Social Distancing and Supply Disruptions in a Pandemic

Martin Bodenstein [1]   Giancarlo Corsetti [2]   Luca Guerrieri [1]

[1]Federal Reserve Board

[2]University of Cambridge

April 2020

Disclaimer

The views expressed in this paper/presentation are solely the responsibility of the authors and should not be interpreted as reflecting the views of the Board of Governors of the Federal Reserve System or any other person associated with the Federal Reserve System.

Why social distancing?

Most advanced economies mandate social distancing and other public health restrictions to slow the spread of COVID-19.

A key argument for these measure highlights a trade-off:
social distancing

1. protects capacity-constrained **health care systems** and lives
   - The mortality rate may increase in the number of infected people when health care system is strained.
   - Surge in the number of infected individuals may cause steep rise in mortality rates.
2. but also entails **high economic costs**.

Could these economic costs be avoided by not implementing a lockdown?

The Core Sector and the Cost of Inaction

We argue that "inaction"—not implementing any social distancing measure—can have dire economic consequences as well.

Central to our argument is the presence of a **"core sector"** in the economy:

- Core-sector industries provide essential inputs to other industries and/or are essential for the economy to run.
- Prime candidates are health care services, food, distribution services, transportation, sanitation, and energy supply.
- An unchecked pandemic, through its effect on labor supply, can incapacitate the core sector and cause a steep fall in economic activity
  - Examples: NY MTA, meat processing plants, air traffic controllers.

was

Core Sector

Sector	% of GDP	% of Employment
Agriculture ...	0.81	2.65
Utilities	1.58	0.52
Food and beverage ...	1.31	1.86
Petroleum and coal products	0.84	0.12
Food and beverage stores	0.76	2.2
Transportation and warehousing	3.2	5.27
Health care and social assistance	7.47	8.66
Federal government, general services	3.54	0.88
State government, general services	7.78	15.38
Total	27.29	37.56

Note: BEA tables on GDP by Industry, employment shares are based by matching the industries in the BEA table with hours worked data by industry in the Productivity Release of the BLS.

Our approach

Rethink the health-economy trade-off using an integrated assessment model that combines:

1. a multi-group but otherwise standard epidemiological model
2. with a multi-sector macroeconomic model that distinguishes between core and non-core industries.

A fall in labor supplied to core industries amplifies aggregate economic contraction via two channels:

1. The output of the core sector is **not easily substitutable**.
2. Production in the core sector is non-homothetic: it is subject to a **minimum-scale** requirement.

Main takeaways

The two sector integrated model

1. highlights the risks of large supply-driven economic contraction relative to one sector model
   - without social distancing, the "missing workers" due to illness in the core and non-core sectors could lead to a cumulative loss of output of 8-to-10 percent over 6 months (1/3 more than in the one sector model).
   - The fall in GDP would reach -30% instead of -20%.

Main takeaways

The two sector integrated model

1. highlights the risks of large supply-driven economic contraction relative to one sector model
   - without social distancing, the “missing workers” due to illness in the core and non-core sectors could lead to a cumulative loss of output of 8-to-10 percent over 6 months (1/3 more than in the one sector model).
   - The fall in GDP would reach -30% instead of -20%.
2. provides a blueprint for assessing structured social distancing measures targeting differentially workers by sectors and occupational tasks
   - workers in the core vs non-core industries
   - those who can work from home

Main takeaways

The two sector integrated model

1. highlights the risks of large supply-driven economic contraction relative to one sector model
   - without social distancing, the "missing workers" due to illness in the core and non-core sectors could lead to a cumulative loss of output of 8-to-10 percent over 6 months (1/3 more than in the one sector model).
   - The fall in GDP would reach -30% instead of -20%.
2. provides a blueprint for assessing structured social distancing measures targeting differentially workers by sectors and occupational tasks
   - workers in the core vs non-core industries
   - those who can work from home
3. puts infection externalities centerstage in the analysis of supply resilience
   - protect workers in core industries

Which Strategy of Social Distancing?

In this paper, we focus on economic contraction due to incidence of disease on labor supply, abstracting from

- precautionary saving, financial friction and economic policy
- uncertainty concerning spread of disease, immunity and vaccine

Main idea: differentiating public health restrictions by sector and occupational tasks can reduce the supply disruption.

In our baseline, sector-specific social distancing

- requires in each sector individuals who can work from home to do so, and be subject to a lockdown,
- affects in total one-third of the population (including people not in the labor force),
- is in place for 8 months, to avoid a resurgence of the epidemic.

Length vs. Intensity of a Lockdown

The baseline measures help by shielding the core sector from surges in infection, and smooth out the trough in activity.

