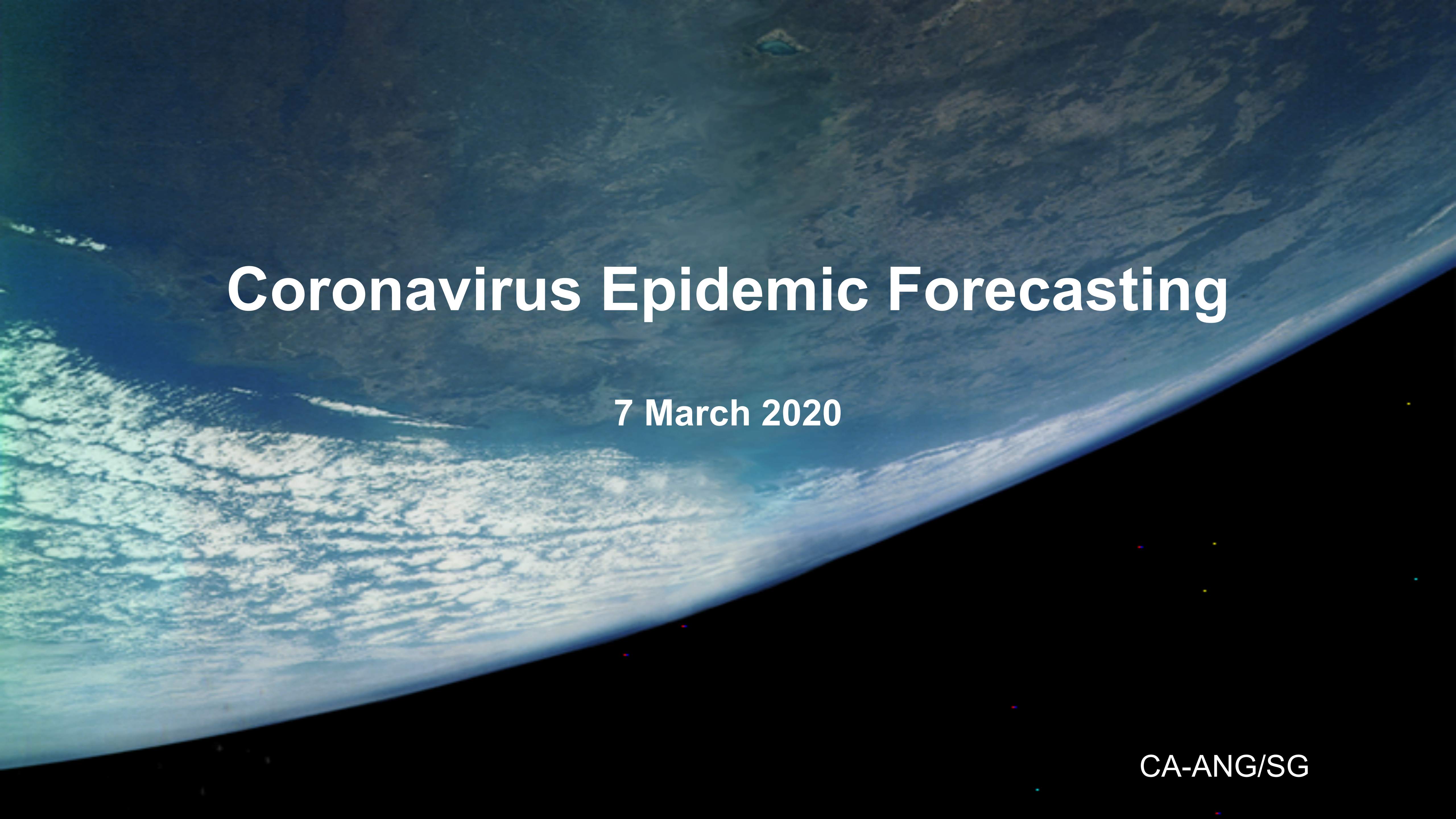


Coronavirus Epidemic Forecasting

7 March 2020

CA-ANG/SG

Summary (1)

- Predictions:
  - Epidemic will end some time after 60% of population is infected
  - That could be before summer or after summer
  - But infection rate could shoot to 90%
  - Epidemic will last about three to five months
- Above predictions apply if public health measures are <u>in</u>effective
  - Substantial improvement possible if public health measures are effective
  - Most difficult and impactful decision: when to relax public health measures

Summary (2)

- Covid-19 is a socially non-neutral disease
- Especially bad for:
  - Elderly
  - Sick
  - Health workers
- If similar to 1918 influenza spread
  - Will be worse in areas of high population density and high illiteracy
  - “Illiteracy” in 1918 was a marker for general poverty

Question to Answer:
Where is Epidemic Going?

