The Macroeconomics of Epidemics

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Introduction

- As COVID-19 spreads throughout the world, governments are struggling with understanding and managing the epidemic.
- Epidemiology models are widely used to predict the course of the epidemic.
- While very useful, they don't allow for the interaction between economic decisions and rates of infection.
  - The epidemic causes a recession as some people shop and work less to reduce the chance of getting infected.
  - The number of people that work or go shopping influences the rate at which infections spread.

Introduction

- In our model, an epidemic has both aggregate demand and supply effects.
- Supply effect: epidemic exposes people who are working to the virus.
  - People react to that risk by reducing their labor supply.
- Demand effect: epidemic exposes people who are purchasing consumption goods to the virus.
  - People react to that risk by reducing their consumption.
- Supply and demand effects work together to generate a large, persistent recession.

Introduction

- Infection externality: people infected with the virus do not fully internalize the effect of their consumption and work decisions on the spread of the virus.

- What policies should gov't pursue to deal with infection externality?

- We study simple containment policies that reduce consumption and hours worked as well as "smart containment" which treats people differently according to their health status.

- Simple containment exacerbates the recession but raises welfare by reducing death toll caused by epidemic.

- Smart containment is dramatically better than simple containment.

Introduction

- To make intuition transparent, we use relatively simple model.
- We can't study many important, epidemic-related policy issues.
- Polices that mitigate household and business hardship
  - Fiscal transfers to people, loans to keep firms from going bankrupt.
  - Central bank interventions to maintain liquidity, health of financial markets.
- Nominal rigidities which could play important role in determining short-run response of economy.
  - With sticky prices, a demand fall generates larger recession.
  - A larger recession would mitigate the spread of the infection.

Introduction

Robust central message:

- There's an inevitable trade-off between severity of recession, health consequences of the epidemic.

SIR-macro model

- Point of departure: SIR model by Kermack and McKendrick (1927).
  - Exogenous transition probabilities between health states.

- Continuum of agents with measure one.

- The population is divided into four groups
  - Fraction S_t: susceptible (not yet been exposed to disease);
  - Fraction I_t: infected (contracted disease);
  - Fraction R_t: recovered (survived disease and acquired immunity);
  - Fraction D_t: deceased (died from disease).

SIR-macro model

- Prior to epidemic, everyone identical and maximize:

$$U = \sum_{t=0}^{\infty} \beta^t \left\{ lnc_t - (\theta/2) {n_t}^2 \right\}$$

- Household budget constraint:

$$(1 + \mu_t)c_t = w_t n_t + \Gamma_t$$

- μ_t: tax rate on consumption; proxy for containment measures that reduce social interactions;

- Γ_t: lump-sum transfers.
  - We refer to μ_t as the containment rate.

SIR-macro model

- Continuum of competitive representative firms of unit measure

$$C_t = AN_t$$

- Gov't budget constraint

$$\mu_t c_t = \Gamma_t.$$

Population dynamics

- Newly infected people given by transmission function:

$$T_t = \pi_1 (S_t C_t^S)(I_t C_t^I) + \pi_2 (S_t N_t^S)(I_t N_t^I) + \pi_3 S_t I_t.$$

- Number of susceptible people at time $t+1$:

$$S_{t+1} = S_t - T_t.$$

- Number of infected people at time $t+1$:

$$I_{t+1} = I_t + T_t - (\pi_r + \pi_d) I_t.$$

- $\pi_r =$ rate at which infected people recover from the infection
- $\pi_d =$ mortality rate.

Population dynamics

- Number of recovered people at time $t+1$:

$$R_{t+1} = R_t + \pi_r I_t.$$

- Number of deceased people at time $t+1$:

$$D_{t+1} = D_t + \pi_d I_t.$$

Population dynamics

- At time zero, a fraction ε of susceptible people is infected,

$$I_0 = \varepsilon,$$

$$S_0 = 1 - \varepsilon.$$

- All agents are aware of the initial infection and understand the laws of motion governing population health dynamics.

- All agents take as given aggregate variables like I_t, C_t^I and N_t^I.

