Behavioral Epidemiology Models

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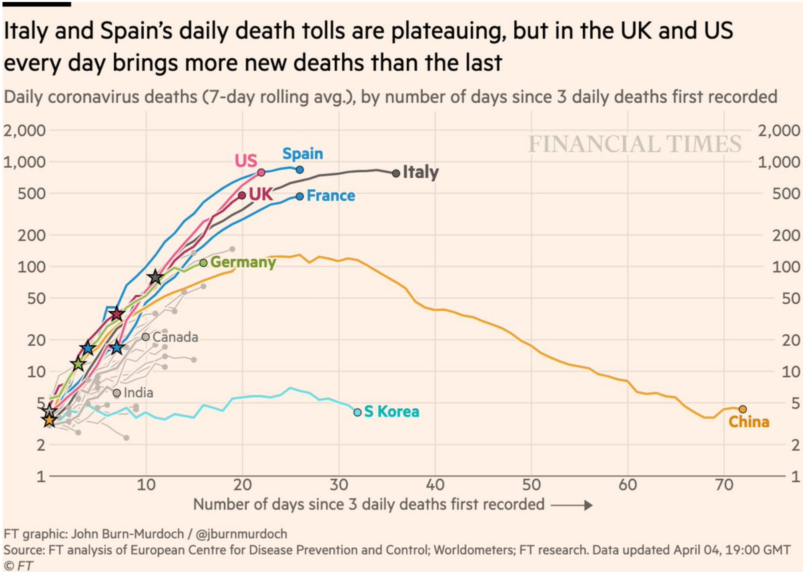
Epidemics - by Country



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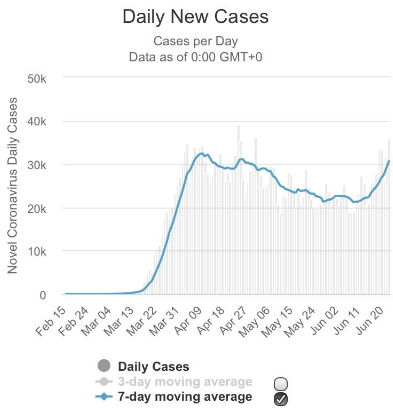

  - But this is a different issue.

How do we interpret these figures, ... data?

- How can we compare different countries? Indeed, several possible determinants of the dynamics vary:
  - geographic characteristics, e.g., population size, density, inflows of infected agents, ...
  - demographic characteristics, e.g., age structure, health conditions ...
  - socio-economic characteristics, e.g., income, public health conditions, dominant living arrangements, social contacts, ...
  - climate.
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- Models ... and statistical /econometrics methods.
  - We concentrate on models in this lecture.

But which models?

Nothing is less real than realism. Details are confusing. It is only by selection, by elimination, by emphasis that we get to the real meaning of things (Georgia O'Keeffe).

- Models are theoretical exercises of abstraction: *ignoring many details in order to focus on the most important elements of the problem.*
- There is no such thing as the right degree of abstraction for all analytic purposes. The proper degree of abstraction depends on the objective of the analysis.
  - A model that is a gross oversimplification for one purpose may be needlessly complicated for another.
  - A map might be an appropriate metaphor for a model: we rarely need 1:1 maps; and sometimes we need a map of the whole American continent, sometimes one of the upper east side of NYC.

But which models?

- Models are not necessarily mathematical models. The following example (taken from Krugman, *Development, Geography, and Economic Theory*, 1995, MIT Press; Ch. 3) illustrates this point:

  > *Dave Fultz at the University of Chicago in the late 40's showed that a dishpan filled with water, on a slowly rotating turntable, with an electric heating device bent around the outside of the pan provides a good representation of the basic pattern of weather. The dishpan was build to model the temperature differential between the poles and the equator and the force generated by the earth's spin (abstracting from most of the the intricacies and complexities of the earth geography) and was successfully shown to exhibit phenomena which could be interpreted as tropical trade winds, cyclonic storms of the temperate regions, and the jet stream.*

- But often models are in fact mathematical models: the most sophisticated weather forecasts nowadays require the estimation of the parameters of a large number (very large, hundreds) of equations.