We analyze the trade-offs between length and intensity of public health measures within and across sectors—under different epidemiological scenarios.

Strict (short and prolonged) lockdowns:

- reduce the peak of the infection,
- but delay immunity,
- and constrain production.

Unless breakthrough on vaccine, treatment, or contact tracing, strict lockdowns may reactivate the epidemic with dire economic effects, on top of the policy-induced reduction in activity .

Roadmap of the Presentation

1. Our framework that integrates:
   - three-group epidemiological model
   - two-sector macroeconomic model.
2. Economic effects of COVID-19 in one- and two-sector models.
3. Tailoring social distancing by sector and occupational tasks.
4. Some ballpark estimates of the costs of waiting for a vaccine.

Literature

The Canonical SIR Model

Canonical discrete-time SIR Model embraces "law of mass action:"

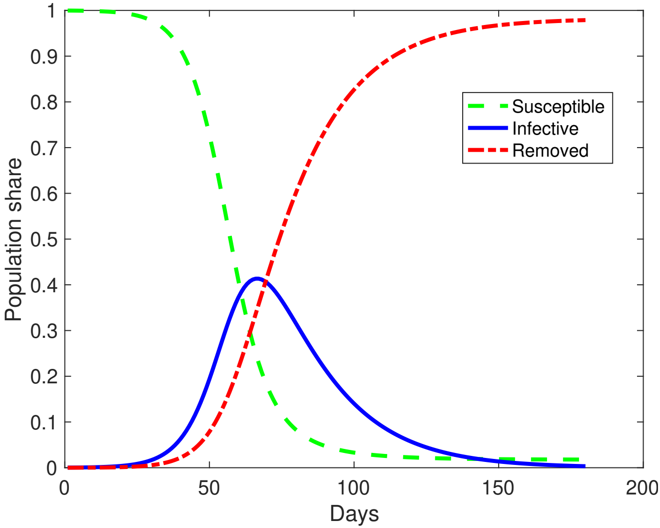
$$\begin{aligned} S_{t+1} - S_t &= -\beta S_t I_t \\ I_{t+1} - I_t &= \beta S_t I_t - \gamma I_t \\ R_{t+1} - R_t &= \gamma I_t. \end{aligned}$$

Notation:

- contact rate β, recovery rate γ,
- basic reproduction number $R_0 \equiv \frac{\beta}{\gamma}$,
- emergence of pandemic if $R_0 > 1$.

In our baseline $R_0 = 4$, but consider range of plausible alternatives.

The Canonical SIR Model with $R_0 = 4$



Our Three-Group SIR Model

To taylor social distancing, we need to track three groups:

$$
\begin{aligned}
S_{j,t+1} - S_{j,t} &= -\sum_{k=1}^{3} \beta_{j,k,t} I_{k,t} S_{j,t}, \\
I_{j,t+1} - I_{j,t} &= \sum_{k=1}^{3} \beta_{j,k,t} I_{k,t} S_{j,t} - (\gamma_j + \varpi_j) I_{j,t}, \\
R_{j,t+1} - R_{j,t} &= \gamma_j I_{j,t},
\end{aligned}
$$

1. Group 1 coincides with the employed individuals in Sector 1
2. Group 2 coincides with the employed individuals in Sector 2
3. Group 3 are the individuals out of the labor force (the young and the elderly)

If $\beta_{j,k,t} = \beta$ model aggregates to the canonical SIR model.

Our Two-Sector Economic Model: Households

Households pool consumption risk, supply labor inelastically, and choose $\{c_{t+i}, i_{t+i}, k_{t+i}, u_{2,t+i}\}_{i=0}^{\infty}$ to maximize

$$U_t = E_t \sum_{i=0}^{\infty} \theta^i \log(c_{t+i} - \kappa c_{t+i-1}).$$

subject to

- the budget constraint

$$c_t + i_t = w_{1,t} l_{1,t} + w_{2,t} l_{2,t} + r_{k,t} u_t k_{t-1} - \nu_0 \frac{u_t^{1+\nu}}{1+\nu},$$

- the capital accumulation constraint

$$k_t = (1-\delta) k_{t-1} + i_t,$$

- and the investment irreversibilty constraint

$$i_t \geq 0.$$

Two-Sector Economic Model: Production Sector 1

Sector 1 (core sector):

- uses labor $l_{1,t}$ only,
- subject to minimum scale requirement governed by χ,
- production function:

$$v_{1,t} = \eta\left(l_{1,t} - \chi\right)$$

- η controls production level in steady state for given l_1 and χ.

