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

Andrew Glover Jonathan Heathcote Dirk Krueger José-Víctor Ríos-Rull

FRB Virtual Bag Lunch

Monday, May 4 2020

Federal Reserve Bank of Kansas City
Federal Reserve Bank of Minneapolis and CEPR
University of Pennsylvania, CEPR, CFS, NBER and Netspar
University of Pennsylvania, CAERP, UCL, CEPR and NBER

Introduction

Introduction

- What is the appropriate economic policy response to the pandemic?
- How extensive should the shut-down be, and when should it end?
- Key item: Large distributional implications of lock down policies.
  - Benefits Are Concentrated among the Old and (to a lesser extent) some particularly vulnerable workers.
  - Costs Are Concentrated among the young and especially, the young displaced who face costly unemployment.
- Need some combination of shut-down and redistribution

What we do

- Build an epidemiological/economic model with heterogeneous agents
- Postulate that transfers across agents are **costly**
- Assess Two Policies
  - Mitigation (less output but also less contagion)
  - Redistribution toward those whose jobs are shuttered
- Characterize preferred mitigation policies
- Key interaction:
  - Mitigation creates the need for redistribution
  - If redistribution is costly, reduces the incentives for mitigation
  - Need heterogeneous agent model to analyze this trade-off.

Epidemiology: 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 E,
  - **R**ecovered (and **D**ead)
- Worst case disease progression: **S** $\rightarrow$ **A** $\rightarrow$ **F** $\rightarrow$ **E** $\rightarrow$ **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: Heterogeneity by Age and Sector

- Age $i \in \{y, o\}$
  - Only young work
  - Old have more adverse outcomes conditional on contagion
  - But young more prone to contagion (they work)
  - Old discount future at higher rate, reflecting shorter life expectancy
- Sector of Production $\{b, \ell\}$
  - Basic (health care/food production/law enforcement/government)
    - Will never want shut-downs in this sector
    - Workers in this sector care for the hospitalized
  - Luxury (restaurants, entertainment etc.)
    - Government chooses how much of this sector to shutter
    - Workers in this sector face shutdown unemployment risk
    - But they are less likely to get infected

Interactions between Health and Wealth

- 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 age/sector people prefer?
- How does the 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 $j \in \{s,a,r\}$)

- Differences in expected longevity through $\rho_y \neq \rho_o$ (no aging)

Technology

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

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

- Output in luxury sector is

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

- Total output given by

$$y = y^b + y^\ell.$$

- 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
  - Work: young S workers infected by A workers w/ prob $\beta_w(m)$
  - Consumption: young & old S infected by A w/ prob $\beta_c(m) \times y(m)$
  - Home: S people infected by A and F w/ prob β_h
  - ER: basic S workers infected by E w/ prob β_e

- Shutdowns (mitigation) help by:
  - Reducing number of workers $\Rightarrow$ less workplace transmission
  - Reducing output $y(m) \Rightarrow$ less consumption transmission
  - Micro-founded via sectoral heterogeneity in social contact rates
  - Smart mitigation shutters most contact-intensive sub-sectors first

Work Infections and Mitigation

$$\dot{x}^{ybs} = -\left[\beta_w(m) \quad \left[x^{yba} + (1-m)x^{y\ell a}\right] + \beta_c(m)x^a y(m) + \beta_h\left(x^a + x^f\right) + \beta_e x^e\right] x^{ybs}$$

$$\dot{x}^{y\ell s} = -\left[\beta_w(m)(1-m) \quad \left[x^{yba} + (1-m)x^{y\ell a}\right] + \beta_c(m)x^a y(m) + \beta_h\left(x^a + x^f\right)\right] x^{y\ell s}$$

$$\dot{x}^{os} = -\left[\beta_c(m)x^a y(m) + \beta h\left(x^a + x^f\right)\right] x^{os}$$

- Reducing number of workers ⇒ less workplace transmission
- Reducing infection rates $\beta_w(m)$

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

  - Micro-founded via sectoral heterogeneity in social contact rates
  - Smart mitigation shutters most contact-intensive sub-sectors first

