Pandemic Risk Management: Resources Contingency Planning and Allocation

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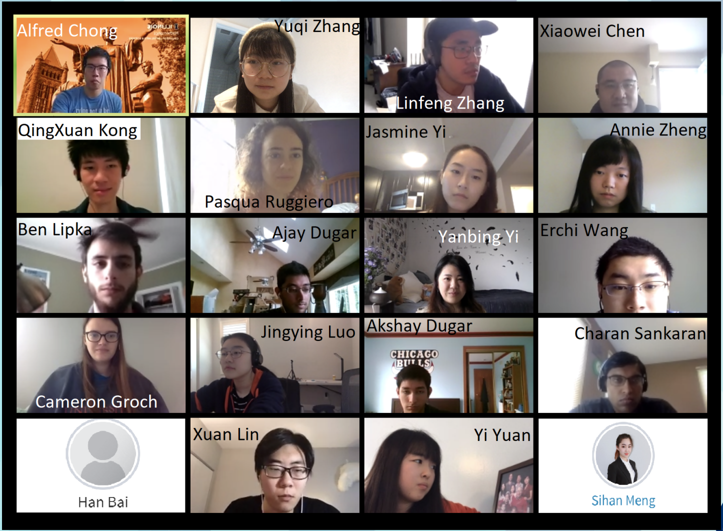
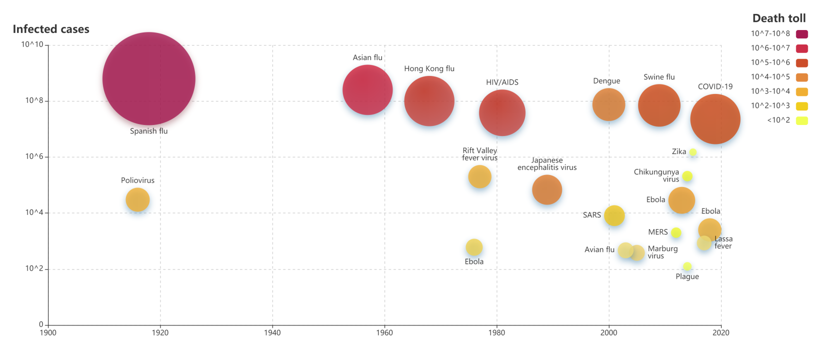
Based on a working paper by Xiaowei Chen (Nankai), Alfred Chong (UIUC), Runhuan Feng (UIUC), and Linfeng Zhang (UIUC).

Illinois Risk Lab



Long history of pandemics

Repeated pandemics taught us that epidemic risk is inevitable.



An example of COVID-19 coverage (JustInCase, Japan)

About COVID-19 Cover

- Procedure is completed on smartphone or web, no face-to-face contact with people is required
- A lump sum benefit payment of ¥100,000 for hospitalization for 2 days 1 night or longer
- Those who are diagnosed with new coronavirus and treat it at home are also covered
- Coverage is effective immediately after the completion of purchase process
- Affordable premium (on monthly basis as shown below)

Entry age of the insured	Male	Female
15～19	¥580	¥560
20～24	¥560	¥660
25～29	¥530	¥940
30～34	¥510	¥960
35～39	¥530	¥760
40～44	¥580	¥650
45～49	¥610	¥630
50～54	¥640	¥670
55～59	¥710	¥710
60～64	¥730	¥770

Compartmental models

S – susceptible, I – infectious, R – removed

$$
\begin{aligned}
S'(t) &= -\beta I(t)S(t)/N, \\
I'(t) &= \beta I(t)S(t)/N - \alpha I(t), \\
R'(t) &= \alpha I(t),
\end{aligned}
$$

where $S(0) = S_0, I(0) = I_0$ and $R(0) = 0$.

- The total number of individuals remains constant, $N = S(t) + I(t) + R(t)$.
- An average susceptible makes an average number β of **adequate** contacts w. others per unit time. (Law of mass action)
- Fatality/recovery rate of the specific disease, α.

