The Macroeconomics of Epidemics

Martin S. Eichenbaum, Sergio Rebelo & Mathias Trabandt

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Presented by Javier Rodríguez for the Macro Reading Group

Universidad Carlos III de Madrid

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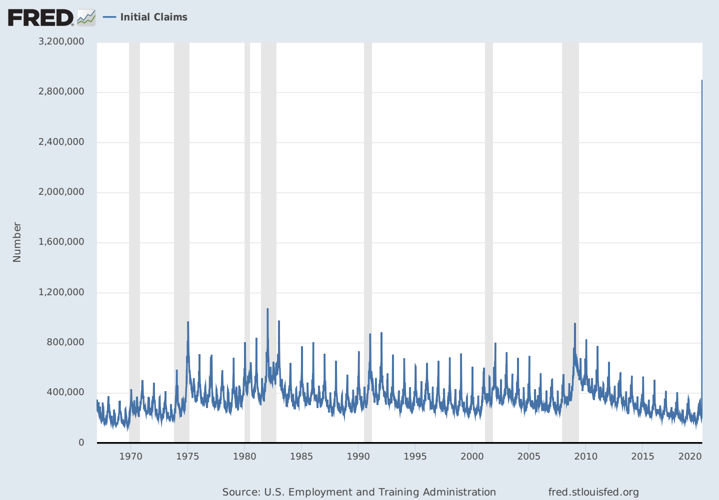
Weekly unemployment insurance initial claims in the US



Motivation and research question

Motivation

- COVID-19.
- Interaction between economic decisions and rates of infection.

Research question

What are the aggregate effects resulting from the interaction between economic decisions and epidemic dynamics? What is the optimal containment policy?

This paper

- Extends the SIR model to include economic decisions.
- Epidemic has both aggregate demand and aggregate supply effects.
- Competitive equilibrium not Pareto optimal.
- Focus on containment policies that reduce consumption and hours worked.
- Containment policies exacerbate the drop in output but raise welfare by saving lives.
- Simple model. No mitigating economic policies, no nominal rigidities.

The SIR model

- S=susceptible, I=infectious, R=removed.
- Canonical epidemiology model.
- Basic form is just a couple of linear difference equations governing the fraction of people in each category:

$$S_{t+1} = S_t - \beta I_t S_t$$
$$I_{t+1} = I_t + \beta I_t S_t - \gamma I_t$$
$$R_{t+1} = R_t + \gamma I_t$$

- Basic reproduction number $R_0 = \frac{\beta}{\gamma}$. Epidemics occur when $R_0 > 1$.

The SIR-macro model: pre-infection economy

- Representative agent solves:

$$\max_{\{c_t,n_t\}_{t=0}^{\infty}} U = \sum_{t=0}^{\infty} \beta^t u(c_t, n_t)$$

$$s.t.$$

$$(1+\mu_{ct})\, c_t = w_t n_t + \Gamma_t \quad \forall t$$

where $u(c_t, n_t) = \ln c_t - \frac{\theta}{2} n_t^2$ and the FOC is $(1+\mu_{ct})\,\theta n_t = c_t^{-1} w_t$.

- Firm solves:

$$\max_{N_t} \Pi_t = AN_t - w_t N_t \quad \forall t$$

- Government's budget constraint is $\mu_{ct} c_t = \Gamma_t \quad \forall t$
- In equilibrium $n_t = N_t$ and $c_t = AN_t$.