Susceptible people

- Lifetime utility of susceptible person:

$$U_t^s = u(c_t^s, n_t^s) + \beta \left[(1 - \tau_t) \, U_{t+1}^s + \tau_t U_{t+1}^i \right].$$

- $\tau_t =$ probability that a susceptible person becomes infected:

$$\tau_t = \pi_1 c_t^s (I_t C_t^I) + \pi_2 n_t^s (I_t N_t^I) + \pi_3 I_t.$$

- Budget constraint:

$$(1 + \mu_t) c_t^s = w_t n_t^s + \Gamma_t.$$

Infected people

- Lifetime utility of infected person:

$$U_t^i = u(c_t^i, n_t^i) + \beta \left[(1 - \pi_r - \pi_d) \, U_{t+1}^i + \pi_r U_{t+1}^r + \pi_d \times 0 \right].$$

- Expression U_t^i embodies common assumption in macro and health economics that the cost of death is the foregone utility of life.

- Budget constraint:

$$(1 + \mu_t) c_t^i = w_t \phi^i n_t^i + \Gamma_t.$$

Recovered people

- Lifetime utility of recovered person:

$$U_t^r = u(c_t^r, n_t^r) + \beta U_{t+1}^r.$$

- Budget constraint:

$$(1 + \mu_t) c_t^r = w_t n_t^r + \Gamma_t.$$

Government budget constraint and equilibrium conditions

- Government budget constraint

$$\mu_t \left(S_t c_t^s + I_t c_t^i + R_t c_t^r \right) = \Gamma_t \left(S_t + I_t + R_t \right).$$

- Equilibrium conditions

$$S_t C_t^s + I_t C_t^i + R_t C_t^r = AN_t,$$

$$S_t N_t^s + I_t N_t^i \phi^i + R_t N_t^r = N_t.$$

Medical preparedness

- Efficacy of healthcare system is likely to deteriorate if substantial fraction of the population becomes infected.
- We model this possibility by assuming that mortality rate increases as number of infections rises

$$\pi_{dt} = \pi_d + \kappa I_t^2.$$

Treatments

- Suppose effective treatment that cures infected people arrives with probability δ_c per period.

- Treatment is implemented immediately, so number of new deaths from disease goes to zero.

- Lifetime utility of infected person before treatment is available:

$$U_t^i = u(c_t^i, n_t^i) + (1 - \delta_c)\beta \left[(1 - \pi_r - \pi_d) U_{t+1}^i + \pi_r U_{t+1}^r \right] + \beta \delta_c U_{t+1}^r.$$

Vaccination

- Vaccines arrives with probability δ_v per period.
- Once vaccine arrives, all susceptible become recovered.
- Infected are not helped by the vaccine.
- Lifetime utility of susceptible person before vacine arrives

$$U_t^s = u(c_t^s, n_t^s) + (1 - \delta_v)\left[(1 - \tau_t)\,\beta U_{t+1}^s + \tau_t \beta U_{t+1}^i\right] + \delta_v \beta U_{t+1}^r.$$

Parameter values

- Each period represents a week.
- It takes on average 18 days to either recover or die from the infection. $\pi_r + \pi_d = 7/18$.
- Mortality rate = 0.5 percent, $\pi_d = 7 \times 0.005/18$.
  - Weighted average of mortality rates by age in South Korea computed using U.S. population weights for people younger than 70 years old.

Parameter values

- Initial infected $= 0.001$.
- $A = 39.835$ and $\theta = 0.001275$.
  - Consistent with in pre-epidemic steady state representative person works 28 hours per week and earns a weekly income of $\$58,000/52$.
- $\beta = 0.96^{1/52}$ so value of life is 9.3 million 2019 dollars in pre-epidemic steady state.
  - Value used by U.S. government agencies.
  - Discuss robustness to value of life of 1.5 million
    - In the range of values in Hall, Jones and Klenow (2020).

Transmission function

- Relative importance of different modes of transmission in respiratory diseases (Ferguson et al. (2006)): 30 percent in the household, 33 percent in general community, and 37 percent in schools and workplaces.