Basic reproduction number

Average number of new infections from a single infection

$$R_t = \frac{\beta}{\alpha} \frac{S(t)}{N}.$$

- Average time between contacts, $T_c = 1/\beta$.
- Average time until removal, $T_r = 1/\alpha$.
- Average number of contacts by an infected person with others before removal, $T_r/T_c = \beta/\alpha$.

(Do not confuse R_t with the size of removed class $R(t)$.)

Importance of basic reproduction number

Average number of new infections from a single infection

$$R_t = \frac{\beta}{\alpha}\frac{S(t)}{N}.$$

- If $R_t > 1$, the epidemic will break out.
- If $R_t < 1$, the epidemic will die out.

Effect of public health policies (non-pharmaceutical interventions)

- Quarantine, social distancing, mandatory face mask: lower transmission rate β;
- Vaccination: lower susceptible $S(t)$;

Infectious disease insurance

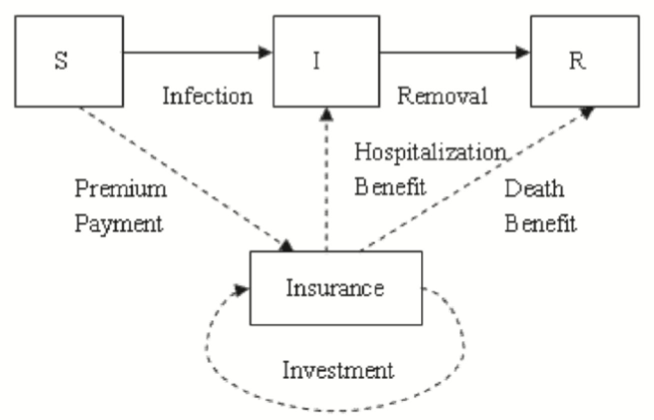


Figure: Transmission and Insurance Dynamics

Insurance reserve

Consider an insurance policy that

- provides 1 monetary unit of compensation per time unit for each infected policyholder for the entire period of treatment; (intended to cover medical costs)
- collects premium at the rate of π per time unit from each susceptible policyholder at a fixed rate per time unit until the pandemic ends or the policyholder is infected; (monthly premium in practice)
- Premium incomes

$$P(t) = \pi \int_0^t s(u)\,\mathrm{d}u, \qquad s(u) = S(u)/N.$$

- Benefit outgoes

$$B(t) = \int_0^t i(u)\,\mathrm{d}u, \qquad s(u) = I(u)/N.$$

- Insurance reserve

$$V(t) = P(t) - B(t).$$

Reserve for a typical term life contract

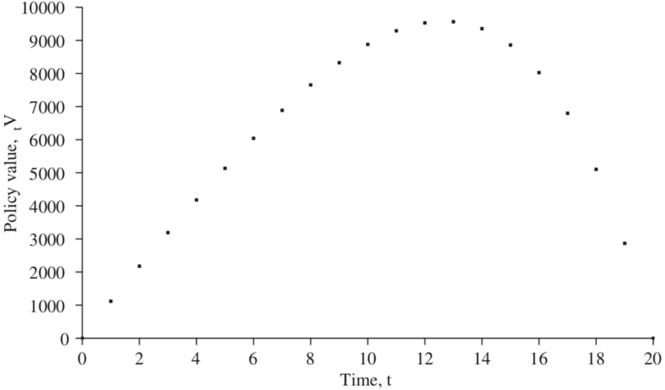
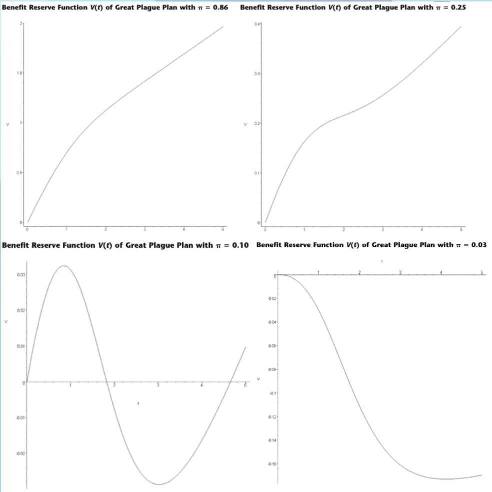


Figure 7.4 Policy values for each year of a 20-year term insurance, sum insured \$500 000, issued to (50).