The SIR-macro model: outbreak of an epidemic

- Population is divided into four groups: S_t, I_t, R_t and D_t.
- $I_0 = \epsilon$, $S_0 = 1 - \epsilon$, $R_0 = D_0 = 0$.
- Total number of newly infected is:

$$T_t = \pi_{s1}(S_t C_t^S)(I_t C_t^I) + \pi_{s2}(S_t N_t^S)(I_t N_t^I) + \pi_{s3} S_t I_t.$$

- Evolution of population stocks:

$$\begin{aligned} S_{t+1} &= S_t - T_t \\ I_{t+1} &= I_t + T_t - (\pi_r + \pi_d) I_t \\ R_{t+1} &= R_t + \pi_r I_t \\ D_{t+1} &= D_t + \pi_d I_t \end{aligned}$$

The SIR-macro model: the economy during the epidemic

- U_t^j is time-t lifetime utility of a type-j agent $(j = s, i, r)$.
- Budget constraint is $(1 + \mu_{ct})\, c_t^j = w_t \phi^j n_t^j + \Gamma_t$, with $\phi^s = \phi^r = 1$ and $\phi^i < 1$.
- Lifetime utilities:
  - Susceptible:

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

$$\text{where } \tau_t = \pi_{s1} c_t^s (I_t C_t^I) + \pi_{s2} n_t^s (I_t N_t^I) + \pi_{s3} S_t I_t$$

  - Infected:

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

  - Recovered:

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

- Government budget constraint: $\mu_{ct} = \left(S_t c_t^s + I_t c_t^i + R_t c_t^r \right) = \Gamma_t \left(S_t + I_t + R_t \right)$.
- Equilibrium: $S_t c_t^s + I_t c_t^i + R_t c_t^r = AN_t$ and $S_t n_t^s + I_t n_t^i + R_t n_t^r = N_t$.

Parameter values

- One time period=one week.
- $\pi_d + \pi_r = 7/18$, $\pi_d = 7 \times 0.01/18$.
- Use of the standard SIR to compute π_{s1}, π_{s2} and π_{s3} assuming 65% of population gets infected (according to Merkel).
- $A = 39.8$, $\theta = 36$ chosen to match pre-epidemic hours worked and GDP per capita in the US.
- $\beta = 0.96^{1/52}$ so that the value of a life in pre-epidemic SS is 9.3 million USD.
- $\phi = 0.8$ percentage of asymptomatic cases.

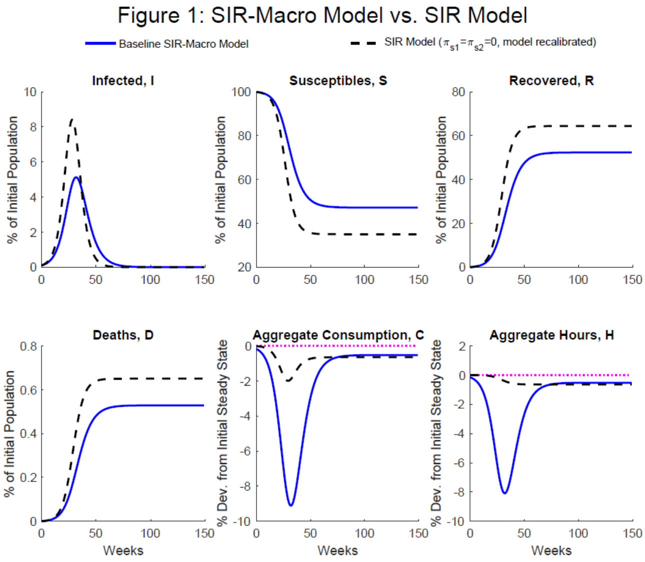


Figure 1: SIR-Macro Model vs. SIR Model
Baseline SIR-Macro Model
SIR Model ($\pi_{s1}=\pi_{s2}=0$, model recalibrated)
Infected, I
Susceptibles, S
Recovered, R
Deaths, D
Aggregate Consumption, C
Aggregate Hours, H
% of Initial Population
% Dev. from Initial Steady State
Weeks

