When the best pandemic models are the simplest

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see:
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Today's Washington Post News: In one week in US new daily Coronavirus cases have gone from 104,000 to 154,000, an increase of 48%. Similar news comes from Europe.

Three recent dangerous Outbreaks

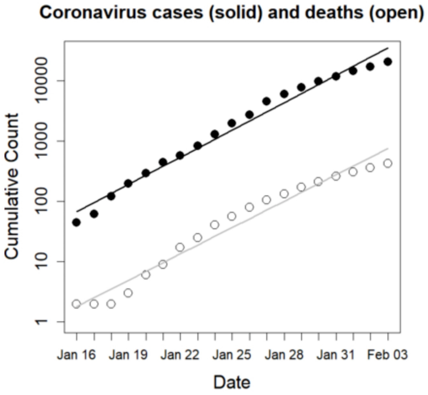
- 2003 Severe Acute Respiratory Syndrome (SARS)
  Cases= 8437
  Fatalities= 813

- 2009 Novel H1N1 Influenza: In March and April 2009, an outbreak of a new strain of influenza commonly referred to as "swine flu" infected many people in Mexico and other parts of the world, causing illness ranging from mild to severe.
  Initially the death rate in Mexico appeared very high.

- 2014-2015 Ebola virus disease occurred in Liberia, Guinea and Sierra Leone.
  Cases = 28610
  Fatalities= 11308

Next: seasonality of Measles

$\beta \approx 2.13 - 3.11$ in China in early days (from Wikipedia)



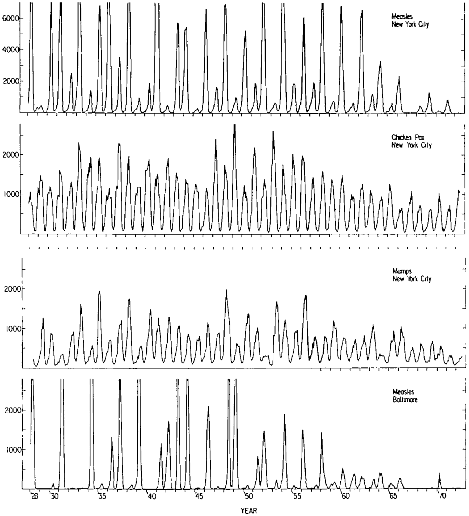
Semi-log plot of confirmed cases and deaths in China[103] (trend lines designate exponential growth)

The spread of the virus between people has been variable, with some affected people not transmitting the virus to others while others have been able to spread the infection to several people.[64] There have been various estimates for the basic reproduction number (the number of people an infected person is likely to infect), ranging from 2.13[104] to 3.11.[105] The new coronavirus has been reportedly able to transmit down a chain of up to four people so far.[106] This is similar to severe acute respiratory syndrome-related

Next: β seasonality

Seasonality of Measles, Chickenpox, Mumps

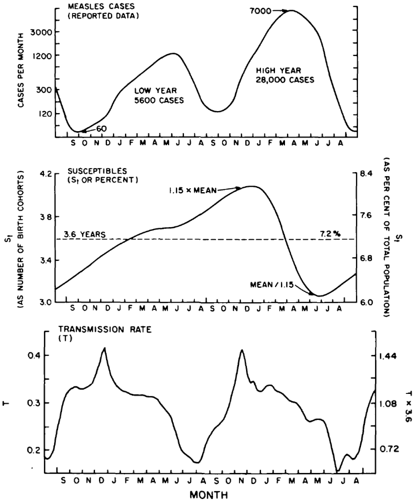
Data from Yorke and London 1973



Next: beta seasonality

Seasonality of Measles Transmission: β: Lots of data required.

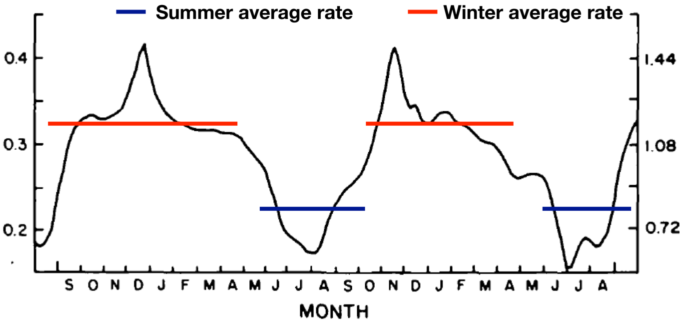
From Nathanson ... Yorke 1979 Amer J Epidemiology



Next: seasonality ratio in β.

