Health versus Wealth: On the Distributional Effects of Controlling a Pandemic

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MMCN Webinar on Macroeconomic Modelling and Pandemics

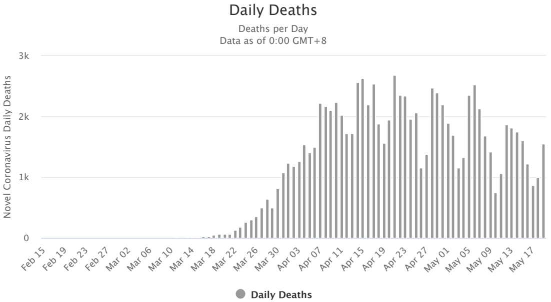
June 3, 2020

Motivation: Dimensions of the CoViD-19 Crisis

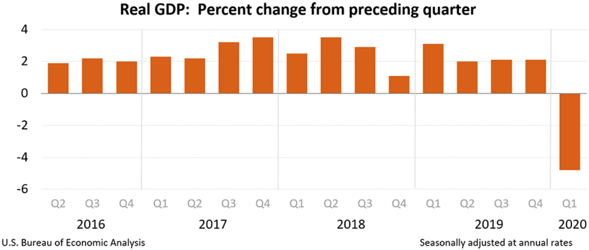
- Health: Covid-19 and the Population Health Distribution
  - Exponential Growth in Daily Deaths in U.S. in March 2020.
  - Age Dependency of Deaths: Disease mainly affects the Old.
- "Wealth": The Real Economy: GDP and Unemployment
  - Record New Unemployment Benefit Claims
  - Spike in Unemployment Rate
  - Massive GDP Decline

Motivation: Dimensions of the CoViD-19 Crisis

Health:
U.S. Daily Deaths
At peak $> 2,000$.



Economics:
Deep recession
Q.II: 25-30%?



Motivation: Health Dimensions of the CoViD-19 Crisis

AGE	Number of Deaths	Share of deaths	With underlying conditions	Without underlying conditions	Unknown if with underlying cond.	Share of deaths of unknown + w/o cond.
0 - 17 years old	9	**0.06%**	6	3	0	0.02%
18 - 44 years old	601	**3.9%**	476	17	108	0.8%
45 - 64 years old	3,413	**22.4%**	2,851	72	490	3.7%
65 - 74 years old	3,788	**24.9%**	2,801	5	982	6.5%
75+ years old	7,419	**48.7%**	5,236	2	2,181	14.3%
TOTAL	**15,230**	100%	11,370 (75%)	99 (0.7%)	1,551 (24.7%)	25.3%

Figure: Covid-19 Fatalities in New York City by Age

Motivation: Economic Dimensions of CoViD-19 Crisis

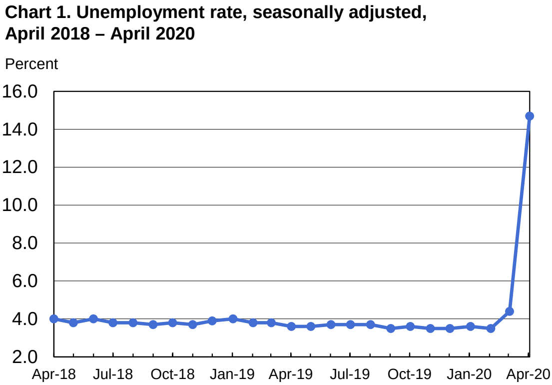


Figure: Unemployment Rate in the U.S.

- Unemployment rate 14.7% in April 2020.
- Labor force participation rate 60.2%, lowest since early 1970's.

The Research Question

- Broad question: What is the appropriate economic policy response to the pandemic?
- Specific Question: How extensive should the macroeconomic shutdown be, and when should it end?
- Key Point of the Paper: Large distributional implications of shutdown policies
    - Health benefits concentrated among the old
    - Economic costs concentrated among the young and especially those working in sectors that are being shut down
- Some combination of shutdown and redistribution policies needed

What we do

- Build an epidemiological/macro model with heterogenous agents
- Assume that transfers across agents are costly
- Assess combination of two policies
  - Shutdown (less output but also less contagion)
  - Redistribution toward those whose jobs are shuttered
- Characterize optimal policy
- Key interaction:
  - Shutdown creates the need for more redistribution
  - But if redistribution is costly, want less severe shutdown
  - Need heterogeneous-agent model to analyze this

Epidemiology ("Health"): The SAFER SIR Model

- Stage of the disease
  - **S**usceptible
  - Infected **A**symptomatic
  - Infected with **F**lu-like symptoms
  - Infected and needing **E**mergency hospital care
  - **R**ecovered (and **D**ead)
- Worst case disease progression: $\mathbf{S} \rightarrow \mathbf{A} \rightarrow \mathbf{F} \rightarrow \mathbf{E} \rightarrow \mathbf{D}$
- But recovery is possible at each stage
- Three infected types spread virus in different ways:
  - **A** at work, while consuming, at home
  - **F** at home
  - **E** to health-care workers

Economics ("Wealth"): Heterogeneity by Age & Sector

- Age $i \in \{\mathbf{y}, \mathbf{o}\}$
  - Only young work
  - Young more prone to contagion (since they work)
  - But old have more adverse outcomes conditional on contagion
  - Old discount future at higher rate, reflecting shorter life expectancy

- Sector of production $\{\mathbf{b}, \ell\}$
  - Basic (health care, food production, law enforcement, government)
    - Never want shut-downs in this sector
    - Workers in this sector care for the hospitalized
  - Luxury (restaurants, entertainment etc.)
    - Government chooses what fraction m of this sector to shutter
    - Workers in this sector face shutdown unemployment risk
    - But they are less likely to get infected

Interaction between Health & Wealth induced by Policy

- Shutdown (Mitigation)
  - Reduces contagion
  - Reduces risk of hospital overload
  - Reduces average consumption
  - Increases inequality (more unemployment)

- Redistribution
  - Helps the unemployed $\Rightarrow$ makes mitigation more palatable
  - But redistribution is costly $\Rightarrow$ makes mitigation more expensive

- What policies do different household types prefer?