Two-Sector Economic Model: Production Sector 2

Sector 2:

- uses labor $l_{2,t}$ and capital k_{t-1} (with capacity utilization u_t)
- production function

$$v_{2,t} = \left(u_t k_{t-1}^{\alpha}\right) l_{2,t}^{1-\alpha}$$

- combines $v_{1,t}$ and $v_{2,t}$ to final output

$$y_t = \left((1-\omega)^{\frac{\rho}{1+\rho}} \left(v_{1,t}\right)^{\frac{1}{1+\rho}} + \omega^{\frac{\rho}{1+\rho}} \left(v_{2,t}\right)^{\frac{1}{1+\rho}}\right)^{1+\rho}.$$

Note: The model reduced to standard one-sector model for $\omega = 1$.

Bridging the Two Models: The Labor Supply

With the disease and no social distancing, sectoral labor supply is

$$l_{j,t} = N_j - (1 - \iota) I_{j,t},$$

for $j \in [1, 2]$.

We assume

- **symptomatic** infected of share $(1 - \iota)$ cannot work,
- **asymptomatic** infected of share ι work.

Calibration: Group Sizes

To size the three groups in the SIR model we use data on the

1. employment-to-population-ratio
   around 65%—in line with the share of working age in the U.S. age distribution
   $\rightarrow \mathbf{N_3 = 0.35}$
2. employment share in the core sector,
   around 38% (next slide)
   $\rightarrow \mathbf{N_1 = 0.65 \times 0.38 \approx 0.25}$ and $\mathbf{N_2 = 0.4}$

Calibration: Core Sector

Sector	% of GDP	% of Employment
Agriculture ...	0.81	2.65
Utilities	1.58	0.52
Food and beverage ...	1.31	1.86
Petroleum and coal products	0.84	0.12
Food and beverage stores	0.76	2.2
Transportation and warehousing	3.2	5.27
Health care and social assistance	7.47	8.66
Federal government, general services	3.54	0.88
State government, general services	7.78	15.38
Total	27.29	37.56

Note: BEA tables on GDP by Industry, employment shares are based by matching the industries in the BEA table with hours worked data by industry in the Productivity Release of the BLS.

Parameterization of the Epidemiological Model

Great uncertainty about the parameters governing the spread of COVID-19.

Absent social distancing, we abstract from heterogeneity and set:

- the effective daily contact rate $\beta = 0.2$ for all groups,
- the recovery rate, based on average infection duration of 20 days, $\gamma = 0.05$ for all groups,
- the death rate at zero,
- the share of asymptomatic $\iota = 0.4$ (value for working-age individuals in the Diamond Princess cruise ship study)

$\rightarrow$ $\mathbf{R_0 = 4}$; estimates for R_0 range from about 1.5 up to 6.

Key Parameters of the Macroeconomic Model

We set:

- the minimum scale parameter for the core sector $\chi = \frac{1}{2}N_1$,
- the Sector 1 quasi-share value added $1 - \omega = 0.27$,
- the elasticity of substitution between the inputs of the core and non-core sectors equal to $\frac{1}{3}$.

Full Calibration Table

The economic model is calibrated at a **monthly** frequency (because of aggregate investment dynamics); we aggregate the **daily** data from the epidemiological model to monthly data.

Solution Method

Effects of COVID-19: One- vs. Two-Sector Models

The economic effects of an unmitigated disease spread via labor supply crucially depend on the structure of the economy.

Our first experiment compares

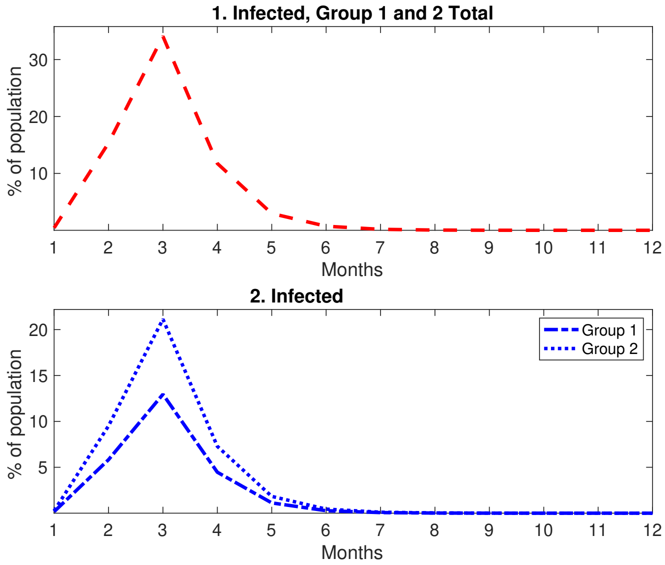
- our two-sector model with core/ non-core distinction and three-group SIR model
- to a standard one-sector model ($\omega = 1$) with SIR model reflecting employment-to-population ratio only.

