On Exit Strategy from Covid-19 Lockdown

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Three main models for handling the Covid-19 outbreak:

1. **Full lockdown**

2. **Precision quarantine** - Isolate positive cases and their immediate contacts using “contact tracing” technologies, until a vaccine/cure is available.

3. **Herd-immunity**: No need to wait for a vaccine; but, high mortality and health system might not contain the outburst

We propose a combination of both models:

**Managed herd-immunity with the RISK-BASED MODEL (1+2+3)**

- High-risk group → 1
- Second phase → High-risk group is gradually released 3+2
- Low-risk group → 3
The Risk-based Model

Without any safety measures

Flattening the curve for the entire population

Risk-based model

ICU cases

Time

ICU cases

Time

ICU cases

Time

Entire population

Low-risk population

High-risk population

Health care system capacity
Questions of Interest

- Define “high-risk” group: age and pre-existing conditions cut-off
  - How to determine without overfitting

- Can the health system capacity (say, ICU beds) contain the number of severe cases among the low-risk group?

- Beyond obvious benefits to the economy, is the risk-based model safer in terms of overall mortality?
Worst-case Analysis

The problem: Covid-19 dynamics (spread and duration) is too complicated at this stage

The solution: adopting worst-case analysis under reasonable assumptions

Worst-case analysis under reasonable assumptions

• Assumptions:
  + Upper-bound on the time from infection → ICU care - 1 weeks*
  + The probability of a low-risk person to be infected and need a critical-bed care is fixed.
    → Why: low-risk group release can be done under social distancing restrictions (to avoid viral load)

• Worst-case:
  + Infection rate among the low-risk group will be 100%
  + All severe cases among the low-risk group will need ICU simultaneously

*research shows the average time is 5-7 days
The analysis below focuses on the low-risk population.

- $m =$ size of the low-risk population
- $b =$ budget of ICUs

\[
P[\text{severe}] = P[\text{severe} \land \text{infected}] = P[\text{infected}] \frac{P[\text{severe} | \text{infected}]}{\leq 1} = \nu
\]

Therefore, we need:

\[
b \geq m \nu.
\]

- Our goal is to derive an upper bound on $\nu$
Upper bounding $\nu$

$$\nu := \mathbb{P}[\text{severe} \mid \text{infected}] \approx \frac{\# \text{ severe today}}{\# \text{ infected today}}$$

- We know $k := \# \text{ severe today}$
  (and to be on the safe size, “today” should be in the time interval $[0, \text{one week}]$)
- We don’t know $\# \text{ infected today}$
- Let $p^* =$ probability to be infected $\text{today}$, then

$$\nu \approx \frac{k}{\# \text{ infected today}} = \frac{k}{p^* m}$$

- So, to prove $b \geq m \nu$ we need

$$b \geq m \nu \approx \frac{k}{p^*}$$

- We now need a lower bound on $p^*$
Lower bounding $p^*$

- By sampling $n$ i.i.d. persons from the low-risk population and finding $S_n$ cases, we have $p^* \approx \frac{S_n}{n}$.
- Overall:
  $b \geq m \nu \approx \frac{k}{p^*} \approx \frac{k}{S_n/n}$
- Example: in Israel, we have $k = 15$ and we estimate $p^* = 0.02$ so we need $b \geq 750$
- But, all of the above involved approximations. We need bounds that hold with sufficient probability!
Tail bounds

We derive concrete bounds based on the following techniques (and some tricks):

- **Bernstein’s inequality:** If $S_n \sim \text{Binom}(p, n)$ then
  \[
  \mathbb{P}[S_n - np > t] \leq e^{-\frac{t^2/2}{np(1-p)+t/3}}
  \]

- **Zubkov and Serov 2013:**
  \[
  \mathbb{P}[S_n \leq k] \leq \Phi \left(-\sqrt{2nD_{KL}(p, (k + 1)/n)}\right)
  \]

  where $\Phi$ is the cumulative distribution function of a standard normal variable and $D_{KL}$ is the KL-divergence.
Results

Recall, we need

\[ b \geq m \nu \]

For sufficiently large sample size \( n \), with high probability we have

\[ m \nu \geq 1.92 \frac{k}{S_n/n}. \]
Israel as a Case Study

As of 3/29/20:
• $k \leq 15$
• $p^*$ indications
  • 1% - pre-outburst situation in Iceland
  • 1.8% - medical crew sampling in Jerusalem
  • 8% - Partners Health, Boston
• We assume 2%
• $p^*$ can be estimated with a relatively small i.i.d. sampling

\[
b > \frac{1.6k}{p^*}
\]

\[
b > \frac{1.6 \cdot 15}{0.02}
\]

\[
b > 1200
\]

Current % of positive cases among the low-risk population

Required # of ICU beds

Low-risk group severe cases that require ICU

12 ICU beds per 100K population

Should be manageable

The Countries With The Most Critical Care Beds Per Capita

<table>
<thead>
<tr>
<th>Country</th>
<th>Critical Care Beds Per 100K Inhabitants</th>
</tr>
</thead>
<tbody>
<tr>
<td>United States</td>
<td>34.7</td>
</tr>
<tr>
<td>Germany</td>
<td>29.2</td>
</tr>
<tr>
<td>Italy</td>
<td>12.5</td>
</tr>
<tr>
<td>France</td>
<td>11.6</td>
</tr>
<tr>
<td>South Korea</td>
<td>10.6</td>
</tr>
<tr>
<td>Spain</td>
<td>9.7</td>
</tr>
<tr>
<td>Japan</td>
<td>7.3</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>6.6</td>
</tr>
<tr>
<td>China</td>
<td>3.6</td>
</tr>
<tr>
<td>India</td>
<td>2.3</td>
</tr>
</tbody>
</table>

*Source: Statistica
### Summary

<table>
<thead>
<tr>
<th>Risk-based model</th>
<th>Precision quarantine</th>
</tr>
</thead>
<tbody>
<tr>
<td>• High infection rate among low-risk group → <strong>low mortality</strong></td>
<td>• Unified infection rate among the entire population → <strong>high mortality</strong> among high-risk group</td>
</tr>
<tr>
<td>• Low infection rate among the high-risk group thanks to herd-immunity of the rest</td>
<td></td>
</tr>
<tr>
<td>• Minor negative effect on the economy</td>
<td>• Extensive negative effect on the economy</td>
</tr>
<tr>
<td>• Clear exit point- result in economic stability and higher civilian cooperation</td>
<td>• Lack of visibility- result in economic instability and civilian despair</td>
</tr>
<tr>
<td>• Short duration and controlled effect on the health care system</td>
<td>• Devastating and prolonged effect on the health care system</td>
</tr>
</tbody>
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