- How does Utilitarian optimal policy vary with the cost of redistribution?

Preferences

- Lifetime utility for old

$$E\left\{\int e^{-\rho_o t}\ \left[u(c_t^o)+\bar{u}+\widehat{u}_t^j\right]\ dt\right\}$$

  - ρ_o: time discount rate
  - $u(c_t^o)$ instantaneous utility from old age consumption c_t^o
  - $\bar{u}$: value of life
  - $\widehat{u}_t^j$: intrinsic (dis)utility from health status j (zero for $j \in \{s, a, r\}$)
- Same lifetime utility function for young.
- Differences in expected longevity: $\rho_y < \rho_o$ (but no explicit aging)

Technology

- Young permanently assigned to sector b or ℓ
- Linear production: output equals number of healthy workers
- Only workers with health $\{s, a, r\}$ work
- Output in basic sector:

$$y^b = x^{ybs} + x^{yba} + x^{ybr}$$

- Output in luxury sector is

$$y^\ell(m) = [1 - m] \left(x^{y\ell s} + x^{y\ell a} + x^{y\ell r} \right)$$

- Total output given by

$$y(m) = y^b + y^\ell(m)$$

- Fixed amount of output $\eta\Theta$ spent on emergency health care
- Θ measures capacity of emergency health system, η its unit cost

Virus Transmission

- Types of transmission
  - **w**ork: young workers infected by **A** workers, prob $\beta_w(m)$
  - **c**onsumption: young & old infected by **A** shoppers, prob $\beta_c(m) \times y(m)$
  - **h**ome: young & old infected by **A** and **F** family, prob β_h
  - **e**mergency: basic workers infected by **E**, prob β_e
- infection-generating rates $\beta_w(m)$ & $\beta_c(m)$ depend *negatively* on extent of mitigation:

$$\beta_w(m) = \alpha_w \left[\frac{y^b + y^\ell(m)(1-m)}{y(m)} \right]$$

  - Similar for $\beta_c(m)$
- Micro-founded: sectoral heterogeneity of contact rates $\beta_w^i = 2\alpha_w i$.
- Smart mitigation shutters most contact-intensive sub-sectors $i \in [m, 1]$ first. Then $E_i[2\alpha_w i | i \leq 1-m] = \alpha_w(1-m)$.

Flow into asymptomatic (out of susceptible) state

$$\dot{x}^{ybs} = -\left[\beta_w(m_t)\mu_w(m_t) + \beta_c(m_t)\mu_c(m_t) + \beta_h\mu_h + \beta_e\mu_e\right]\ x^{ybs}$$
$$\dot{x}^{y\ell s} = -\left[\beta_w(m_t)\mu_w(m_t)(1-m_t) + \beta_c(m_t)\mu_c(m_t) + \beta_h\mu_h\right]\ x^{y\ell s}$$
$$\dot{x}^{os} = -\left[\beta_c(m_t)\mu_c(m_t) + \beta_h\mu_h\right]\ x^{os}$$

- The μ's are the numbers of contagious people an **s**-type meets. E.g. $\mu_e = x^e, \mu_h = x^a + x^f$ and so on.
- Shutdowns (mitigation) reduce infections by:
  - Reducing number of workers ⇒ less workplace transmission
  - Reducing output $y(m)$ ⇒ less consumption transmission
  - No impact on home or hospital transmission

Flows into other health states

- For each type $j \in \{yb, y\ell, o\}$

$$
\begin{aligned}
\dot{x}^{ja} &= -\,\dot{x}^{js} - \left(\sigma^{jaf} + \sigma^{jar}\right)\ x^{ja} \\
\dot{x}^{jf} &= \sigma^{jaf}\ x^{ja} - \left(\sigma^{jfe} + \sigma^{jfr}\right)\ x^{jf} \\
\dot{x}^{je} &= \sigma^{jfe}\ x^{jf} - \left(\sigma^{jed} + \sigma^{jer}\right)\ x^{je} \\
\dot{x}^{jr} &= \sigma^{jar} x^{ja} + \sigma^{jfr} x^{jf} + (\sigma^{jer} - \varphi) x^{je} \\
\varphi &= \lambda_o \max\{x^e - \Theta, 0\}.
\end{aligned}
$$

- where all the flow rates σ vary by age
- $x^e - \Theta$ measures excess demand for emergency health care. Reduces flow of recovered (Increases flow into death)

Redistribution

- Costly transfers between workers, non-workers (old, sick, unemployed)
- Utilitarian planner: taxes/transfers don't depend on age/sector/health
  - Workers share common consumption level c^w
  - Non-workers share common consumption level c^n
- Define measures of non-working and working as

$$\begin{aligned}
\mu^n &= x^{y\ell f} + x^{y\ell e} + x^{ybf} + x^{ybe} + m\left(x^{y\ell s} + x^{y\ell a} + x^{y\ell r}\right) + x^o \\
\mu^w &= x^{ybs} + x^{yba} + x^{ybr} + [1-m]\left(x^{y\ell s} + x^{y\ell a} + x^{y\ell r}\right) \\
\nu^w &= \frac{\mu^w}{\mu^w + \mu^n}
\end{aligned}$$

- Aggregate resource constraint

$$\mu^w c^w + \mu^n c^n + \mu^n T(c^n) = y - \eta\Theta = \mu^w - \eta\Theta$$

  - where $T(c^n)$ is per-capita cost of transferring c^n to non-workers

Instantaneous Social Welfare Function

- Consumption allocation does not affect disease dynamics $\Rightarrow$ optimal redistribution is a static problem
- With log-utility and equal weights, the period social welfare is

$$W(x,m) = \max_{c^n, c^w} \left[\mu^w \log(c^w) + \mu^n \log(c^n)\right] + (\mu^w + \mu^n)\bar{u} + \sum_{i,j \in \{f,e\}} x^{ij} \widehat{u}^j$$

- Maximization subject to resource constraint gives $\frac{c^w}{c^n} = 1 + T'(c^n)$.

