Quantitative analysis on the effectiveness of contact-tracing apps

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Contents

Overview

Contact-tracing apps as policy tools

- Lockdown generates a large amount of economic costs.
- High hopes for the combination of testing and apps.
- Substantial reduction of cases when the apps are downloaded by 56% of the population. (Fraser et al., 2020)
- Several fundamental questions unanswered:
  - Why apps work?
  - In what condition apps work?
  - Are the apps more effective than the other policies?
  - Trade-off between the epidemic suppression and quarantine.

Quantitative analysis most in need

- A model should be detailed such that
  - it includes multi-dimensional heterogeneity in population.
  - it characterizes coronavirus.
  - it serves as a platform to compare various policies.
- Limitation in analytical models (SIR)
- What the present research does:

A comprehensive study on contact-tracing apps,
using an agent-based model (ABM) and individual census data

Summary

1. Fraser-type apps (the alerted contacts get quarantined) excludes the virus outbreak if sufficiently large number of people download them.
2. Such strong prevention of virus outbreak cannot be achieved by Japan-type apps (the alerted contacts get tested).
3. The effectiveness of Fraser-type apps lies in the quarantine of the noninfectious contacts, who turn infectious later.
4. Extremely high download rate of Fraser-type apps not only excludes the virus but also reduces the number of the quarantined.

Features of the analysis

- A hypothetical society constructed by individual census data.
- Detailed modeling of coronavirus and human networks.
- Intuition on mechanisms and conditions where apps work.
    - Configuration of the apps
    - Download rate
    - Probability of testing the symptomatic
- Trade-off between the epidemic suppression and quarantine.

Model and Data

Model outline

Kerr et al. (2020)

- An uninfected person becomes infected probabilistically if she meets with an infected person.
- An infected person gets worse or recover probabilistically.

Complication of the model to reflect the real world and to introduce policies

- Attribution of individuals (age, sex, prefecture, job, and industry).
- Places where people meet with each other （home, workplace, school, community, customer service, and nursing home）.
- Super-spreader(infection is more likely in 20% of all environment).
- Isolation of severe and critical patients due to the inability to go out.
- Contact-tracing apps that search for the contacts in the last 7 days.

Definition of each status

State	Definition	Detected by tests	Infectious	Infected	Symptomatic
Uninfected	Not infected	—	—	—	—
Noninfectious	Infected, but not infectious yet	×	×	○	×
Pre-symptomatic	Infectious, but not symptomatic yet	○	○	○	×
Moderate	Symptomatic, but not in need for hospitalization	○	○	○	○
Severe	In need for hospitalization	○	○	○	○
Critical	In need for intensive care	○	○	○	○

- All of the noninfectious turn pre-symptomatic.
- People in each stage after pre-symptomatic probabilistically recover.

	Duration of transition (days)	Probability of transition								
		～9	10~	20~	30~	40~	50~	60~	70~	80～
(Proceed)										
Not infectious → Pre-symptomatic	~LN(4.6, 4.8)	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Pre-symptomatic → Moderate	~LN(1.0, .9)	0.500	0.550	0.600	0.650	0.700	0.750	0.800	0.850	0.900
Moderate → Severe	~LN(6.6, 4.9)	0.000	0.000	0.000	0.155	0.151	0.198	0.365	0.360	0.408
Severe → Critical	~LN(3.0, 7.4)	0.000	0.000	0.000	0.029	0.029	0.147	0.368	0.491	0.490
Critical → Death	~LN(6.2, 1.7)	0.000	0.000	0.000	0.146	0.182	0.218	0.255	0.291	0.327
(Recover)										
Pre-symptomatic → Recovered	~LN(8.0, 2.0)	0.500	0.450	0.400	0.350	0.300	0.250	0.200	0.150	0.100
Moderate → Recovered	~LN(8.0, 2.0)	1.000	1.000	1.000	0.845	0.849	0.802	0.635	0.640	0.592
Severe → Recovered	~LN(14.0, 2.4)	1.000	1.000	1.000	0.971	0.971	0.853	0.632	0.509	0.510
Critical → Recovered	~LN(14.0, 2.4)	1.000	1.000	1.000	0.854	0.818	0.782	0.745	0.709	0.673