- Use BLS 2018 Time Use Survey to estimate percentage of time spent on "general community activities" devoted to consumption.

- To compute the fraction of transmissions in workplace, we computed the weighted fraction of workers in workers plus students.

- Weight students and workers by average number of daily contacts, 10 and 4, respectively (Lee (2009)).

Transmission function

- Choose π_1, π_2 and π_3 so that:

$$\frac{\pi_1 C^2}{\pi_1 C^2 + \pi_2 N^2 + \pi_3} = 1/6,$$

$$\frac{\pi_2 N^2}{\pi_1 C^2 + \pi_2 N^2 + \pi_3} = 1/6.$$

- In addition, in the limit of the simple SIR model 60 percent of the population either recovers from the infection or dies (Merkel scenario).

Figure 1: Basic SIR-Macro Model vs. SIR Model

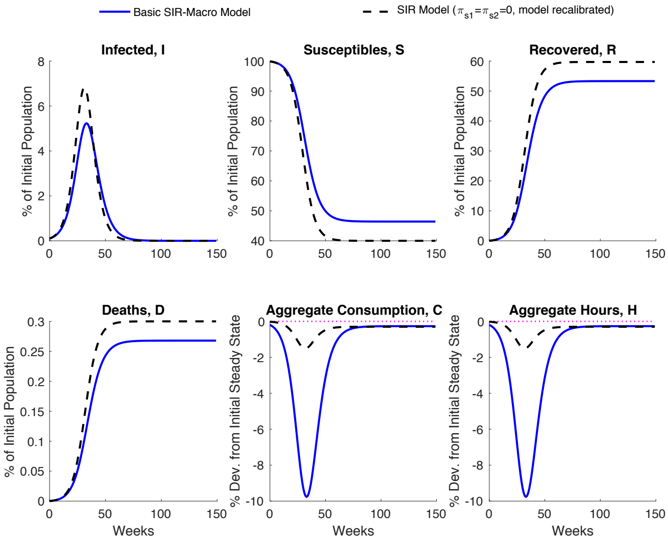


Figure 3: Basic SIR-Macro Model With and Without Containment

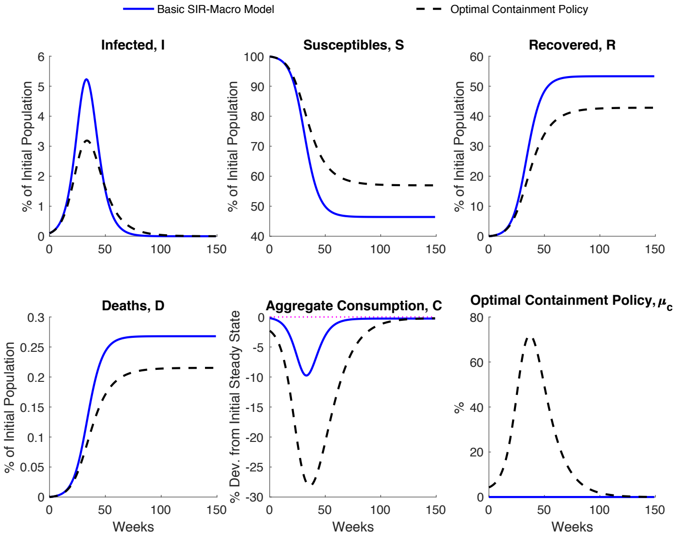


Figure 7: Benchmark SIR-Macro Model (Vaccines, Treatment, Med. Preparedness)

