Seasonality of COVID-19

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Coming momentarily
At 12:30 p.m.
1. How much does your fear of Covid-19 affect your daily life?
   a. A lot
   b. Moderately
   c. Not at all

2. When do you believe the US will get Covid-19 under control?
   a. By the end of spring 2021
   b. By the end of 2021
   c. Later than 2021

3. Will major universities (like Princeton) mostly return to traditional forms of teaching post-Covid or do you expect the teaching to change fundamentally?
   a. Return
   b. Change
1. Health crisis
   - Behavioral response (social distancing) matters
     - Fear/anxiety or externality

2. Economic crisis
   - Record unemployment, GDP drop, ...
   - K-recession (winner and losers)

3. Financial crisis
   - Record stock market levels, IPO issuance of stocks (SPACs) and bonds, ...
   - Financial market disconnect?
   - The illusory health-wealth tradeoff and long-run congruence
     - Lockdown vs. shutdown
     - Social distancing -> lower GDP now, but higher GDP in the long-run

Special purpose acquisition companies
Health crisis is the driver!
  - Aerosols, UV light

Weather, seasonal patterns

Questions:
  - Should the stringency of COVID measures depend on sunshine/humidity/temperature (on that day)?
  - Should we equip our AC units with UV lights?

X Niels Finsen
(Nobel Prize in medicine, 1903)
Thank you!

markus@princeton.edu
Seasonality of Covid-19 - why it matters

Marcus’ Academy, Princeton

October 22, 2020

Bengt Holmström (MIT), Martti Hetemäki (Helsinki GSE), Juhana Hukkinen (Bank of Finland)
Two hypotheses

1. Covid-19 is seasonal
   Strong wave in the fall, weak (or no) wave in the spring
   Historical and current evidence

2. Seasonality is driven by UV
   Physical and empirical case for UV
   UV strong relative to other factors
Outline

Historical vs current patterns

The case for UV

Mobility and stringency

Regression results

Qualifications

Conclusion
Historical vs current patterns
Data from all corona tests in seven hospitals in Stockholm area in 2010-2019

Mortality rate (per 10 000) in 14 European countries from 1917 to 1921.

“Excess-death curves showed high synchrony in 1918–1919 with peak mortality occurring in all countries during a 2-month window (Oct–Nov 1918).”


New Covid-19 cases, 14 day sum of new Covid-19 cases per 100 000 persons March 1 – 20, October 2020
New Covid-19 cases, 14 day sum of new Covid-19 cases per 100 000 persons 1 March 2020 – 20 October 2020

Source: European Centre for Disease Prevention & Control.
The case for UV
UV load (left scale) and new Covid-19 cases (right scale) in France, March 1 – 17 October 2020

New Covid-19 cases in France and South Africa March 1 – 20, October 2020

Source: European Centre for Disease Prevention & Control.
UV load in South Africa and France August 2019 – October 2020

Source: NASA, Goddard Space Flight Center.
New Covid-19 cases in France, South Africa and Australia March 1 – 20 October, 2020

France
South Africa
Australia

Source: European Centre for Disease Prevention & Control.
Mobility and Stringency
New Covid-19 cases in Finland, Germany, France and Sweden March 1 – October 20, 2020

Source: European Centre for Disease Prevention & Control, Google.
Mobility (Retail & Recreation, left scale) and new Covid-19 cases (right scale) 1 March 2020 – 20 October 2020

Source: European Centre for Disease Prevention & Control, Google.
Policy stringency (left scale) and new Covid-19 cases 1 March 2020 – 20 October 2020 (right scale)

Source: European Centre for Disease Prevention & Control, University of Oxford.
Regression
Model for new Covid-19 cases

Low immunity → exponential case growth
UV drives seasonality
Policy to control Covid-19
Mobility

\[ \log C = \eta + \mu t + \vartheta \log UV + \omega \log P + \phi \log M \]

C=14 day sum of new Covid-19 cases/100 000 persons (ECDC data)
t=time trend
UV=14 day sum of UV radiation load (country satellite data)
P=Policy stringency index, relative to pre-Covid time (Oxford University data)
F=Mobility, % deviation from pre-Covid-19 time at the start of 2020 (Google and Apple data)
New Covid-19 cases equation with a lag structure and alternative additional explanatory variables

France

<table>
<thead>
<tr>
<th>Dependent Variable:</th>
<th>∆logC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Coefficient</td>
</tr>
<tr>
<td>Constant</td>
<td>0,73290</td>
</tr>
<tr>
<td>Trend</td>
<td>0,00060</td>
</tr>
<tr>
<td>logC 1 day lag</td>
<td>-0,04520</td>
</tr>
<tr>
<td>logUV 3 week lag</td>
<td>-0,16623</td>
</tr>
<tr>
<td>logUV difference 3 week</td>
<td>-0,03428</td>
</tr>
<tr>
<td>logUV deviation of long run level</td>
<td>-0,17247</td>
</tr>
</tbody>
</table>

| logStringency 3 week lag | -0,06619 | -2,81220 |
| logTransit mobility 3 week lag | 0,01883 | 1,52490 |

| R-squared | 0,48612 | 0,50119 | 0,51937 | 0,50668 |
| F-statistic | 49,89979 | 42,19993 | 37,64158 | 35,77611 |
| Durbin-Watson stat | 1,90173 | 1,96275 | 2,06519 | 1,99389 |
| LM(2) # | 3,78586 | 1,99549 | 1,34634 | 1,81105 |
| LM / Prob. Chi-Square(2) # | 0,15060 | 0,36870 | 0,51010 | 0,40430 |