Instantaneous Social Welfare Function

- Assume $\mu^n T(c^n) = \mu^w \frac{\tau}{2}\left(\frac{\mu^n c^n}{\mu^w}\right)^2$
- Optimal allocation

$$
\begin{aligned}
c^n &= \frac{\sqrt{1+2\tau\frac{1-\nu^2}{\nu}\tilde{y}}-1}{\tau\frac{1-\nu^2}{\nu}} \\
c^w &= c^n(1+T'(c^n))) = c^n\left(1+\tau\frac{1-\nu}{\nu}c^n\right)
\end{aligned}
$$

where $\tilde{y} = \nu - \frac{\eta\Theta}{\mu^w+\mu^n}$.

- $\left(1+\tau\frac{1-\nu}{\nu}c^n\right)$ is the effective marginal cost of transfers.
- It increases with c^n and τ, decreases with share of workers ν
- Higher mitigation m reduces ν, thus increases marginal cost
- $\Rightarrow$ policy interaction between m, τ.

Calibration: Overview

- Households Preferences calibrated externally:
  - Young < 65 (85% of population), Old ≥ 65
  - Value of Life: VSL is \$11.5m $\Rightarrow$ \$515k flow value (11.4 pc cons.)
  - Log-utility, bad health reduces utility
- Production Technology calibrated externally:
  - Size of basic Sector: 45%
  - $\Theta = 0.042\%$ (100,000 beds), mortality rates up 20% if above capacity
- Virus Transmission and Health Evolution (many parameters)
  - Medical data on transition probabilities, average length in A, F, E
  - Data on frequency of contacts at work, shopping, social settings
  - Implied case fatality rates: 2.5% for old, 0.1% for young
- Mitigation Time Path (γ_0 controls level, γ_2 length, γ_1 speed of opening up):

$$m(t) = \frac{\gamma_0}{1 + \exp(-\gamma_1(t - \gamma_2))}$$

- Redistibution: Costs \$1.38 to transfer \$1 (Saez et al., 2012) $\Rightarrow T(.)$
- Initial Conditions: Try to get U.S. right on April 12.

Calibration: Preferences:

- $u(c) = \log(c)$
- Young < 65 (85% of population), Old ≥ 65
- $\rho_y = 4\%$ and $\rho_o = 10\%$: pure discount rate of 3% plus adjustment for 47.5 & 14 years of residual life expectancy
- $\bar{u} = 11.4 - \log(\bar{c})$: VSL is \$11.5m $\Rightarrow$ \$515k flow value or $11.4 \times$ US cons. pc
  - Static trade-off: pay 10.8% of cons. to avoid 1% death probability
  - Dynamic: give up 25% of cons. for 6 months for 0.16% increase in chance of living 10 more years
- $\hat{u}^f$, $\hat{u}^e$: flu reduces baseline utility by 30%, hospital by 100%

Calibration: Disease Progression (Imperial Model)

1. Avg. duration asymptomatic: 5.3 days
   - 50% recover (important unknown)
   - 50% develop flu
2. Avg. duration of flu: 10 days
   - 96% of young recover
   - 75% of old recover
   - rest move to emergency care
3. Avg. duration of emergency care: 8 days
   - 95% of young recover (absent overcapacity)
   - 80% of old recover (absent overcapacity)
   - rest die

- These moments pin down all the σ parameters
- Implied death rates (absent overuse) 2.5% for the old, 0.1% for young

Calibration: Economics

- Production
  - Size of basic Sector: 45%
    - ★ basic = health, agriculture, utilities, finance, federal govt
    - ★ luxury = manuf., constr., mining, educ., leisure & hospitality
    - ★ split the rest similarly
  - $\Theta = 0.042\%$ (100,000 beds), λ_o s.t. mortality up 20% at infection peak
- Redistribution
  - Marginal excess burden 38% pre-COVID ($\tau = 3.5$, Saez, Slemrod, Giertz 2012)
  - $\Rightarrow$ planner chooses $\frac{c^n}{c^w} = \frac{1}{1.38}$
- Mitigation time path

$$m(t) = \frac{\gamma_0}{1 + \exp(-\gamma_1(t - \gamma_2))}$$

Calibration: Virus Transmission

- Set α_w/β_h, α_c/β_h to match evidence on number of potentially infectious contacts Mossong et al. (2008)
  - 35% of transmission occurs in workplaces and schools (model work)
  - 19% occur in travel and leisure activities (model consumption)
- Set β_e so that 5% of infections are to health care workers as of April 12, 2020
- β_h then determines basic reproduction number R_0 (next slides)

Calibration: Initial Conditions

- Will focus on alternative mitigation policies starting from April 12
- But how many people are already infected? How fast is the virus spreading?
- Data challenges:
  - Estimates of COVID-19 R_0 from early days in Wuhan are outdated: behaviors and policies have changed drastically
  - Limited testing $\Rightarrow$ positive test counts understate true infection levels
  - Most reliable numbers are for deaths (even those under-counted)