Models in Epidemiology and Economics

- Models in both in Epidemiology and Economics are mathematical models.
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  Models in in Epidemiology are more like those employed in sophisticated weather forecasts: lots of equations, very detailed data:

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- Last, but not least,
  - Models in Economics include (explicitly, formally) behavioral factors - (rational) choice of agents.

In this lecture ...

- We shall introduce the (stylized, abstract) core component of epidemiological models - the SIR model
- We shall introduce a spatial extension of SIR - for concreteness
- We shall introduce rational choice/behavior into these models - i.e., some economics
- All the way simulating the dynamics of an epidemic - to illustrate the models and their different implications

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  - I am an economist after all :)

Epidemiological models: SIR

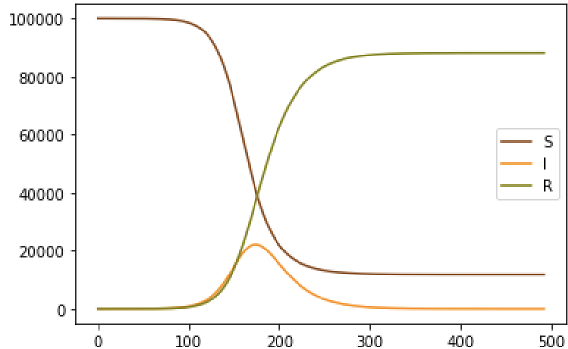
- Stylized model (Kermack and McKendrick 1927) - without bells and whistles for prediction accuracy:

	State	*Transition*
Susceptibles	$S \to I$:	$-\beta \frac{I}{N} S$
Infected	$I \to R$:	$-\gamma I$
Recovered	$R \to R$	

$\mathcal{R}_0 = \beta/\gamma$: number of agents a single infected agent infects, on average, at $I_0 = R_0 = 0$.

$\beta = \pi c$: infection rate per-contact times random matching contacts per unit of time.

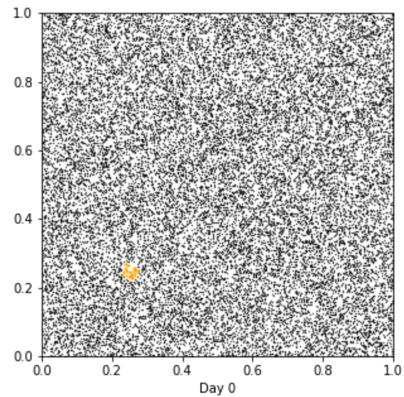
Dynamics of an epidemic; with $\mathcal{R}_0 = 2.4$



Epidemiological models: Spatial-SIR

- *N* people located randomly in a 1-sized square
- 5 states:
  - **S**: ☹ Susceptibles (can become infected)
  - **A**: Asymptomatics (infected, but unaware)
  - **Y**: sYmptomatics (infected, aware)
  - **D**: Dead
  - **R**: Recovered
- Transitions between states
- Contagion occurs if:
  within contagion circle + random draw