# Breusch-Godfrey Serial Correlation LM Test.

Sample: 3/04/2020 10/05/2020
Included observations: 216

Long-run elasticity of new Covid-19 cases;
Underlying growth rate, % / day 1,32 1,12 0,97 0,89
Elasticity w.r.t. UV -3,68 -3,43 -3,22 -3,27
Median lag from UV 35,98 35,37 43,94 37,64
Long-run elasticity of new Covid-19 cases w.r.t. UV

New Covid-19 cases equation with alternative additional explanatory variables

<table>
<thead>
<tr>
<th>Country</th>
<th>Model 1</th>
<th>Model 2</th>
<th>Model 3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>= Model 1 + policy</td>
<td>= Model 1 + mobility</td>
</tr>
<tr>
<td>France</td>
<td>-3.43</td>
<td>-3.22</td>
<td>-3.27</td>
</tr>
<tr>
<td>Germany</td>
<td>-3.13</td>
<td>-2.60</td>
<td>-2.84</td>
</tr>
<tr>
<td>Finland</td>
<td>-2.99</td>
<td>-2.74</td>
<td>-3.77</td>
</tr>
</tbody>
</table>
"Natural experiment" - Sweden versus Finland

Differences in transit mobility deviations from pre-Covid-19 time and in new Covid-19 cases between Sweden and Finland

Mobility deviation in Sweden—Mobility deviation in Finland, (left scale), %-points

New cases in Sweden—New cases in Finland, (right scale), cases per 100,000

Source: Apple (mobility), EDCD (new Covid-19 cases)
$\Delta(\log C^S - \log C^F) = 0.015 - 0.028(\log C^S - \log C^F)(-1) + 0.277(\log M^S - \log M^F)(-42) - 0.203(\log UV^S - \log UV^F)(-21)$

Differences in transit mobility deviations from pre-Covid-19 time and in new Covid-19 cases between Sweden and Finland.

**Source:** Apple (mobility), EDCD (new Covid-19 cases)
Qualifications
Conclusions still tentative - but risks are high

• UV effects may come through other factors (behavioral patterns)

• Endogeneity and collinearity problems (possible instrument: UV affected by altitude – but also infections)

• We haven’t seen full cycle yet (US may still fall in line)

• Increase in testing affects case count and positivity rate
Test Done (left scale) and new Covid-19 cases (right scale) in France, March 1 – 20 October 2020

Positivity Rate (left scale) and new Covid-19 cases (right scale) in France, March 1 – 20 October 2020

Source: European Centre for Disease Prevention & Control, French National Institute of Statistics & Economic Studies (INSEE), Google.
Conclusions
Main takeaways

• Asymmetric waves:
  • Virus has tail-winds in the fall – the next months may be very severe
  • Virus has head-winds in the spring – we’ll get a rest over the summer

• Seasonality important for:
  • Proactive policy
  • Correct modeling
THANKS!
APPENDICES
Annexes

Annex B: Data
Annex C: Possible reasons for large effects of mobility and UV on spread of Covid-19
Annex D: Challenges in modelling Covid-19
Annex E: Estimation results with robustness analysis

Assumption 1: New Covid-19 cases per capita (or per 100 000), \( C \), depend positively on the initial exponential growth rate of the epidemic, \( \mu \), and negatively on UV radiation load, \( UV \), policy, \( P \), and behavioral (fear), \( F \), variables and population Covid-19 immunity rate, \( I \).

\[
c = f(\mu, uv, p, f, I)
\]

(1) where \( c = \log C \), \( uv = \log UV \), \( p = \log P \), \( f = \log F \).

Annex C reports evidence that population Covid-19 immunity rate has stayed so low (e.g. 0.3% in Finland) that \( I = 0 \) is a reasonable approximation.

Assumption 2: Covid-19 deaths per capita depend positively on \( C \) and negatively on \( UV \), \( P \) and \( F \).

\[
d = g(c, uv, p, f), \text{ where } d = \log D.
\]

(2) Assumption 3: Control and behavioral variables do not have statistically significant additional explanatory power in equations (1) and (2).

Assumption 3 was not made a priori, but empirical results provided partial support for it. This does not mean that, say, mobility does not affect spread of Covid-19. Rather, it indicates that it difficult to infer the effect of mobility on Covid-19 from equations (1) and (2). An apparent interpretation to this finding is that \( \mu \) and \( UV \) explain, via their effects on Covid-19 cases and deaths, also the policy and behavioral reactions. This leads to the following empirically testable assumption.

Assumption 4: The responses of control and behavioral variables, \( M \), to Covid-19 cases and deaths are determined by \( \mu \) and \( UV \) so that one can write

\[
p = p(\mu, uv), \quad f = h(\mu, uv).
\]

(3)
Substituting first (3) into (1), and taking into account that I=0 in (1), and substituting c from this into (2), one can write

\[ d = j(\mu, uv). \]

The model leads into a testable hypothesis that the deviation of the economy from its pre Covid-19 path is determined, other things being equal, by \( \mu \) and UV, which are exogeneous and reliably forecastable variables where \( \mu \) is, in fact, a constant as long as \( I=0 \).

