Inequality of Fear and Self-Quarantine: Is There a Trade-off Between GDP and Public Health?

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NPI Policies and Recessions

"Global economy will experience the worst recession since the Great Depression", "The Great Lockdown, ... , is projected to shrink global growth dramatically" Gita Gopinath, IMF WEO

"If there is, as we assume, a lifting of the lockdown over the months to come, we think activity in the economy will recover much more quickly than you'd get in a normal recession"

Andrew Bailey, BOE

- Many people take a "trade-off" between Economic cost & Virus containtment as given
- But how can high infections be good for GDP?

Our Contributions

1. Infections and deaths growing out of control is also bad for the economy:
   - **Fear of Infection, aka "Fear Factor"**
2. Based on real-world, not "optimal" policies: SK vs UK:
   - **Targeted quarantine from testing** vs **blanket lock-down**
   - **making sure you stay home** vs **sending you home**
3. Predictions on **inequality** as well as GDP:
   - Low-wage workers more exposed to virus
   - Also more exposed to job/wage losses

Main Results

1. From January-October 2020,
   - SK's test/trace/tracking (TTT) policy contains virus with
     1.2% GDP loss with 837 cumulative deaths
   - UK's lockdown partly contains virus with
     11% GDP loss with 65253 cumulative deaths

   ⇒ Demographics and economic structure make little difference

2. SK: targeted quarantine enforcement more important than aggressive asymptomatic testing

3. UK: early (extended) lockdown would have cut deaths by more than 50% (25%) with only 1.2% (2%) point extra loss in GDP

4. Low-skill workers and self-employed bear brunt of crisis
   - Higher infection risk at work + larger fear of infection
   - Lower productivity when WFH

Overview

1. Model — **Fear of Infection and Self-Quarantines**
2. Policy Tools — **Test/Trace/Track/Lockdown**
3. Calibration — **Economics and Policies**
   GDP and Inequality
4. Counterfactual Analysis — **Early and Long Lockdowns**
   A. Testing and Quarantine Enforcement

Model

Environment

- No capital, **labor-only economy**
  1. **{Young vs Old}**: latter don't work
  2. **{High vs Low}** skill, perfectly segregated labor market

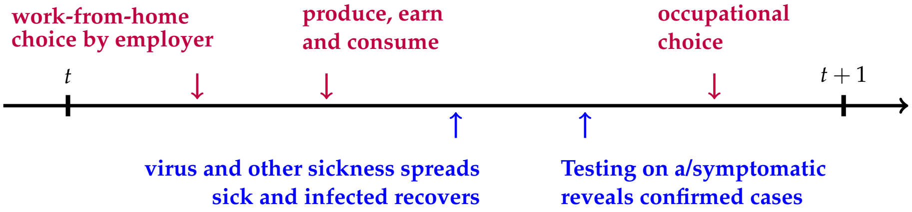
     indexed by $x \in \{h, l\}$
  3. Occupation choice: **{self-employed, manager, worker}**

     indexed by $j \in \{1, 2, 3\}$

- Infection status evolves by $i \in \{(x, j), o, q\}$: quarantined
  1. Unobserved, true status: $E_i \in \{S, I, R, D\}$
  2. Observed status: a/sympomatic$\times$un/tested/recovered

     $e_i \in \{a^0, s^0, a^c, s^c, a^r, s^r, d = D\}$

Timeline (Daily)



- Economic model (in red) only applies to young

True, Unobserved Infection Status: SIR Model

- Unobserved, true infection status evolves as

$$\frac{\bar{S}_i}{1-\delta_i} = [1 - v_i(I^*)]\, S_i$$

$$\frac{\bar{I}_i}{1-\delta_i} = v_i(I^*)S_i + (1-\gamma_i)(1-m_i)I_i$$

$$\frac{\bar{R}_i}{1-\delta_i} = \gamma_i(1-m_i)I_i + R_i$$

$$\bar{D}_i = D_i + \delta_i(S_i + I_i + R_i) + (1-\delta_i)m_i I_i$$

- Bare-bones SIR model, but infection rates separately evolve by i

$$v_i(I^*) = \bar{v}_i \cdot I^*/N, \quad N : \text{population size}$$

- Unmitigated mass of infections:

$$I^* = I - QI_q, \quad \mathbf{0} \leq Q \leq \mathbf{1}$$

Observed Status

- **Sick**: has Covid-like symptoms
  1. may or may not have Covid
  2. can have symptoms regardless of (S, I, R)