Containment

- The competitive equilibrium is NOT Pareto optimal.
- This is due to a classical externality: infected people do not take into account the impact of their actions on the infection and death rates of other agents.
- Containment measures by the government are modeled as a tax on consumption μ_{ct}.
- The optimal containment policy is a sequence $\{\mu_{ct}\}_{t=0}^{249}$ that maximizes social welfare:

$$U_0 = s_0 U_0^s + i_0 U_0^i + r_0 U_0^r$$

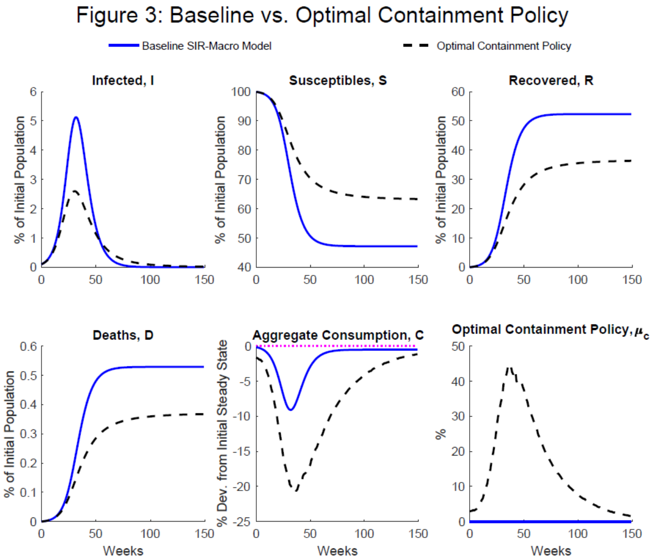


Figure 3: Baseline vs. Optimal Containment Policy
Baseline SIR-Macro Model
Optimal Containment Policy
Infected, I
Susceptibles, S
Recovered, R
Deaths, D
Aggregate Consumption, C
Optimal Containment Policy, μ_c
% of Initial Population
% Dev. from Initial Steady State
%
Weeks

Medical preparedness, treatment and vaccines

- Medical preparedness:

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

- Treatment:

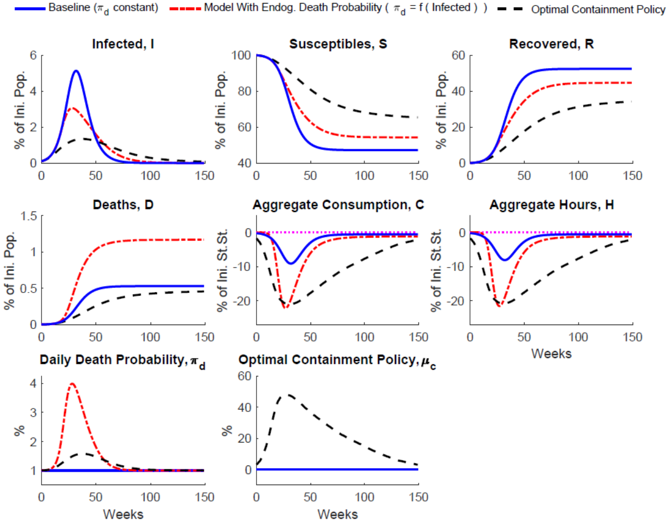
$$U_t^i = u(c_t^i, n_t^i) + \beta (1-\delta) \left[(1 - \pi_r - \pi_d) U_{t+1}^i + \pi_r U_{t+1}^r \right] + \beta \delta U_{t+1}^r$$
$$D_t = D_{t^*} \quad \forall t \geq t^*$$
$$R_t = 1 - D_t \quad \forall t \geq t^*$$

- Vaccine:

$$U_t^s = u(c_t^s, n_t^s) + \beta (1-\delta) \left[(1 - \tau_t) U_{t+1}^s + \tau_t U_{t+1}^i \right] + \beta \delta U_{t+1}^r$$
$$S_{t^*}' = 0$$
$$R_{t^*}' = R_{t^*} + S_{t^*}$$

- Parameter values:
  - $\kappa = 12.5$ for peak mortality of 4 percent.
  - $\delta = 1/52$.