with no social distancing and

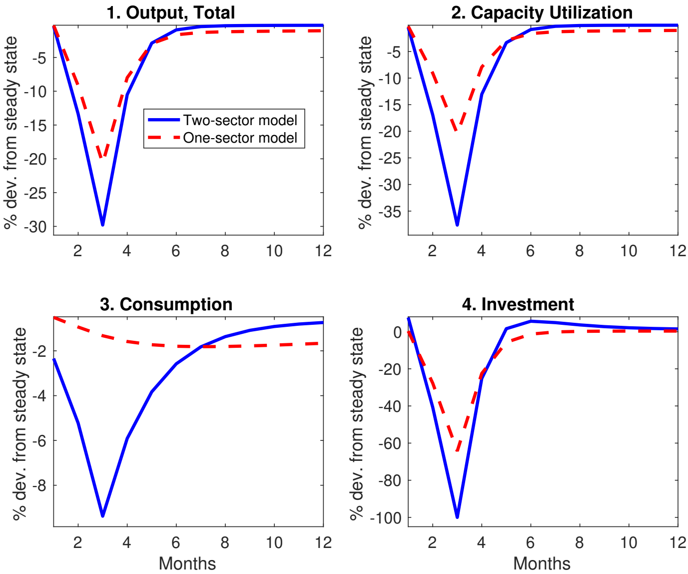
The cumulative loss of output in the two-sector model is 10 percent over 6 months, 1/3 more than in the one sector model).

Disease Dynamics—No Social Distancing

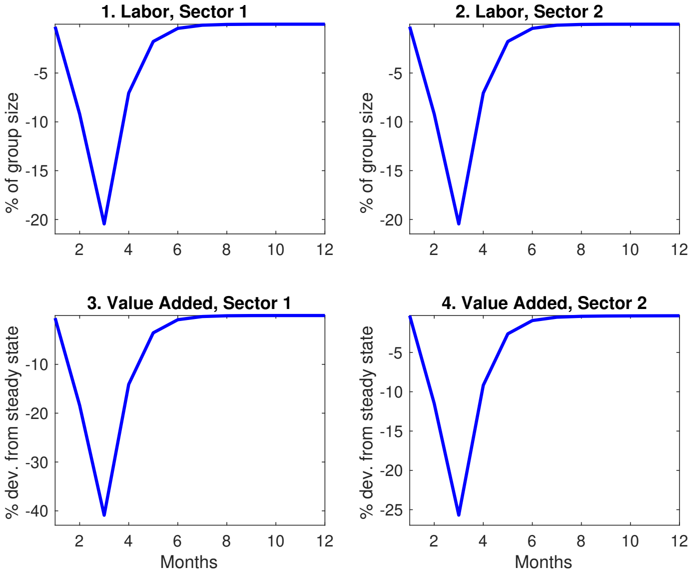
Monthly Frequency



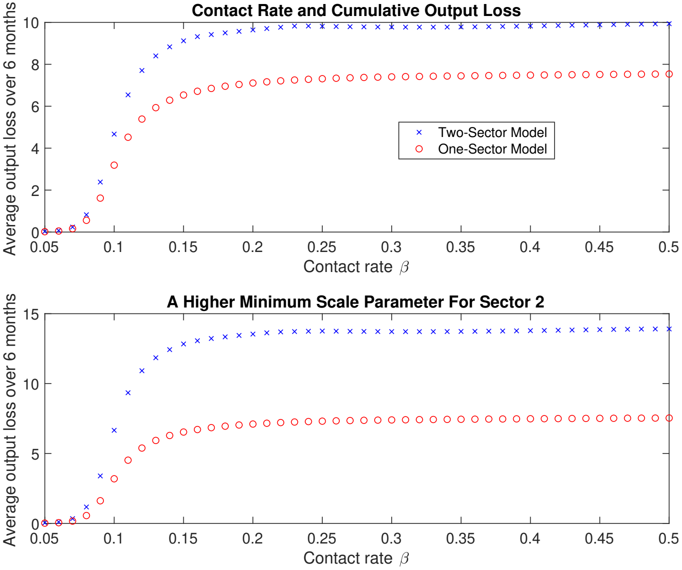
The Two-Sector Model Implies a Deeper Contraction



Sectoral Detail: Role of Minimum Scale Requirement



Robustness to Contact Rate



Social Distancing by Sector and Occupational Tasks

Absent social distancing, we assumed a group-independent effective contact rate β.