- **Testing**:
  1. infection status may or may not be detected
  2. differential testing of a/sympotmatic
  3. Covid cannot be detected after recovery

  $\Rightarrow$ Recovery only confirmed if tested positive during infection

Observed Status: Pre-Testing

- Some abuse of notation: e_i denotes mass of state e
- c_i, r_i: mass confirmed and known recoveries

$$c_i \equiv a_i^c + s_i^c, \quad r_i \equiv a_i^r + s_i^r$$

- Infected and recovered of unknown status:

$$\hat{I}_i = \bar{I}_i - (1-\delta_i)(1-m_i)(1-\gamma_i)c_i$$
$$\hat{R}_i = \bar{R}_i - (1-\delta_i)\left[\gamma_i(1-m_i)c_i + r_i\right]$$

* **Individual E is unobserved, but aggregate mass E is observed**

Observed Status: Post-Testing

- Mass of still unknown status:

$$\bar{a}_i^0 = (1 - f_i)\bar{S}_i + (1 - \omega\tau^a)(1 - \eta_i)\hat{I}_i + (1 - f_i)\hat{R}_i$$
$$\bar{s}_i^0 = f_i\bar{S}_i + (1 - \omega\tau^s)\eta_i\hat{I}_i + f_i\hat{R}_i$$

f_i : probability of getting sick (symptomatic) without COVID

η_i : probability of getting sick when infected

τ^a, τ^s, ω : **testing probabilities and true positives**

- Confirmed and known recoveries:

$$\bar{c}_i = (1 - \delta_i)(1 - m_i)(1 - \gamma_i)c_i + \omega\left[\tau^a(1 - \eta_i) + \tau^s\eta_i\right]\hat{I}_i$$
$$\bar{r}_i = (1 - \delta_i)\left[r_i + \gamma_i(1 - m_i)c_i\right]$$

Preference and Technology

- Stone-Geary type utility (not important):

$$u(c) = \log(1 + c),$$

to allow zero hand-to-mouth earnings

- Production (with no sickness or quarantine):

$$Y = \left[\theta^{\frac{1}{\sigma}} Y_l^{\frac{\sigma-1}{\sigma}} + (1-\theta)^{\frac{1}{\sigma}} Y_h^{\frac{\sigma-1}{\sigma}}\right]^{\frac{\sigma}{\sigma-1}}$$

$$Y_x = z_{x,1} + y_{x,2}, \quad y_{x,2} = z_{x,2}^{\alpha_x} l_{x,3}^{1-\alpha_x}$$

$z_{x,j}$: effective productivity of skill x in job j
$l_{x,3}$: effective skill-x labor hired by skill x-manager

Work-from-home Choice: Self-employed

$$V_{x,1}(e;\mathbf{p}) = \max_{\iota\in\{n,q\}} \left\{ V^n_{x,1}(e;\mathbf{p}) + \epsilon_n, V^q_{x,1}(e;\mathbf{p}) + \epsilon_q \right\},$$

$$V^n_{x,1}(e;\mathbf{p}) = u\left[\bar{\phi}_{x,1}(e)\cdot p_x z_{x,1}\right] - \kappa(e) - \chi_{x,1}\left(I^*, e\right)$$

$$V^q_{x,1}(e;\mathbf{p}) = u\left[\psi_{x,1}\bar{\phi}_{x,1}(e)\cdot p_x z_{x,1}\right] - \chi_q\left(I^*, e\right)$$

- $\mathbf{p} \equiv [p_x, w_x]$: aggregate price vector **from yesterday**
- ι: choice between commuting and self-quarantine

- $\bar{\phi}_{x,1}(e), \kappa(e)$: productivity and utility discount if $e \in \{s^0, s^c, s^r\}$
- $\psi_{x,1}$: productivity discount from working from home