Source: Dickson et al. (2013) *Actuarial Mathematics for Life Contingent Risks*. Cambridge University Press.

Four shapes of reserves

(We use various premium rate, not necessarily net level premium)



Importance of basic reproduction number in reserving

Shape of $V(t)$	Premium π
Increasing and concave	$[\frac{1}{R_\infty} - 1, \infty)$
Increasing and concave-then-convex	$[\frac{1}{R_{t_m}} - 1, \frac{1}{R_\infty} - 1)$
Non-monotonic and concave-then-convex	$[\frac{1}{R_0} - 1, \frac{1}{R_{t_m}} - 1)$
Non-monotonic and convex	$[-\infty, \frac{1}{R_0} - 1)$

Since $S(t)$ is a decreasing function, then $R_0 > R_{t_m} > R_\infty$.

The exact expression of R_{t_m} is provided in Feng and Garrido (2011).

Bubonic plague in 1665-1666

A classic example of the SIR model fitted to data from the bubonic plague in Eyam near Sheffield, England.

Date	Susceptible	Infective
Initial	254	7
July 3-4	235	14.5
July 19	201	22
August 3-4	153.5	29
September 3-4	108	8
September 19	97	8
October 20	83	0

- $s_0 = 254/261 = 0.97318, s_\infty = 83/261 = 0.31801$ and $i_0 = 7/261 = 0.02682$;
- From clinical observations, an infected person stays infectious for an average of 11 days, $\alpha = 1/0.3667 = 2.73$;
- $\beta/\alpha \approx \ln(s_0/s_\infty)/(1 - s_\infty)$, which implies $\beta = 4.4773$.
- Design a policy that pays $1,000$ per month to all infected. The minimum monthly premium to keep positive reserves is 114.58 for each susceptible. Each survivor receives a reward of 49.44 at the end.

Contingency planning

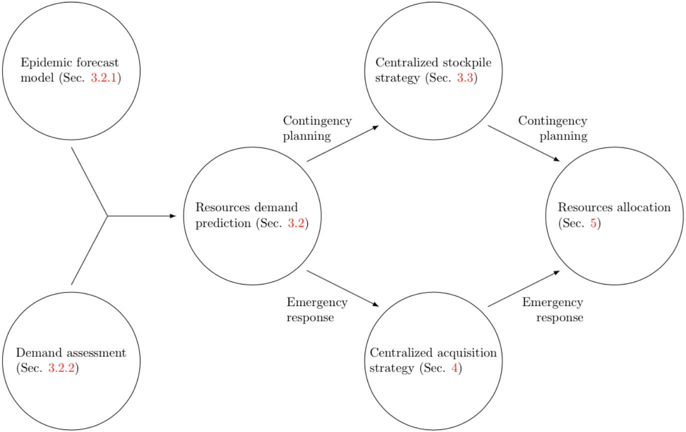
Emerging viral pandemics "can place extraordinary and sustained demands on public health and health systems and on providers of essential community services."