	～9	10~	20~	30~	40~	50~	60~	70～
Relative susceptibility	.34	.67	1.00	1.00	1.00	1.00	1.24	1.47

Expansion of virus outbreak

- The probability with which an uninfected person B catch the virus from an infected person A
  - Likelihood of transmission where A and B meet (detailed in the next section)
  - A's relative transmissibility
  - B's relative susceptibility
- Transmissibility in the early stage is twice as high as that in the later.
- Susceptibility of the elderly is higher than that of the young.
- Super-spreader: Likelihood of transmission in randomly selected 20% of all contacts is 50 times as high as that in the rest.

An artificial small society

Randomly select 25 thousand people from 1.25 million in individual census data in Japan, and create each selected person's family. To maintain the ratio among the age groups, single households of age over 60 are duplicated.

- Area: Japan
- Population：75,614
- Attribution：Age, sex, prefecture, job, industry and size of her workplace

Networks in each place

Layer	Methods to construct networks	Average size (number of people)	Relative likelihood of transmission
Home	Constructed by the answers to the questions on families.	3	50
Workplace	Group the working individuals who live in the same prefecture and work for the same industry with the size that follows the firm-size-distribution in the industry.	5	5
School	Group the educated individuals who live in the same prefecture with size up to 25, and add up to 2 teachers to each group.	25	5
Community	Group all the individuals randomly with the size that follows Poisson distribution with mean 10.	10	1
Customer service	Link each sales or customer service person and a group of randomly selected people of the size that follows Poisson distribution with mean 20.	21	5
Nursing home	Group the individuals of age over 64 who live in the same prefecture and live in nursing homes with size up to 20, and add up to 6 care workers to each group.	25	50

- Severe and critical patients are quarantined. (Their contacts at homes and nursing homes decrease by 20%, those in their communities decrease by 90%, and those other places cease.)

Simulations

- Each result shows the value averaged over simulations of 100 times.
- Period: 500 days starting from February 14th .
- Every policy is introduced on the 33rd day of the simulation.

- Evaluation of each scenario for practical use: whether the virus is excluded (less than around 5 incidents at its peak).

The effects of contact-tracing apps

How are contact-tracing apps effective?

- Fraser et al.(2020) concludes that the apps prevent the outbreak of pandemics, assuming that the contacts of the symptomatic becomes isolated upon getting the alert.
- In Japan, the most common app recommends the contacts of the confirmed positive to get tested.
- The analysis clarifies the difference of the effects these two different apps bring. (*Fraser*-type vs. *Japan*-type)
- Target age: All of the people of age between 15 and 70 (65.8% of all population) have smartphones, whereas the rest of them do not.

Scenario with Japan-type apps

1. On the 33rd day, X% of the people of the target age download the app.
2. Daily PCR tests are conducted on a certain fraction of the symptomatic.
3. It takes a day that the tested symptomatic receive the results.
4. The confirmed positive are hospitalized＊ (All of her contact networks become inactive) and register the test results if she has the app.
5. The alerted contacts get tested.
6. It takes a day that the tested contacts receive the results. The confirmed positive are hospitalized and register the test results.

＊Hospitalized until recovery.