$\frac{\text{summer } \beta}{\text{winter } \beta} \approx \frac{2}{3}$

Measles seasonal contact rate times a constant



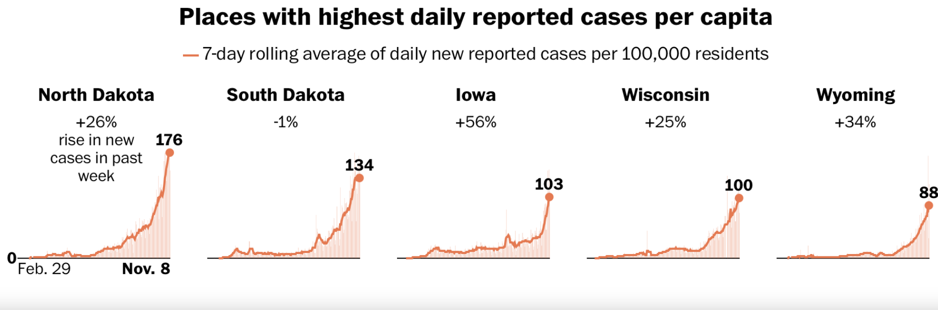
Summer average is roughly $\frac{2}{3}$ winter average

The same ratio applies to Chicken pox and Mumps

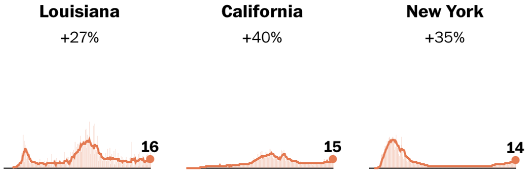
London-Yorke 1973 Amer J Epidemiology

Washington Post
Next: places in US where Covid is growing.

Where Covid is growing in US: $\beta \approx 1.25$ (average)



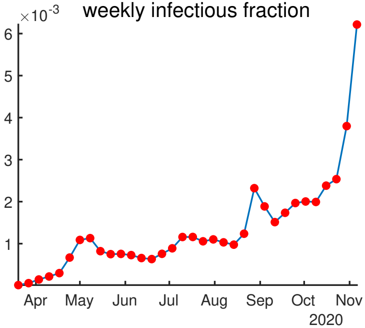
Low daily rates

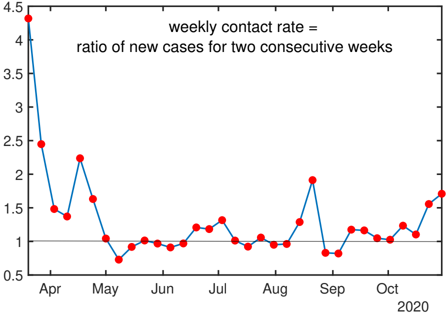


IOWA: sudden changes in β

Iowa

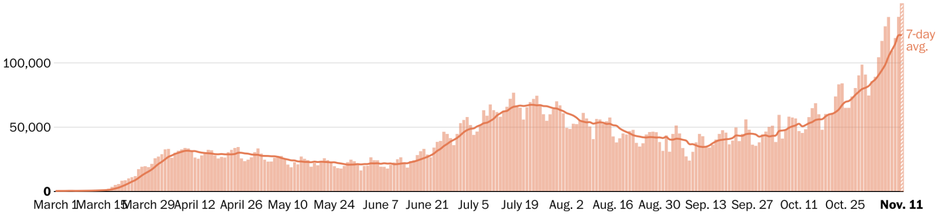
The start point of figures is March 20





Next: US β

US $\beta = 1.34$ in November 2020



In the past week in the U.S....