Strategic National Stockpile (SNS)

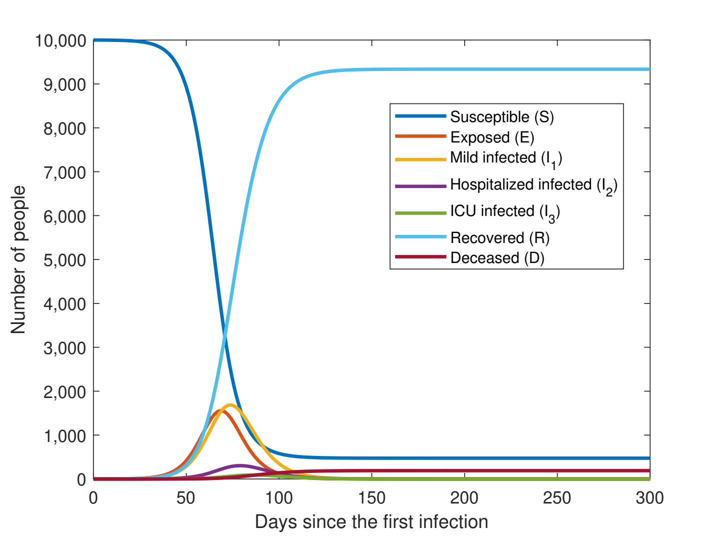
United States' national repository of antibiotics, vaccines, chemical antidotes, antitoxins, and other critical medical supplies.

US underprepared for COVID-19

- Failure of Congress to appropriate funding for SNS and to authorize actions to replenish stockpiles
- Supply-chain changes such as just-in-time manufacturing and globalization
- Lack of a coordinated Federal/State plan to deploy existing supplies rapidly to locations of great need.


Epidemic forecast model (Sec. 3.2.1)
Demand assessment (Sec. 3.2.2)
Resources demand prediction (Sec. 3.2)
Contingency planning
Emergency response
Centralized stockpile strategy (Sec. 3.3)
Centralized acquisition strategy (Sec. 4)
Contingency planning
Emergency response
Resources allocation (Sec. 5)

Evolution of epidemic in an SEIR model



Prediction of healthcare demand

An assessment of needs for personal protective equipment (PPE) set (respirator, goggle, face shield) by ECDC

	Suspected case	Confirmed case Mild symptoms	Confirmed case Severe symptoms
Healthcare staff	Number of sets per case θ^S	Number of sets per day per patient θ^{I_1}	θ^{I_2}
Nursing	1-2	6	6-12
Medical	1	2-3	3-6
Cleaning	1	3	3
Assistant nursing and other services	0-2	3	3
Total	3–6	14–15	15–24

Recall the SIR model (S – susceptible, I – infectious)

