Voluntary and Mandatory Social Distancing: Evidence on COVID-19 Exposure Rates from Chinese Provinces and Selected Countries

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Introduction

- The COVID-19 pandemic has already claimed many lives and is causing an unprecedented and widespread disruption to the world economy.

- China responded with draconian social distancing policies, other countries have responded differently, and some more timidly.

- In this paper, we consider both government-mandated social distancing, and voluntary self-isolation within a standard Susceptible-Infected-Recovered framework (SIR).

The paper reports several results

- Theory
  - A SIR Model with mandatory and voluntary social distancing
  - A model of the impact of the epidemic on employment
  - We also derive a reduced form regression model that takes measurement error in reported cases and deaths into account

- Empirical
  - For Chinese provinces, we estimate a homogeneous recovery rate of **3 weeks** and a **very small fractions of exposed population** (except in Hubei province)

  - Fore selected other countries for which we had sufficient data as of end-March 2020, we estimate **much higher, and more heterogeneous, exposure rates**

Today's presentation

- A discrete-time SIR Model with social distancing
- Comparison between mandatory and voluntary social distancing
- Selected empirical results on exposure rates
- Economic and policy implications of the analysis for the reopening of the economy

Basic SIR model

- Consider a given population of fixed size, P, composed of susceptible at time t (S_t), 'removed' individuals who can no longer contract the disease because recovered or deceased (R_t), and those who remain infected, I_t:

$$P = S_t + I_t + R_t. \tag{1}$$

- The SIR model is typically cast in terms of a set of differential equations, which we discretize and write as the following difference equations (for $t = 1, 2, ..., T$)

$$S_{t+1} - S_t = -\beta s_t I_t, \tag{2}$$
$$I_{t+1} - I_t = \beta s_t I_t - \gamma I_t, \tag{3}$$
$$R_{t+1} - R_t = \gamma I_t, \tag{4}$$

- Here, $s_t = S_t / P$, β is the rate of transmission, γ is the recovery or removal rate, and $R_0 = \beta / \gamma$ is the basic reproduction rate.

Social distancing in the SIR model

- Divide total population, P into those who are exposed (they have not been infected yet, P_E), and those who are isolated, P_I.
- We denote the strength of the mitigation policy by $1 - \lambda$, where λ is the proportion of population that is exposed, defined as $\lambda = P_E / P$.
- In practice, λ is time-varying and there is feedback from the epidemic to $\lambda = P_E / P$.

SIR model with mitigation policies

- Consider the case where λ is set at the outset of the spread of the epidemics, by mandated policy, i.e., what we China in Wuhan.

- With social distancing, the SIR model becomes

$$
\begin{aligned}
P_E = \lambda P &= S_t + I_t + R_t \\
S_{t+1} - S_t &= -\beta \left(\frac{S_t}{P_E} \right) I_t, \\
I_{t+1} - I_t &= \left[\beta \left(\frac{S_t}{P_E} \right) - \gamma \right] I_t.
\end{aligned}
$$

SIR model with mitigation policies (Cont.)

- Dividing both sides of the above equation by P and using the fractions $s_t = S_t/P$, $i_t = I_t/P$ and $r_t = R_t/P$, we have

$$s_{t+1} - s_t = -\left(\frac{\beta}{\lambda}\right) s_t i_t, \quad (5)$$

$$i_{t+1} - i_t = \left[\left(\frac{\beta}{\lambda}\right) s_t - \gamma\right] i_t, \quad (6)$$

  and

$$\lambda = s_t + i_t + r_t. \quad (7)$$

- **Given β, the fraction of total exposed population, λ, determines the effective transmission rate, $\theta = \beta/\lambda$.**

Solution

- The system equations (5) and (6) can be solved by iterating forward from some non-zero initial values.
- We obtain $lim_{t \to \infty} s_t = s^* = \lambda (\gamma / \beta) = \lambda / R_0$, and (for the total number of infected cases as a fraction of the population, denoted by c^*):

$$c^* = r^* = \lambda - \lambda / R_0 = \frac{\lambda (R_0 - 1)}{R_0}. \quad (8)$$

- The choice of λ affects the steepness and the peak of the epidemic curve, and can be used to flatten the trajectory of i_t.
- In particular, i_t is given by the following second-order non-linear difference equation in i_t

$$i_{t+1} = i_t^2 / i_{t-1} + \theta \left[i_t i_{t-1} (1 - \gamma) - i_t^2 \right], \quad t = 1, 2, ..., T, \quad (9)$$

with the initial values i_1 and $i_2 = (1 - \gamma + \theta s_1) i_1$, where $s_1 = \lambda - i_1$.