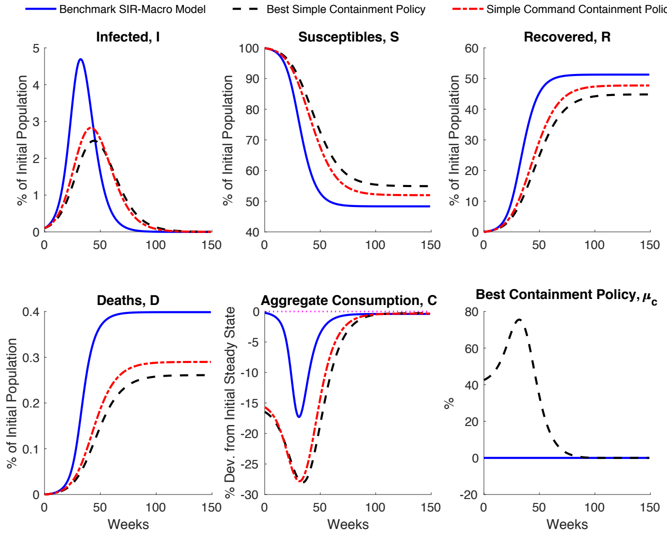
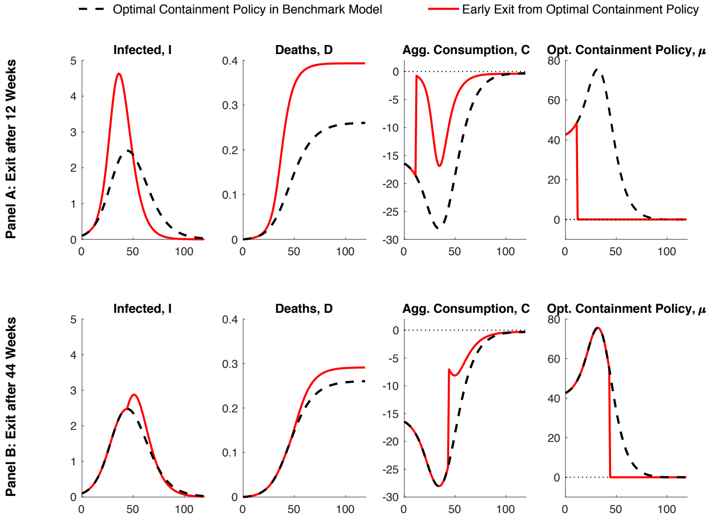
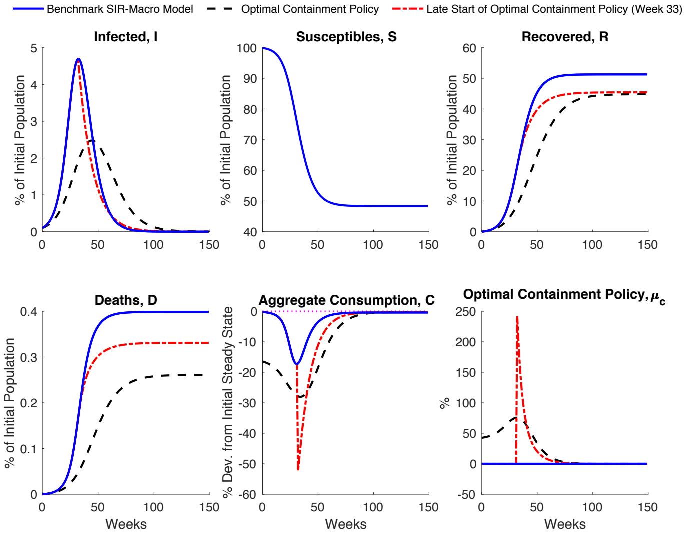


Figure 8: Benchmark SIR-Macro Model (Vaccines, Treatment, Med. Preparedness)



Notes: x-axis in weeks; infected and deaths in % of ini. population; consumption in % dev. from ini. steady state; opt. containment policy in %.