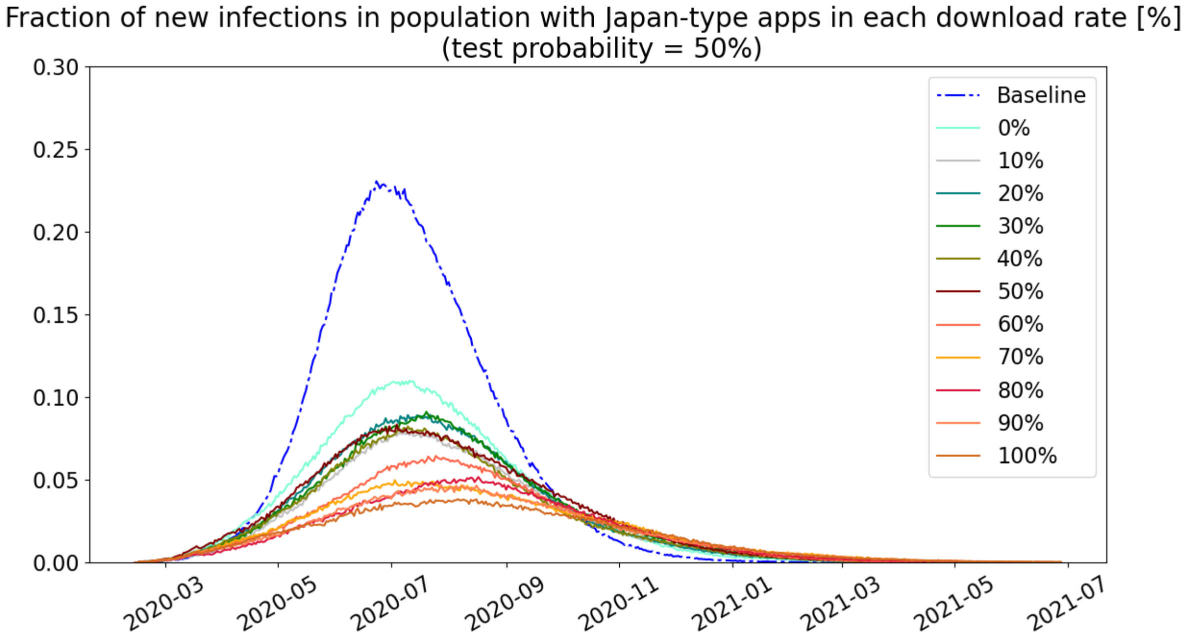
Scenario with Fraser-type apps

1. On the 33rd day, X% of the people of age between 15 and 70 download the app.
2. From then on, daily PCR tests are conducted on a certain fraction of the symptomatic.
3. It takes a day that the tested symptomatic receive the results.