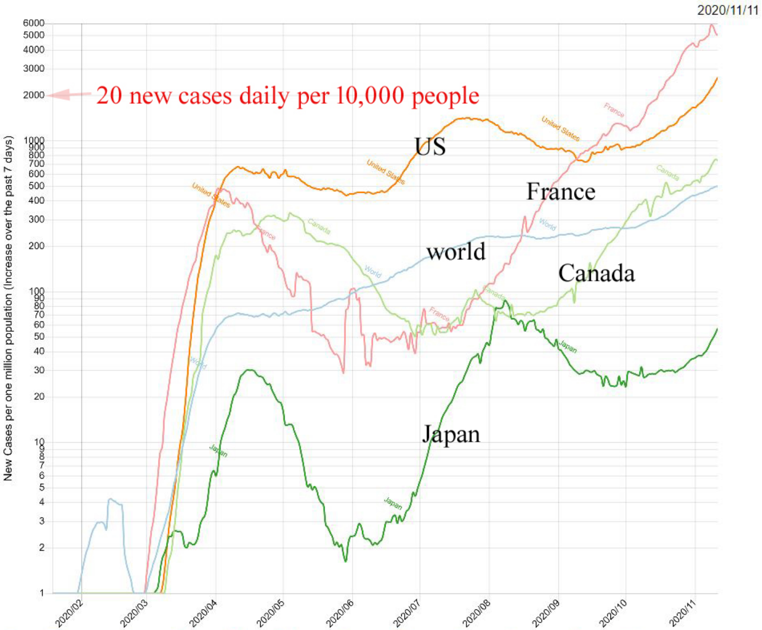
New daily reported **cases rose 34.3%** ↑

New daily reported **deaths rose 9.1%** ↑

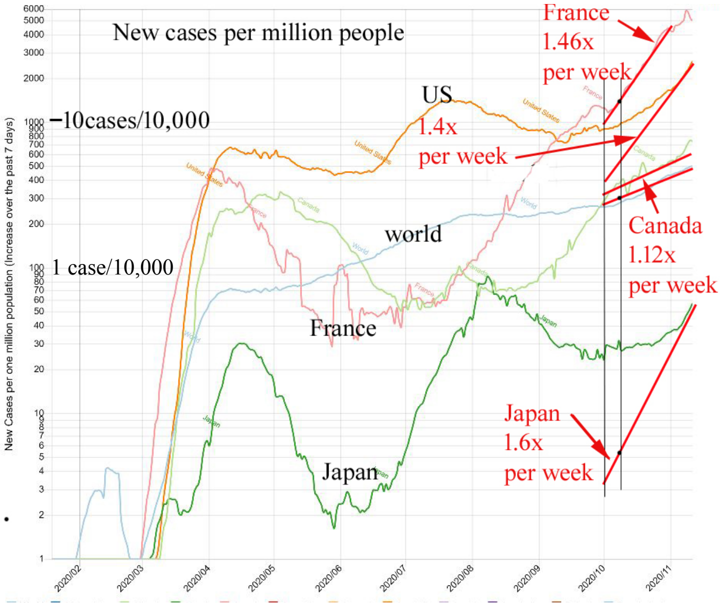
Covid-related **hospitalizations rose 23%** ↑

Next: Log plot of new cases

Log plots of new cases are rarely seen in the news media.



Four countries' $\beta = 1.12 - 1.60$ in November 2020



Next: simple model

The simplest model, what everyone can understand

A model is called **SIMPLE** when it has only one parameter in the equation(s).
We have two simple models Model E and Model E+. Both have **CONTACT RATE** β_n, as the only parameter. It can depend on time "n". It is the number of people that an infectious person would infect if everyone else was susceptible.

Model E

When almost everyone is susceptible, we have

$$I_{n+1} = \beta_n I_n$$

I_n: The fraction of infected individuals in period n.
β_n: The contact rate in period n.