Figure 1: Simulated values of $i_t(\lambda)$ for different social distancing coefficients: $\lambda = 1$ (blue), 0.75 (red), and 0.5 (green)

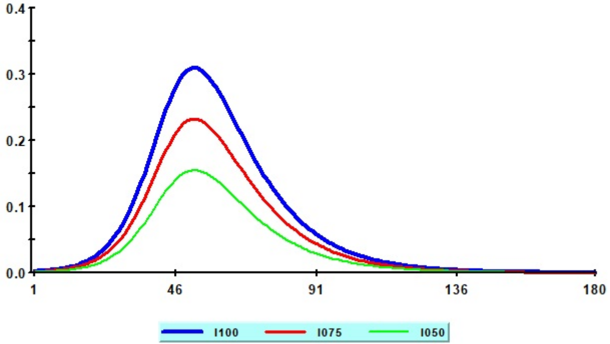


Figure 1 we show the time profile of $i_t(\lambda)$ using the parameter values $R_0 = 3$ and $\gamma = 1/d = 1/14$ and the initial values $i_1(\lambda) = \lambda/1000$, and $i_2(\lambda) = [1 - \gamma + (\gamma R_0/\lambda)\, s_1(\lambda)]\, i_1(\lambda)$, where $s_1(\lambda) = \lambda - i_1$.

A model of voluntary social isolation: the case of time-varying lambda

- So far λ, the proportion of population that can be infected is fixed and set exogenously by central authorities.
- Individuals are likely to isolate voluntarily when (i) the probability of contracting the disease is sufficiently high. However, people also weigh the contagion risk against (ii) income losses and (iii) the inconvenience of living in isolation. As a consequence, voluntary social distancing can keep people at home only when the infection risk is high and visible.
- Even authorities, internalizing individuals' preferences, can be slow to respond when the number of active cases is small and they might delay or start with a low level of mandatory social distancing, and then begin to raise it as the number of infected cases increases.
- In the context of our modified SIR model we can allow for such time variations in λ

Model ingredients

- Consider an individual j is faced with the voluntary decision of whether to isolate or not.
- Under self-isolation the individual incurs the loss of wages net of transfers, amounting to $(1-\tau_j)w_j$, plus the inconvenience cost, a_j, of being isolated.
- On the other hand, if the individual decides not to self-isolate then he/she receives the uncertain pay-off of $(1-d_{jt})w_j - d_{jt}\phi_j$, where d_{jt} is an indicator which takes the value of unity if the individual contracts the disease and zero otherwise.
- ϕ_j represents the cost of contracting the disease and is expected to be quite high. We are ruling out the possibility of death as an outcome.
- The individual decides to self-isolate if the sure loss of self-isolating is less than the expected loss of not self-isolating:

$$(1-\tau_j)\,w_j + a_j < E\left[d_{jt}\phi_j - (1-d_{jt})w_j\,|\mathcal{I}_{t-1}\right], \qquad (10)$$

where $\mathcal{I}_{t-1}$ is the publicly available information that includes i_{t-1}, the proportion of population being infected in day $t-1$.

Individual decision rule

- We assume that the probability of anyone contracting the disease is uniform across the population and this is correctly perceived to be given by π_{t-1}. Hence $E\left(d_{jt}\left|\mathcal{I}_{t-1}\right.\right) = \pi_{t-1}$, and the condition for self-isolating can be rewritten as

$$\frac{2-\tau_j + (a_j/w_j)}{1+\left(\phi_j/w_j\right)} = \mu_j < \pi_{t-1}. \tag{11}$$

  Since $\pi_{t-1} \leq 1$, then for individual i to self-isolate we must have $\mu_j < 1$, (note that $\mu_j \geq 0$, with $\mu_j = 0$ when $\phi_j \to \infty$) or if

$$\phi_j/w_j > a_j/w_j + (1-\tau_j). \tag{12}$$

- This can also captures the differential incentive to self-isolate across different age groups and sectors of economic activity: namely $\phi_{old} > \phi_{young}$ (and the old are more likely to self-isolate), or low-wage earners are more likely to self-isolate as compared to high-wage earners with the same preferences (ϕ_j), and facing the same transfer rates, τ_j.

Share of exposed population falls as the epidemic peaks

Figure 2: Simulated values of λ_t in the case of the SIR model with parameters $R_0 = 3, \gamma = 1/14, \lambda = 0.5$ and $\kappa = 1.5$.