- ϵ_n, ϵ_q: i.i.d. extreme value for discrete choice

Work-from-home Choice: Managers and Workers

- Managers choice identical, but returns to skill π_x instead of p_x:

$$\pi_x = \alpha_x p_x \cdot \left[\frac{(1-\alpha_x) p_x}{w_x} \right]^{\frac{1-\alpha_x}{\alpha_x}},$$

solution to profit-maximizing effective labor choice

- Workers: **managers decide whether they can stay home:**

$$\max_{\iota \in \{n,q\}} \left\{ u \left[\bar{\phi}_{x,3}(e) \cdot w_x z_{x,3} \right] + \epsilon_n,\ u \left[\psi_{x,3} \bar{\phi}_{x,3}(e) \cdot w_x z_{x,3} \right] + \epsilon_q \right\},$$

so resulting values are

$$V^n_{x,3}(e; \mathbf{p}) = u \left[\bar{\phi}_{x,3}(e) \cdot w_x z_{x,3} \right] - \kappa(e) - \chi_{x,3}\left(I^*, e \right)$$
$$V^q_{x,3}(e; \mathbf{p}) = u \left[\psi_{x,3} \bar{\phi}_{x,3}(e) \cdot w_x z_{x,3} \right] - \chi_q\left(I^*, e \right).$$

Fear Factor and Discrete Choice

- **Fear factor** linear in force of infection:

$$\chi_i(I^*, e) = \begin{cases} 0 & \text{if } e \in \{a^r, s^r\} \\ \bar{\chi} \cdot v_i(I^*) & \text{otherwise.} \end{cases}$$

- $\chi_i(I^*, e)$: differs by $i \in \{(x, j)\}$, but equal if at home $i = q$
- Resulting fraction who self-quarantine:

$$\Pr^q_{x,j}(e, \mathbf{p}) = \frac{1}{1 + \exp\left[V^n_{x,j}(e; \mathbf{p}) - V^q_{x,j}(e; \mathbf{p})\right]}.$$

for $j \in \{1, 2\}$, manager-decided values for workers

$\Rightarrow$ **Government may restrict** $\Pr^q_{x,j}(e, \mathbf{p}) \Rightarrow \overline{\Pr}^q_{x,j}(e, \mathbf{p})$

Daily Market Clearing

$$\bar{w}_x = (1-\alpha_x)\bar{p}_x \cdot \left(\frac{\Lambda_{x,2}}{\Lambda_{x,3}}\right)^{\alpha_x}$$

$$\frac{\bar{p}_h}{\bar{p}_l} = \left[\frac{(1-\theta)Y_l}{\theta Y_h}\right]$$

$$1 = \bar{p} = \left(\frac{\bar{p}_l}{\theta}\right)^{\theta}\left(\frac{\bar{p}_h}{1-\theta}\right)^{1-\theta}$$

- $\bar{\mathbf{p}} \equiv [\bar{p}_x, \bar{w}_x]$: realized price vector today
- $\Lambda_{x,j}$: total efficiency units (account for sickness and quarantine)
- Y_x: output from self-employed and managers
- Final good is numeraire
- Realized prices different from prices used to make work-from-home choice

Occupation Choice

$$\max_{j=1,2,3} \left\{ \overline{\Pr}^{q}_{x,j}(\bar{e}, \mathbf{p}) \cdot V^{q}_{x,j}(\bar{e}, \bar{\mathbf{p}}) + \left[1 - \overline{\Pr}^{q}_{x,j}(\bar{e}, \mathbf{p})\right] \cdot V^{n}_{x,j}(\bar{e}, \bar{\mathbf{p}}) + \epsilon_j \right\}.$$

- ϵ_j: i.i.d. extreme value for discrete choice
- Values are updated ($\bar{e}$, $\bar{p}$: new state, new price)
- But expects to make same WFH choice tomorrow as someone who had same state today
  - * **Only fraction $\nu = 1/365$ make occupational choice** **$\Rightarrow$ smooth transitions**

$\Rightarrow$ **Assumptions eliminate fixed-points for fast computation**

Policy Tools

Test/Trace/Track, Lockdown

1. τ_a, τ_s: Testing & Tracing, testing asymptomatic is tracing

2. Q: "Tracking" is quarantine-enforcement

3. $\rho_{x,j}(e)$: Lockdown

$$\overline{\text{Pr}}^q_{x,j}(e, \mathbf{p}) = \max\left\{\rho_{x,j}(e), \text{Pr}^q_{x,j}(e, \mathbf{p})\right\}$$

$$\rho_{x,j}(e) = \begin{cases} \max\{\bar{\rho}_{x,j}, \bar{Q}\} & \text{if } e \in \{s^0, a^c, s^c\} \\ \bar{\rho}_{x,j} & \text{otherwise.} \end{cases}$$

$\bar{\rho}_{x,j}$: differs by essence of work (0 for SK)