Shopping Infections and Mitigation

$$\dot{x}^{ybs} = -\Big[\beta_w(m) \quad \big[x^{yba} + (1-m)x^{y\ell a}\big] + \beta_c(m)x^a y(m) + \beta_h\left(x^a + x^f\right) + \beta_e x^e \Big]\, x^{ybs}$$

$$\dot{x}^{y\ell s} = -\Big[\beta_w(m)(1-m) \quad \big[x^{yba} + (1-m)x^{y\ell a}\big] + \beta_c(m)x^a y(m) + \beta_h\left(x^a + x^f\right) \Big]\, x^{y\ell s}$$

$$\dot{x}^{os} = -\Big[\beta_c(m)x^a y(m) + \beta h\left(x^a + x^f\right) \Big]\, x^{os}$$

- Reducing output $y(m) \Rightarrow$ less consumption transmission
- Reducing infection rates $\beta_c(m)$

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

  - Micro-founded via sectoral heterogeneity in social contact rates
  - Smart mitigation shutters most contact-intensive sub-sectors first

Infections at Home

$$\dot{x}^{ybs} = -\left[\beta_w(m) \quad \left[x^{yba} + (1-m)x^{y\ell a}\right] + \beta_c(m)x^a y(m) + \beta_h\left(x^a + x^f\right) + \beta_e x^e \right] x^{ybs}$$

$$\dot{x}^{y\ell s} = -\left[\beta_w(m)(1-m) \quad \left[x^{yba} + (1-m)x^{y\ell a}\right] + \beta_c(m)x^a y(m) + \beta_h\left(x^a + x^f\right) \right] x^{y\ell s}$$

$$\dot{x}^{os} = -\left[\beta_c(m)x^a y(m) + \beta_h\left(x^a + x^f\right) \right] x^{os}$$

- Infections at home by asymptomatic and people with flu-like symptoms
- Not mitigated by shutdown policy

Infections at Hospital

$$\dot{x}^{ybs} = -\left[\beta_w(m) \left[x^{yba} + (1-m)x^{y\ell a}\right] + \beta_c(m)x^a y(m) + \beta_h\left(x^a + x^f\right) + \beta_e x^e\right] x^{ybs}$$

$$\dot{x}^{y\ell s} = -\left[\beta_w(m)(1-m) \left[x^{yba} + (1-m)x^{y\ell a}\right] + \beta_c(m)x^a y(m) + \beta_h\left(x^a + x^f\right)\right] x^{y\ell s}$$

$$\dot{x}^{os} = -\left[\beta_c(m)x^a y(m) + \beta_h\left(x^a + x^f\right)\right] x^{os}$$

- Infections at hospital - 5% of total on April 12, 2020
- Cannot be mitigated

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 $\frac{c^w}{c^n} = 1 + T'(c^n)$.
- Period welfare

$$\begin{aligned} W(x,m) &= [\mu^w + \mu^n]\, w(x,m) \\ w(x,m) &= \log(c^n) + \nu \log(1 + T'(c^n)) + \bar{u} + \sum_{i,j \in \{f,e\}} \frac{x^{ij}}{\mu^w + \mu^w} \widehat{u}^j \end{aligned}$$

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.

Mapping to Data

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_0 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

$$m(t) = \frac{\alpha_0}{1 + \exp(-\alpha_1(t - \alpha_2))}$$

Calibration: Virus Transmission

- Set α_w/β_h, α_c/β_h to match evidence on number of potentially infectious contacts from 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_h to target basic reproduction number R_0
  - One time proportional shift in all infection-generating rates on March 21 (next slide)
- Set β_e so that 5% of infections are to health care workers as of April 12, 2020

Calibration: Initial Conditions

- Counterfactuals: 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
    - Hardest facts: deaths (but even these likely under-measured)

Calibration: Our Strategy for Initial Conditions

- Assume America changed on March 21
  - Assume initial arrival of infected individuals on Feb 12
  - $m = 0 \Rightarrow m = 0.5$ plus one-time proportional drop in infection generating rates (social distancing) $\Rightarrow R_0$ falls.
  - 27.7% fall in employment implied by $m = 0.5$ (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 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

	t_1	t_2	t_3
Target	$I_{t_1} = 12$	$D_{t_2} = 69$	$D_{t_3} = 22,055$ $D_{t_3} - D_{t_3-1} = 1,632$ $I_{t_3} = 7.4$ mill.
Parameter	$R_{t_1} = 3.61$	$R_{t_2} = 1.02$, under $m_{t_2} = 0.5$ (1.4)	