Our Strategy

- Assume initial arrival of infected individuals on Feb 12
- Assume America changed on March 21
  1. One-time proportional drop in infection-generating rates α_w, α_c, β_h $\Rightarrow R_0$ falls
  2. $m = 0 \rightarrow m = 0.5 \Rightarrow 27.7\%$ fall in employment (consistent with Faria-e-Castro (2020) and Bick & Blandin (2020))
- Set infection-generating rates pre-and post March 21 and Feb 12 infected population to match NY Times deaths data:
  1. Cumulative deaths on March 21: 343
  2. Cumulative deaths on April 12: 22,055
  3. Daily death toll around April 12: 1,632

Calibration: Initial Conditions and R_0

Target	$I_{t_1} = 12$	$D_{t_2} = 343$	$D_{t_3} = 22,055$ $D_{t_3} - D_{t_3-1} = 1,632$	
Parameter	$R_{t_1} = 3.61$	$R_{t_2} = 1.02$, under $m_{t_2} = 0.5$		
t_0	Febr. 12 (t_1)	March 21 (t_2)	April 12 (t_3)	Time t

Millions of People in Each Health State

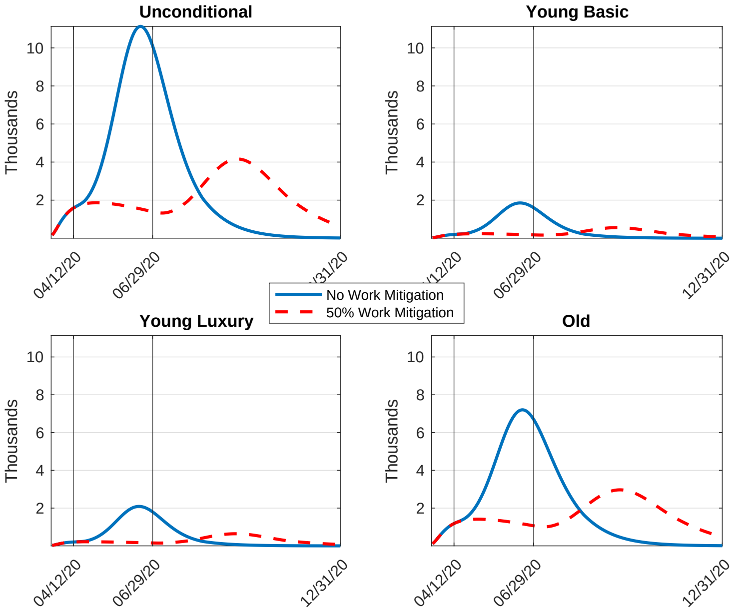
	S	**A**	**F**	**E**	**R**	**D (actual)**
03/21/20	323.71	4.17	0.84	0.01	1.27	343
04/12/20	311.31	2.95	2.72	0.12	12.88	22,055

Experiments

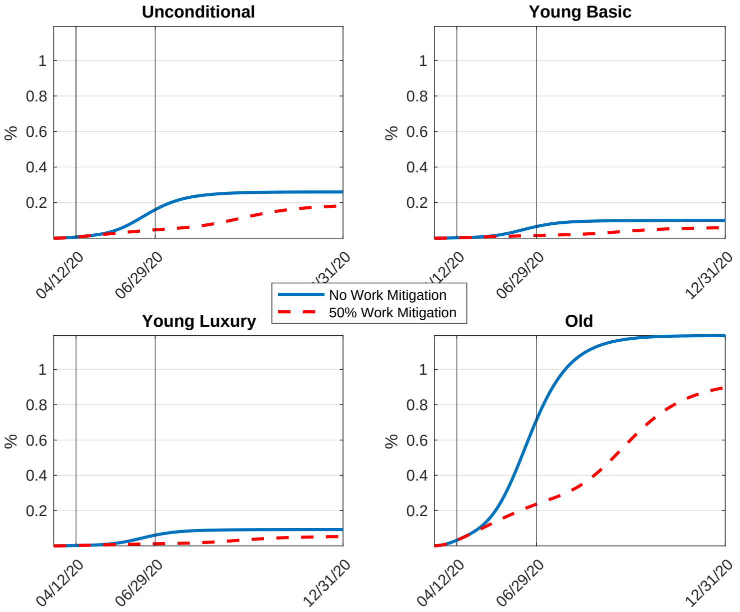
1. Baseline comparison: $\gamma_0 = 0.5$, $\gamma_1 = -0.5$, $\gamma_2 =$ March 21 +100 (mitigation ends around June 29), vs. no mitigation from April 12
2. Optimize (starting April 12) over γ_0, γ_1, γ_2

- For each policy, compute welfare gains rel. to no mitigation by type
- How do gains from mitigation vary with cost of redistribution τ?
- How does optimal mitigation vary with cost of redistribution?