$\bar{Q} = Q$: minimum fraction of sick or confined to home

Calibration

Initial Distribution: Pre-COVID

- Economic parameters calibrated to SK EAPS / UK APS
- Demographics calibrated to census
- l-, h-skill to below/above median wage industries
- Set manager=employer+managerial employee
- Home productivity $\psi_{x,j}$ from ACS and ATUS 2014-2018

Pre-COVID Calibration

- Suppose no extreme value shocks. Set
  1. $z_{x,1}$ so self-employed and managers indifferent
  2. $\phi_{x,j}, \kappa$ so everyone indifferent between $\iota \in \{n, q\}$
  3. θ assuming only h-skill SE and managers stay home when sick

- Then choose extreme value distribution in a steady state
  1. home scale parameter σ so that 11.12 percent of all workers stay home (ATUS 2014-2018)
  2. occupation location parameters $\mu_{x,j}$ to match employment shares

Parameter	Value		Description
	South Korea	United Kingdom	
L_y	1	1	Mass of young
L_o	0.2432	0.3711	Mass of old
$L^0_{l,j}$	[0.0810, 0.0420, 0.3268]	[0.0654, 0.0641, 0.4484]	Initial employment share
$L^0_{h,j}$	[0.0543, 0.0322, 0.4637]	[0.0584, 0.0444, 0.3192]	by industry/occupation
$\psi^0_{l,j}$	[0.6836, 0.6675, 0.6433]	[0.6780, 0.6721, 0.6427]	Home productivity discounts
$\psi^0_{h,j}$	[0.7687, 0.7801, 0.7605]	[0.7723, 0.7798, 0.7648]	by industry/occupation
$\phi^0_{l,j}$	[0.4850, 0.5711, 0.5207]	[0.6532, 0.6710, 0.5986]	Sick productivity discounts
$\phi^0_{h,j}$	[0.5819, 0.9967, 0.8722]	[0.9368, 0.9975, 0.8976]	by industry/occupation
$z_{l,j}$	[1.2586, 1.0 1.0]	[1.0529, 1.0, 1.0]	Effective productivities
$z_{h,j}$	[2.0566, 1.3, 1.3]	[1.3117, 1.3, 1.3]	by industry/occupation
κ	0.0861	0.0884	Sickness disutility
α_l, α_h	[0.2996, 0.1747]	[0.2406, 0.2133]	Manager wage share by industry
θ	0.4133	0.5172	l-skill wage share in final good prod
σ	0.0323	0.0345	Scale parameter, EV distribution for home-work choice
$\mu_{l,j}$	[0, -0.6467, 1.7461]	[0, -0.0141, 2.1442]	Location parameter, EV distribution
$\mu_{h,j}$	[0, -0.5137, 2.5460]	[0, -0.2657, 1.9116]	for occupation choice
ν	1/365		Can switch occupation once a year

SIR and Policy

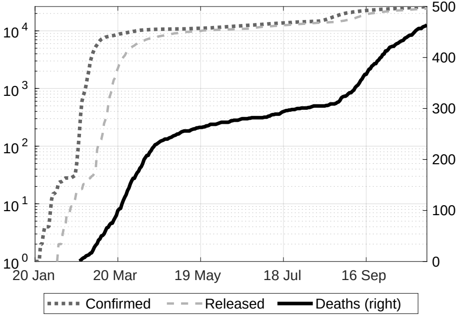
- Timing assumption: Patient 0 arrives on December 22

Exposure	$\bar{v}_i$:	O*NET and ACS 2014-2018
Lockdown	$\bar{\rho}_{x,j}$:	UK March/April GDP drop
Fear	$\bar{\chi}$:	SK peak GDP drop (in May)

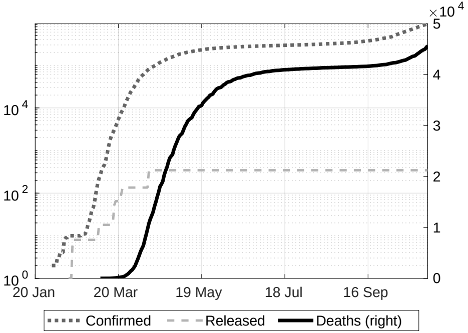
- **True path** in the model is outcome of **SIR and policies**
- **Observed path** is outcome of **testing**

- Choose SIR and policy jointly so that **observed path** matches **reported path** of infection/deaths in SK and UK
  1. Big departure from the literature
  2. All epidemic parameters equal for SK/UK, except death rates: CFR