Relaxing assumption 4 that responses of control and behavioral variables to cases and deaths are determined by \( \mu \) and UV, one can write

\[ c = k(\mu, uv, p, f). \]

\[ d = l(\mu, uv, p, f). \]

Assuming that \( P \) and \( F \) can be measured jointly with mobility \( M \), and denoting \( m = \log M \), one can write

\[ c = k(\mu, uv, m). \]

\[ d = l(\mu, uv, m). \]

(7) and (8) are used to estimate the empirical country difference equation in the presentation. Note that assuming the same underlying growth rates \( \mu \) in two countries, A and B, conditional on UV and its causes in terms of policy and behavior reactions, \( \mu \) cancels out in the difference Equations. One can then write the equations for Covid-19 cases and deaths as (9) and (10), which are used to estimate Sweden-Finland equations.

\[ (c^A - c^B) = m((m^A - m^B), (uv^A - uv^B)) \]

\[ (d^A - d^B) = n((m^A - m^B), (uv^A - uv^B)). \]
Annex B: Data

This annex lists the data sources and it provides graphs of the variables used in estimation. From the graphs on Covid-19 deaths, it is apparent that there are irregularities in that data in the case of Spain. Assuming that these irregularities are due to reporting lags and corrections made afterwards but that the total cumulative number of deaths is measured correctly, a mechanical smoothing was applied by, in case of a negative death observation that negative observation was evenly distributed to 30 previous days and similar smoothing was applied for a very large positive observations. For Italy’s Covid-19 cases equation, 14 days moving averages, instead of 14 days cumulative numbers, were used.

Data source: Covid-19 cases and deaths
All the data on Covid-19 cases and deaths used in the empirical analysis are from European Centre for Disease Prevention and Control (ECDC).

Data sources: UV load
The UV load is measured as Erythemal Daily Dose (J/m^2) or EDDose
The UV data used in the estimation was obtained from following national data sources:
Finland: https://avdc.gsfc.nasa.gov/pub/data/satellite/Aura/OMI/V03/L2OVP/OMUVB/aura_omi_l2ovp_omuvb_v03_helsinki.kumpula.txt
Sweden https://avdc.gsfc.nasa.gov/pub/data/satellite/Aura/OMI/V03/L2OVP/OMUVB/aura_omi_l2ovp_omuvb_v03_norrkeping.txt
https://avdc.gsfc.nasa.gov/pub/data/satellite/Aura/OMI/V03/L2OVP/OMUVB/aura_omi_l2ovp_omuvb_v03_vindeln.txt
Germany https://avdc.gsfc.nasa.gov/pub/data/satellite/Aura/OMI/V03/L2OVP/OMUVB/aura_omi_l2ovp_omuvb_v03_offenbach.txt
France https://avdc.gsfc.nasa.gov/pub/data/satellite/Aura/OMI/V03/L2OVP/OMUVB/aura_omi_l2ovp_omuvb_v03_palaiseau.txt
Italy https://avdc.gsfc.nasa.gov/pub/data/satellite/Aura/OMI/V03/L2OVP/OMUVB/aura_omi_l2ovp_omuvb_v03_ispra.txt
Spain https://avdc.gsfc.nasa.gov/pub/data/satellite/Aura/OMI/V03/L2OVP/OMUVB/aura_omi_l2ovp_omuvb_v03_el.arenosillo.txt
The authors thank experts at the Finnish Meteorological Institute for advice and help with satellite data.

Data source: Mask wearing (This data was not used to estimate the equations of Annex B. Next slide shows the limited variability in that data.)
Variables used in Covid-19 cases and deaths equations

Definitions of variables used in estimating the regression equations:

$logC = \log(14 \text{ days cumulative number of Covid-19 cases}/100\,000\,\text{persons})$

$logD = \log(14 \text{ days cumulative number of Covid-19 deaths}/100\,000\,\text{persons})$

$logUV14 = \log(14 \text{ days cumulative sum of UV radiation load})$.

$logUV28S$ and $logUV35S$ are the corresponding 28 and 35 days sums, respectively.

$logWork\,mobility = \log(14 \text{ days moving average of Google work-related mobility variable})$.

This and other publicly available Google mobility variables are percentage differences from the beginning of year reference period. Hence, if, e.g., mobility was 75% below the reference period level, the variable would have a value of -75. In this case, the corresponding variable would be reported as 25, i.e. the percent level from reference period.

In the empirical application, the Google variables were used in a similar way as the Apple variables are reported. This obtained by adding 100 to reported Google mobility variables.

$logRec.\,mobility\,Google = \log(14 \text{ days moving average of Google recreation-related mobility variable})$.

$logTransit\,mobility\,Apple = \log(14 \text{ days moving average of Apple transit mobility variable})$.

$logStringency = \log(\text{policy stringency index, relative to pre-Covid time})$ (Oxford University data)

$T = \text{Time trend}$.
UV radiation estimated by satellites

Background

- Local private Davis Enviromonitor weather station in Palojoki Finland [https://www.davisinstruments.com/enviromonitor/]
- Dutch-Finnish built Ozone Monitoring Instrument (OMI) on-board Nasa’s EOS-Aura satellite was launched in 2004. It provides global and nearly daily UV radiation estimates. UV radiation products are developed by the Finnish Meteorological Institute.

Satellite UV algorithm

- The UV radiation that reaches the Earth surface depends on atmospheric ozone, aerosols, clouds and surface reflection. Satellite measures ozone and clouds in the atmosphere. The UV radiation is estimated using radiative transfer modeling and climatology for aerosols and surface reflection.
- Global data are available via [https://avdc.gsfc.nasa.gov/pub/data/satellite/Aura/OMI/V03/L2OVP/OMUVB/](https://avdc.gsfc.nasa.gov/pub/data/satellite/Aura/OMI/V03/L2OVP/OMUVB/)
Mask wearing, %

Annex C: Possible reasons for large effects of mobility and UV on the spread of Covid-19

This annex provides short explanations of possible reasons why mobility and UV may have large effects on spread of Covid-19.

Why leisure & work mobility may have large effects on spread of Covid?