Group-specific social distancing measures introduces contact rate heterogeneity in line with the "law of mass action:"

$$\beta_{j,k,t} = \beta \left(1 - \vartheta \frac{\bar{N}_{j,t}}{N_j}\right) \left(1 - \vartheta \frac{\bar{N}_{k,t}}{N_k}\right).$$

where

- $\frac{\bar{N}_{j,t}}{N_j}$ denotes the share of group j under lockdown,
- ϑ is the lockdwon effectiveness,
- measures do not distinguish between health status.

The Labor Supply with Social Distancing Measures

$$
\begin{aligned}
l_{j,t} &= N_j - \max\left[\frac{\bar{N}_{j,t}}{N_j} - \upsilon_j, 0\right] N_j - \min\left[\frac{\bar{N}_{j,t}}{N_j}, \upsilon_j\right](1-\iota)I_{j,t} \\
&- \left(1 - \frac{\bar{N}_{j,t}}{N_j}\right)(1-\iota)I_{j,t}.
\end{aligned}
$$

- $\max\left[\frac{\bar{N}_{j,t}}{N_j} - \upsilon_j, 0\right] N_j$ individuals under lockdown, in addition to the share υ_j of individuals who can continue working from home,
- $\min\left[\frac{\bar{N}_{j,t}}{N_j}, \upsilon_j\right](1-\iota)I_{j,t}$ sick and symptomatic individuals who are under lockdown and are working from home,
- $\left(1 - \frac{\bar{N}_{j,t}}{N_j}\right)(1-\iota)I_{j,t}$ individuals who get sick and are symptomatic but are not under lockdown.

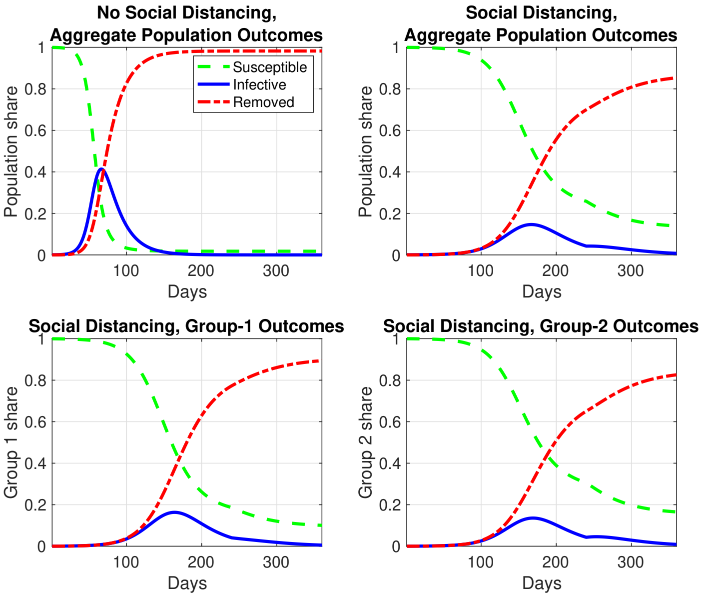
Baseline Social Distancing Parameters

Social distancing could be targeting first and foremost workers can continue working from home.

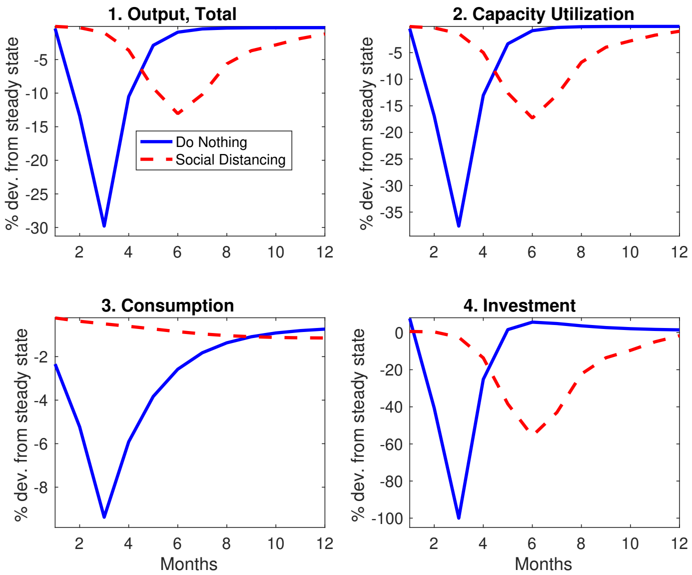
Details:

- BLS American Time Use Survey: 15% of workers in Group 1 and 40% of workers in Group 2 can work from home—and we assume only these workers will be under lockdown.
- We also assume that 30% of Group 3 will be under lockdown, the same proportion as for the overall population.
- Keeping these measures for 8 months can avoid a resurgence of the epidemic once these measures are lifted.