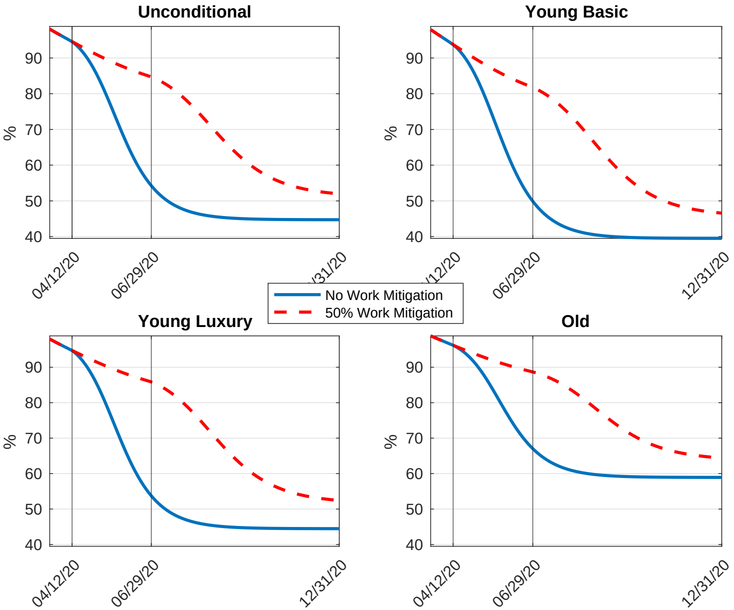
Number of Deaths



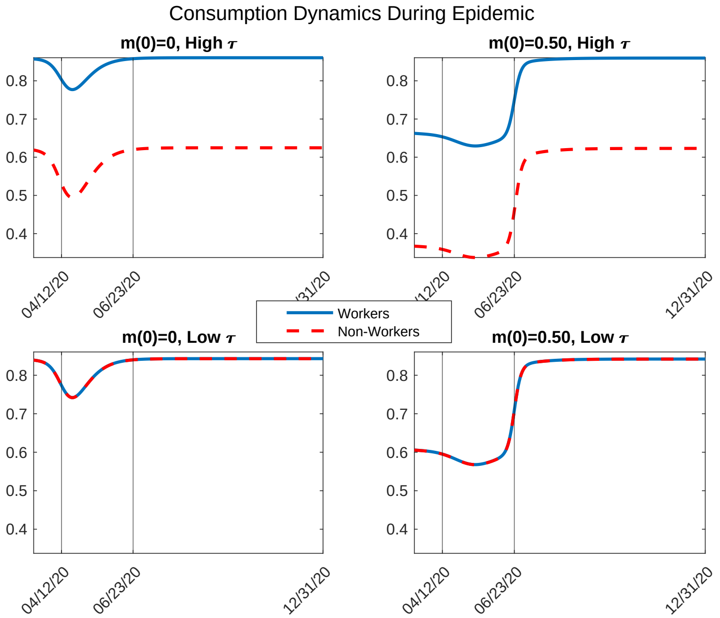
Cumulative Deaths



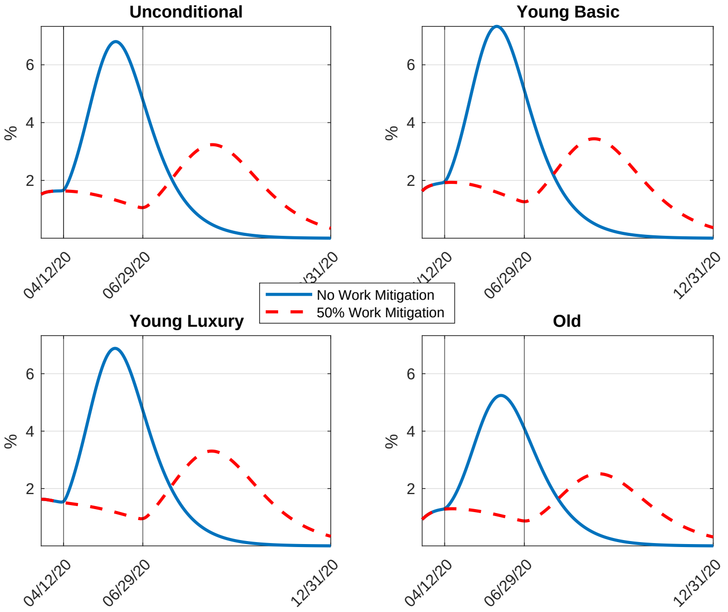
Shares Never Infected



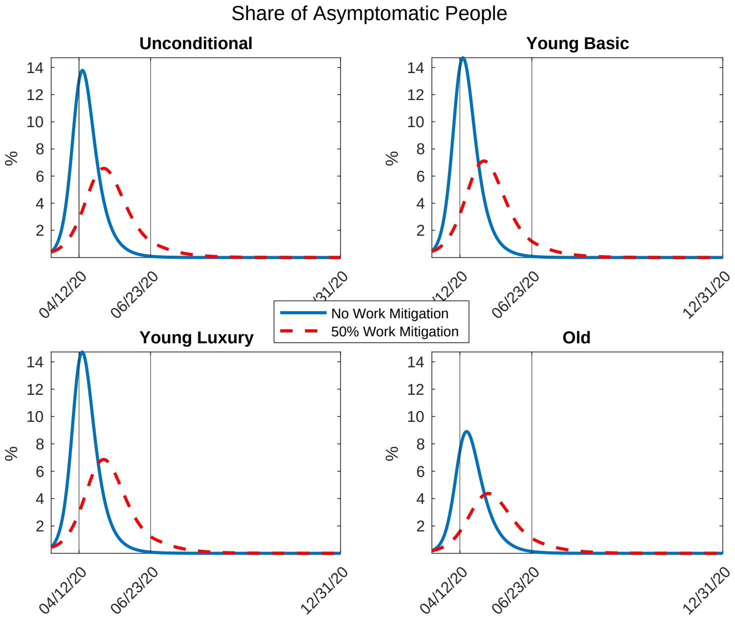
Consumption



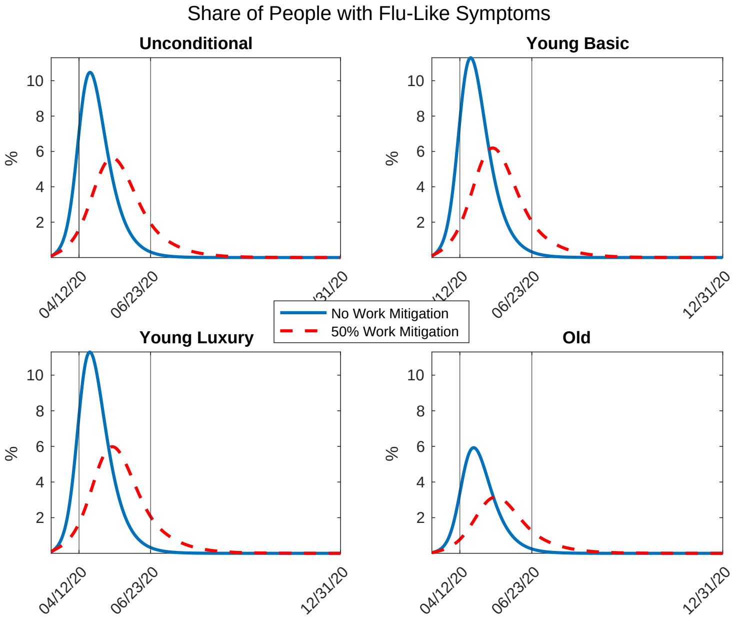
Shares Currently Infected



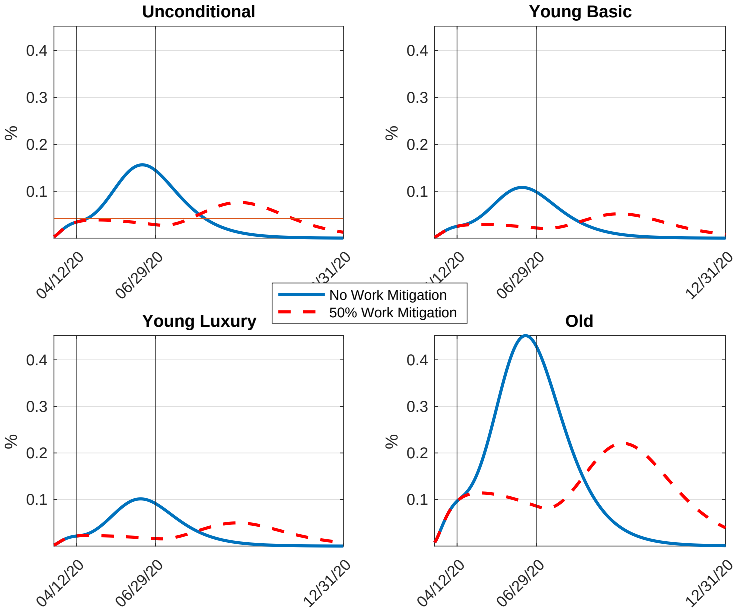
Shares Asymptomatic



Shares with Flu Symptoms



Shares Hospitalized



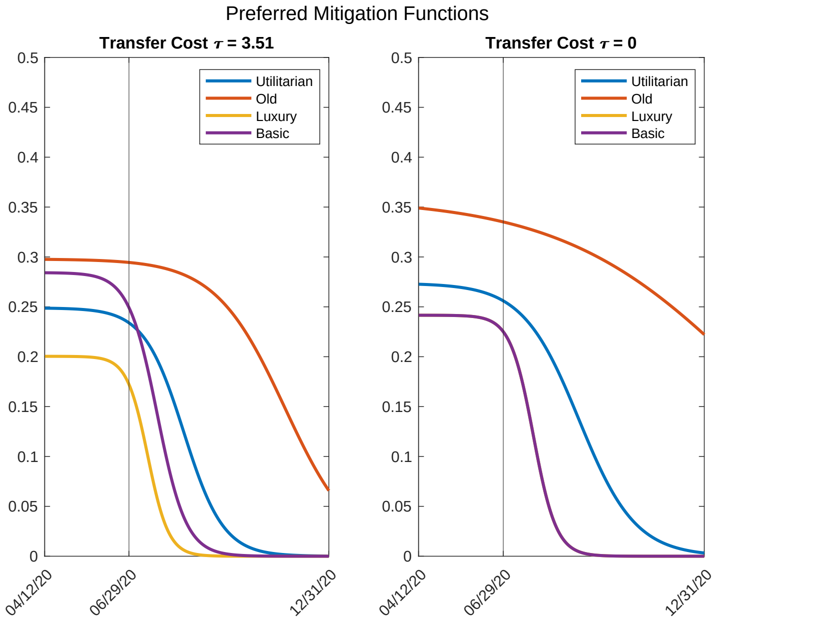