- All epidemics are a math problem
- All epidemics are a medical problem
- All epidemics are a social problem
- All epidemics are a political problem ← **Won't discuss this one!**

- This briefing is not for busy leadership
- This briefing is for planners with time to dig in deeper

Math

Key reference: The effect of public health measures on the 1918 influenza pandemic in U.S. cities. PNAS. 2007; 104: 7588.

Math Overview

- Math tells us exactly how far the epidemic will go and when it will end

- Proves false this corrosive misbelief:
  - “It doesn’t matter what we do, we’re all going to get infected”

- Proves that our public health actions are supremely important
  - Not just what actions to apply and when
  - Also how long to maintain them ← **The more difficult aspect**

Math Basics

- Key parameter of any virus:
  - R0 = “R-naught” = “basic reproduction number”
  - Average number of cases that result from a single case
- Key equation:
  - F = Fraction of population ultimately infected = 1 – (1/R0)
- F determines two critical behaviors of an epidemic…

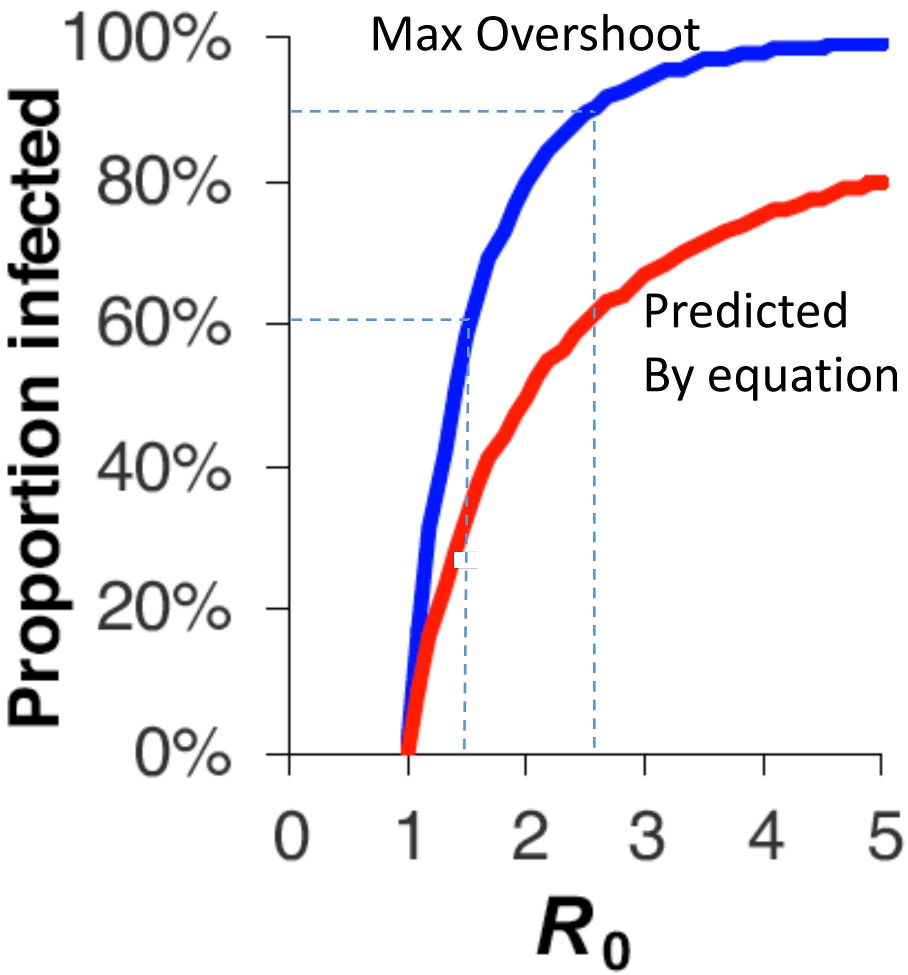
First Key Meaning of “F”