Figure 9: Benchmark SIR-Macro Model (Vaccines, Treatment, Med. Preparedness)



Smart containment

- How well can a social planner who chooses consumption and hours worked of susceptible, infected and recovered people do?
- We call this solution "smart containment."
- The planner maximizes the social welfare, U_0. Since at time zero $R_0 = D_0 = 0$, the value of U_0 is

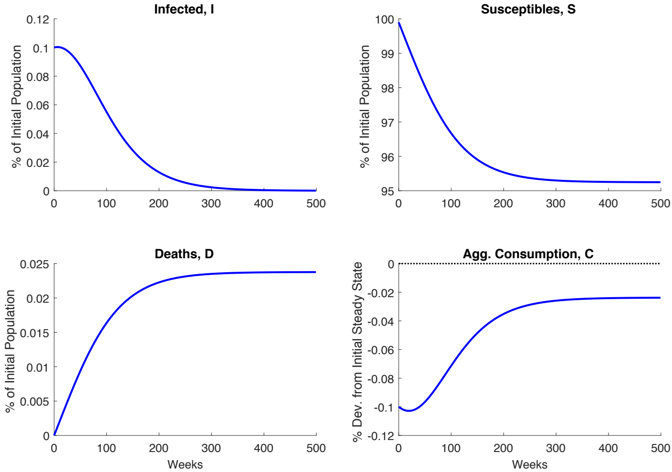
$$U_0 = S_0 U_0^s + I_0 U_0^i.$$

Smart containment

The constraints of the problem are

- the transmission function;
- the laws of motion for the population;
- the lifetime utility of infected and recovered and
- the lifetime utility of susceptible people computed using the aggregate transition probabilities because the planner internalizes the infection externalities.

Figure 10: Smart Containment in the Benchmark SIR-Macro Model



Smart containment

- Infected people do not work unless they recover. As a result, all susceptible people can work without fear of becoming infected.
- The planner sets the consumption of infected people to a minimum.
  - There is no maximum to the social planning problem, only a supremum.
- Because infected people are completely isolated, the initial infection quickly dies out without causing a recession.
- Solution can be improved if planner can directly deliver consumption goods to those infected.
  - Infected people don't work but they consume the same as other people.

Smart containment

- Implementing smart containment requires policy makers to know the health status of different individuals.
- What happens in a world where people do not know their true health status?

The Macroeconomics of Testing and Quarantines

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Figure 3: Model with Testing and Smart Containment