SK vs UK: Covid



(a) SK

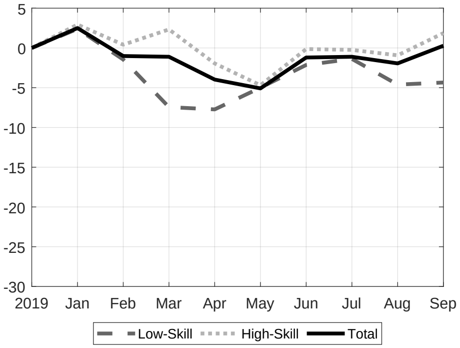


(b) UK

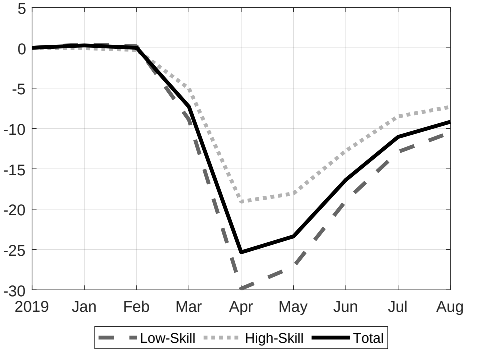
- Daily confirmed in log-10 scale, cumulative death counts on right

Source: Korea Center for Disease Control and Prevention & UK Department of Health and Social Care

SK vs UK: Production



(a) SK



(b) UK

- Percentage point deviations from 2019 average
- SK IP production and UK GDP

Source: Statistics Korea and UK ONS

Parameter	Value	Description
δ_y	0	Young daily natural death rate
δ_o	5.48e-05	Old annual natural death rate of 2 percent
γ_y	1/14	Young recover in 2 weeks
γ_o	$\gamma_y/2$	Old recover in 4 weeks
m_o	[0.0042,0.0054]	Age 65+ CFR of [11.8,15.2] in SK,UK as of 30 Oct 2020
m_y	$=m_o/30$	Age 15-65 CFR of [0.4,0.5] in SK,UK as of 30 Oct 2020
$v_{l,j}$	[0.3174, 0.0838, 0.4383]	Exposure index in Aum et al. (2020)
$v_{h,j}$	[0.1456, 0.0000, 0.2118]	for SK employment structure
$v_{l,j}$	[0.3083, 0.0570, 0.3644]	for UK employment sturcture
$v_{h,j}$	[0.1397, 0.0000, 0.2606]	(normalized to have mean v_o and $v_{h,1} = 0$)
v_q	$=v_o/7$	Reduce social contact to 1 day a week in quarantine
v_o	0.2786	Old infection rate to match $R_0 = 3.9$
I_0	[2.6, 2.3]$\times$1e-08	1 person infected on Dec 22nd ($t = 0$)
$\bar{\chi}$	5000	Fear factor: 6 percent GDP drop in SK at peak infection
ω	0.8	20 percent false negatives (Yang et al., 2020)
$f_y = f_o$	0.03	Sick without COVID: annual respiratory illnesses
(η_y, η_o)	[0.3,0.6]	Young and old infected with symptoms (Davies et al., 2020)
$\rho_{l,j}$	[0.7463, 0.7101, 0.6891]	Fraction locked down from Palomino et al. (2020)
$\rho_{h,j}$	[0.9014, 0.8179, 0.7992]	for SK employment structure (only for counterfactuals)
$\rho_{l,j}$	[0.7370, 0.7456, 0.7303]	for UK employment structure
$\rho_{h,j}$	[0.9598, 0.8135, 0.7818]	

Policy Timeline

- Fit UK lockdown with time-varying sigmoid function

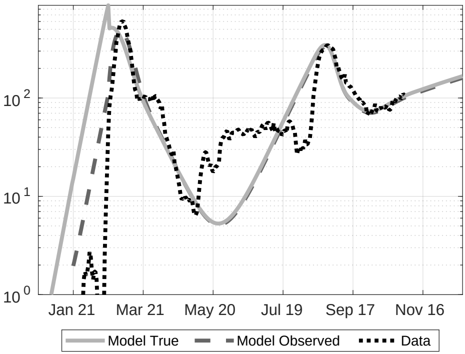
$$\varphi(t; t_\lambda, T_\lambda, \lambda) = \max\left(0, \min\left\{\left[1 + \left(\frac{t - t_\lambda}{T_\lambda - t}\right)^\lambda\right]^{-1}, 1\right\}\right)$$

- Fit SK's quarantine parameter Q also piecewise sigmoid to match tightening and easing of restrictions