4. The confirmed positive become hospitalized* (All of her contact networks become inactive) and register the test results if she has the app.
5. The alerted contacts are isolated (For 14 days, their contact networks in workplaces, schools, communities and services decrease to 10% of those in normal times).

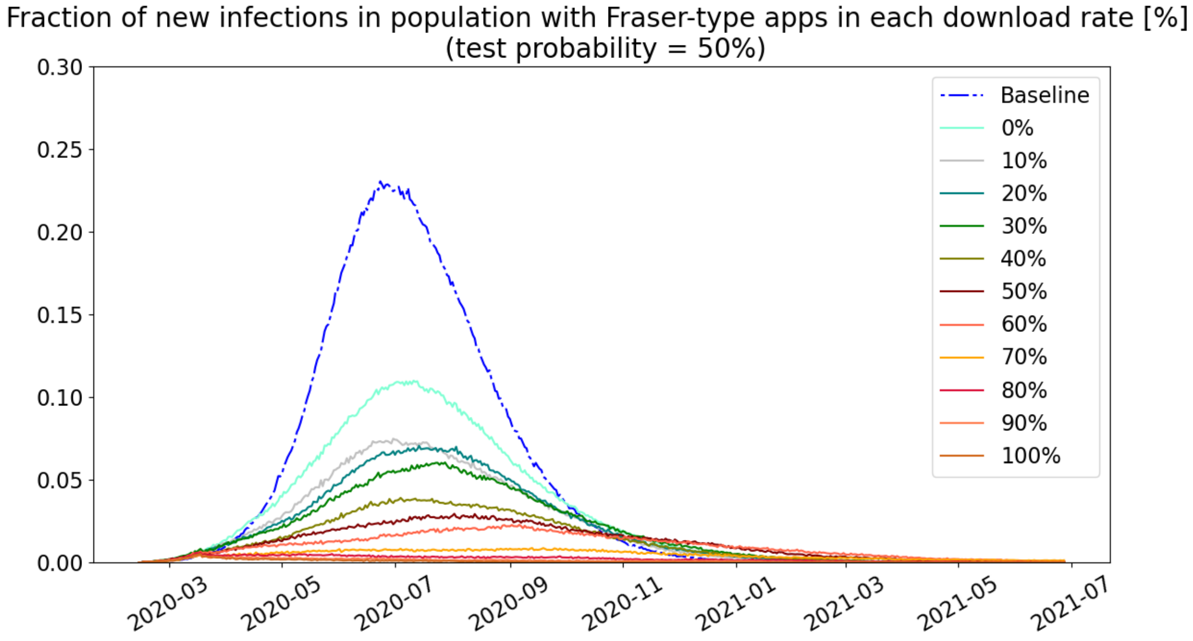
* Hospitalized until recovery.