t_0 — Febr. 16 (t_1) — March 21 (t_2) — April 12 (t_3) — Time t

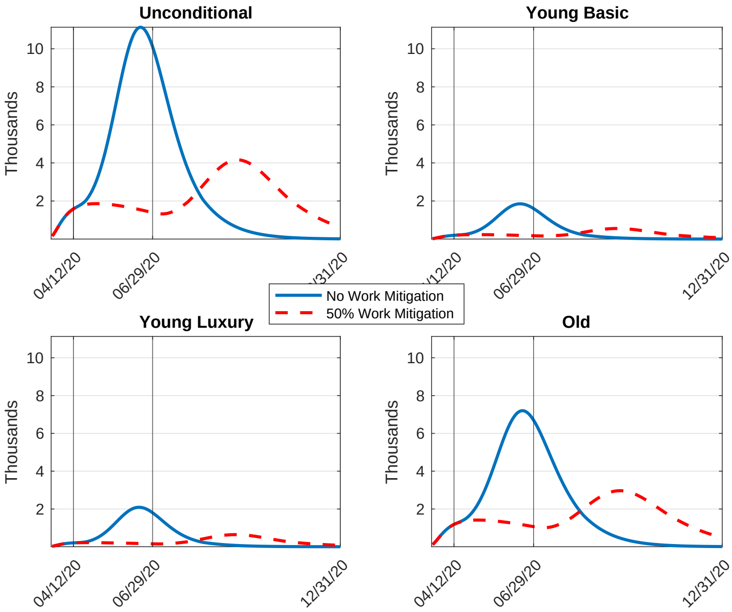
Millions of People in Each Health State

	S	A	F	E	R	$D \times 1000$
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

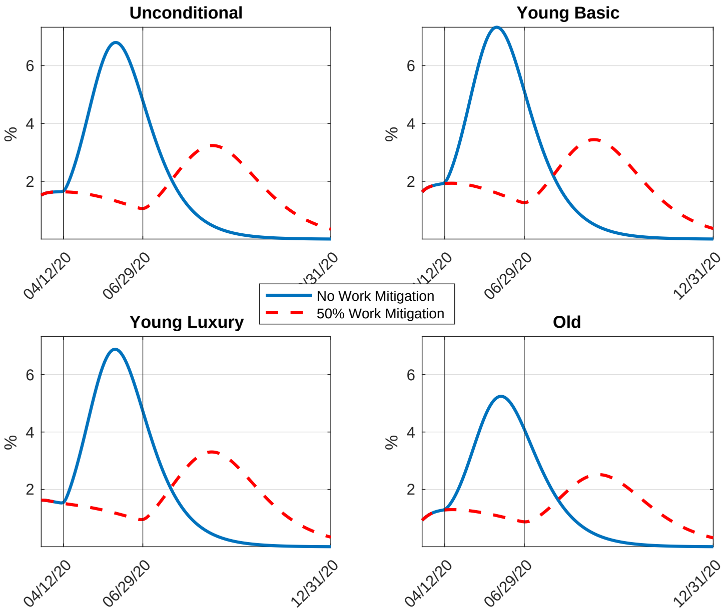
1. Baseline policy: $\alpha_0 = 0.5$, $\alpha_1 = -0.5$, $\alpha_2 =$ March 21 $+100$ (mitigation ends around June 23), vs having had no mitigation since March 21.
2. Alternative severity: $\alpha_0 = 0.25$, 0.10
3. Optimize (starting in March 15) over α_0, α_1, α_2

- 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?