- Is the fraction of the population that ends up being infected
  - [Not completely true, because virus usually overshoots, but assume true for now]

- Estimates of R0 for Covid-19 virus
  - R0 = 1.5 F = 1-(1/1.5) = 0.33 = 33% of population
  - R0 = 2 F = 1-(1/2) = 0.5 = 50% of population
  - R0 = 2.5 F = 1-(1/2.5) = 0.6 = 60% of population ← We assume
  - R0 = 3 F = 1-(1/3) = 0.67 = 67% of population

- So, is false to say “We’re all going to get infected.”

How Big is the Overshoot?



- At R0=2.5: F=60% → overshoots to 90%
- At R0=1.5: F=33% → overshoots to 60%

- These results are based on a mathematical model
  - "Deterministic susceptible-infected-recovered" (SIR) model

- So, **estimate** that 60-90% of population will get infected with coronavirus R0=2.5
  - If we do nothing

Second Key Meaning of “F”

- Is when the epidemic stops

- Mathematically, an epidemic stops when **<u>either</u>**:
  - (a) R0 becomes less than 1
  - (b) Fraction of resistant population reaches F
    - ”Herd immunity” kicks in when F fraction of population is resistant
    - At this fraction, sustained transmission of the virus becomes impossible
    - Assumes: People become resistant after recovering from infection
    - Assumes: People become resistant after being vaccinated (not currently an option)

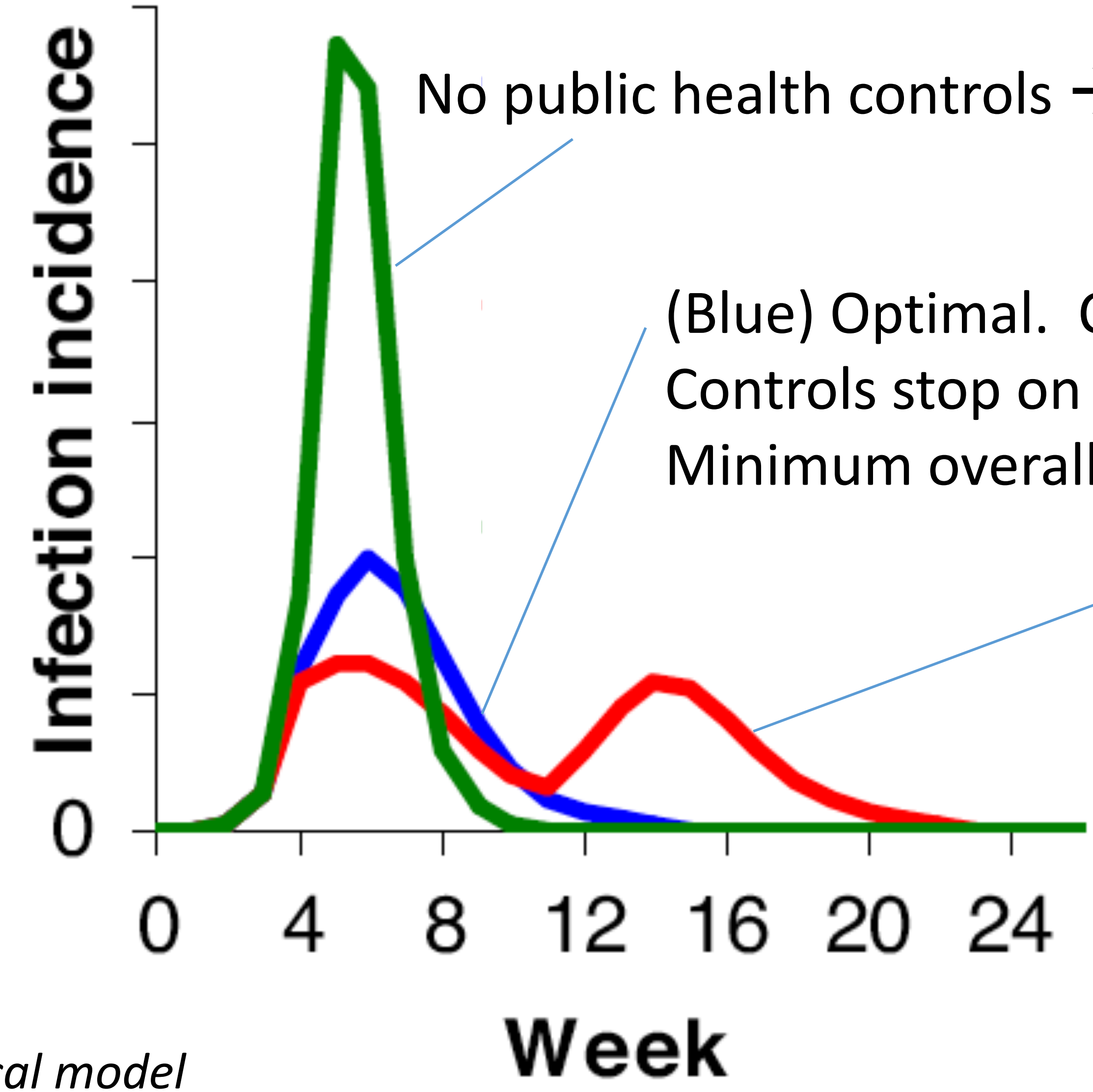
- For this meaning we use the calculated F, not the overshoot F
  - At R0=2.5: F=60% → epidemic peters out soon after 60% of population infected
  - At R0=1.5: F=33% → epidemic peters out soon after 33% of population infected