Only Fraser-type shows significant effects.

Japan-type apps



Fraser-type apps



Three possible factors that create the inferiority of Japan-type to Fraser-type

① False-negative effect

Sensitivity of 70% means that 30% of symptomatic people slip through the tests and possibly scatter the virus

② Noninfectious effect

The noninfectious, who have caught the virus recently and have not become infectious yet, cannot be detected.

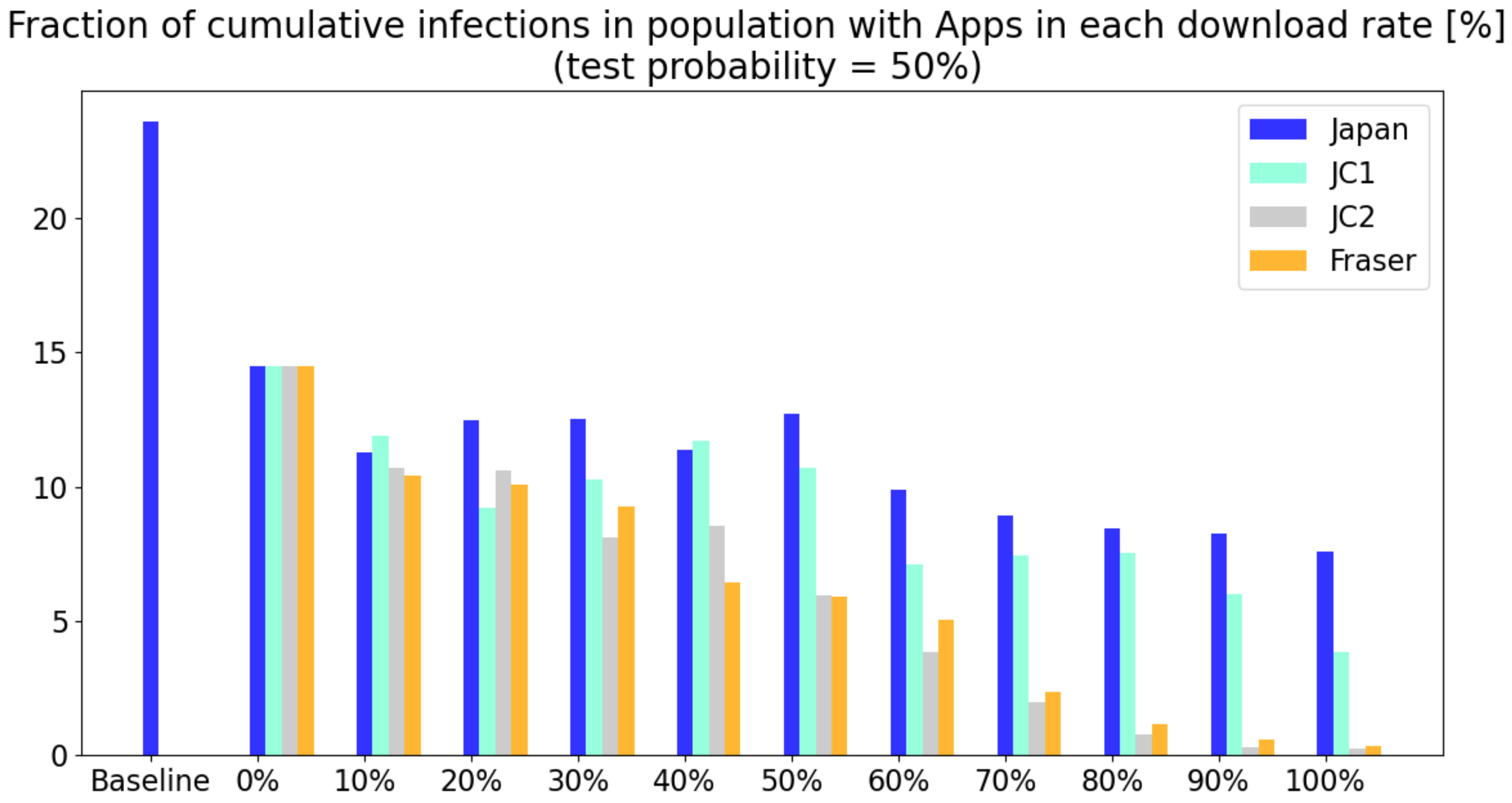
③ Lockdown effect

For the uninfected alerted app-users, quarantine has the similar effects as lockdown.

Scenarios to identify the main factor: Why do Fraser-type apps work?

Scenario	Contents	Daily tests on the randomly selected symptomatic	Detectable status of contacts	Sensitivity and days required for testing contacts	Difference from Japan scenario
Baseline	Without any policy	×	—	—	—
Japan	Daily tests on the randomly selected symptomatic + Apps in Japan type	○	Infectious	70%、1	—
JC1	Counterfactual (variant of Japan scenario)	○	Infectious	100%、0	①False-negative effect
JC2	Counterfactual (variant of Japan scenario)	○	Infected	100%、0	①False-negative effect ②Noninfectious effect
Fraser	Daily tests on the randomly selected symptomatic + Apps in Fraser type	○	—	—	①False-negative effect ②Noninfectious effect ③Lockdown effect

Noninfectious effect dominates.



Benefits and costs of Fraser-type apps

- An *efficient* policy would reduce the number of the infected at a small number of quarantine.
- Evaluate the efficiency of Fraser-type apps by measuring the duration of total inactive time caused by quarantine and the one caused by illness.