Social Distancing Flattens the Curve



Social Distancing smooths out economic contraction



Takeaways

Social distancing (lockdown) saves lives and can significantly smooth the output and consumption costs of the disease.

Characteristics of lockdown:

- skewed towards the non-active population and workers in the non-core sector
- targets the share of workers who could reasonably keep performing their occupational tasks from home.

Effects of lockdown:

- higher share of individuals at home, reduces the infection rate among the workers in core industries (**infection externality**),
- contraction in value added in the two sectors now comparable.

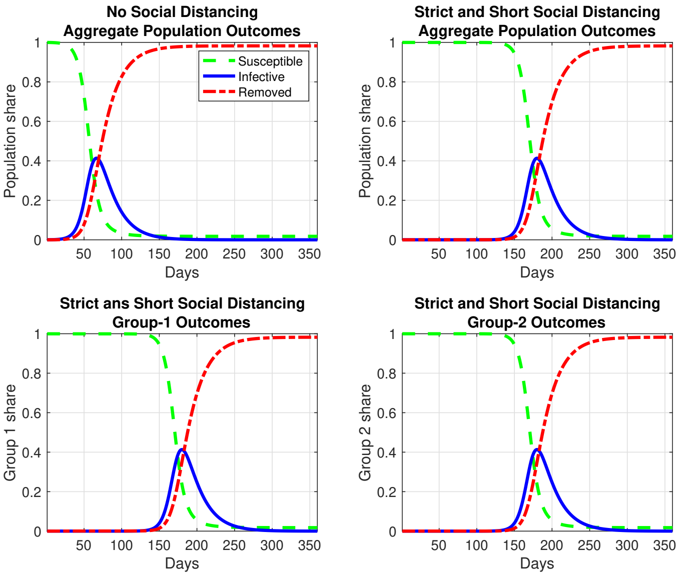
→ **Decline in economic activity mitigated vis-à-vis inaction**

Stricter but Shorter Social Distancing

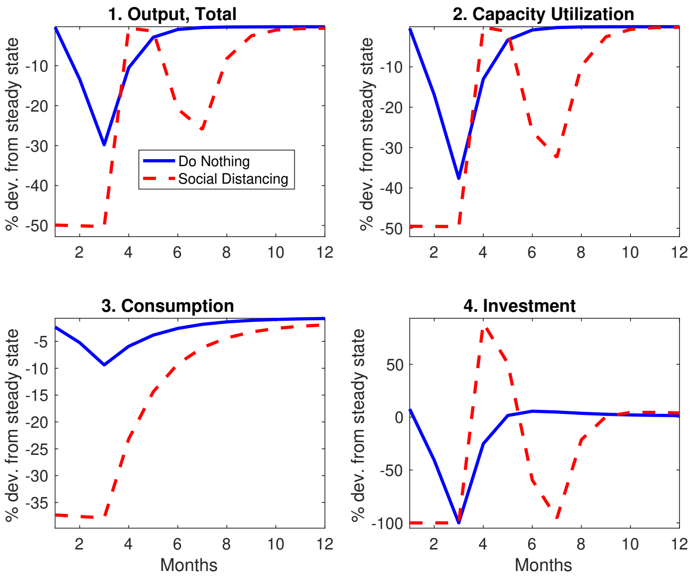
Experiment

- 40 percent of individuals in Group 1 under lockdown,
- 90 percent of individuals in both Group 2 and Group 3 under lockdown,
- lockdown lasts 3 months, then all measures are removed.

Social Distancing Gone Wrong



Social Distancing Gone Wrong



Takeaways

Strict lockdowns may temporarily prevent the share of infected individuals from surging.

But,

- the economic costs might be steep
- and with little herd immunity developed, disease spreads after lifting measures causing additional severe economic harm.

Waiting for a Vaccine

Two aspects featuring strongly in public debate are:

- the need to reduce the peak of infected individuals
- the possible arrival of a vaccine.