Millions of People in Each Health State

	S	**A**	**F**	**E**	**R**	**D** × 1000
03/21/20	323.71	4.17	0.84	0.01	1.27	0.34
04/12/20	311.31	2.95	2.72	0.12	12.88	22.1
04/30/20	303.11	2.57	2.53	0.13	21.60	53.38
06/29/20	249.42	1.68	1.72	0.09	46.86	154.81
09/30/20	201.42	4.31	4.59	0.24	119.03	406.81
12/31/20	171.52	0.47	0.62	0.04	156.74	599.38
12/31/21	168.82	0.00	0.00	0.00	160.56	621.95

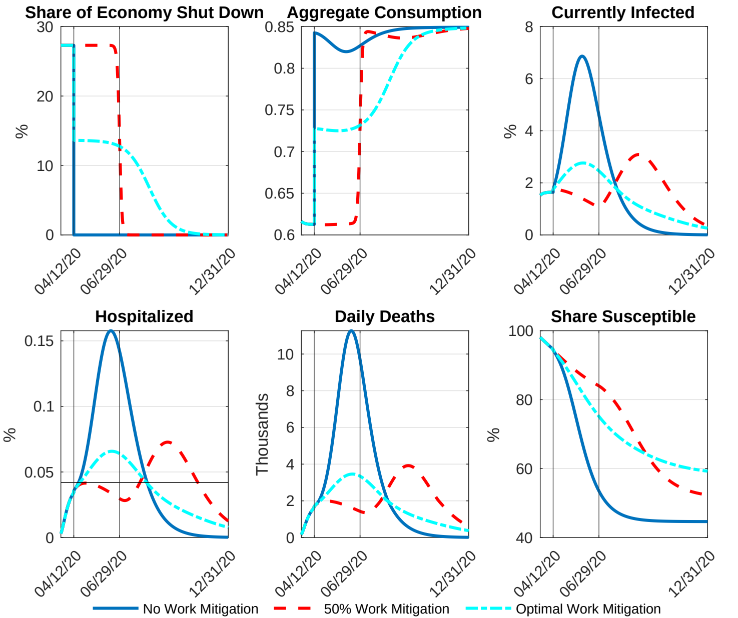
Welfare Gains (+) or Losses (-) From Mitigation