Next: exponential growth

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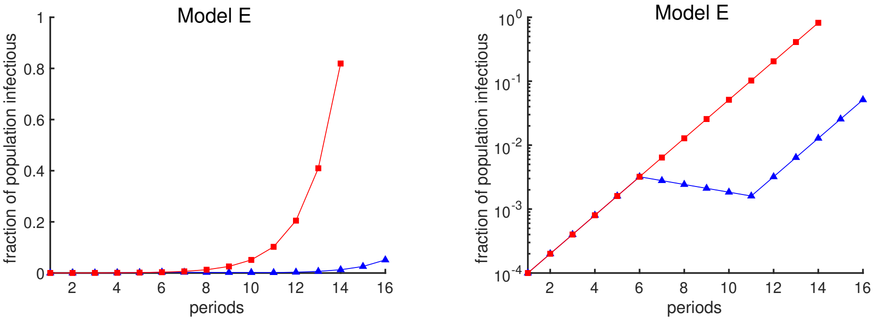
Model E: showing exponential growth to the public

Model E is a nice model for communicating with general audience.
Example: Red curves tells us epidemic grows by a constant factor of $\beta = 2$.
Blue curve shows an intervention from week 6-11, during intervention $\beta = 0.9$.



Next: Model E+

Model E+

When susceptible fraction drops by 10 % or so, we will use a **Kermack-McKendrick SIR** model.

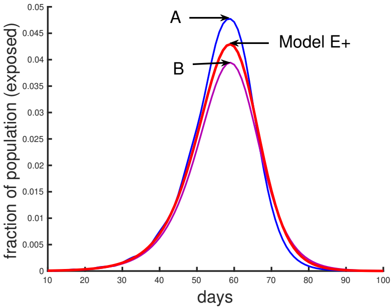
Model E+

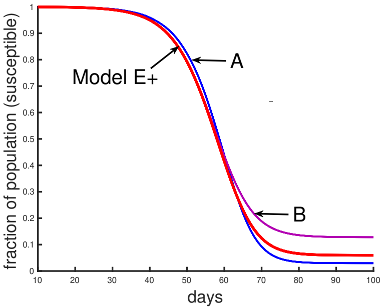
$$
\begin{aligned}
I_{n+1} &= S_n \cdot (1 - e^{-\beta_n I_n}), \\
S_{n+1} &= S_n - I_{n+1},
\end{aligned}
$$

- S_n is the fraction of the population that is susceptible at the beginning of period n,
- I_n is the fraction of the population that is infectious during period n. Those who were exposed in week $n-1$.
- n time step is mean transmission time
- β_n is the contact rate in week n.

Next:compared with a model with groups of differential infectiousness

When infectiousness period varies within subpopulations





Label	contact rate	infectiousness days (after exposure)	final size
A	3	6-10	97%
Model E+	3		94 %
B	3	4-8	87%

Next: Satellite equations concept

Our concept of "Satellite equations"

- Satellite equations use I_n and S_n, but do not affect them. They answer questions about epidemic using additional data.
- Models E or E+ tell us of the environment people find themselves in.
- Satellite equations allow us to assess the consequences of the pandemic for each individual and for uninfected isolated populations.

Next: probability of remaining uninfected by the end of epidemic

E+ satellite: Probability of remaining uninfected by the end of epidemic

If a person's contact rate in week n is γ_n, then, the probability that he/she will not catch infection by week n+1 will be

$$P_{n+1} = \exp(-\sum_{j=1}^{n} \gamma_j \cdot I_j)$$

If a person maintains a constant γ, then $\sum \gamma \cdot I_j = \gamma \cdot (S_0 - S_{n+1})$. Choosing $S_0 = 1$ yields the probability of remaining uninfected at the end of the epidemic,

$$P = \exp(-\gamma \cdot (1 - S_{\text{final}})). \quad (1)$$

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Example: Sana has 0.5 contacts per week and is otherwise isolated. That means $\gamma = 0.5$. If $S_{\text{final}} = 0.1$, then

$$P = exp(-0.5 \cdot 0.9) = 0.64$$

Next: Infecting an isolated population

Infecting an isolated population: A nursing home

N:= Number of visitors from main population per period. (We should add in employees as an extra contributor, but we ignore them here.)
I_n:= Probability of visitors being infectious
Assumption: Each visitor has $\frac{1}{2}$ of a contact at the nursing home; i.e., if the visitor is infected there is a 50% chance of transmission to a nursing home resident.
T(n): expected number of transmissions into the nursing home.