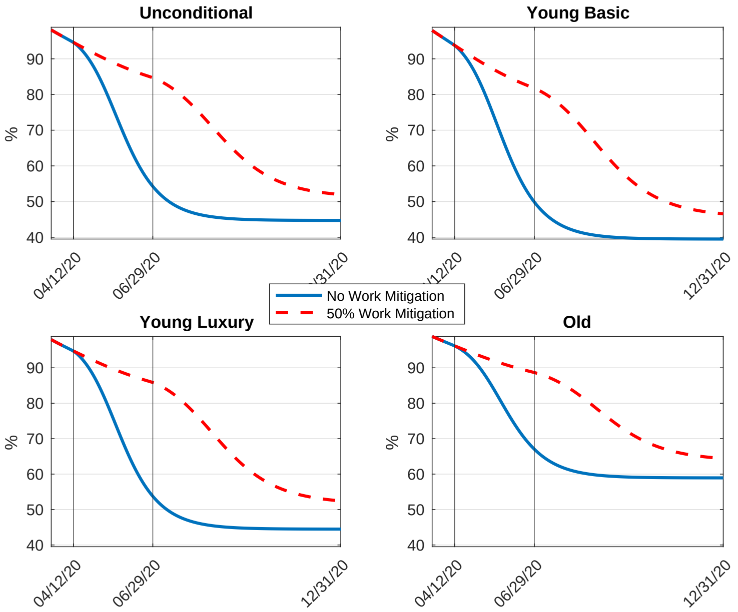
Number of Deaths



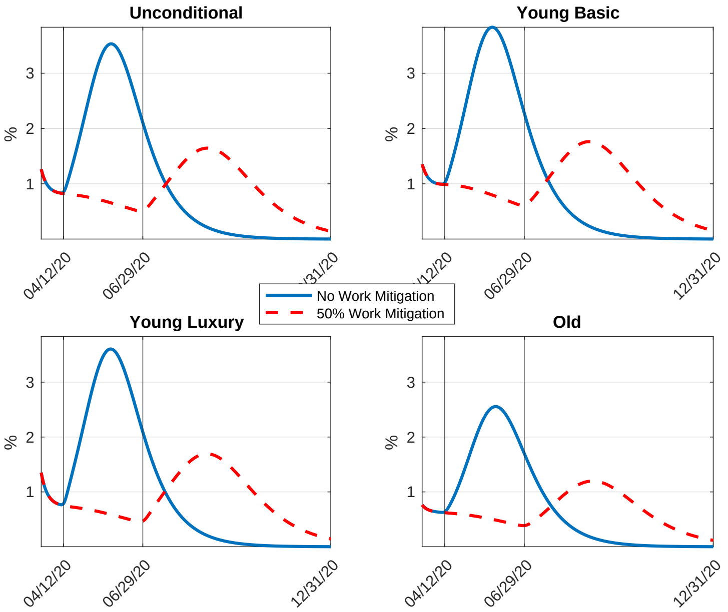
Shares Infected (Starting as of March 21)