Day 0: initial cluster



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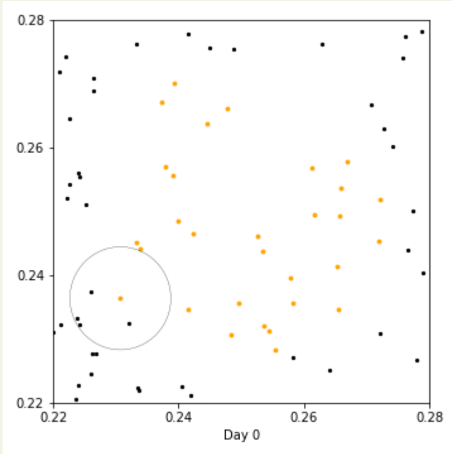
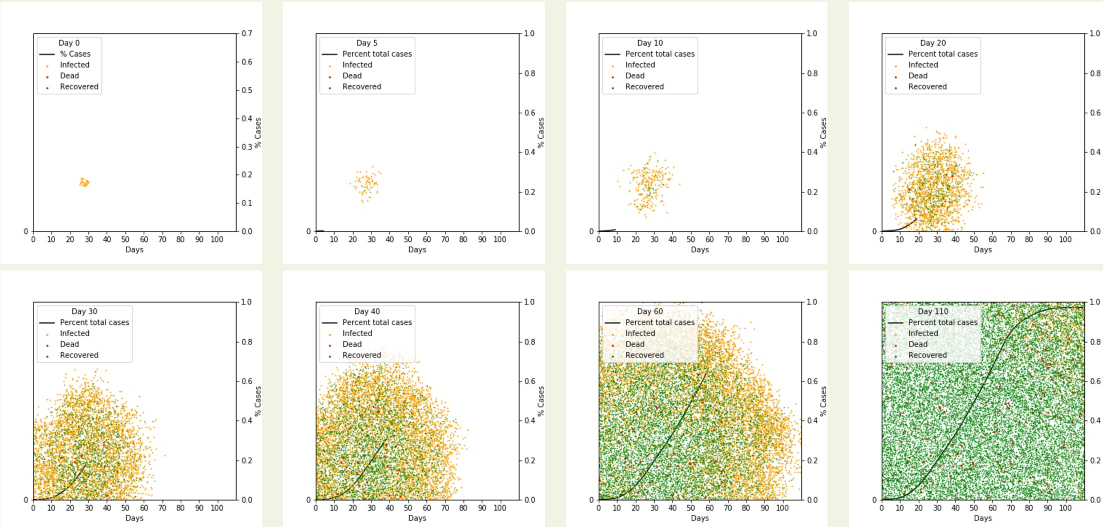
Day 0: near the cluster



How the infection evolves in space

People move in random direction at given speed

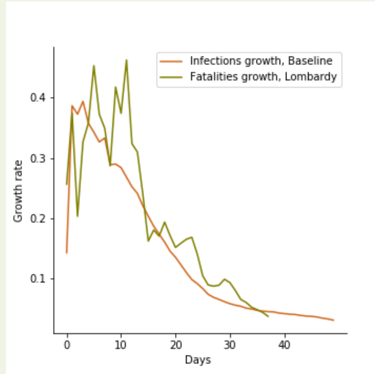


Calibration

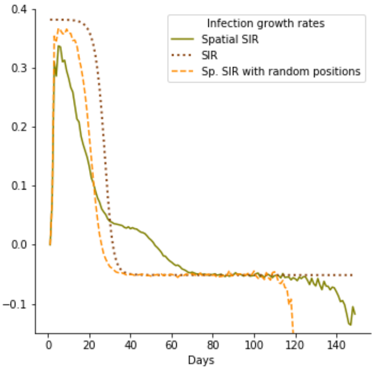
Parameter	Value		Match
N	26,600	}	13.5 contacts/day
Contagion radius	0.0125		
Contagion prob π	0.014	}	First 30 days of fatalities growth in Lombardy
Speed of movement μ	0.025		

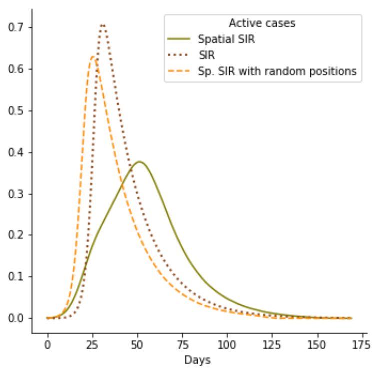
*Alvarez et Al (2020), Ferguson (2020)

