Formulating Optimal Policies using Behavioural Models

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Modelling Behaviour to Inform Policy for Pandemics
Newton Gateway to Mathematics

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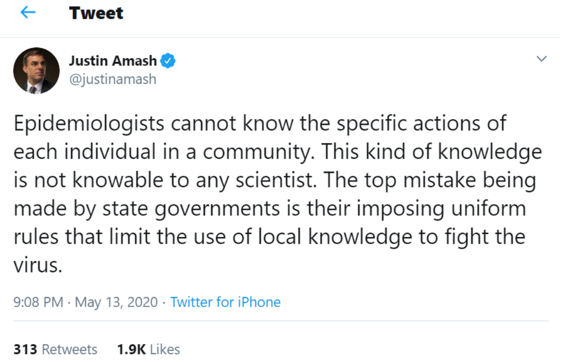
Background

- Graham Medley, Chair of SPI-M, 22/10/2021:

  "The critical problem for decision-making is that the future is unpredictable — models cannot predict numbers accurately. This is mostly because of behaviour that is often completely unpredictable"

- Similarly:


Tweet

Justin Amash
@justinamash

Epidemiologists cannot know the specific actions of each individual in a community. This kind of knowledge is not knowable to any scientist. The top mistake being made by state governments is their imposing uniform rules that limit the use of local knowledge to fight the virus.

9:08 PM · May 13, 2020 · Twitter for iPhone

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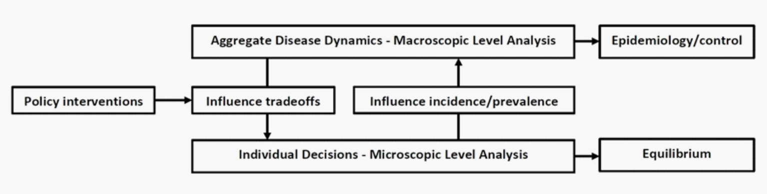
Background

- **Understanding behaviours**
  - What drives behaviour and can it be modelled?
  - Decision theory, choice under uncertainty
- **Integrating behaviour into models**
  - How can behaviour be embedded into epidemic dynamics?
  - Coupled behavioural-epidemiological system
  - Behaviour modifies force of infection
- **Using behavioural models to inform policy**
  - How can optimal policy be formulated?
  - Optimal control theory + subsidies/taxes (first-best)
  - Controlled equilibrium dynamics (second-best)
- Central idea in post-WWII economics: **the neoclassical synthesis**

Micro-macro interactions

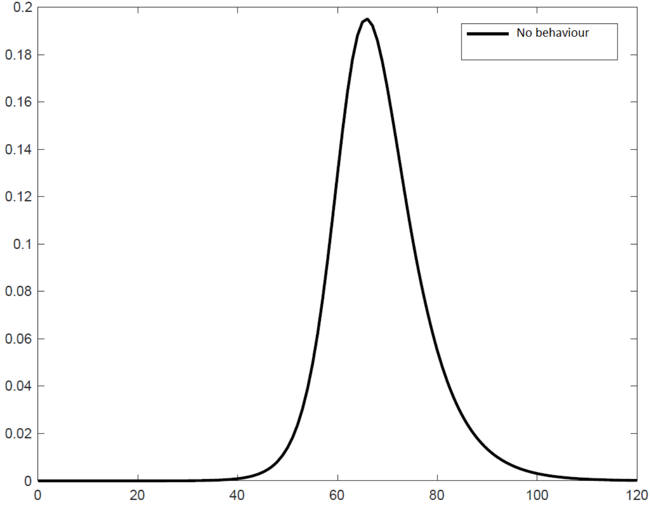
- Aggregate dynamics understood via underlying mechanisms and behaviour
- Build model "from the ground up"
- Microfoundations ensure consistency
- Allows study of tradeoffs and how they change across epidemic
- Enables analysis of policy impact
- Micro-macro interactions and feedback:



- Behaviour (micro) influences aggregate dynamics (macro)
- But aggregate dynamics influence behaviour...
- Integrated model also allows us to study (i) intertemporal feedback and (ii) interactive behaviour

The epidemiological model

- Disease prevalence without behaviour:



The epidemiological model

- Ferguson (2007):
- *"Most basic models assume that all parameters are static, but in fact people's responses often shift as the epidemic progresses. Individuals are most likely to change their contact patterns when mortality or the perception of risk is high, and resume a normal life as the perceived risk declines"*
- Let's consider decision problem of single individual in a large population

Equilibrium behaviour

- Individual's problem: choose $d(t) \in [0,1]$ to max

$$\int_0^T e^{-\rho t} \{[p_{\mathcal{S}}(t)\overline{\pi} + p_{\mathcal{I}}(t)\underline{\pi} + p_{\mathcal{R}}(t)\overline{\pi} - p_{\mathcal{S}}(t)c(d(t))\} \, dt$$
$$+e^{-\rho T}[p_{\mathcal{S}}(T)V_{\mathcal{S}} + p_{\mathcal{I}}(T)V_{\mathcal{I}} + p_{\mathcal{R}}(T)V_{\mathcal{R}}]$$

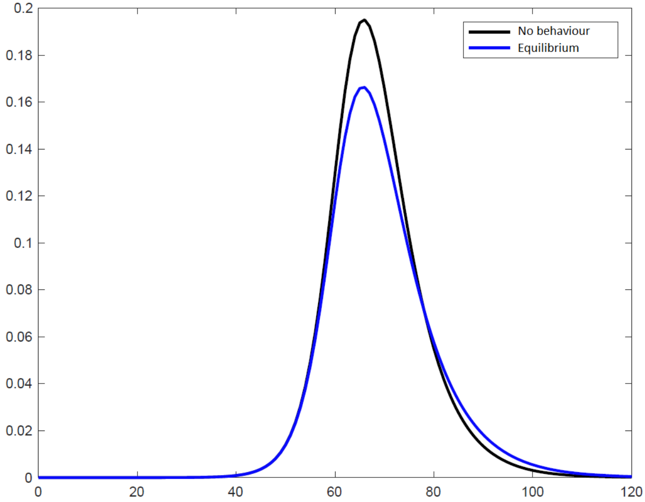
- Constraints:

$$\begin{aligned} \dot{p}_{\mathcal{S}}(t) &= -(1-d(t))\beta I(t)p_{\mathcal{S}}(t), \quad p_{\mathcal{S}}(0)=1 \\ \dot{p}_{\mathcal{I}}(t) &= (1-d(t))\beta I(t)p_{\mathcal{S}}(t) - \gamma p_{\mathcal{I}}(t) \\ \dot{p}_{\mathcal{R}}(t) &= \gamma p_{\mathcal{I}}(t) \end{aligned}$$

- State var. $p_i(t) \in [0,1]$ prob. of being in state $i = \mathcal{S}, \mathcal{I}, \mathcal{R}$
- Aggregate dynamics not influenced by single individual

The economic model

- Disease prevalence with spontaneous self-protection:



Optimal behaviour

- Planner's problem: choose $d(t) \in [0,1]$ to max

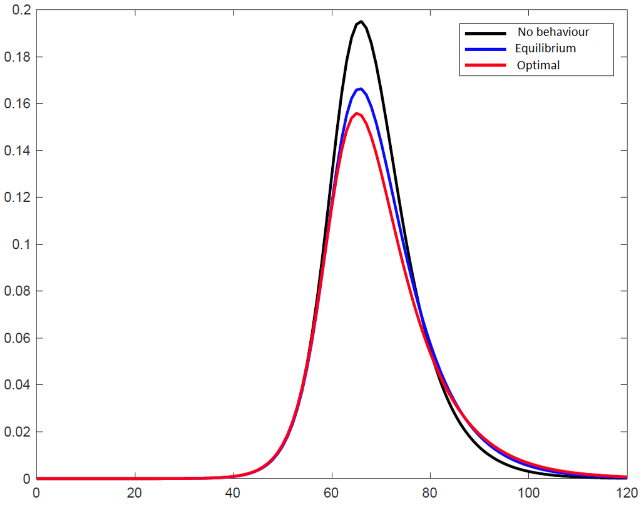
$$\int_0^T e^{-\rho t} \left\{ S(t)\overline{\pi} + I(t)\underline{\pi} + R(t)\overline{\pi} - S(t)c(d(t)) \right\} dt$$
$$+ e^{-\rho T} \left[S(T)V_{\mathcal{S}} + I(T)V_{\mathcal{I}} + R(T)V_{\mathcal{R}} \right]$$