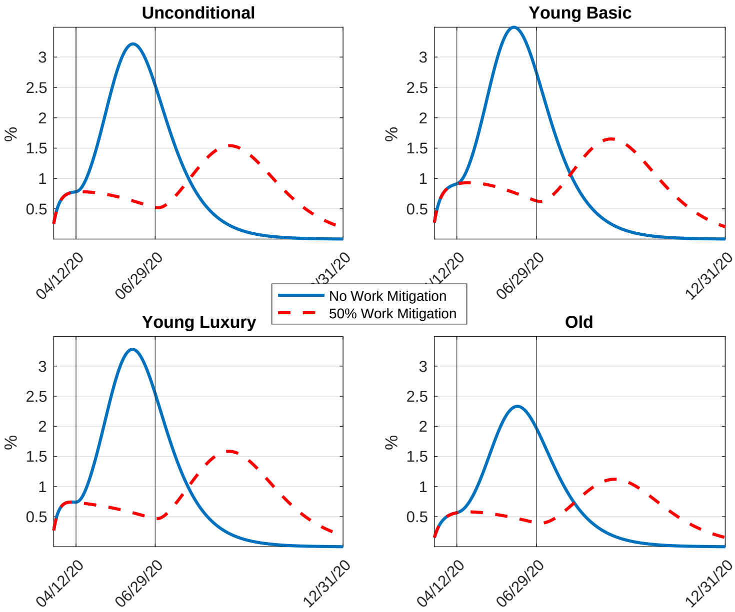
Shares Never Infected



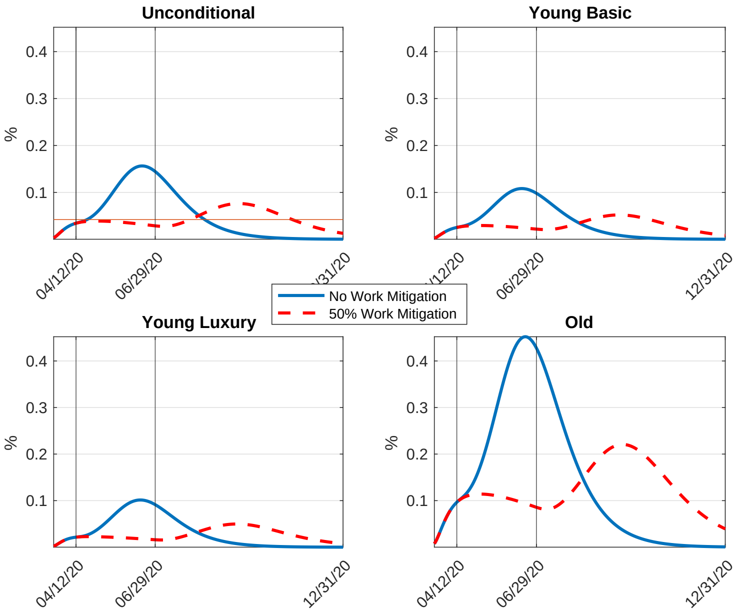
Shares Asymptomatic



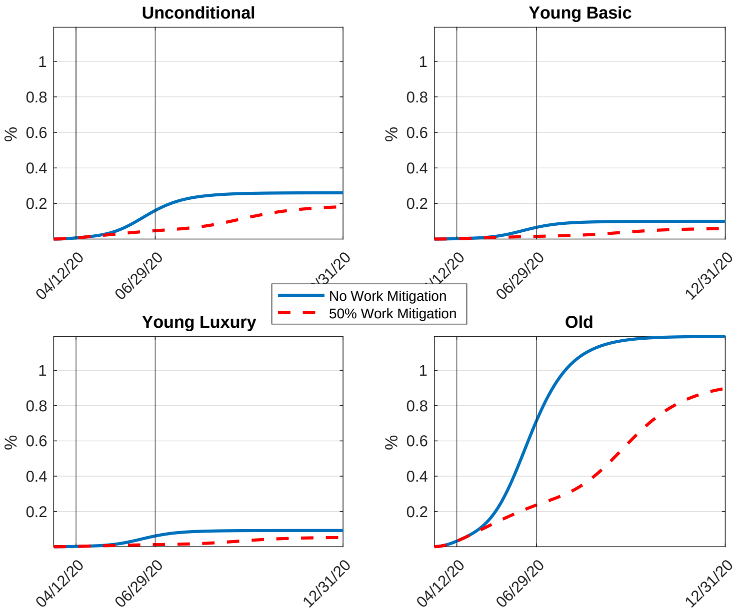
Shares with Flu Symptoms



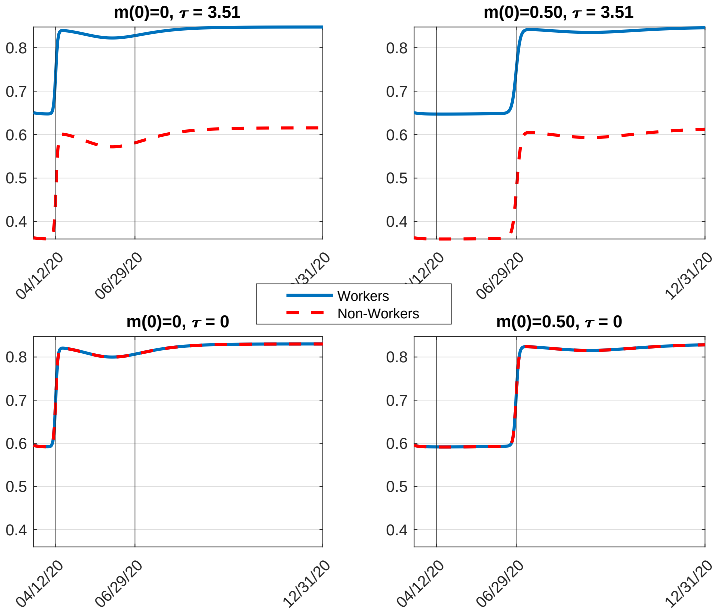
Shares Hospitalized



Cumulative Deaths



Consumption



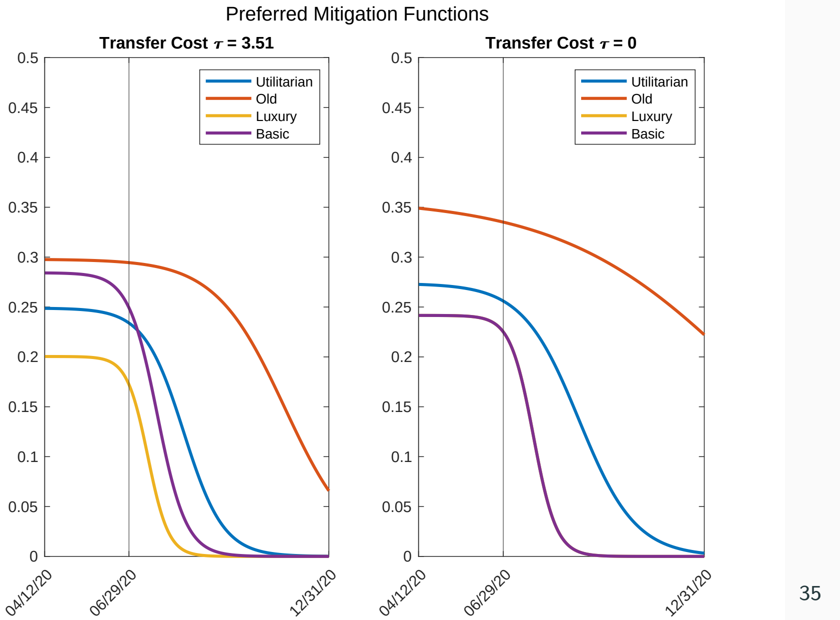