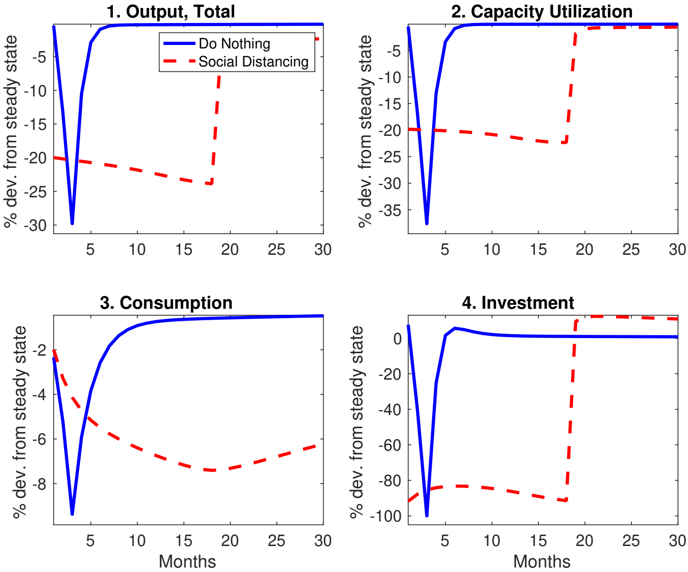
The following experiment assumes:

- arrival of a vaccine in 18 months,
- lockdown shares of 25, 60, and 47% for groups 1, 2, and 3.

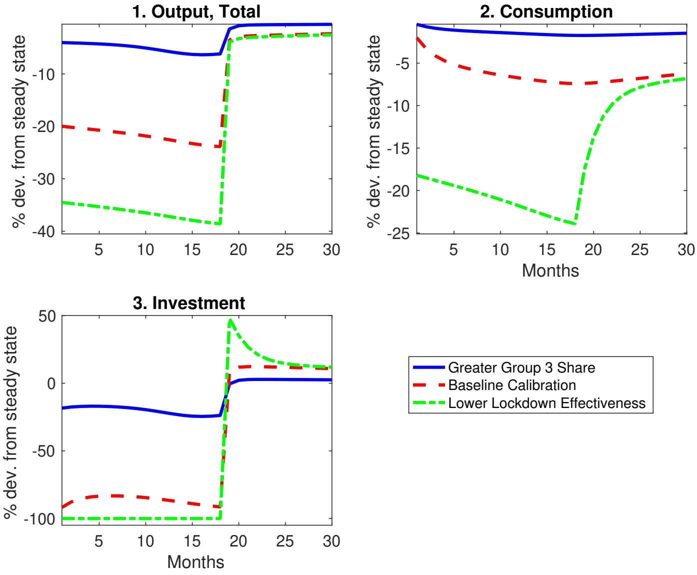
Goal is to:

- limit peak infection share to 1.5 percent,
- reduce costs by equalizing loss in value added across sectors.

Waiting for a Vaccine



Waiting for a Vaccine



Range of Estimates of the Cost of Waiting for a Vaccine

The cost estimates are sensitive to:

- The **lockdown effectiveness**—lowering effectiveness from $\vartheta = 1$ to 0.8 as in Alvarez et al (2020) could almost double the output cost.
- The **share of individuals in lockdown** for Group 3—pushing the lockdown for Group 3 to 80% could lower the cost to about 5% of output.

  Not shown in the figure:

- The **effective contact rate**—with $\beta = 0.1$ and $R_0 = 2$ limiting lockdown to those who can work from home reduces peak share of infective individuals to 0.3 % indefinetely, with no reduction in the labor supply.

A Lower Contact Rate

- Using the canonical one-group SIR model, what share of the population should be under lockdown to achieve an effective $R_0 = 1$?
- Assuming the lockdown is fully effective, $R_0 \left(1 - \frac{\bar{N}}{N}\right)^2 = R_{target}$.
- If $R_0 = 2$ and $R_{target} = 1$, then $\frac{\bar{N}}{N} \approx 30\%$.
- Given that the BLS American Time Use Survey points to about 30% of the workforce as able to work from home, with these parameters an extended lockdown would entail no reduction in labor supply — we could achieve it by skewing the lockdown towards our Group 2.
- And the peak share of infected individuals would drop to 0.3% of the population, which would be unlikely to strain the capacity of the health care sector, as other studies point out.

Conclusion

- In our model, the **direct** economic cost of the disease stems from the inability of symptomatic infected individuals to continue working.
- The **indirect** costs come from the constraint that malfunctioning core industries may place on other industries via input-output linkages.
- Simulations of our integrated assessment model for infectious diseases suggest that structured public health restrictions may actually improve economic outcomes relative to inaction.
- Model estimates suggest that the cost of waiting for a vaccine can span a wide range.
- Because of the lingering uncertainty on the way the disease spreads, these estimates cannot be but useful blueprints for further analysis.

Conclusion

We abstracted from a range of aspects

- financial frictions
- nominal rigidities
- fiscal and monetary policy
- consumption demand channel

But investment dynamics, capital utilization capture some of these issues and we go well beyond the literature.