Mitigated Share	75%		50%		25%	
Transfer Cost (τ)	3.51	0.001	3.51	0.001	3.51	0.001
Young Basic	0.06%	-0.04%	0.24%	0.18%	0.33%	0.30%
Young Luxury	-0.37%	-0.05%	-0.01%	0.16%	0.23%	0.29%
Old	1.44%	2.00%	2.17%	2.64%	2.60%	2.93%

Optimal Policies



Outcome Comparisons



Welfare Gains under Optimal Policies

Welfare Gains (+) or Losses (-) From Preferred Mitigation, $\tau = 3.51$

	Utilitarian	Old	Young Luxury	Young Basic
Young Basic	0.36%	0.29%	0.34%	0.36%
Young Luxury	0.21%	-0.05%	0.25%	0.22%
Old	3.60%	4.15%	2.89%	3.37%

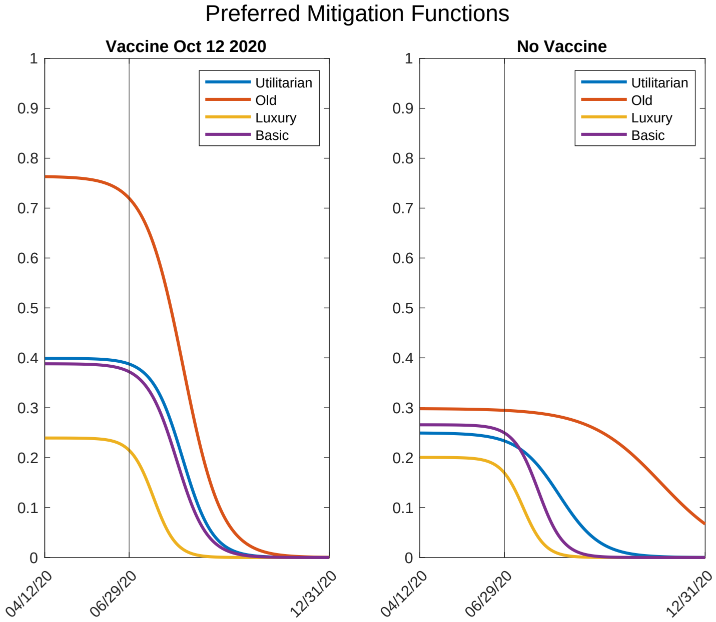
Welfare Gains (+) or Losses (-) From Preferred Mitigation, $\tau \approx 0$

	Utilitarian	Old	Young Luxury	Young Basic
Young Basic	0.30%	-0.05%	0.32%	0.32%
Young Luxury	0.29%	-0.06%	0.32%	0.32%
Old	4.49%	5.30%	3.68%	3.68%

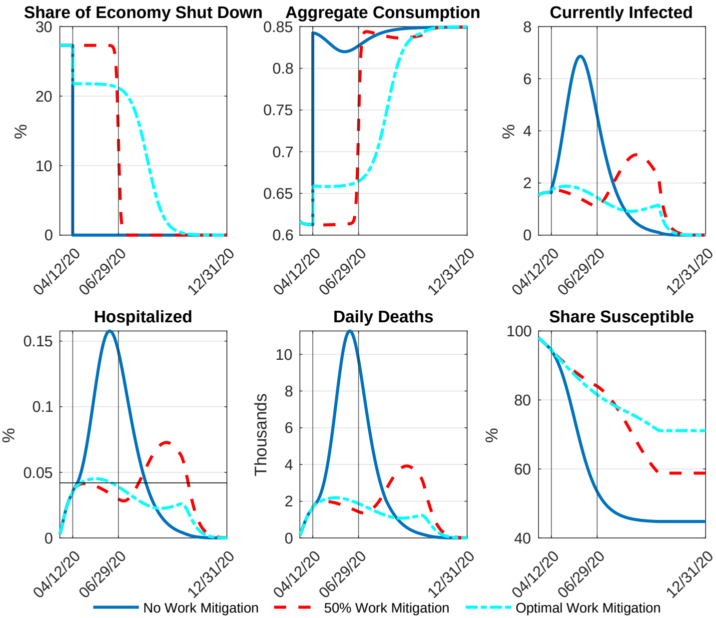
Exit Strategy Changes

- We now put on our optimist hats - assume that a vaccine is readily available on Oct 12, 2020
- This ends new infections
- Sickness and deaths last a bit longer
- Key: infections end before herd immunity is reached

Optimal Policies Comparison with/without Vaccine



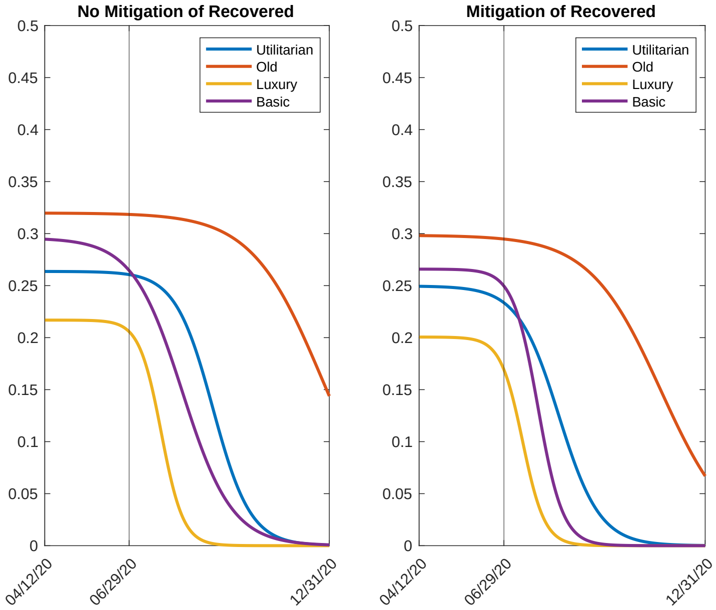
Outcomes With Vaccine Arriving Oct. 12



Gains From Antibody Tests

- In the last month, antibody tests are becoming available
- With widespread antibody testing, the recovered can be given immunity passports and avoid mitigation
- Optimal mitigation higher than without antibody tests