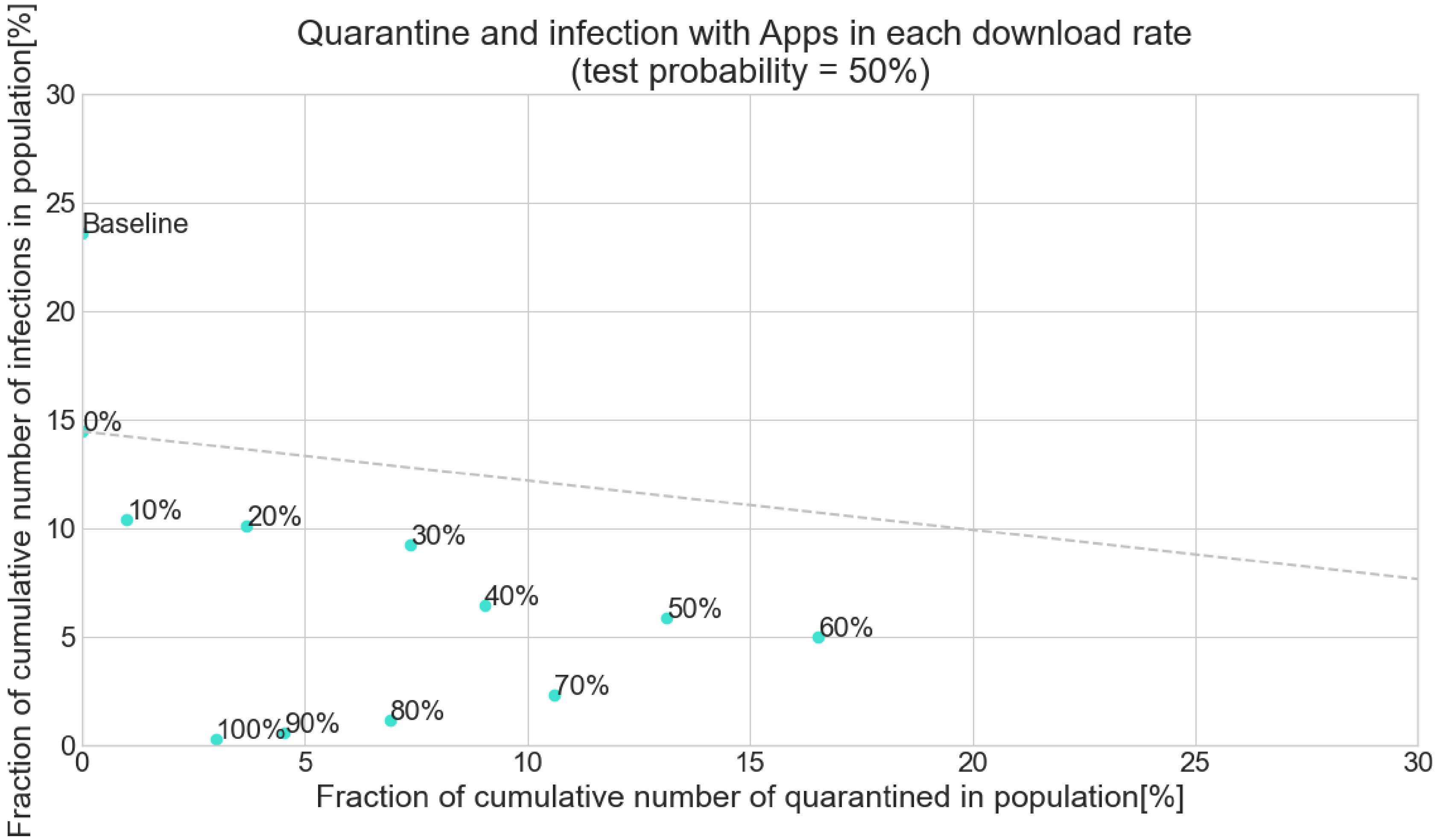
Benefit: The inactive time due to hospitalization（The smaller, the better）

Cumulative number of the infected × Their expected duration of hospitalization

Cost: The inactive time due to quarantine （The smaller, the better）

Cumulative number of the quarantined × Their expected duration of quarantine（14 days）

Extremely high download rate gains efficiency.