Millions of People in Each Health State

	S	A	F	E	R	$D \times 1000$
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

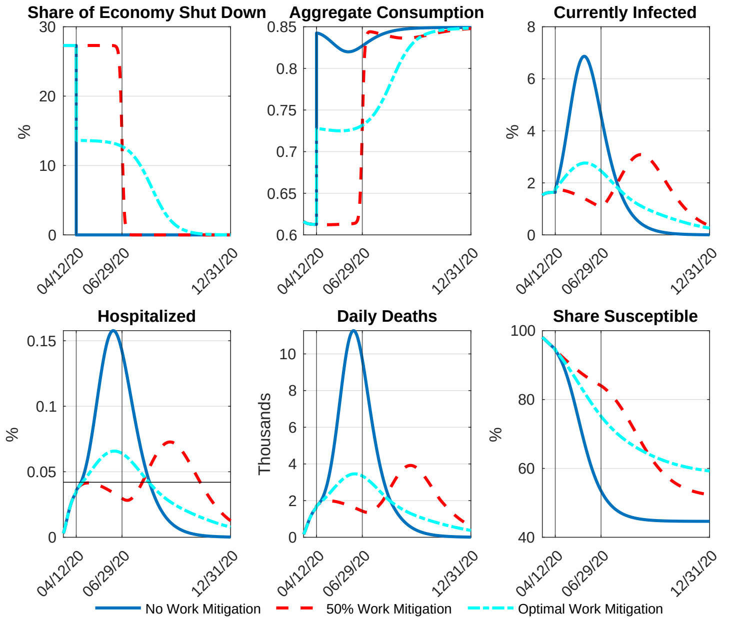
Table 1: Welfare Gains (+) or Losses (-) From Mitigation

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	0.37%	0.29%	0.34%	0.37%
Young Luxury	0.21%	-0.05%	0.25%	0.22%
Old	3.30%	4.15%	2.89%	3.32%