The basic reproduction number \( R_0 = \beta \gamma \), where \( \beta = \text{average infection}-\text{producing contacts per unit time} \) and \( \gamma = \text{mean infectious period} \). Assume:
- Leisure- and work-related mobility involve contacts with other people.
- Under normal conditions \( R_0 = 2.5 \), i.e. one infected infects 2.5 others.
- An infected person infects for 5 days while she is asymptomatic.
- After 5 days she gets symptoms, quarantines and stops infecting others.
- Reduce \( R_0 \) by 50% (\( R_0 = 1.25 \)) or by 75% (\( R_0 = 0.625 \)).

Consider one infected person. The total number of people that would become infected in 30 days = \( 1 + R_0 + R_0^2 + R_0^3 + R_0^4 + R_0^5 + R_0^6 \), i.e.

\[
\text{Infected people at 30 days} = \sum_{n=0}^{6} R_0^n
\]

One caveat is that when \( R_0 < 1 \), the number of cases will actually decline over time and eventually go to zero. This is because an infected person cannot infect 0.625 people, it is either zero, one or more. When it is zero, transmission chain ends. Exact calculation of the 75% reduction thus requires more complex probability calculations.

The text and graph are based on “Coronavirus Calculations & Infographic” by Robert A.J. Signer, Ph.D., Assistant Professor of Medicine, University of California San Diego. [https://robertsigner.wordpress.com/coronavirus/]
Why UV radiation may have large effects on spread of Covid-19?

- In, e.g., Europe and the US, annual corona virus and influenza cycles are closely aligned with the strong UV cycle (following four slides).

Ultraviolet light is usually divided into three groups by radiation wavelengths:

1. Ultraviolet A or UVA that has wavelength of 320-400 nanometers (nm). UVA from sun reaches earth’s surface.
2. Ultraviolet B or UVB has wavelength of 280–320 nm
3. Ultraviolet C or UVC that has wavelength of 200–280 nm. UVC from sun does not reach, or reaches to a limited extent, earth’s surface.

UVC’s germicidal effectiveness peak wavelength is 260–265 nm, which is equivalent to the peak of ultraviolet radiation absorption of nucleic acids. Since UVA radiation is insufficiently absorbed by viral nucleic acid, UVA is not considered germicidal. However, in a recent article, Rezaie et al (2020)* report results that UVA effectively reduces bacteria and viruses including coronavirus. Rezaie et al (2020) note that:

- "Our study has several limitations. While multiple daily short-term UVA treatments did not harm human cells and appeared safe in vivo, longer term use may require further study. We assessed UVA against several microbes, but more studies are needed to address additional pathogens, including multi-drug resistant organisms, mycobacteria, and archaea. We did not evaluate UVA against SARS-CoV-2 specifically. However, given the efficacy of UVA against coxsackievirus and CoV-229 (both positive sense, single-stranded RNA viruses), SARS-CoV-2 is likely also UVA-sensitive."

In a recent article, Ratnesar-Shumate et al (2020)** find that simulated sunlight rapidly inactivates SARS-CoV-2 on surfaces. They note that:

- "Simulated sunlight rapidly inactivated SARS-CoV-2 suspended in either simulated saliva or culture media and dried on stainless steel coupons. Ninety percent of infectious virus was inactivated every 6.8 minutes in simulated saliva and every 14.3 minutes in culture media when exposed to simulated sunlight representative of the summer solstice at 40°N latitude at sea level on a clear day. Significant inactivation also occurred, albeit at a slower rate, under lower simulated sunlight levels. The present study provides the first evidence that sunlight may rapidly inactivate SARS-CoV-2 on surfaces, suggesting that persistence, and subsequently exposure risk, may vary significantly between indoor and outdoor environments."

Merrow and Urban (2020)*** note also the possible immune resistance enhancing effect of UV:

- "Ultraviolet (UV) light effectively inactivates many viruses (19), especially larger coronaviruses (24) like SARS-CoV-1 (25). Sunny days might decrease outdoor transmission or promote immune resistance via vitamin D production (26)."


https://www.pnas.org/content/early/2020/10/14/2008590117
Daily satellite data of UV load, 14 day moving average

Influenza-like illness (ILI) by WHO Influenza virus activity peaks at similar times at similar latitude, e.g. during winter and early spring in the northern hemisphere.

Heat maps of global monthly activity of seasonal coronaviruses (sCoVs), influenza virus (IFV), and respiratory syncytial virus (RSV). Each square indicates share of virus cases are observed in a month. AAP=annual average % as the strength of virus.


Next slide shows the seasonality of positive corona test results in the four census regions

Source: Tang et al (2020)
For simplicity, consider only peak UV

At peak UV, rate of positive corona test results close to zero %

Source: Tang et al (2020)
Annex D: Challenges in modelling Covid-19

Empirical modelling of Covid-19 includes following challenges:
- The epidemic is still at a relatively early stage. In Europe, the epidemic started more generally in March 2020.
- There seems to be already a strong seasonal component because the epidemic slowed abruptly in Spring.
- That slowdown, in spite of simultaneous easing of control measures and low immunity rate, supports strong seasonality.
- In practice, all control and behavioral variables, to explain Covid-19 cases or deaths, are endogenous to those variables.
- Moreover, instrumental variable estimation is hard when potential instruments seem to be endogenous to cases or deaths.

In earlier research, following solutions have been applied due to lack of data and other difficulties:
- [https://science.sciencemag.org/content/early/2020/04/14/science.abb5793.full](https://science.sciencemag.org/content/early/2020/04/14/science.abb5793.full)
- Many studies use time varying and multiple parameter functional forms to fit models to Covid-19 data.