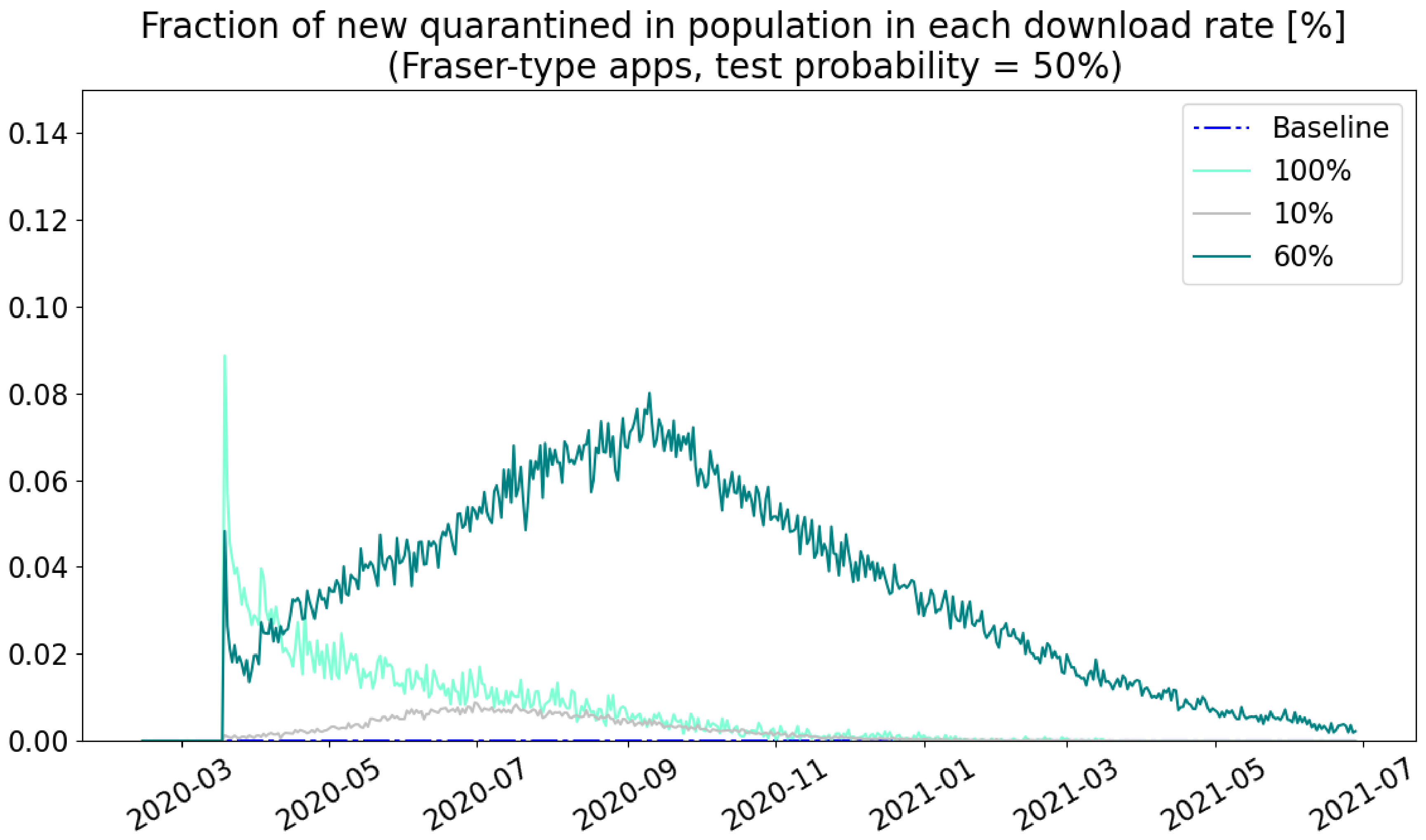
U-curve in the efficiency plots

Case 1: Download rate is extremely low.
- Virus outbreak spreads.
- Only a small number of people get the alert and quarantined.

Case 2: Download rate is extremely high.
- Spread of the virus outbreak is prevented, since the contacts of the confirmed positive are thoroughly quarantined.
- Thus, the number of quarantine is kept small. (**Positive feedback**)

Case 3: Download rate is intermediate (Neither of the case 1 and 2).
- Limited effects on the spread of the virus.
- Not a small number of the contacts of the infected get the alert and quarantined.

Sharp decrease in the number of quarantined under high download rate.