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

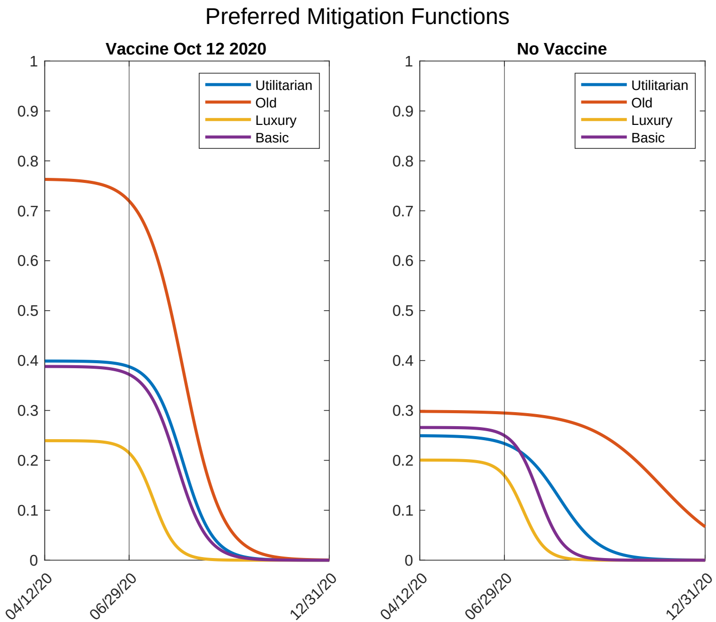
	Utilitarian	Old	Young Luxury	Young Basic
Young Basic	0.30%	-0.05%	0.32%	0.32%
Young Luxury	0.29%	-0.06%	0.32%	0.32%
Old	4.49%	5.30%	3.68%	3.68%

What if there is a Vaccine?

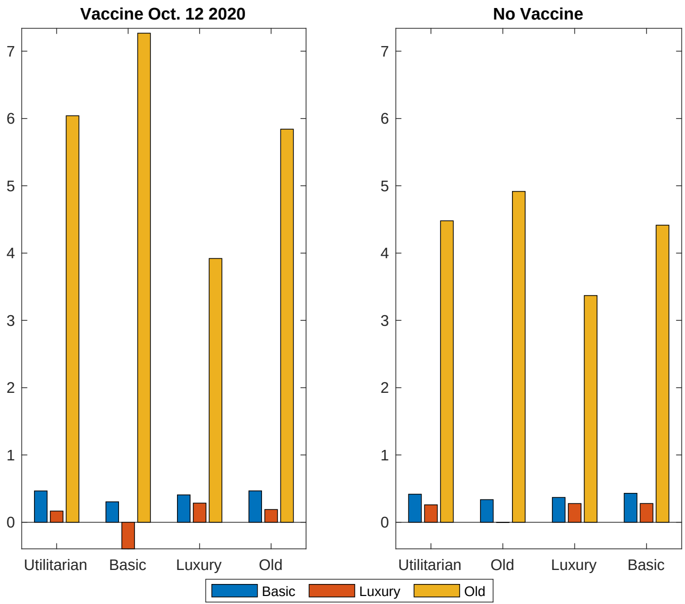
Now the exit Strategy Changes

- We now put on our optimist hats - assume that vaccine is readily available on Oct 12, 2020
- A vaccine comes that immediately makes all $\beta' s = 0$.
- Costlessly and Swiftly but deaths and sickness last a bit longer.
- So no need to wait for herd immunity to get out of this mess.

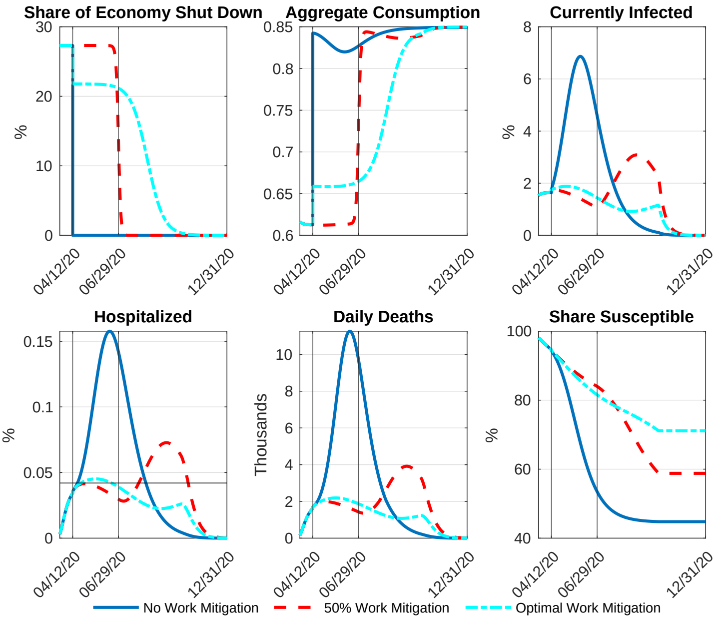
Optimal Policies Comparison with/without Vaccine