The drawbacks of these approaches include the following:
- Covid-19 seasonality remains a black box.
- When the drivers of seasonality are unknown, it is difficult to infer the true parameters of other drivers of Covid-19 epidemic.
- With time varying and increasing number of parameters, the models become less informative.
- These models may still be of use in forecasting, but they may not help one to understand the epidemic.

To overcome these drawbacks, this presentation:
- Uses previous research on corona and influenza seasonality to model seasonality explicitly.
- Takes into account that the Covid-19 epidemic does not seem to follow, say, a SIR-model given the very low immunity rate.
- Aims, based on previous research, at a as simple and parsimonious model as possible.
- Puts forward an empirically easily refutable hypothesis about the drivers of Covid-19.

Epidemiologist Marc Lipsitch*: “...at least three things that are affecting the growth rate or decline rate of the epidemic.”
1. “The first is control measures...” “...control measures are not just what the government says to do, but what people actually do...”
2. “The second is seasonal variation in terms of the suitability of environmental conditions for transmission.
3. “… the third is population level immunity.”

14 day cumulative Covid-19 cases/100 000 in Finland from March 2020 when Covid-19 cases/100 000 >1 to 9 October 2020

14 day cumulative Covid-19 cases/100 000 in France from March 2020 when Covid-19 cases/100 000 >1 to 9 October 2020

14 day cumulative Covid-19 cases/100 000 in Germany from March 2020 when Covid-19 cases/100 000 >1 to 9 October 2020

The above figure in log-scale

Source: ECDC
Weekly report of serological population study of Covid-19 in Finland based on random samples

<table>
<thead>
<tr>
<th>Sample week</th>
<th>Tested samples</th>
<th>Positive tests</th>
<th>Share with positive tests</th>
<th>Samples which belong to an MNT test set</th>
<th>MNT-tested samples</th>
<th>MNT-positive samples</th>
<th>Share of MNT positive samples</th>
</tr>
</thead>
<tbody>
<tr>
<td>2020-W16</td>
<td>362</td>
<td>9</td>
<td>2.49% (1.31–4.66)</td>
<td>362</td>
<td>9</td>
<td>1</td>
<td>0.28% (0.05–1.55)</td>
</tr>
<tr>
<td>2020-W17</td>
<td>674</td>
<td>17</td>
<td>2.52% (1.58–4)</td>
<td>674</td>
<td>17</td>
<td>2</td>
<td>0.3% (0.08–1.08)</td>
</tr>
<tr>
<td>2020-W18</td>
<td>426</td>
<td>12</td>
<td>2.82% (1.62–4.86)</td>
<td>426</td>
<td>12</td>
<td>2</td>
<td>0.47% (0.13–1.7)</td>
</tr>
<tr>
<td>2020-W19</td>
<td>514</td>
<td>8</td>
<td>1.56% (0.79–3.04)</td>
<td>514</td>
<td>8</td>
<td>0</td>
<td>0% (0–0.74)</td>
</tr>
<tr>
<td>2020-W20</td>
<td>401</td>
<td>4</td>
<td>1% (0.39–2.54)</td>
<td>401</td>
<td>4</td>
<td>1</td>
<td>0.25% (0.04–1.4)</td>
</tr>
<tr>
<td>2020-W21</td>
<td>210</td>
<td>9</td>
<td>4.29% (2.27–7.94)</td>
<td>210</td>
<td>9</td>
<td>1</td>
<td>0.48% (0.08–2.65)</td>
</tr>
<tr>
<td>2020-W22</td>
<td>178</td>
<td>5</td>
<td>2.81% (1.21–6.61)</td>
<td>178</td>
<td>5</td>
<td>0</td>
<td>0% (0–2.11)</td>
</tr>
<tr>
<td>2020-W23</td>
<td>214</td>
<td>8</td>
<td>3.74% (1.91–7.2)</td>
<td>214</td>
<td>8</td>
<td>1</td>
<td>0.47% (0.08–2.6)</td>
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<tr>
<td>2020-W24</td>
<td>174</td>
<td>5</td>
<td>2.87% (1.23–6.55)</td>
<td>174</td>
<td>5</td>
<td>0</td>
<td>0% (0–2.16)</td>
</tr>
<tr>
<td>2020-W25</td>
<td>78</td>
<td>0</td>
<td>0% (0–4.69)</td>
<td>78</td>
<td>0</td>
<td>0</td>
<td>0% (0–4.69)</td>
</tr>
<tr>
<td>2020-W26</td>
<td>32</td>
<td>0</td>
<td>0% (0–10.72)</td>
<td>32</td>
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**Share of positives:** 2.5 %  

**Tested samples:** Number of samples which have arrived at THL and for which an antibody test has been performed until the reporting day.  
**Samples with positive antibodies:** Number of tested samples with positive antibodies  
**Samples which belong to an MNT test set:** Number of samples which have been possible to consider in a microneutralisation test (MNT). The number of MNT positives should be compared to this number.  
**MNT tested samples:** Number of samples with positive antibody results for which a microneutralisation test was performed until the reporting date.  
**MNT positive samples:** Number of microneutralisation tested samples with a positive result.  


The Finnish Institute for Health and Welfare (THL) publishes regular results on a serological population study on its website. The main purpose of the study is to obtain up-to-date information on how large a proportion of the population among different age groups and regions have developed antibodies to coronavirus (seroprevalence).

The study is based on random sampling. The presence of antibodies is studied using two different tests developed at THL. First, a sensitive test is used to measure whether the sample contains antibodies identifying coronavirus SARS-CoV-2. Positive results are then verified with a microneutralisation test that measures the ability of antibodies to neutralise the virus, which provides a very reliable indication whether the sample contains antibodies that have formed specifically for the new coronavirus. Neutralizing antibodies can be considered the most reliable method to detect coronavirus infection, but only a few microneutralization (MNT) positive results have been observed.