$$S'(t) = -\beta S(t)I(t)/N,$$
$$I'(t) = \beta S(t)I(t)/N - \alpha I(t).$$

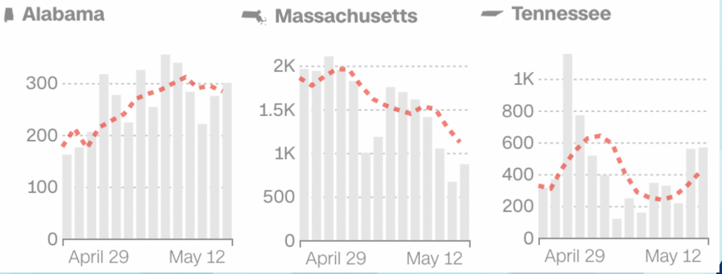
The demand for PPE can be estimated by

$$X(t) = \theta^S \beta S(t)I(t)/N + \theta^I I(t).$$

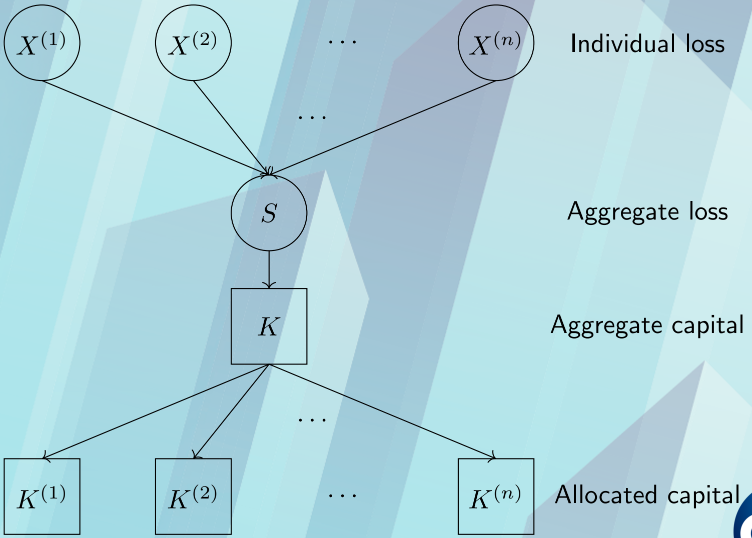
(Better estimate requires a refined compartmental model such as SEIR models)

Resources allegiance

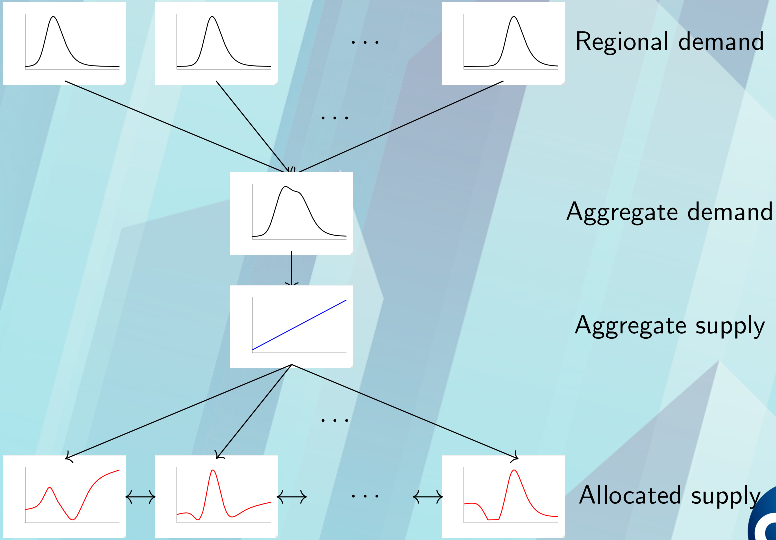
- A central authority acts in the interest of a union to manage and allocate supply among different regions.
- Six US northeastern states formed a coalition in April 2020 to purchase COVID-19 medical equipment to avoid price bidding competition.
- US states at different phases of the pandemic:



Risk aggregation and capital allocation

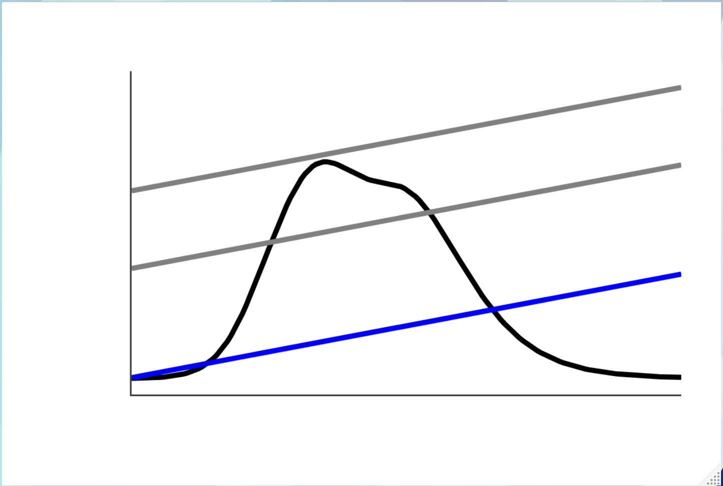


Durable resources stockpiling and allocation



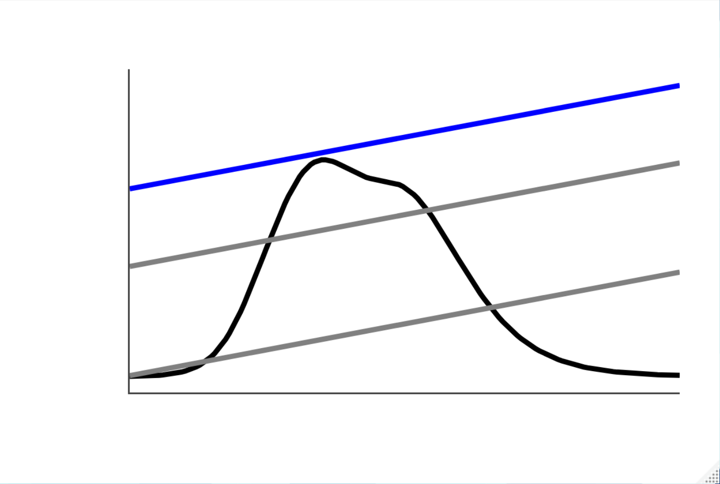
Durable resources (ventilator, ICU bed, hospital bed, etc.)

Shortage stockpiling



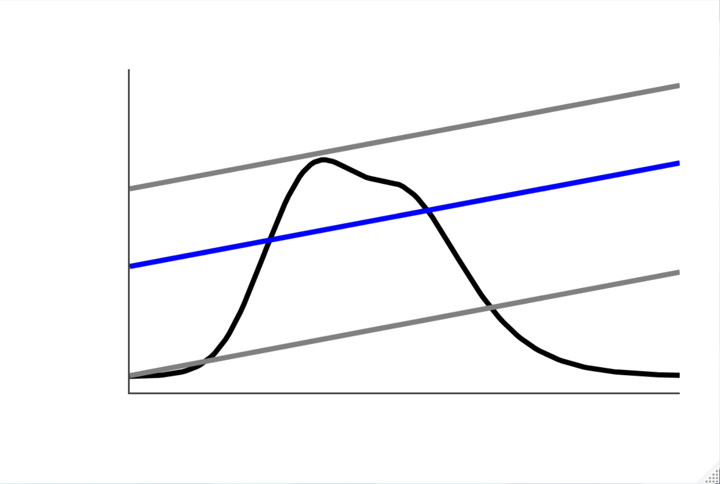
Durable resources (ventilator, ICU bed, hospital bed, etc.)

Oversupply stockpiling



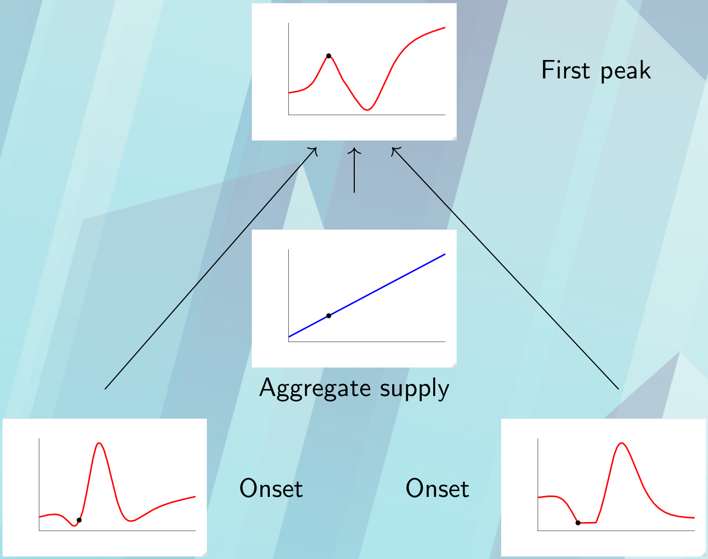
Durable resources (ventilator, ICU bed, hospital bed, etc.)