Welfare Gains with/without Vaccine



Outcomes With Vaccine Arriving Oct. 12

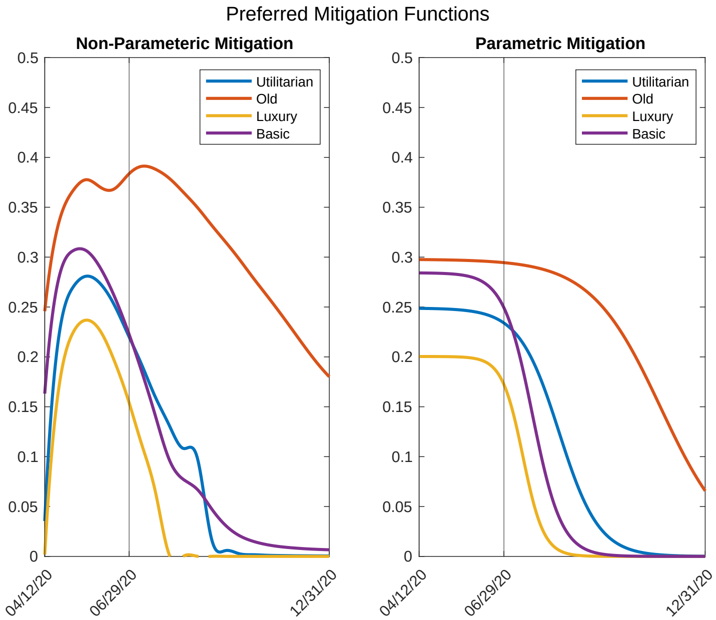


Could We Do Better With More Flexible Policies?

Optimal Control Approach – Flexible MItigation

- We think that our parametric form of policy well approximates reality and would be simple to implement.
- What if we allowed for a fully flexible path of m?
- Set up optimal control problem, solve for each group's preferred non-parametric policy.
- Lots of computer time, complicated policies, very small real effects!

Optimal Non-Parametric vs Simple Policies

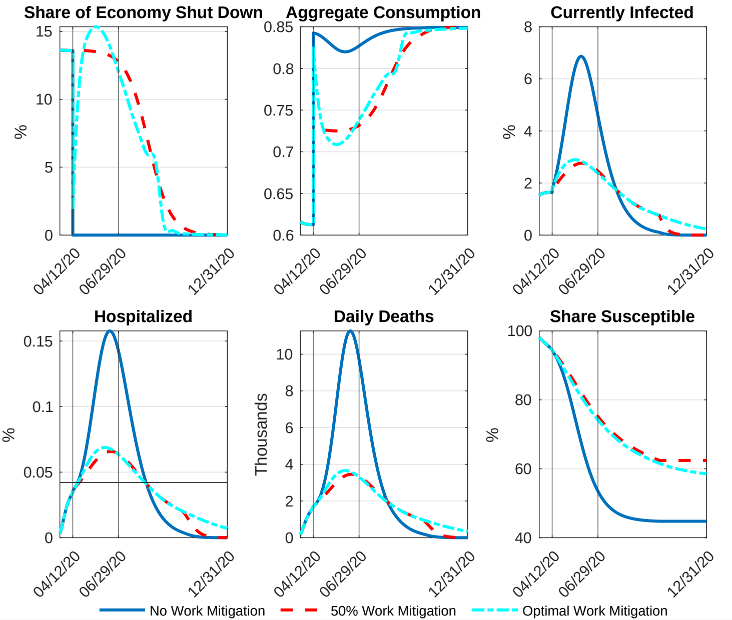


Welfare Gains With Non-Parametric vs Simple Policies

Table 2: Welfare Gains (+) or Losses (-): Non-Parametric vs. Parametric Policies

	Utilitarian		Old		Luxury	
Policy Form τ	Non-Par	Par	Non-Par	Par	Non-Par	Par
Young Basic	0.36%	0.36%	0.15%	0.29%	0.34%	0.34%
Young Luxury	0.22%	0.21%	-0.36%	-0.05%	0.25%	0.25%
Old	3.47%	3.30%	4.22%	4.15%	2.85%	2.89%

Outcomes With Non-Parametric vs Simple Policies



Thanks very much