Growth rates calibration



SIR and Spatial-SIR: Simulations of the calibrated model





Epidemics and spatial characteristics

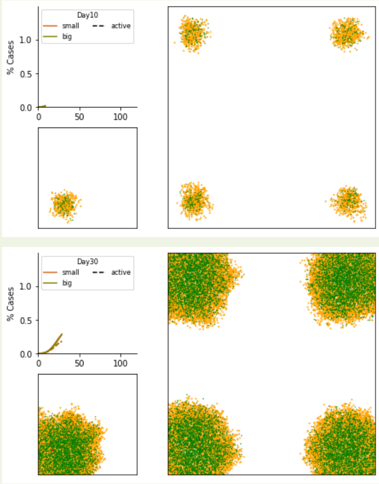
Take the calibrated Spatial-SIR, and change one factor at a time

- number of clusters, I_0, and their spatial distribution
- size, N
- density, $\frac{area}{N}$
- speed of movement, μ

Initial outbreaks

- Dynamics is invariant to the initial condition:
  - Scaling in size obtains if we scale initial conditions,

Two cities - same density



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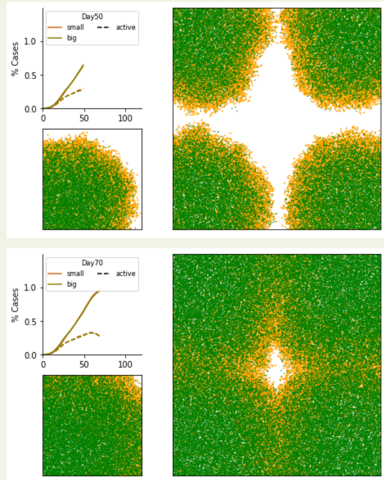
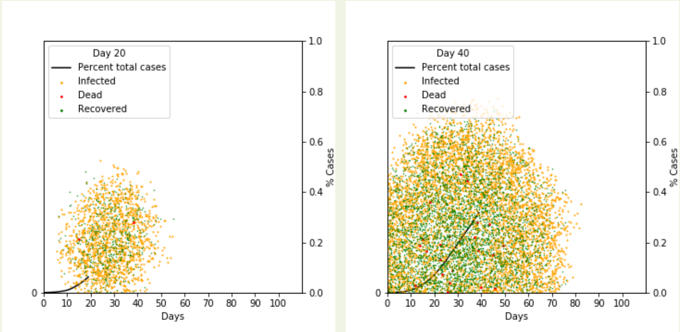


Initial outbreaks

- Dynamics is invariant to the initial condition:
  - Scaling in size obtains if we scale initial conditions,
  - but only if the initial conditions are appropriately homogeneously spaced.

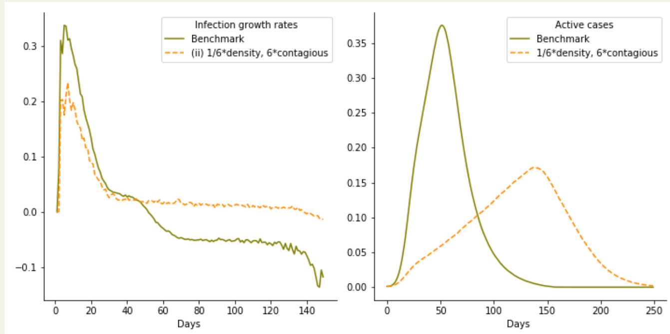
All initial outbreaks in one cluster



City density

- City density has distinct role from the inverse of the probability of infection:
  - Lower density flattens the curve of infected

Figure: The effect of varying city density with constant population



City density

- The peak of Infected $\frac{I}{N}$ is very sensitive to density:
  - halving density flattens dramatically the peak (more than a half, after more than twice as many days).