Optimal stockpiling



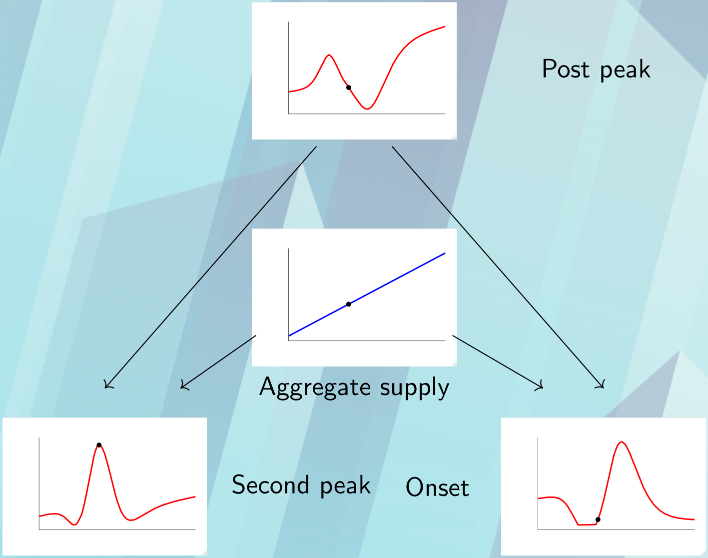
Durable resources (ventilator, ICU bed, hospital bed, etc.)

Optimal allocation at the FIRST peak



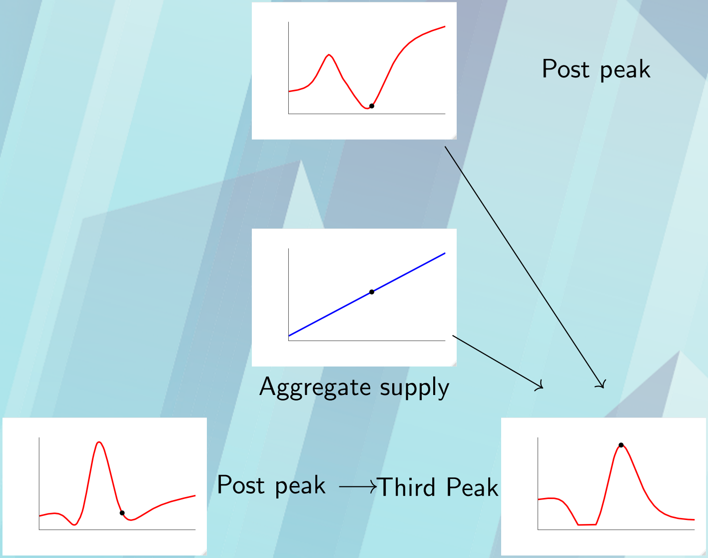
Durable resources (ventilator, ICU bed, hospital bed, etc.)

Optimal allocation at the SECOND peak



Durable resources (ventilator, ICU bed, hospital bed, etc.)

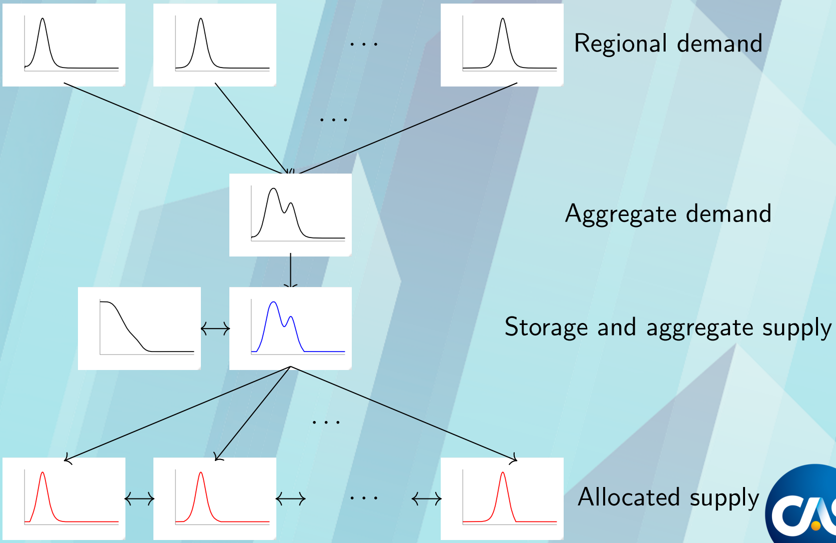
Optimal allocation at the THIRD peak



Durable resources (ventilator, ICU bed, hospital bed, etc.)