- Constraints:

$$\begin{aligned}
\dot{S}(t) &= -\beta(1-d(t))I(t)S(t) \\
\dot{I}(t) &= I(t)\left[\beta(1-d(t))S(t) - \gamma\right] \\
\dot{R}(t) &= \gamma I(t) \\
1 &= S(t) + I(t) + R(t) \\
I(0) &\approx 0, I(0) + S(0) = 1, S(0) > \gamma/\beta
\end{aligned}$$

The economic model

- Disease prevalence correcting for externalities:



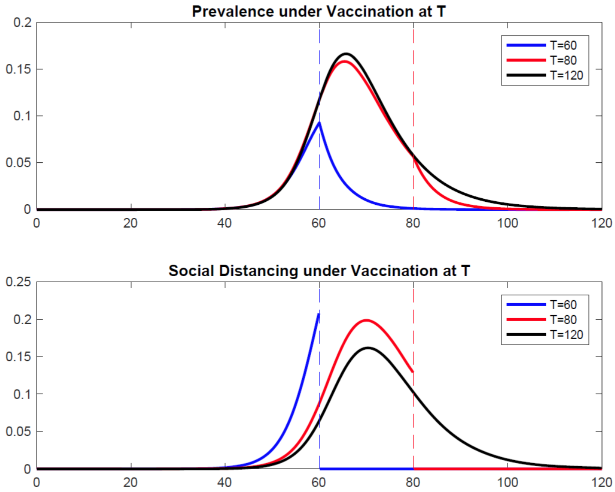
Policy interventions

- Presence of (uninternalised) externalities may create role for public policy intervention
- Interventions can two forms:
- Modify incentives (private tradeoffs) through taxes and subsidies
  - Statutory sick pay, furlough schemes, payment for self-isolation...
- Modify choice sets to restrict what people can do
  - Lockdowns, school closures, stay-in-place orders...

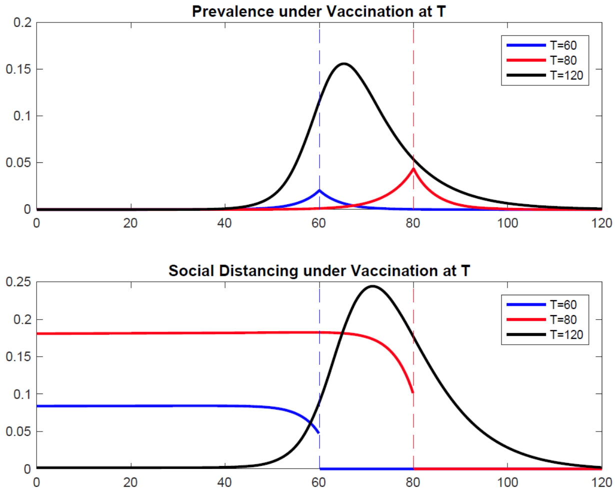
Policy experiment: perfect vaccine

- Makris and Toxvaerd (2021): Great Expectations: Social Distancing in Anticipation of Pharmaceutical Innovations, COVID Economics 56, 9 November
- Assume that perfect vaccine given to everyone at predetermined date
- Announced in advance
- How does that change pre-vaccine behaviour?
- Note that only susceptible people can benefit from vaccine
- As date approaches, more valuable to stay healthy