Results reported by several countries on the proportion of antibody-positive samples (seroprevalence) vary greatly and are mostly based on the results of individual antibody tests where neutralizing antibodies have not been measured. There are differences between study samples and the performance of the tests used. Even with an accurate antibody test, the risk of false positives is significant when the actual number of infections in the population is low.

So far, samples have only been collected from people aged 18 to 69. Approximately 750 subjects are invited to participate in the study each week, but participation is spread across several calendar weeks. So far, around 60% of those invited have participated in the study.
Low population Covid-19 immunity

Epidemiological models assume typically that infections result in permanent or long lasting immunity. To take into account the decreasing effect of the increasing population immunity, typically a logistic model is fitted to explain the evolution of the epidemic. However, serological studies on Covid-19 suggest that seroprevalence has stayed low. For example, Stringhini et al (2020)* note (see also next slide):

“At what appears to be the tail end of the first wave of the pandemic in Switzerland, about one in ten people have developed detectable antibodies against SARS-CoV-2, despite the fact that it was one of the more heavily affected areas in Europe. Thus, assuming that the presence of the IgG antibodies measured in this study is, at least in the short term, associated with protection, these results highlight that the vast majority of the population is still immunologically naive to this new virus.”

The seroprevalence figures for France, Germany, Italy, Spain and Finland are even lower than in Switzerland. On July 13, the German authorities reported on a study that showed that only 1.3 % had antibodies in blood sample of 12 000 persons. https://www.reuters.com/article/us-health-coronavirus-germany-immunity-idUSKCN24E0X7 Also in the other four countries, low levels of antibodies have been detected. The results from a weekly random sample in Finland are presented in the previous slide. The possible explanations for the very low Covid-19 immunity rate in populations include that a) not all infected persons create antibodies and b) antibodies decrease relatively rapidly. According to recent study by Edridge et al (2020)**:

“Caution should be taken when relying on policies that require long-term immunity, such as vaccination or natural infection to reach herd immunity. Other studies have shown that neutralizing SARS-CoV-2 antibody levels decrease within the first 2 months after infection, especially after mild COVID-19\textsuperscript{14}, and we observed a similar decrease in anti-nucleocapsid antibodies of seasonal coronaviruses…” An exponential model is warranted as long as seroprevalence for Covid-19 continues to be very low.

https://www.thelancet.com/journals/lancet/article/PIIS0140-67362031304-0/fulltext

Empirical finding: higher altitude reduces Covid-19 growth rate (two recent studies)

Arias-Reyes et al (2020a)
- “... we analyze the epidemiologic data of COVID-19 of Tibet and high-altitude regions of Bolivia and Ecuador, and compare to lowland data, to test the hypothesis that high-altitude inhabitants (+2500 m above sea-level) are less susceptible to develop severe adverse effect in acute SARS-CoV-2 virus infection. ...Our epidemiological analysis of the Covid-19 pandemic clearly indicates a decrease of prevalence and impact of SARS-CoV-2 infection in populations living at altitude of above 3,000 masl. ... Although the data of the present study suggest a strongly decreased pathogenicity of SARS-CoV-2 in high-altitude, there is yet no evidence of an underlying physiological mechanisms that could affect to severity of infection.”
  https://www.researchgate.net/publication/340793665_Does_the_pathogenesis_of_SARS-CoV-2_virus_decrease_at_high-altitude

Arias-Reyes et al (2020b):
- “We have suggested previously that the infection rate of this virus might be lower in people living at high altitude (over 2,500 m) compared to that in the lowlands. Based on data from official sources, we performed a new epidemiological analysis of the development of the pandemic in 23 countries on the American continent as of May 23, 2020. Our results confirm our previous finding, further showing that the incidence of COVID-19 on the American continent decreases significantly starting at 1,000 m above sea level (masl).”
- “Finally, evaluating the differences in the recovery percentage of patients, the death-to-case ratio, and the theoretical fraction of undiagnosed cases, we found that the severity of COVID-19 is also decreased above 1,000 m. We conclude that the impact of the COVID-19 decreases significantly with altitude.”
  https://www.medrxiv.org/content/10.1101/2020.07.22.20160168v2

An apparent explanation for the finding is the effect of altitude on UV radiation load. According to the WHO:
- “... at higher altitudes, a thinner atmosphere filters less UV radiation. With every 1000 metres increase in altitude, UV levels increase by 10% to 12%.”
  https://www.who.int/uv/uv_and_health/en/

Consider Mexico City and Havana in Cuba. These cities are roughly in the same latitude. Havana is 50 meters and Mexico City is 2268 meters above sea level. During last 12 months, sum of daily UV radiation load has been 39 % higher in Mexico City compared to Havana (see next slide).
Evidence on 23 countries in the American continent: higher altitude reduces Covid-19 cases and the death-to-case ratio (annex C). Apparent reason, WHO: “... at higher altitudes, a thinner atmosphere filters less UV radiation. With every 1000 metres increase in altitude, UV levels increase by 10% to 12%.”
Annex E: Estimation results with robustness analysis

1. Robustness of Covid-19 model for France, Germany and Finland with respect to adding alternatively the policy stringency index variable or one of the Apple or Google mobility variables
   a) Using cases as dependent variable
   b) Using deaths as dependent variable

2. Robustness od Sweden-Finland difference model with respect to adding alternatively the policy stringency index variable or one of the Apple or Google mobility variables
   a) Using cases as dependent variable
   b) Using deaths as dependent variable
Covid-19 cases are assumed to depend on an exponential growth rate and UV radiation load. A log-linear functional form is assumed. The long run equation for Covid-19 cases is written as

\[ \log C = \eta + \mu t + \theta \log UV + \omega \log P + \xi \log M, \]

where \( C \) is the 14 day sum of new Covid-19 cases per 100,000 persons, \( t \) is time trend, \( UV \) is the load of UV radiation, \( P \) is the policy stringency index, and \( M \) is the mobility variable (either a work- or recreation-related mobility variable based on data provided publicly by Google or Apple).