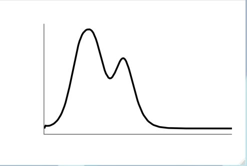
Ventilator example

Single-use resources stockpil., distribution, and allocation



Single-use resources (testing kit, PPE, etc.)

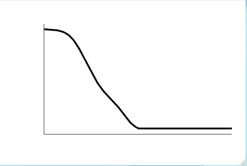
Stockpiling and early distribution

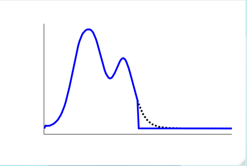


Aggregate demand

Storage

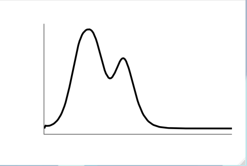
Aggregate supply





Single-use resources (testing kit, PPE, etc.)

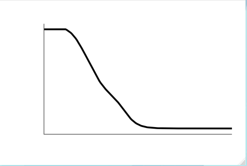
Stockpiling and late distribution

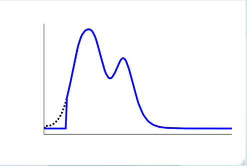


Aggregate demand

Storage

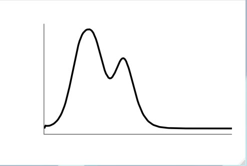
Aggregate supply





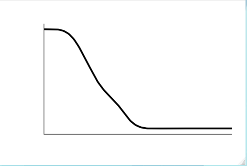
Single-use resources (testing kit, PPE, etc.)

Optimal stockpiling and distribution

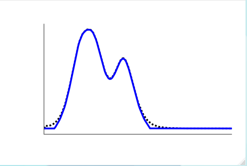


Aggregate demand

Storage

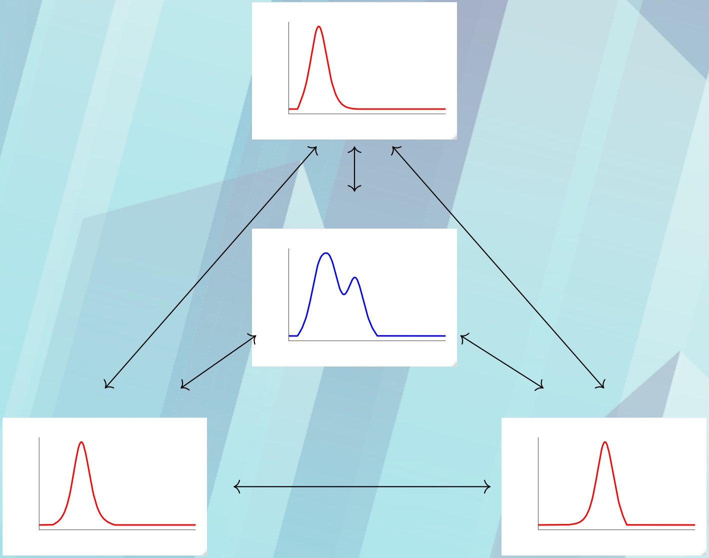


Aggregate supply



Single-use resources (testing kit, PPE, etc.)

Optimal allocation



Single-use resources (testing kit, PPE, etc.)

Testing kit example

COVID Plan website

`covidplan.io`

References

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Thank you!

COVID Plan website
covidplan.io

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