reported cases, admissions or deaths
  • Assumption that reporting is stable
  • Assuming hospitalisation rate is stable
  • Assuming IFR is stable
R around the world

Cases

Deaths
Select Countries

United_States_of_America

Canada

South_Africa

Kenya
Europe

- Germany
- Sweden
- Switzerland
- Poland
Modelling

• Bayesian Hierarchical Model to calibrate model parameters based on observed death data and prior assumptions.
  • Canada: Reported Deaths
  • South Africa: 90% of Excess Deaths (with uncertainty)
• Reproductive number is linked to mobility data as well as mask wearing laws
• Weekly AR(2) drift in reproduction number
  • Uncaptured behaviour or error term, probably both.
• Reproductive number generates infections
• Population weighted IFRs to model deaths from infections
• Single combined model for all provinces
  • shares information between provinces
  • province specific effects
• Produces updated parameter estimates based on priors and data

Models
• South Africa by Province
• Canada by Province
Reported COVID-19 Deaths

Ontario

British Columbia

Western Cape

Eastern Cape
Infections vs. Reported Cases

Ontario

British Columbia

Western Cape

Eastern Cape
Mobility & Mask Wearing

Impact of a 100% reduction in average mobility

Province
- Saskatchewan
- Quebec
- Ontario
- Maritime Provinces
- Manitoba
- British Columbia
- Alberta

Percentage reduction in R[t]

Impact of Mandatory Indoor Mask Wearing

Province
- Saskatchewan
- Quebec
- Ontario
- Maritime Provinces
- Manitoba
- British Columbia
- Alberta

Percentage reduction in R[t]

https://lrossouw.github.io/covid-19/modelling_covid-19_in_canada_at_a_provincial_level.html#7_Parameter_Estimates
## Projections*

### 24 November 2020

<table>
<thead>
<tr>
<th>Country</th>
<th>Attack Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Canada</td>
<td>3.8% [3.3%-4.5%]</td>
</tr>
<tr>
<td>South Africa</td>
<td>25.8% [18.9%-36.4%]</td>
</tr>
</tbody>
</table>

### 31 December 2020

<table>
<thead>
<tr>
<th>Projection</th>
<th>Attack Rate</th>
<th>Deaths</th>
</tr>
</thead>
<tbody>
<tr>
<td>Canada</td>
<td>11.5% [7.0%-19.2%]</td>
<td>18 394 [15 090-23 616]</td>
</tr>
<tr>
<td>Current Mobility</td>
<td></td>
<td></td>
</tr>
<tr>
<td>South Africa</td>
<td>35.8% [23.1%-52.8%]</td>
<td>89 088 [61 504-127 408]</td>
</tr>
<tr>
<td>Current Mobility</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Data limitations
* Simplistic models
* IFRs key parameter
  - Impacts if different
  - And is changing over time

* Taleb et al. (2020):
  - Tail Risk
  - Decision making in the face of uncertainty

* ‘All models are wrong, but some are useful’ - George Box

Lessons I’m learning as a professional

Technical
• Why model?
• New techniques
• Automation of processes
• Research
• Systemic Risk / EVT

Professional
• Public interest
• Passion
• Differing opinions
• Prudence & Uncertainty
Some of the best predictions remain relevant…

Duck tape your underpants.

2020 is going to be a wild ride.

#coronavirus #CoronavirusOutbreak

8:17 AM · Feb 1, 2020 · Twitter Web App

26 Retweets 20 Quote Tweets 218 Likes

https://twitter.com/andrewnoymer/status/1223490472473059328
Communicating Model Results

Stuart McDonald
“Our overall approach rests on the assumption that only a very small proportion of the population is at risk of hospitalisable illness. This proportion is itself only a fraction of the risk groups already well described in the literature, including the elderly and those carrying critical comorbidities (e.g. asthma).”
What Could Possibly Go Wrong?

**The Times**
Coronavirus deaths could be less than seasonal flu
Friday March 27 2020

**Evening Standard**
UK lockdown to cut coronavirus death toll by 254,000, experts say
Saturday 28 March 2020

**Mail Online**
Expert who predicted just 5,700 may die from coronavirus in the UK says he was wrong and Britain is in a 'dangerous state' as daily deaths surge past his estimated maximum number just TWO DAYS later
Sunday 29 March 2020
“They were old and had comorbidities”

Life expectancy of an obese male smoker with example medical conditions.

By age 65 the majority of people have two or more comorbidities.
It can happen to the best of us!

“Risk is no higher than normal”
Scenarios vs Predictions

Vallance and Whitty’s Fishy Predictions Given a Grilling
Wednesday November 4 2020

DOESN'T ADD UP Sir Patrick - Vallance regrets terrifying Brits with doomsday 4,000 daily coronavirus deaths prediction
Tuesday 3 November 2020
A Timeline of COVID Denial

“It’s only the flu”

“They were at death’s door”

“It’s a casedemic”

“Back to normal by summer”

“Deaths caused by lockdown”

“It’s false positives”

“There’s no Excess Deaths”
Discussion – of these or related aspects ...

• Data, 
  Matt Fletcher

• Model parameters, 
  Matthew Edwards

• International perspectives, 
  Louis Rossouw

• Communicating model results, 
  Stuart McDonald