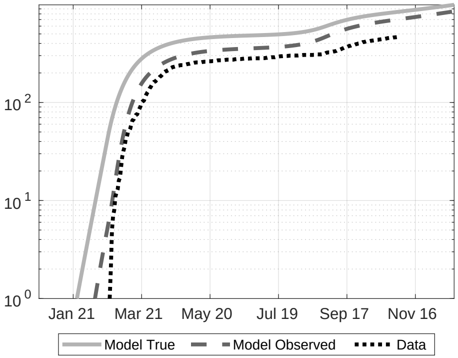
* Neither UK's 2nd lockdown(s) nor SK's third wave considered (data and policies up to 30 Oct 2020)

Parameter	Value	Description		
λ	4	UK lockdown: [April,August] year-on-year GDP drop [-24,-10]%		
t_λ, T_λ	[92,362]	UK lockdown: start and end dates		
(τ_a, τ_s)	[timeline below]	Test rates for a/symptomatic		
$Q = \bar{Q}$	[timeline below]	Tracking policy		
Country	**Date**	**Event**	**Testing**	**Quarantines**
SK	Dec 22, $t = 0$	No detection	$(\tau_a, \tau_s) = 0$	$Q = 0$, no quarantines
	Jan 20, $t = 29 = \tau$	First detection	$(\tau_a, \tau_s) = (0, 0.03)$	$Q = 0.1$
	Feb 20, $t = 60$	Shincheonji outbreak	$(\tau_a, \tau_s) = \tau_1$	$Q = q_1$
	Apr 18, $t = 116$	Social restrictions eased	$(\tau_a, \tau_s) = 0.8$	$Q = q_2 + (q_1 - q_2) \cdot \varphi_2$
	Aug 15, $t = 235 = \tau$	New restrictions on Seoul	$(\tau_a, \tau_s) = 0.8$	$Q = q_3 + (q_2 - q_3) \cdot \varphi_3$
	Sep 13, $t = 264$	Seoul restrictions eased	$(\tau_a, \tau_s) = 0.8$	$Q = q_4 + (q_3 - q_4) \cdot \varphi_4$
			$\tau_1 = 0.03 + 0.77 \cdot \frac{t-59}{116-59}$	$q_1 = 0.94$ $q_2 = 0.61$, $\varphi_2 = \varphi(116, 235, 3)$ $q_3 = 0.90$, $\varphi_3 = \varphi(235, 265, 2)$ $q_4 = 0.78$, $\varphi_4 = \varphi(265, 323, 2)$
UK	Dec 22, $t = 0$	No detection	$(\tau_a, \tau_s) = 0$	$Q = 0$, no quarantines
	Feb 1, $t = 41 = \tau$	First detection	$(\tau_a, \tau_s) = (0, 0.0001)$	$Q = 0$, no quarantines
	Feb 10, $t = 50$	First quarantine	$(\tau_a, \tau_s) = (0, 0.0001)$	$Q = 0$
	Feb 24, $t = 64$	Testing system commences	$(\tau_a, \tau_s) = (0, \tau_1)$	$Q = 0.0$
	Mar 23, $t = 92 = t_\lambda$	Lockdown	$(\tau_a, \tau_s) = (0, \tau_2)$	$Q = 0.55$
	May 30, $t = 160$	Test/Tracing complete	$(\tau_a, \tau_s) = (0, 0.3)$	$Q = 0.55$
			$\tau_1 = 0.0001 + 0.0299 \cdot \frac{t-63}{91-63}$ $\tau_2 = 0.03 + 0.27 \cdot \frac{t-91}{160-91}$	

South Korea: Results



(a) Infections

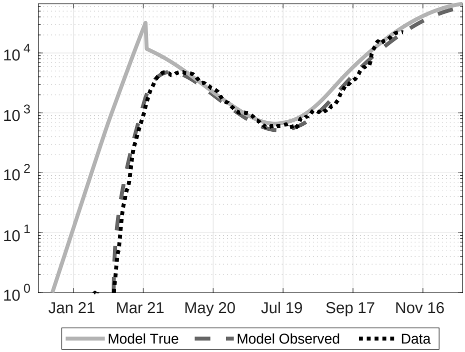


(b) Deaths

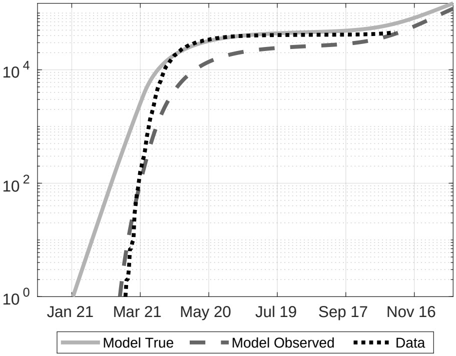
- Daily new infections and cumulative deaths in log-10 scale