Appendix

Literature

Quickly growing economic and epidemiological literature including, e.g.,

- Optimal policy on social distancing: Alvarez, Argente, and Lippi (2020); Eichenbaum, Rebelo, and Trabandt (2020); Jones, Philippon, and Venkateswaran (2020).
- Moghadas et al (2020).

return

Literature

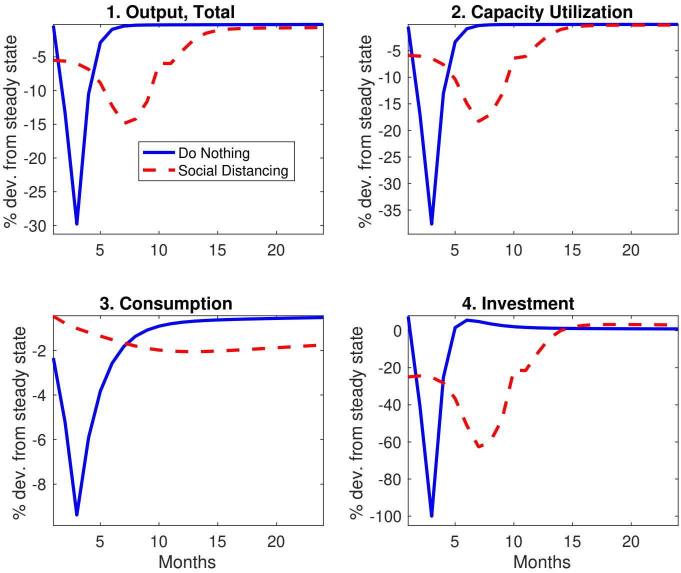
Quickly growing economic literature:

- Optimal policy on social distancing: Alvarez, Argente, and Lippi (2020); Eichenbaum, Rebelo, and Trabandt (2020); Jones, Philippon, and Venkateswaran (2020);
- economic effects and policies: Bayer, Born, Luetticke, and Mueller (2020); Glover, Heathcote, Krueger, and Rios-Rull (2020); Guerrieri, Lorenzoni, Straub, and Werning (2020);
- other: Kremer (1996); Greenwood, Kirchner, Santos, Tertilt (2020); Alfaro, Chari, Greenland, and Viratyosin; Baker, Bloom, Davis, Kost, Sammon, and Viratyosin (2020), Correia, Luck and Verner (2020).

Long tradition of mathematical epidemiology:

- Epidemiological models: Kermack and McKendrick (1927); Hethcote (1989); Brauer, Driesche, and Wu (2008);
- COVID-19: Russel et al (2020); Moghadas et al (2020).

Deeper and Longer Social Distancing



return

Solution Method

The solution method has three important characteristics:

1. It allows for a solution of the SIR model that is exact up to numerical precision;
2. It conveys the expected path of the labor supply in each group to the economic model as a set of predetermined conditions;
3. It resolves the complication of the occasionally binding constraints, implied by capital irreversibility, with a regime switching approach following using OccBin, the solution method of Guerrieri and Iacoviello (2015).

The modular solution approach has the advantage of allowing us to consider extensions of either module without complicating the solution of the other. The advantage of OccBin is that it is remarkably resilient to the curse of dimensionality, while still accurate for the class of models we consider. return

Calibration

Parameter	Used to Determine
$\beta = 0.2$	contact rate (daily)
$\gamma = 1/20$	removal rate (daily)
$\varpi = 0$	death rate (daily)
$\vartheta = 1$	effectiveness social distancing
$\iota = 0.40$	share of symptomatic infectives
$N_1 = 0.25$	size Group 1
$N_2 = 0.40$	size Group 2
$N_3 = 0.35$	size Group 3
$\upsilon_1 = 0.15$	share working from home Sector/Group 1
$\upsilon_2 = 0.40$	share working from home Sector/Group 2

return

Calibration Continued

Parameter	Used to Determine
$\theta = 1 - \frac{4}{100}/12$	discount factor (monthly)
$\delta = \frac{1}{10}/12$	capital depreciation rate (monthly)
$\kappa = 0.6$	habit persistence
$\nu = 0.001$	elasticity capacity utilization
$\phi = 0$	degree of capital reversibility
$1 - \omega = 0.27$	quasi-share value added Sector 1
$\eta = 2$	scaling parameter Sector 1
$\chi = \frac{1}{2} N_1$	minimum scale Sector 1
$\rho = \frac{1}{1-1/3}$	substitution elasticity Sectors 1 and 2
$\alpha = 0.3$	share capital in production Sector 2

return