Figure 4: Medical Preparedness



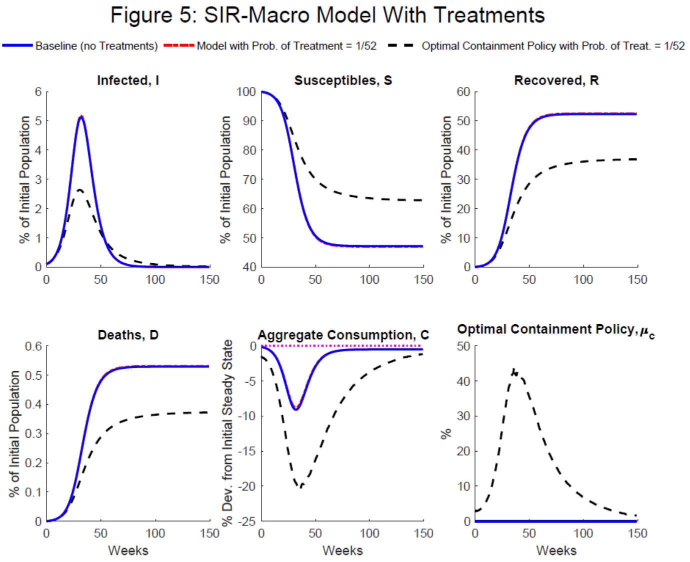


Figure 5: SIR-Macro Model With Treatments
Baseline (no Treatments)
Model with Prob. of Treatment = 1/52
Optimal Containment Policy with Prob. of Treat. = 1/52
Infected, I
Susceptibles, S
Recovered, R
Deaths, D
Aggregate Consumption, C
Optimal Containment Policy, μ_c
% of Initial Population
% Dev. from Initial Steady State
%
Weeks

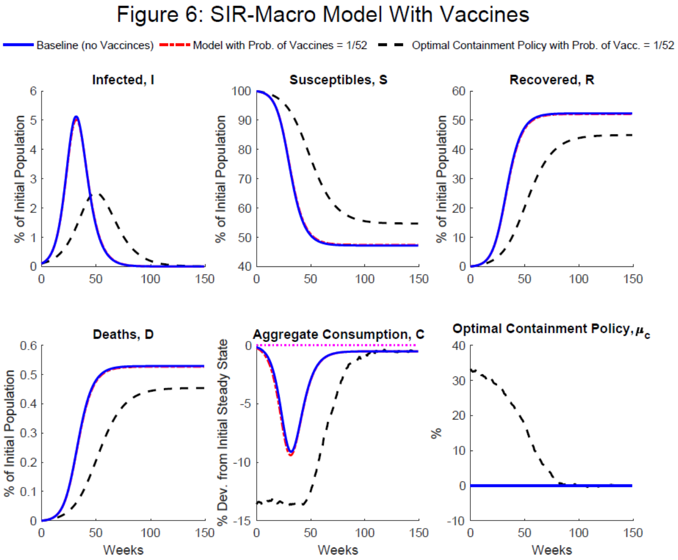


Figure 6: SIR-Macro Model With Vaccines
Baseline (no Vaccinces)
Model with Prob. of Vaccines = 1/52
Optimal Containment Policy with Prob. of Vacc. = 1/52
Infected, I
Susceptibles, S
Recovered, R
Deaths, D
Aggregate Consumption, C
Optimal Containment Policy, μ_c
% of Initial Population
% Dev. from Initial Steady State
%
Weeks

Conclusions

- Bottom line: inevitable trade-off between severity of recession and health consequences of the epidemic.
- Other important forces not considered here:
  - Bankruptcy costs.
  - Hysteresis.
  - Supply chain disruptions.
  - Uncertainty.

More thoughts

Fatih Guvenen
@fatihguvenen

For economists who write models on COVID-19, the unprecedented scale of the shock makes computational methods that linearize around a steady state all but obsolete.
There will be enormous nonlinearities whose nature one can't conjecture without solving model fully nonlinearly.

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