Source: Korea Center for Disease Control and Prevention

United Kingdom: Results



(a) SIR

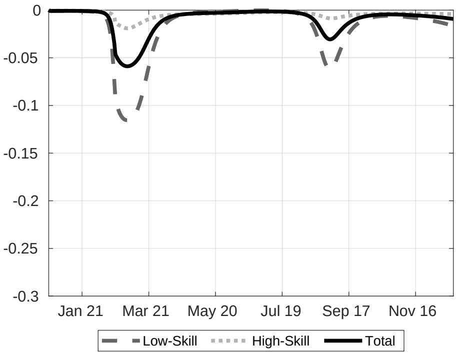


(b) Deaths

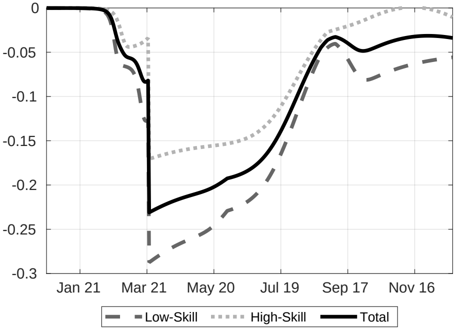
- Daily new infections and cumulative deaths in log-10 scale

Source: UK Department of Health and Social Care: delayed reports...

GDP Losses and Inequality



(a) SK



(b) UK

- SK peak drop similar in magnitude

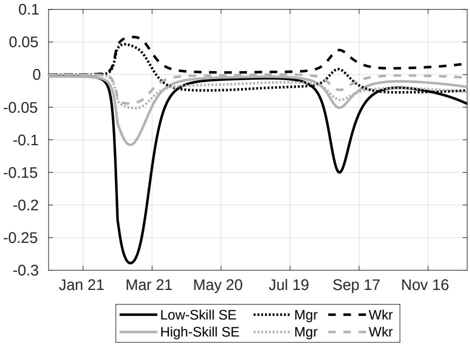
  (but 5-6% drop in data occurs in May)

- UK path comparable to data

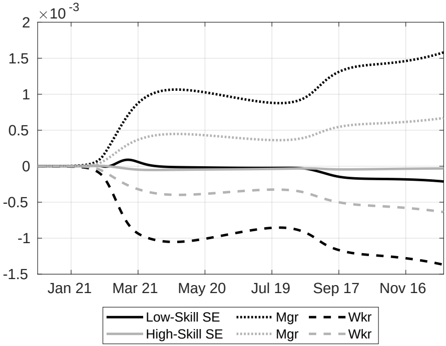
  (5-10% drop in Feb-Mar, >20% drop in Mar-Apr)

- **Aggregate GDP losses predominantly from low-skill**

SK Inequality Dynamics



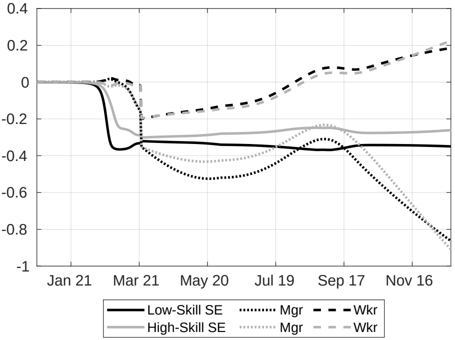
(a) Earnings



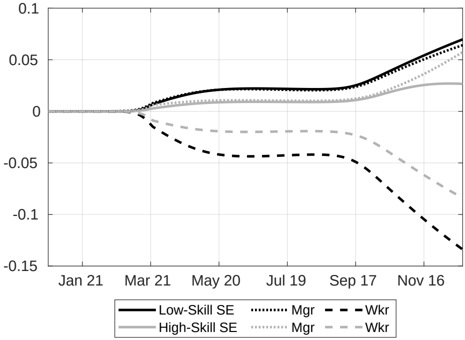
(b) Employment Shares

- Losses predominantly SE due to fear factor, especially low-skill
- But employment shares stay nearly constant
- Fear effect also quickly wears out