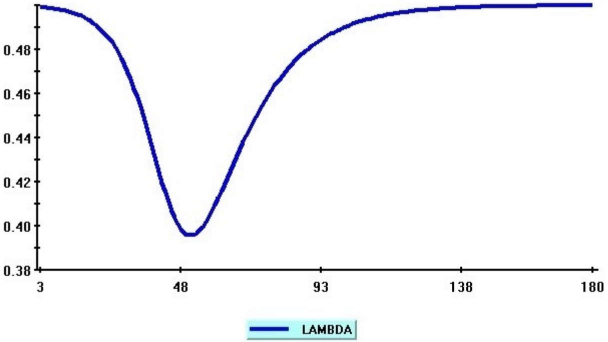
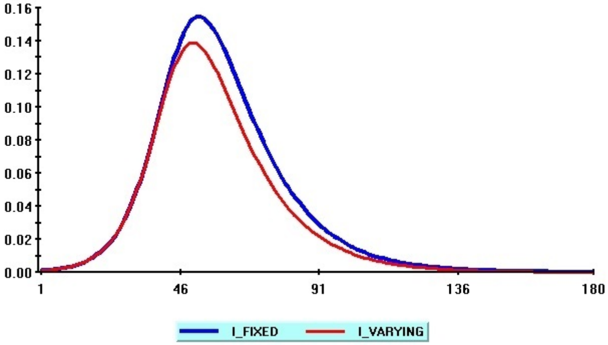


Figure 2 shows the simulated values of λ_t from iterating equations (**??**), (**??**) and (**??**) forward with parameters $R_0 = 3, \gamma = 1/14, \lambda = 0.5$ and $\kappa = 1.5$.

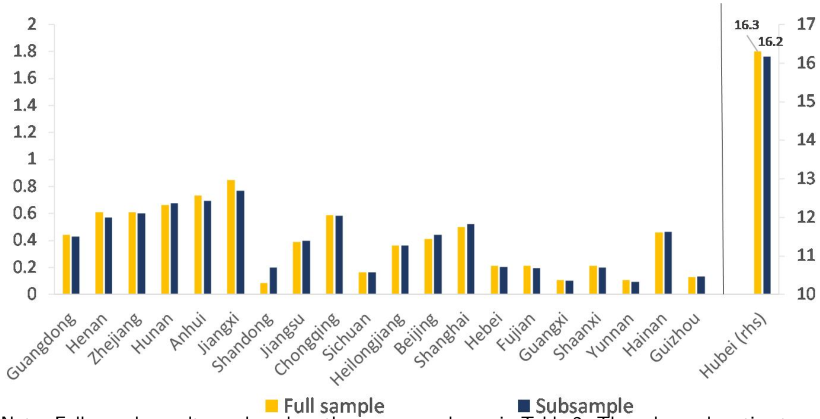
But flattening impact is small

Figure 3: Time profiles of i_t with a fixed $\lambda = 0.5$ and time-varying lambda with $\kappa = 0$ (blue) and $\kappa = 1.5$ (red)



Estimated exposure (or social distancing) rates across Chinese provinces

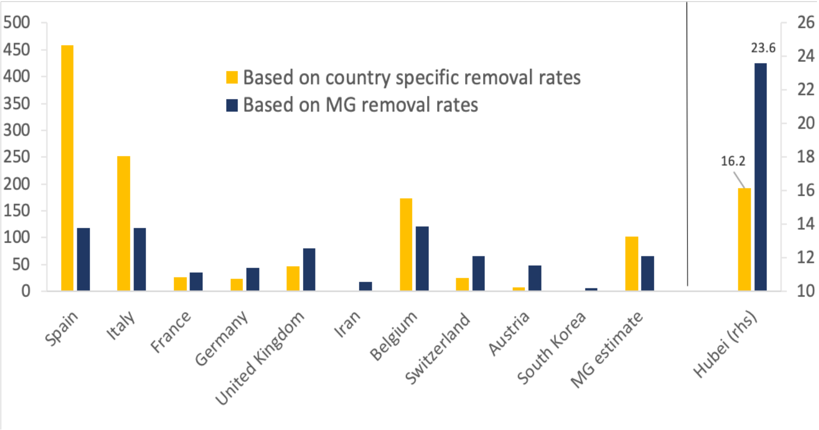
Figure 6: Full sample and subsample estimates of exposure rate (λ) per 100,000 population across Chinese provinces ($\pi = 0.5$, $R_0 = 3$)



Note: Full sample results are based on the same samples as in Table 2. The subsample estimates are based on the sample Jan-22 to Feb-20, 2020. ρ_j, γ_j are country-specific as estimated in Table 2.