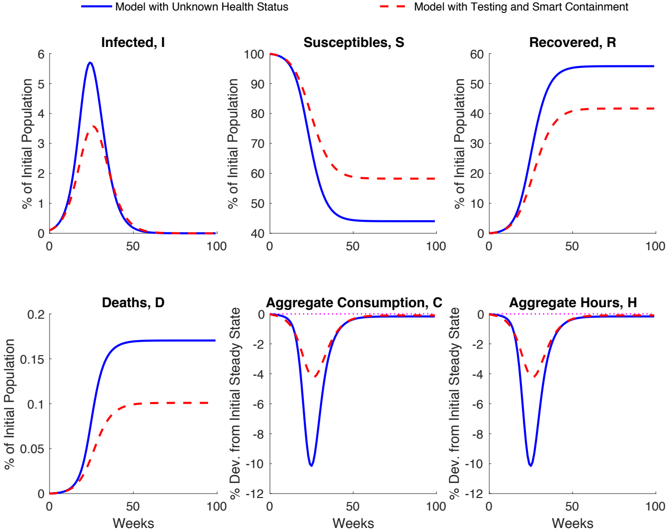


Figure 6: Model with Testing and Strict Containment

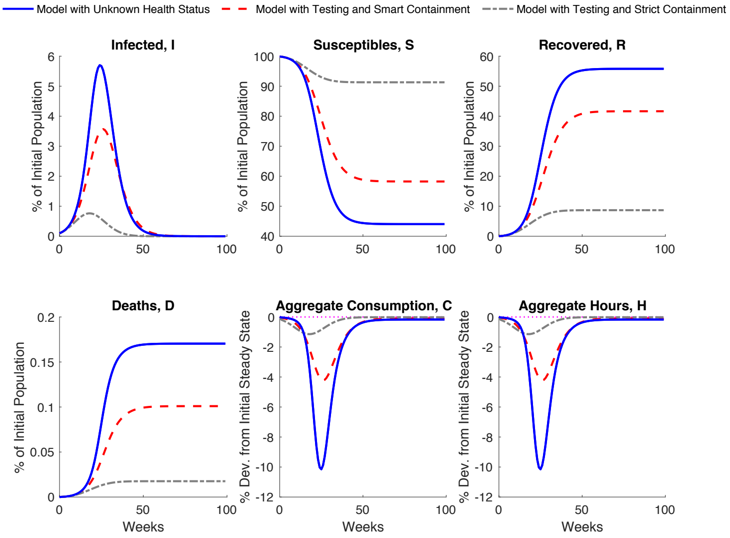
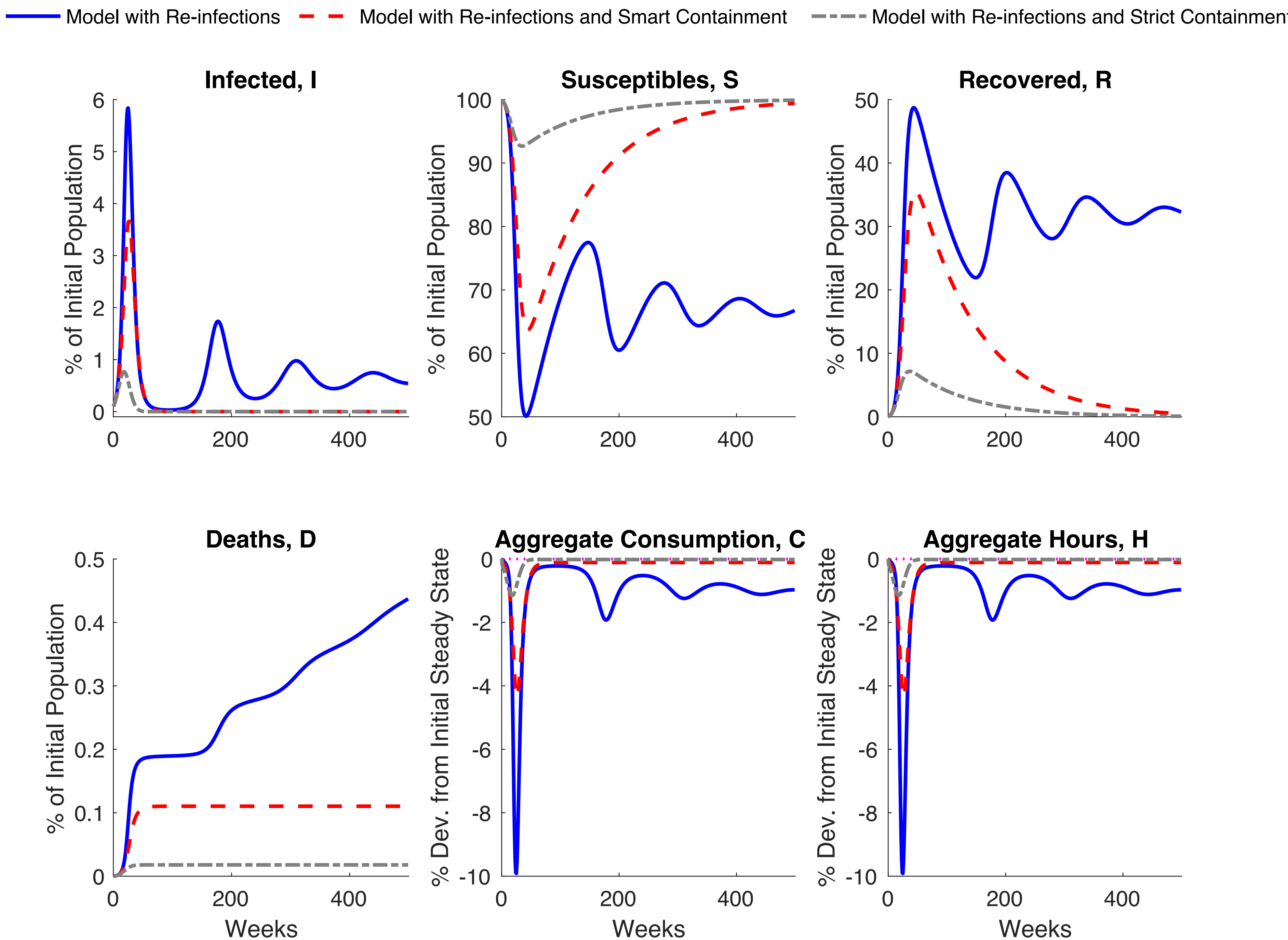