In estimating the relation, a geometric lag distribution is assumed. Moreover, also initial lags from \( UV \) and \( M \) are allowed. If coefficients of \( P \) and \( M \) are not statistically significant at 5% level, they are left out and the estimation equation reduces to

\[ \Delta \log C = \alpha + (\lambda - 1) \log C_{t-1} + \delta t + \beta \log UV_{t-n} + u_t, \]

where \( u_t \) is an error term and \( \Delta \log C = \log C_t - \log C_{t-1} \).

The parameters of (1) are obtained as \( \mu = \delta / (1 - \lambda) \), \( \theta = \beta / (1 - \lambda) \), and \( \omega = \varphi (1 - \lambda) n \). \( n \) and \( p \) are the number of days due to, e.g., reporting lags. The median lag from UV to \( C \) is obtained as \( m_1 = n + (\log 0.5 / \log \lambda) \).

The long run relation of (1) exits only if \( \lambda < 1 \), i.e., only if the coefficient of \( \log C_{t-1} \) is significantly negative. Breusch-Godfrey test is used to test that residuals do not deviate from white noise.

In estimating (2), differences in \( \log UV \) where included as explanatory variables to reduce autocorrelation in the error term. In addition, UV deviation from its 2005-2019 average was included to reduce autocorrelation. This variable may capture effects of an omitted variable. An omitted variable can be the amount of UVC radiation. As the second slide in annex C notes, UVC’s germicidal effectiveness (virus destroying effectiveness) peak wavelength is 260–265 nm. Normally UVC from sun does not reach, or reaches to a limited extent, earth’s surface. When daily UV deviates from its long-term average, possible causes for that include weather conditions (e.g., clouds) and thickness of the ozone layer. The thinner the ozone layer is, the more UVC reaches earth’s surface and vice versa. If, e.g., the ozone layer is unusually thin, or if it has a hole, UV’s germicidal effect is likely be unusually large.
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^logUVdev.LRAv. = log(42 day moving sum of UV) - log(42 day moving sum of the daily average of UV in 2005-2019).

^^Breusch-Godfrey Serial Correlation LM Test.

Long-run elasticity of new Covid-19 cases

Underlying growth rate, % / day

Elasticity w.r.t. to UV

Median lag from UV

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### Germany

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^logUVdev.LRAVv. = log(42 day moving sum of UV) - log(42 day moving sum of the daily average of UV in 2005-2019).

^^ Breusch-Godfrey Serial Correlation LM Test.

Long-run elasticity of new Covid-19 cases

| Underlying growth rate, % / day | 0,79 | 0,63 | 0,61 | 0,14 | 0,34 |
| Elasticity w.r.t. to UV         | -3,50 | -3,13 | -2,60 | -2,51 | -2,84 |
| Median lag from UV              | 45,14 | 45,04 | 55,81 | 46,91 | 43,19 |

^logUVdev.LRAVv. = log(42 day moving sum of UV) - log(42 day moving sum of the daily average of UV in 2005-2019).
Finland

<table>
<thead>
<tr>
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<th>$\Delta \log C$</th>
<th>Coefficient</th>
<th>t-Statistic</th>
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Sample (adjusted): 3/10/2020 10/09/2020
Included observation: 214

$^\wedge$ $\Delta \log UV dev. LRAv. = \log(14\text{ day moving sum of } UV) - \log(14\text{ day moving sum of the daily average of } UV\text{ in 2005-2019}) - \log(14\text{ day moving sum of the daily average of } UV\text{ in 2005-2019}(-14))$.

$^{\wedge\wedge}$ Breusch-Godfrey Serial Correlation LM Test.

Long-run elasticity of new Covid-19 cases

| Underlying growth rate, % / day | 0.88 | 0.91 | 0.90 | 1.06 | 1.25 |
| Elasticity w.r.t. to UV        | -2.89 | -2.99 | -2.74 | -2.74 | -3.77 |
| Median lag from UV             | 38.48 | 39.47 | 32.78 | 33.55 | 51.04 |
### France

<table>
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<th>Dependent Variable:</th>
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<th>$\Delta \log D$</th>
<th>$\Delta \log D$</th>
<th>$\Delta \log D$</th>
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<td>183</td>
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</table>

^^Breusch-Godfrey Serial Correlation LM Test.

**Long-run elasticity of Covid-19 deaths**

- Underlying growth rate, % / day: 0.86, 0.25, 1.05, 1.95
- Elasticity w.r.t. to UV: -5.43, -3.98, -5.63, -6.67
- Median lag from UV: 62.17, 77.87, 60.80, 80.91
## Germany

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<th>Coefficient</th>
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<th>Coefficient</th>
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<td></td>
<td>-0,07047</td>
<td>-2,18239</td>
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</tbody>
</table>

- logStringency(-42) | 0,0417 | 1,25015 |
- logTransit mobility(-42) Apple | -0,05938 | -2,27440 |
- logRecreation mob.(-42) Google | -0,02367 | -0,78111 |

| R-squared | 0,59547 | 0,59864 | 0,60577 | 0,29757 |
| F-statistic | 73,23298 | 59,06467 | 60,84949 | 14,99639 |
| Durbin-Watson stat | 1,72775 | 1,71443 | 1,76045 | 1,63353 |
| LM(2)^^ | 1,45088 | 1,15653 | 1,52273 | 7,94453 |
| LM / Prob. Chi-Square(2) ^^ | 0,48410 | 0,56090 | 0,46700 | 0,01880 |

Included observation: 204 204 204 183

^^Breusch-Godfrey Serial Correlation LM Test.