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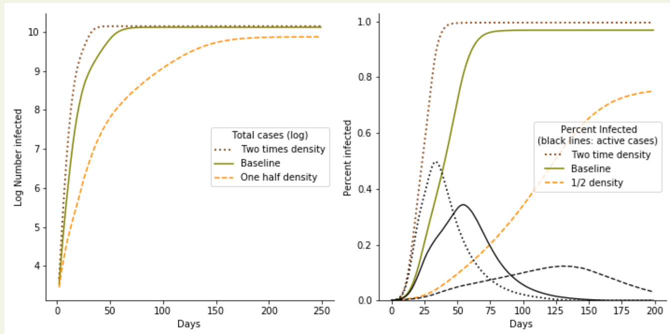

Behavioral Spatial-SIR

- Growth rate of cases is $\beta = \pi c$: infection rate times contacts. Rational agents
  - will choose to limit their social interactions, their contacts c - the more so, the higher the risk of being infected:

$$c = \alpha\left(\frac{I_t}{N}\right)c_0, \qquad \text{where } c_0 \text{ is pre-epidemic number of contacts per unit of time.}$$

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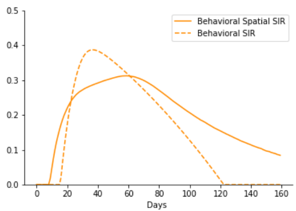
  - E.g.,

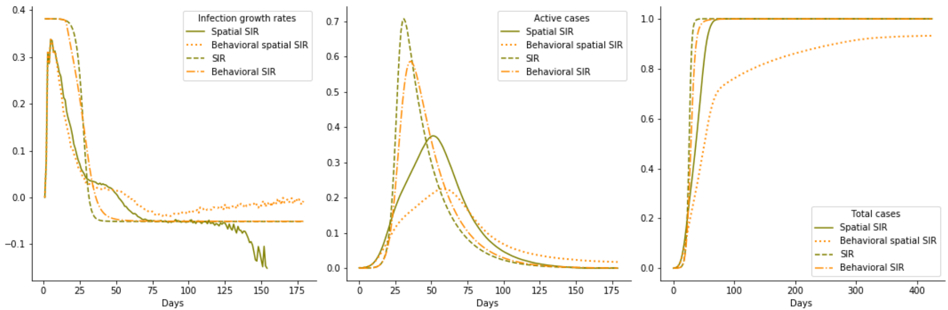
$$\alpha(\frac{I_t}{N}) = \begin{cases} 1 & \text{if } \frac{I_t}{N} \leq \underline{I} \\ \left(\frac{\underline{I}}{\frac{I_t}{N}}\right)^{1-\phi} & \text{if } \frac{I_t}{N} > \underline{I} \end{cases} .$$

Figure: Reduction in contacts according to a very cautious behavioral response



Behavioral SIR and Spatial-SIR

- Behavioral response in Spatial-SIR
  - Peak of active cases is halved,
  - Total cases reduced by 10%.



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- Epidemiological model - built for prediction but without rational choice/behavior - delivered hardly meaningful worst-case scenarios

16 March 2020 *Imperial College COVID-19 Response Team*

Report 9: Impact of non-pharmaceutical interventions (NPIs) to reduce COVID-19 mortality and healthcare demand

Neil M Ferguson, Daniel Laydon, Gemma Nedjati-Gilani, Natsuko Imai, Kylie Ainslie, Marc Baguelin, Sangeeta Bhatia, Adhiratha Boonyasiri, Zulma Cucunubá, Gina Cuomo-Dannenburg, Amy Dighe, Ilaria Dorigatti, Han Fu, Katy Gaythorpe, Will Green, Arran Hamlet, Wes Hinsley, Lucy C Okell, Sabine van Elsland, Hayley Thompson, Robert Verity, Erik Volz, Haowei Wang, Yuanrong Wang, Patrick GT Walker, Caroline Walters, Peter Winskill, Charles Whittaker, Christl A Donnelly, Steven Riley, Azra C Ghani.

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In the (unlikely) absence of any control measures or spontaneous changes in individual behavior, we would expect a peak in mortality (daily deaths) to occur after approximately 3 months. In such scenarios, given an estimated R0 of 2.4, we predict 81% of the G.B. and U.S. populations would be infected over the course of the epidemic... In total, in an unmitigated epidemic, we would predict approximately 510,000 deaths in G.B. and 2.2 million in the U.S., not accounting for the potential negative effects of health systems being overwhelmed on mortality.