$$T(n) = \frac{1}{2} \cdot I_n \cdot N$$

Over the entire outbreak, suppose only 2% of population is infected and $N = 200$,

$$T_{\text{total}} = \frac{1}{2} \cdot N \cdot (1 - S_{\text{final}}) = \frac{200}{2} * .02 = 2$$

$$\text{Probability (nurs. home becomes infected)} = 1 - e^{-2} \sim 86\%$$

E+: Infecting an isolated population like New Brunswick, CA

N:= number of visitors from other states per period
I_n:= probability of visitors being infectious
Suppose each visitor has had half of their contacts before arrival.
$T(n)$= expected number of transmissions into New Brunswick.

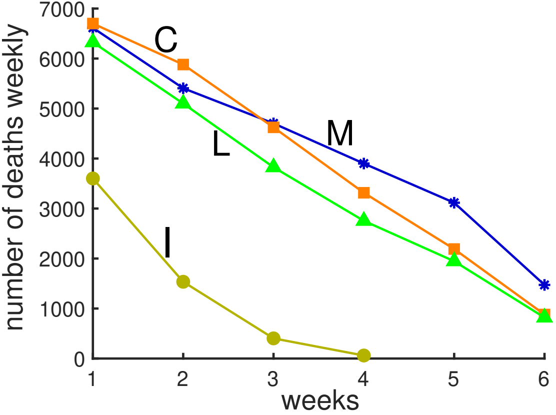
$$T(n) = \frac{\beta}{2} \cdot I_n \cdot N$$

Over the entire outbreak under the same assumption,

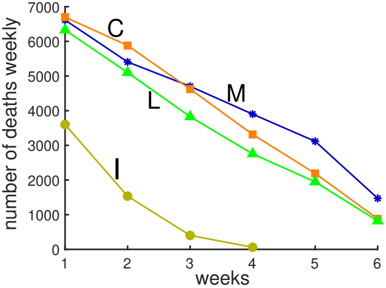
$$T_{\text{total}} = \frac{\beta}{2} \cdot N \cdot (1 - S_{\text{final}})$$

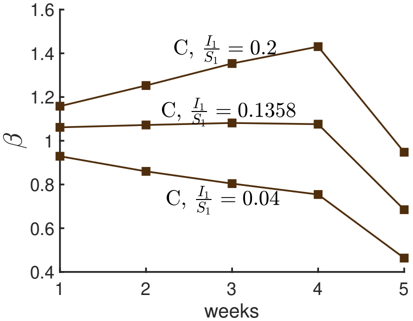
Next: New York City (4 complex model)

New York Times article (First 6 weeks of lockdown) Comparing predictions from 4 centers using E+



Finding the initial $\frac{I_1}{S_1}$





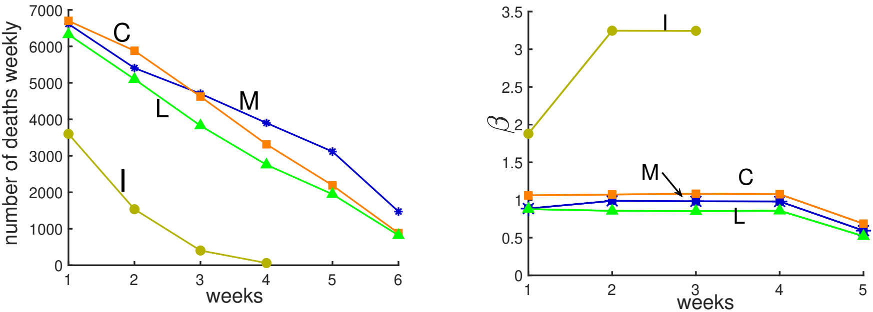
We choose $\frac{I_1}{S_1} = 0.1358$, because the β it produces is relatively constant.

Next:...