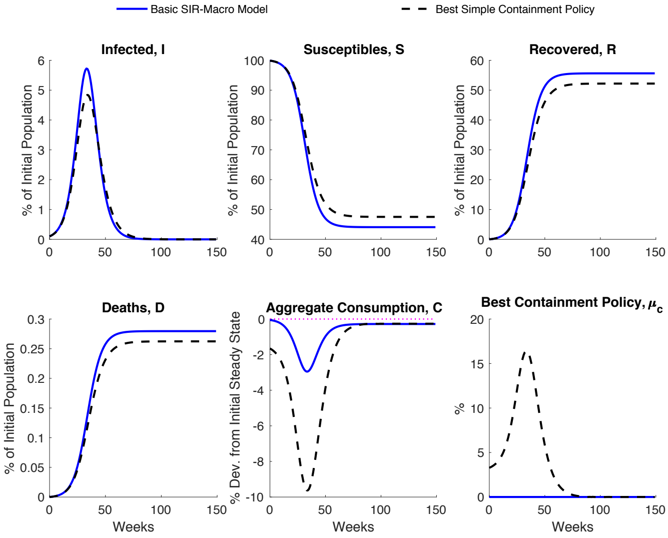
Figure 10: Model with Re-infections, Testing and Containment



Conclusion

- We extend the canonical epidemiology model to study the interaction between economic decisions and epidemics.
- The model allows us to explore the trade off between the severity of the short-run recession caused by the epidemic and the health consequences of that epidemic.
- We abstracted from forces that affect the long-run performance of the economy: bankruptcy costs, unemployment hysteresis effects, and the destruction of supply-side chains.
- It is important to embody these forces in macroeconomic models of epidemics and study their positive and normative implications.

Figure 3: Basic SIR-Macro Model With and Without Containment (Lower Value of Life)



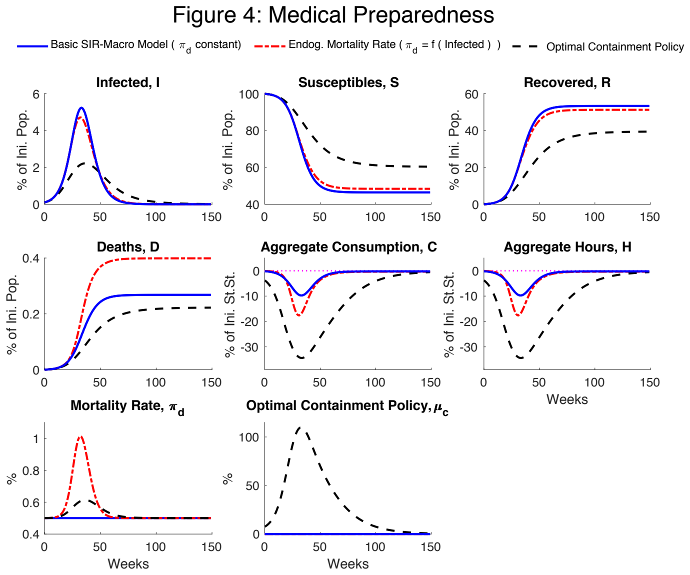


Figure 4: Medical Preparedness
Basic SIR-Macro Model (π_d constant)
Endog. Mortality Rate (π_d = f (Infected))
Optimal Containment Policy
Infected, I
Susceptibles, S
Recovered, R
Deaths, D
Aggregate Consumption, C
Aggregate Hours, H
Mortality Rate, π_d
Optimal Containment Policy, μ_c
% of Ini. Pop.
% of Ini. St.St.
%
Weeks