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  - "the (unlikely) absence of any control measures or spontaneous changes in individual behavior"
  - is a zero-probability scenario for economists - whose core job modeling "spontaneous changes in individual behavior."

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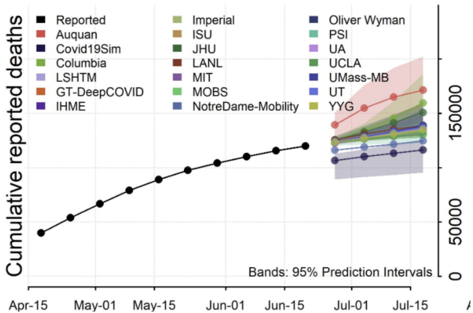
- Indeed current predictions (from various epidemiological models - reported by the CDC - which include behavioral effects - but just ex-post):



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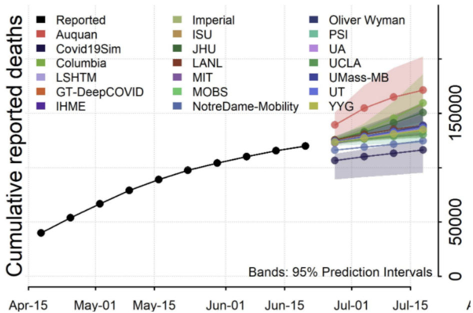

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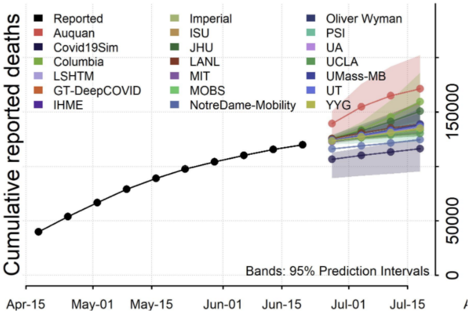

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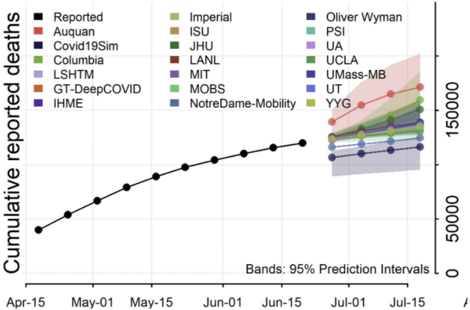
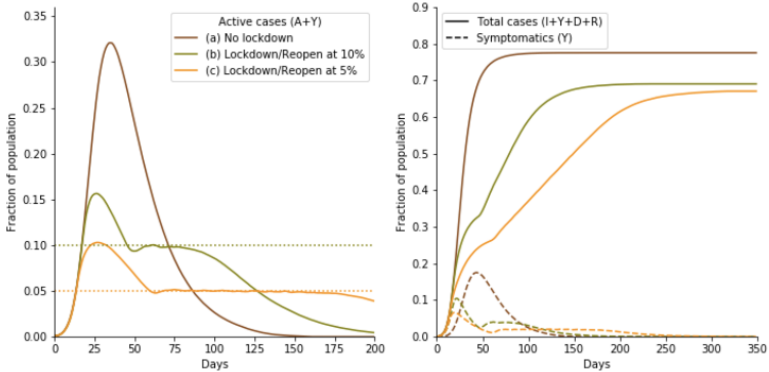


- imply that accounting for behavior and Non-Pharmaceutical Interventions (lockdown policies) reduced deaths to less than one tenth of the worst case scenario.
  - Distinguishing the effect of behavior from the effect of the lockdown is for statistical/econometric methods.
  - Another lecture :)

Peak into simulating a lockdown

Figure 8: Counterfactual: Reopen when stably declining



Conclusions

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