Optimal Mitigation with Immunity Passports



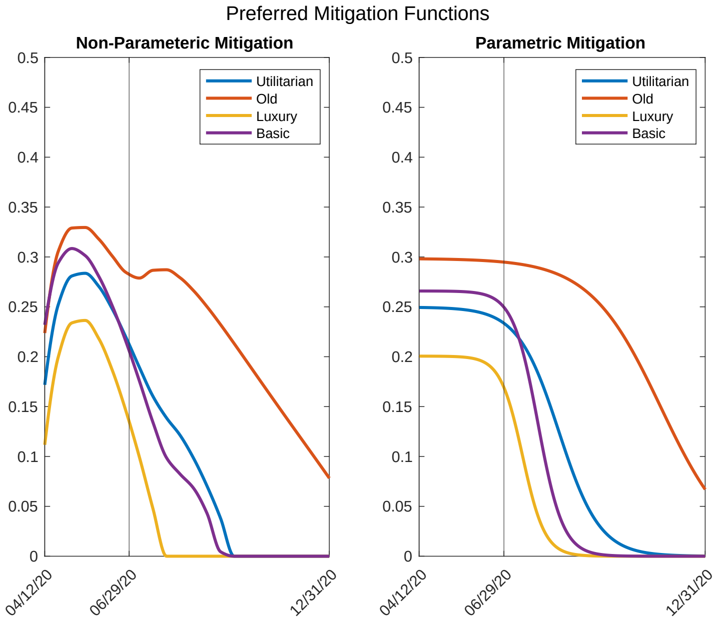
Welfare Gains from Antibody Tests

	Utilitarian		Old		Luxury		Basic	
Policy Form	Tests	No Tests	Tests	No Tests	Tests	No Tests	Tests	No Tests
Young Basic	0.38%	0.36%	0.32%	0.29%	0.36%	0.34%	0.39%	0.36%
Young Luxury	0.23%	0.21%	0.01%	-0.05%	0.28%	0.25%	0.24%	0.22%
Old	3.91%	3.60%	4.39%	4.15%	3.13%	2.89%	3.72%	3.37%

Optimal Control Approach - Flexible Mitigation

- Our parametric mitigation function is simple to implement.
- Now allow for a fully flexible path for m
- Set up optimal control problem, solve for each group's preferred non-parametric policy
- Lots of computer time, very small marginal gains!

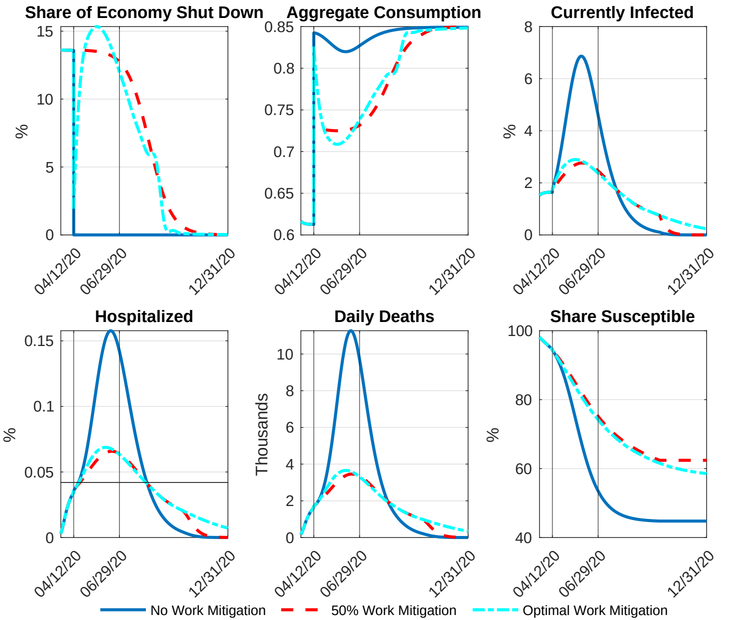
Optimal Non-Parametric vs Simple Policies



Welfare Gains With Non-Parametric vs Simple Policies

	Utilitarian		Old		Luxury		Basic	
Policy Form τ	Non-Par	Par	Non-Par	Par	Non-Par	Par	Non-Par	Par
Young Basic	0.36%	0.36%	0.29%	0.29%	0.34%	0.34%	0.37%	0.36%
Young Luxury	0.22%	0.21%	-0.04%	-0.05%	0.25%	0.25%	0.23%	0.22%
Old	3.62%	3.60%	4.15%	4.15%	2.89%	2.89%	3.26%	3.37%

Outcomes With Non-Parametric vs Simple Policies



Conclusions

- Current baseline simulation suggests current shutdowns should be partially relaxed but extended
- Welfare gains are uneven: large for the old, small for the young
- Cost of redistribution matters: harder shutdown optimal when redistribution is costless
- Results sensitive to parameters:
  - Value of life
  - Importance of economic activity in disease transmission
  - Disease lethality
  - Timing of vaccine arrival
  - Reading of current state: how many infections? how fast spreading?

THANKS FOR LISTENING