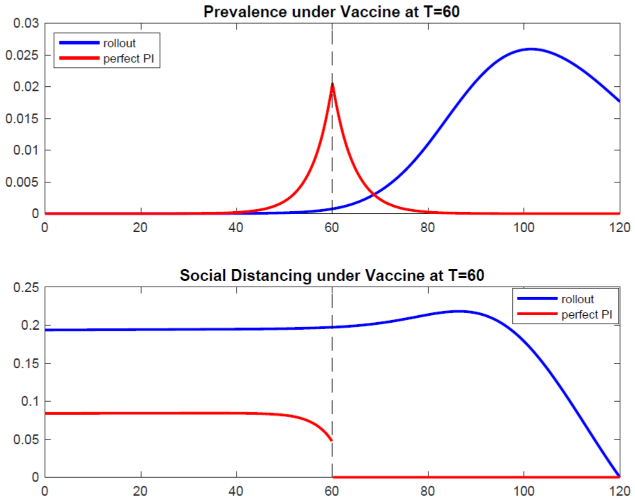
Equilibrium before vaccination



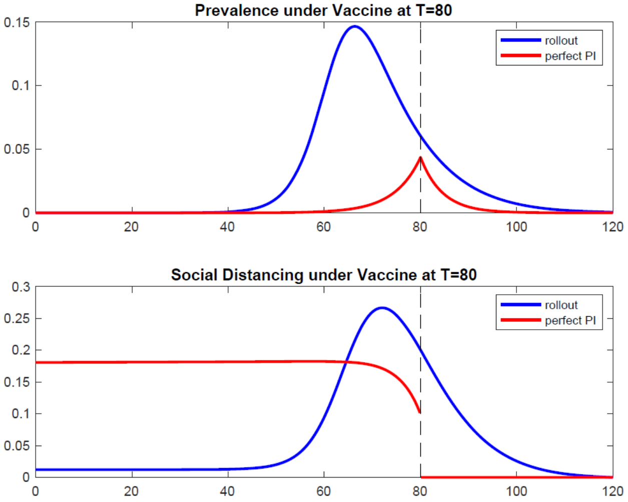
Optimal policy before vaccination



Vaccine rollout



Vaccine rollout



Pitfalls: ignoring incentives

- Behaviour can have odd effects:

> - **The prevalence of infection (over all age groups) should continue to decline until mid-December.**
> - **The basic reproduction number R_0 is currently estimated to be 6.0.** This corresponds to an 37% increase in transmission risk, relative to the average since 1 Feb 2020. This estimate includes seasonality effects and will rise as winter approaches.
> - **Current estimates of the vaccination efficacy are:**
>
>   preventing infection: -9.5% (CI -14.2 to -4.9)
>
>   preventing transmission following infection 91.3% (CI 90.7 to 91.9))
>
>   preventing serious illness when symptomatic (age 15-34) 78.0% (CI 77.3 to 78.7)
>
>   preventing serious illness when symptomatic (age 35-70) 51.9% (CI 50.7 to 53.1)
>
>   preventing fatality when seriously ill 44.8% (CI 43.9 to 45.8)
>
>   A negative efficacy means vaccination increases risk. For example, people who are vaccinated may expose themselves to more close contacts than people who are not.

- *"[...] a study led by Public Health England of vaccination in the over 70s found a "notable" rise in covid-19 infections in people immediately after they received the Pfizer-BioNTech or AstraZeneca vaccine. Similarly, a study of Israel's vaccination programme, reported in February, found a similar spike in cases among people who had just been jabbed" - Day (2021)*
- Phenomenon known as disinhibition and easily rationalised

Pitfalls: ignoring interdependent choices

- Strategic behaviour can cause unexpected aggregate phenomena
- Sometimes (privately) optimal not to do what others do
- Example: vaccination and herd immunity
- Sometimes (privately) optimal to do what others do
- Example: head lice in a nursery
- Different interactions lead to different aggregate behaviour
- Can have important policy implications

Policy and control

- Gersovitz and Hammer (2004) observe that
- *"The economic approach to infectious disease is in its infancy, somewhat oddly because many economists have long had the intuition that epidemics and infectious diseases are quintessential manifestations of the principle of an externality, itself a central concept in economics [...]"*
- *"Furthermore, epidemiology provides ready-made dynamic models of disease transmission and economics provides methods of valuing the costs and benefits of health interventions and methods of dynamic optimization to guide policy. Policy toward infections is of great importance. Yet only recently have economists begun to look at these questions in a formal way"*
- We have come a long way since then
- Happy to talk about integrating these ideas into more sophisticated epi models

More information

- Economic epidemiology site:
- https://sites.google.com/site/toxvaerd11/home/economic-epidemiology
- Research, policy writing, podcasts, talks
- Tweet new research and events at @toxvaerd1