Estimated exposure across selected other countries

Figure 7: Estimates of exposure rate (λ) per 100,000 population across Selectd Countries ($\pi = 0.5$, $R_0 = 3$)



Economic impact

COVID-19 has led to unprecedented drops in output and employment worldwide, as many governments have been forced to place varying restrictions on day-to-day business and social activities in order to prevent the spread of the deadly virus.

Table 1: Our simulated average employment loss (in per cent per annum) due to epidemic under different social distancing (λ) and economic impact (α) scenarios

Employment loss elasticity	Social distancing coefficient (λ)				
α	1.0	0.75	0.50	0.25	0.10
1.0	3.6	7.7	11.8	15.9	18.4
1.5	3.6	5.2	8.9	13.9	17.4
2.0	3.6	4.0	6.8	12.2	16.6

Notes: This table reports results of a simulation of the epidemic under different social distancing (λ) and economic impact (α) scenarios. The epidemic is simulated using SIR model with $R_0 = 3$ and $\gamma = 1/14$. λ is the fraction of the population exposed to the virus. α determines the economic cost of the isolation measures, as defined by $(1-\lambda)^a$. The losses are given in per cent per annum over 120 days which is the simulated length of the epidemic.

Policy implications

- No economy in the world is anywhere close to herd immunity.
- Under the most optimistic scenario, a vaccine is 6-12 months away.
- What are governments to do?
  - It is extremely costly to keep economies closed, and shutdowns are not sustainable going forward.
  - But just reopening infected economies and letting them reach herd immunity is also not viable.
  - How best to allow the resumption of normal interactions while maintaining health and safety?

Admittedly hard to make the right choice

- The experience of the countries that are ahead of the pack in terms of reopening is too diverse to provide definitive answers.
- Sweden was the only country that did not impose mandatory social distancing, and initially performed better than most economically. However, new data show that expenditure fell only marginally less than in neighboring Denmark, which had a shutdown. Sweden's epidemic curve, on the other hand, not only has not yet peaked, but now is also accelerating. Denmark's curve, by contrast, is heading downwards. Both economies, because small and interconnected to the rest of the world, are bound to be hit very hard regardless of what they do at home.
- Germany took a yet another approach. It started to boost medical capacity to cope with COVID-19 in January adopting mild social distancing policies. Notably, it also brought health care services to COVID patients rather than bringing patients to infected hospitals, as in Italy. Both its epidemic and recession curves are the best in Europe. Yet, Germany too is now facing a second wave of infections as it started to loosen up its controls.

Some lessons from natural disasters can be helpful here

- We are routinely alerted to natural disasters, like hurricanes, floods, earthquakes, and fires. But months into the ongoing COVID-19 crisis, we still have no idea about the precise infection risk that we face going to the grocery store, the gas station, or the risk we would face resuming work outside the home.

- For sure, for such a strategy to work testing, contact tracing and isolating are essential and should continue, but the scale required in order to be the main policy tool to support reopening is **just beyond reach**, requiring to test and isolate millions of individuals a day.

- What is needed is above all **reliable** information disseminated **locally** on the true state of the epidemic in a **timely manner**. This means reliable statistics on the **infection risk that individuals and communities face**.

A proposal: turn to people's informed "common sense" for lack of better alternatives

- As many governments turn to their people's "common sense" for lack of better ideas and alternatives (to use the words of British Prime Minister, Boris Johnson in his recent address), it is becoming increasingly important that they provide an environment in which individuals can take well informed decisions about voluntary social distancing.
- Yes, during the early stages of the epidemic the aversion to isolation is strong; the expected income loss is uncertain, and the information on the individual infection risk is all but absent; the incentive to isolate voluntarily is thus very weak. On its own, voluntary self-isolation is not effective in flattening the curve.
- But now as the pandemic curve peaked, and people become more aware, more accustomed to isolation, and governments support the income losses, voluntary decisions are likely to be more effective.
- Individuals and businesses need to be well informed and have the right incentives.

Conclusions

- Mandatory social distancing was critical in flattening the first COVID-19 pandemic wave, even though it caused an unprecedented drop in the level of social and economic activity.
- To fend off the risk of a second wave without killing the economy, we need an environment for responsible individual decisions about social distancing.
- While we have access to zip-code level weather forecasts at the touch of our screens, we can look up crime and car accident statistics neighborhood by neighborhood, the quality of the COVID-19 information is still remarkably low.
- To allow economies to reopen relying on widespread and pervasive voluntary social distancing we need random testing at the local level, together with the transparent dissemination of the outcomes via local news, social media, and even direct text messaging to local residents.