Model E+ Vs Complex models: example of NEW York Times article (First 6 weeks of lockdown)

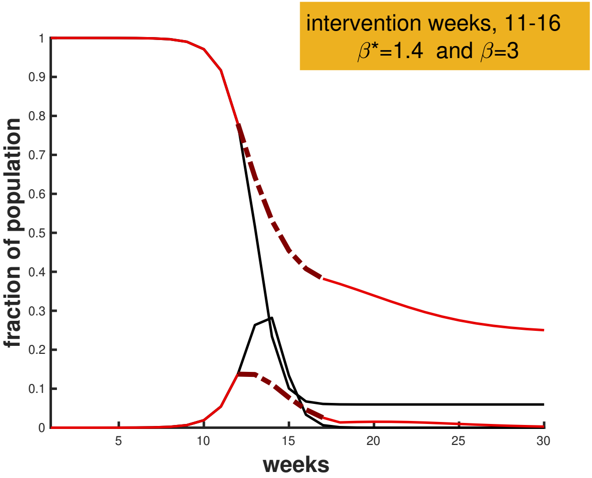
Our model E+ perfectly reproduces each of these curves. Given S_0 and I_n for $n \geq 1$, We have

$$\beta_n = -\frac{1}{I_n} ln(1 - \frac{I_{n+1}}{S_n})$$



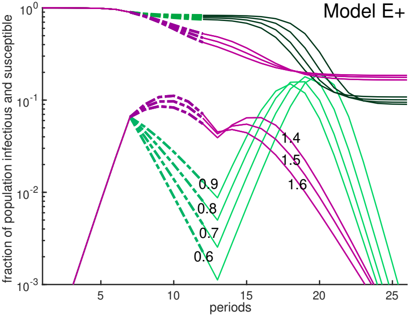
Next:Policy I

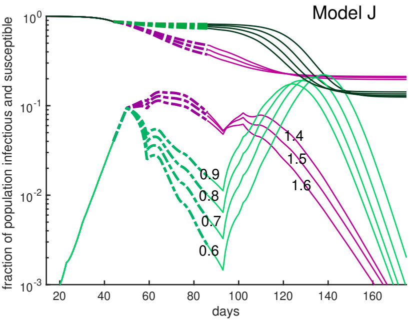
Policy one



Next: harsh vs mild

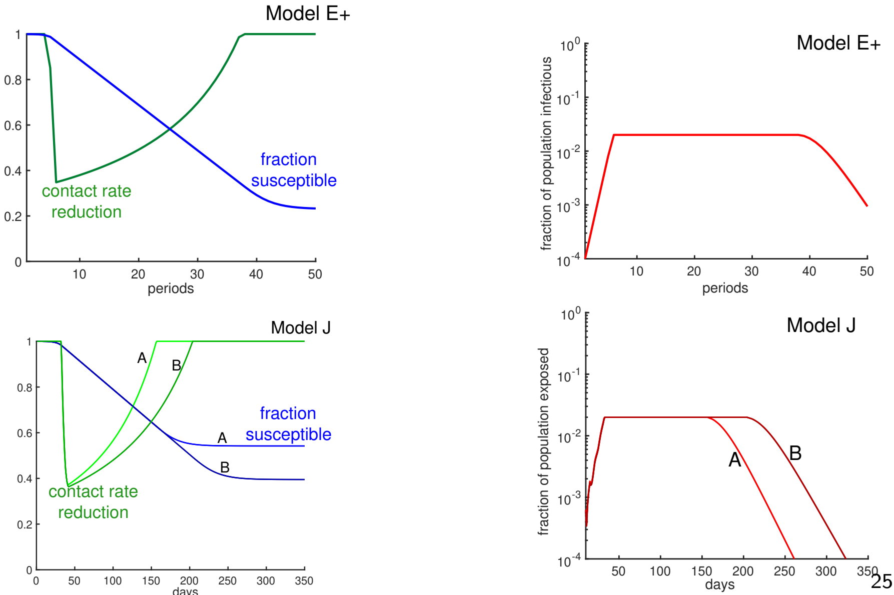
Model E+ evaluates policy I as effectively as a complex model does





Next:Policy II

Policy II: Put a cap on weekly new infected cases Model E+ evaluates it as effectively as a complex model



Conclusions

- We believe the population should know the goal is to keep β below 1 and perhaps far below 1.
- The model E is easy to communicate to the general audience and public officials.
- We show that E and E+ can be used to do things that complex models cannot (like comparing the 4 New York predictions).