Long-run elasticity of Covid-19 deaths
- Underlying growth rate, % / day: 0,22 0,24 0,73 1,30
- Elasticity w.r.t. to UV: -3,04 -3,21 -3,70 -5,08
- Median lag from UV: 55,92 53,94 54,99 69,16
Finland

<table>
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<th>$\Delta \log D$</th>
<th>$\Delta \log D$</th>
<th>$\Delta \log D$</th>
<th>$\Delta \log D$</th>
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<td>logRecreation mob.(-42) Google</td>
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$^\text{^\text{^\^}}} \Delta \log UV_{dev.LRAV.} = \log(14 \text{ day moving sum of UV}) - \log(14 \text{ day moving sum of the daily average of UV in 2005-2019}) - \log(14 \text{ day moving sum of UV(-14)}) - \log(14 \text{ day moving sum of the daily average of UV in 2005-2019(-14)})$.

$^{^\text{^\text{^\^}}} \text{Breusch-Godfrey Serial Correlation LM Test}$.

<table>
<thead>
<tr>
<th>Long-run elasticity of Covid-19 deaths</th>
</tr>
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<tbody>
<tr>
<td>Underlying growth rate, % / day</td>
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<tr>
<td>Elasticity w.r.t. to UV</td>
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<tr>
<td>Median lag from UV</td>
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^^Breusch-Godfrey Serial Correlation LM Test.
Including Covid-19 policy stringency indicator (Oxford) or other mobility variables in the Sweden-Finland new Covid-19 cases equation

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<th>ΔlogC Coefficient</th>
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<td>-0,02277</td>
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3/08/2020

Sample (adjusted): 10/08/2020
Included observation: 215

^Breusch-Godfrey Serial Correlation LM Test.

Long-run elasticity of new Covid-19 cases

<table>
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</tr>
<tr>
<td>Recreation Mobility (Google)</td>
<td>5.6</td>
</tr>
<tr>
<td>Work Mobility (Google)</td>
<td>5.2</td>
</tr>
<tr>
<td>Stringency</td>
<td>-1.8</td>
</tr>
<tr>
<td>Median lag, days</td>
<td>66</td>
</tr>
<tr>
<td></td>
<td>69</td>
</tr>
<tr>
<td></td>
<td>72</td>
</tr>
<tr>
<td></td>
<td>78</td>
</tr>
</tbody>
</table>
Including Covid-19 policy stringency indicator (Oxford) or other mobility variables in the Sweden-Finland new Covid-19 deaths equation

Sweden minus Finland

<table>
<thead>
<tr>
<th>Dependent Variable:</th>
<th>$\Delta \log D$</th>
<th>$\Delta \log D$</th>
<th>$\Delta \log D$</th>
<th>$\Delta \log D$</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Coefficient</td>
<td>t-Statistic</td>
<td>Coefficient</td>
<td>t-Statistic</td>
</tr>
<tr>
<td>Constant</td>
<td>0.04184</td>
<td>1.49421</td>
<td>0.03810</td>
<td>1.21132</td>
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<tr>
<td>logD(-1)</td>
<td>-0.08404</td>
<td>-3.40532</td>
<td>-0.06023</td>
<td>-1.90776</td>
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<tr>
<td>logUV(-21)</td>
<td>0.53280</td>
<td>2.89641</td>
<td>0.33580</td>
<td>1.39404</td>
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<tr>
<td>logTransit mobility(-63) Apple</td>
<td>0.83789</td>
<td>4.43932</td>
<td>1.40873</td>
<td>3.48733</td>
</tr>
<tr>
<td>logRecreation mob.(-63) Google</td>
<td>-0.08440</td>
<td>-1.68532</td>
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<tr>
<td>logWork mob.(-63) Google</td>
<td>0.34518</td>
<td>0.95206</td>
<td></td>
<td></td>
</tr>
<tr>
<td>logStringency(-63)</td>
<td>0.68614</td>
<td>3.25278</td>
<td>0.77689</td>
<td>0.72242</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Coefficient</th>
<th>t-Statistic</th>
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<tbody>
<tr>
<td>R-squared</td>
<td>0.12543</td>
<td>0.14739</td>
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<td>F-statistic</td>
<td>7.31450</td>
<td>5.18613</td>
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<tr>
<td>Durbin-Watson stat</td>
<td>2.26096</td>
<td>2.42841</td>
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<tr>
<td>LM(2)^</td>
<td>0.68614</td>
<td>3.25278</td>
</tr>
<tr>
<td>LM / Prob. Chi-Square(2)^</td>
<td>0.70960</td>
<td>0.19660</td>
</tr>
</tbody>
</table>

3/29/2020

Sample (adjusted): 10/05/2020 5/01/2020 10/05/2020 5/01/2020 10/05/2020 5/11/2020 10/05/2020

Included observation: 157 125 125 115

^Breusch-Godfrey Serial Correlation LM Test.

Long-run elasticity of new Covid-19 deaths

<table>
<thead>
<tr>
<th></th>
<th>Transit Mobility (Apple)</th>
<th>Recreation Mobility (Google)</th>
<th>Work Mobility (Google)</th>
<th>Stringency</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>10.0</td>
<td>23.4</td>
<td>7.3</td>
<td>-0.4</td>
</tr>
</tbody>
</table>

Median lag, days 71 74 70 71
THANKS!