UK Inequality Dynamics



(a) Earnings



(b) Employment Shares

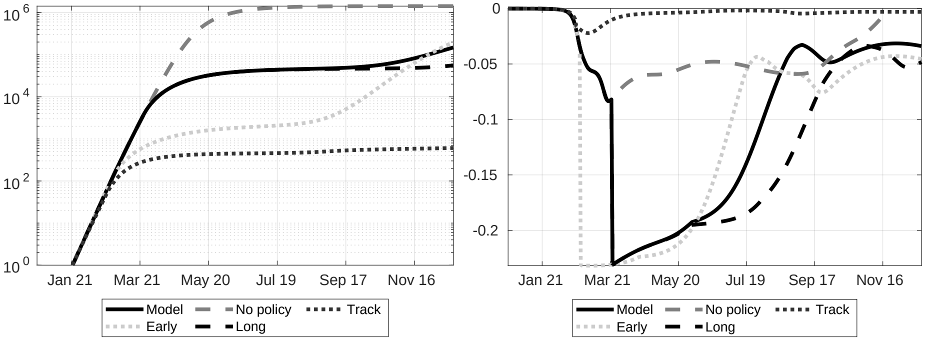
- **Fear factor** takes over, employment shares change dramatically
- Workers lose jobs; SE and managers lose earnings
  - Workers' job losses ⇒ managers earnings losses

Counterfactual Analysis

What Did Policies Do?

1. How important were UK lockdown and SK TTT?
2. What if UK did SK policy, and vice versa?
3. SK: Was it testing, or self-quarantines?
4. UK: Was lockdown too late or lifted too early?

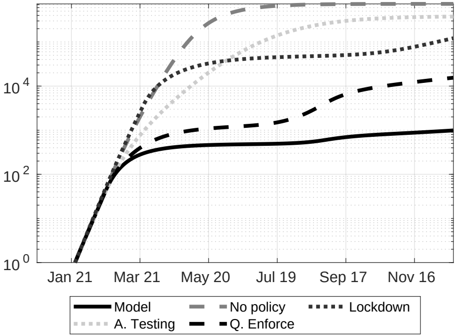
UK Counterfactuals



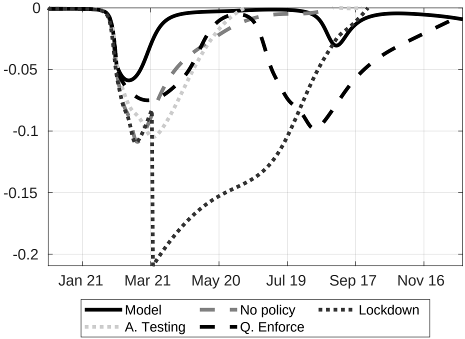
(a) SIR (b) GDP

1. Lockdown ''flattens'' both infection **and GDP curve**
2. **TTT policy** lowers infection and GDP loss by order of magnitude
3. Early and long lockdown reduces deaths at minimal cost to GDP

SK Counterfactuals



(a) SIR



(b) GDP

- SK and UK outcomes different due to differences in policy& behavior, not economic or demographic environment
- Asympotmatic testing alone less effective
- Enforcement effective even without aggressive testing

Policy Effects: Summary

UK	**Lockdown**	No policy	Track	Early	Long
Deaths	65253	1424800	573	31402	47501
GDP	-11.0	-4.8	-0.5	-12.2	-13.0
SK	**Track**	No policy	Lockdown	A. Testing	Q. Enforce
Deaths	837	729641	65403	356228	10933
GDP	-1.2	-2.0	-8.4	-2.2	-4.7

- Cum. deaths and average GDP loss from 1 Jan to 30 Oct, 2020
- GDP loss in log-point deviations from 2019 average

Conclusion

Main Takeaways

1. GDP and COVID containment not necessarily trade-off
    - **Fear Factor** reduces economic activity
    - Certain NPI's can reduce both infections and GDP cost
2. Template for analyzing different types of policies

    quarantine **intensity** vs **extensive** lockdowns
3. Template for simulating **distributional outcomes** in conjunction with aggregate outcomes
    - Low-skill more exposed to virus **and** adverse economic outcomes
    - Easy to model subsidies for SE and employer-backed furloughs

* In progress:
    - SK model with fiscal policies (✓)
    - UK model with fiscal policies + extra demographics and finer economic structure

Thank You

Happy New Year!

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