Medical / Public Health

How to Relate R0 and F to Real World?

- R0 is not a fixed property of the virus
- R0 depends on the interaction between virus + people + environment
- **R0 can be lowered by public health interventions**
  - Less mathematically: **Lowering the number of people whom each case infects will shrink the total size of the epidemic**
  - This is not obvious to lots of physicians (proof available on request)
  - Impact is substantial. Recall previous data:
    - R0 = 2.5 requires infection of 60% of population before epidemic ends
    - R0 = 1.5 requires infection of 33% of population before epidemic ends
    - So our actions could spare on-the-order-of 27% of the population from infection

Good Strategies and Bad Strategies



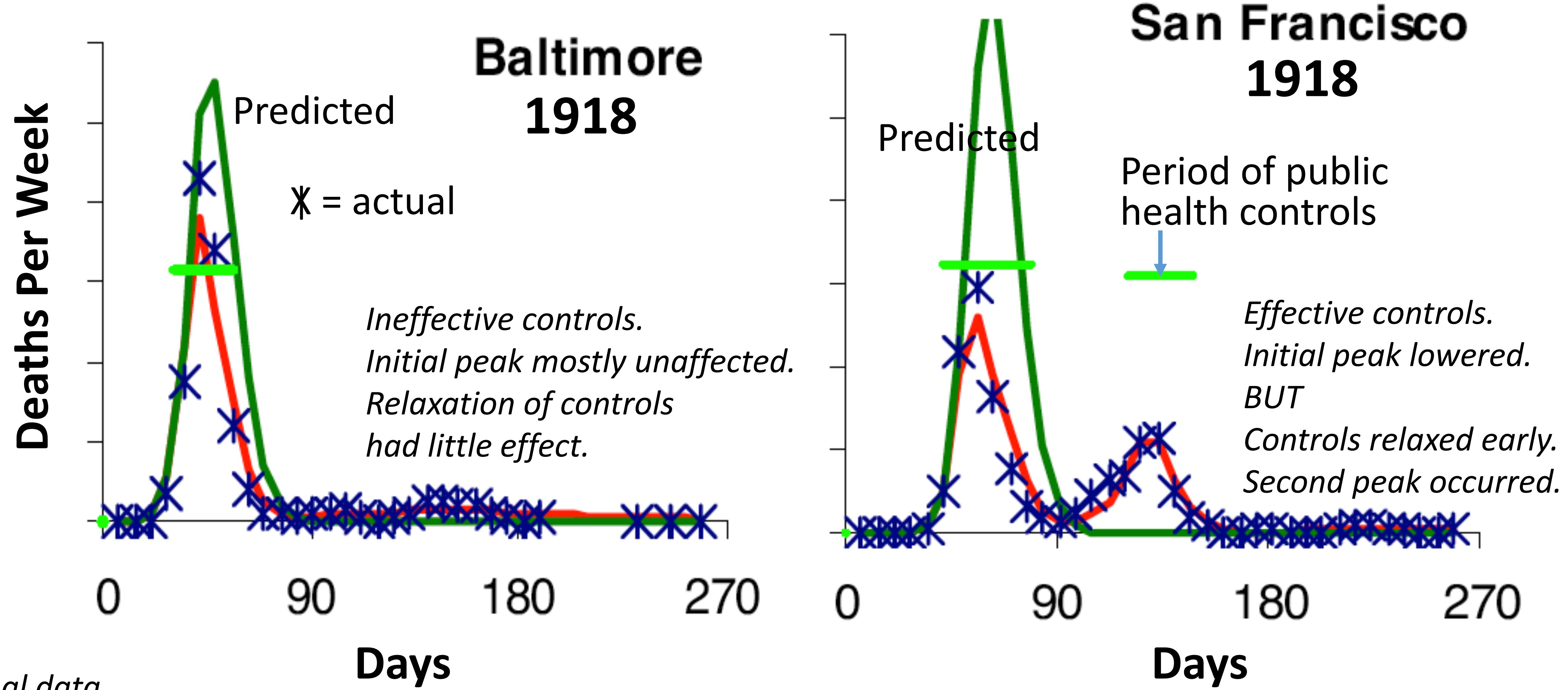
No public health controls → 80% infected (includes overshoot)

(Blue) Optimal. Controls ↓ R0 by 32%.
Controls stop on day 110.
Minimum overall epidemic size.

Over-effective. R0 initially ↓ by 40%.
Controls relaxed too early (day 75).
Second wave occurs because R0 has bounced back up, and F % of population is not yet resistant, and so sustained transmission re-ignites.

Mathematical model

Real-World Confirmation



Actual data

Key Question for Planners

- Long-term, what R0 will the population be able to sustain?
  - Example: Suppose closing schools reduces R0 from 2.0 (F=50%) to 1.5 (F=33%). Huge benefit, but closing schools until a vaccine appears is not a viable long term option.
  - If 33% of the population is infected and schools are closed and the epidemic has ceased, when the schools re-open, R0 will increase back to 2.0 and another wave of infections will occur, to bring F up to 50% (or higher, with overshoot).