Figure 5: SIR-Macro Model With Treatments

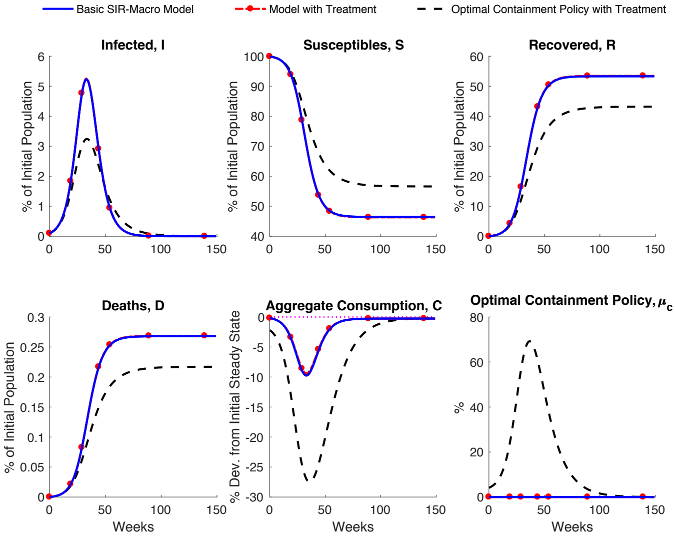


Figure 6: SIR-Macro Model With Vaccines

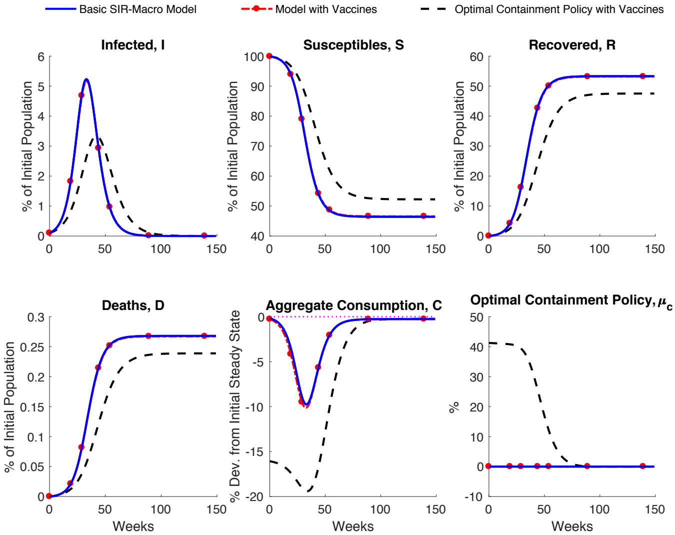


Figure 7: Benchmark SIR-Macro Model (Vaccines, Treatment, Med. Preparedness)

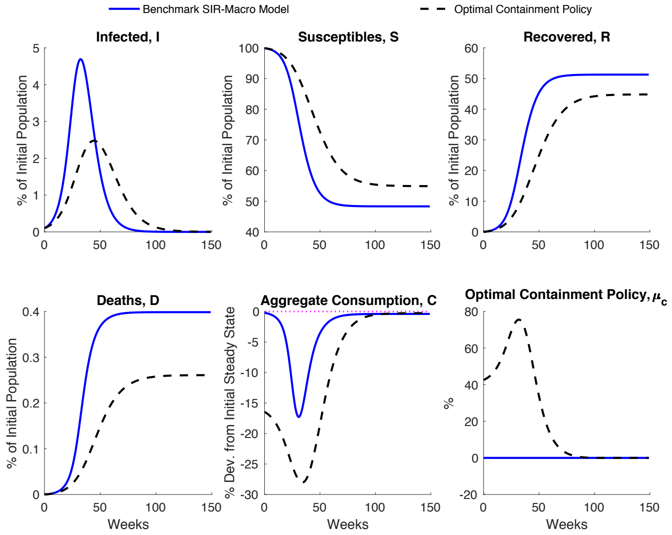


Figure 7: Benchmark SIR-Macro Model (Vacc., Treat., Med. Prep.; Lower Value of Life)