- With a Covid-19 vaccine predicted to be 18 months away, optimal strategy *for general population* is to apply only enough controls to reduce R0 to a level sustainable for 18 months.

Caveats

- These are principles only.
- Not possible to know change in R0 for each control.
- Individual behaviors are large components of any change in R0.
- Summertime may have a different R0 than spring and fall.
- “Over-effective” (two-wave) strategy may prolong pain, but would also reduce peak demand on health care system.

Social Non-Neutrality

R0 is <u>Not</u> the Same Everywhere

- Based on 1918 influenza data…
  - R0 is higher where population density is higher
  - R0 is higher where poverty is higher

- Scenarios of very high virus transmission in Covid-19 epidemic
  - Korean psychiatric ward: 99 of 101 contract the disease
  - Diamond Princess cruise ship: 700 cases
  - Homes: data from China suggests most secondary transmission is at home

R0 is <u>Not</u> the Whole Story

- R0 refers only to spread of disease
- Does not refer to consequences of disease
  - Older – high mortality
  - Sick – comorbities, including hypertension + other common diseases, raise mortality
  - Health care workers
    - Dire consequences for health care system.
    - Also seem to have higher mortality. Reasons are wholly unclear.

Conclusion

- Course of the epidemic is not pre-ordained by biology

- Our actions will be a large determinant of the ultimate outcome

- Mathematics is helpful for proving a framework to think about actions
  - But is not a rigid guide