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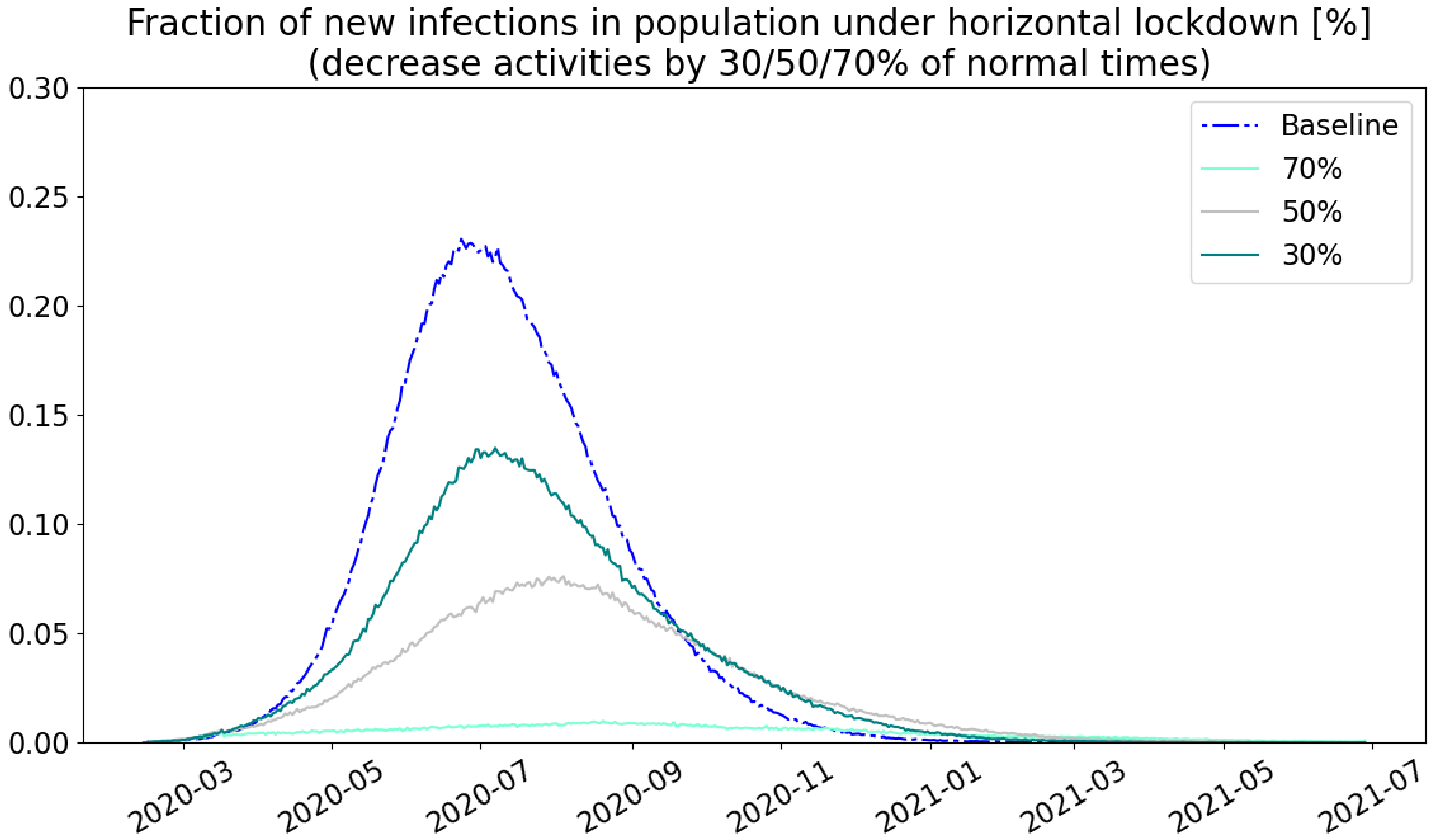
4. Extremely high download rate of Fraser-type apps not only excludes the virus but also reduces the number of the quarantined, which improves the efficiency.

The next step

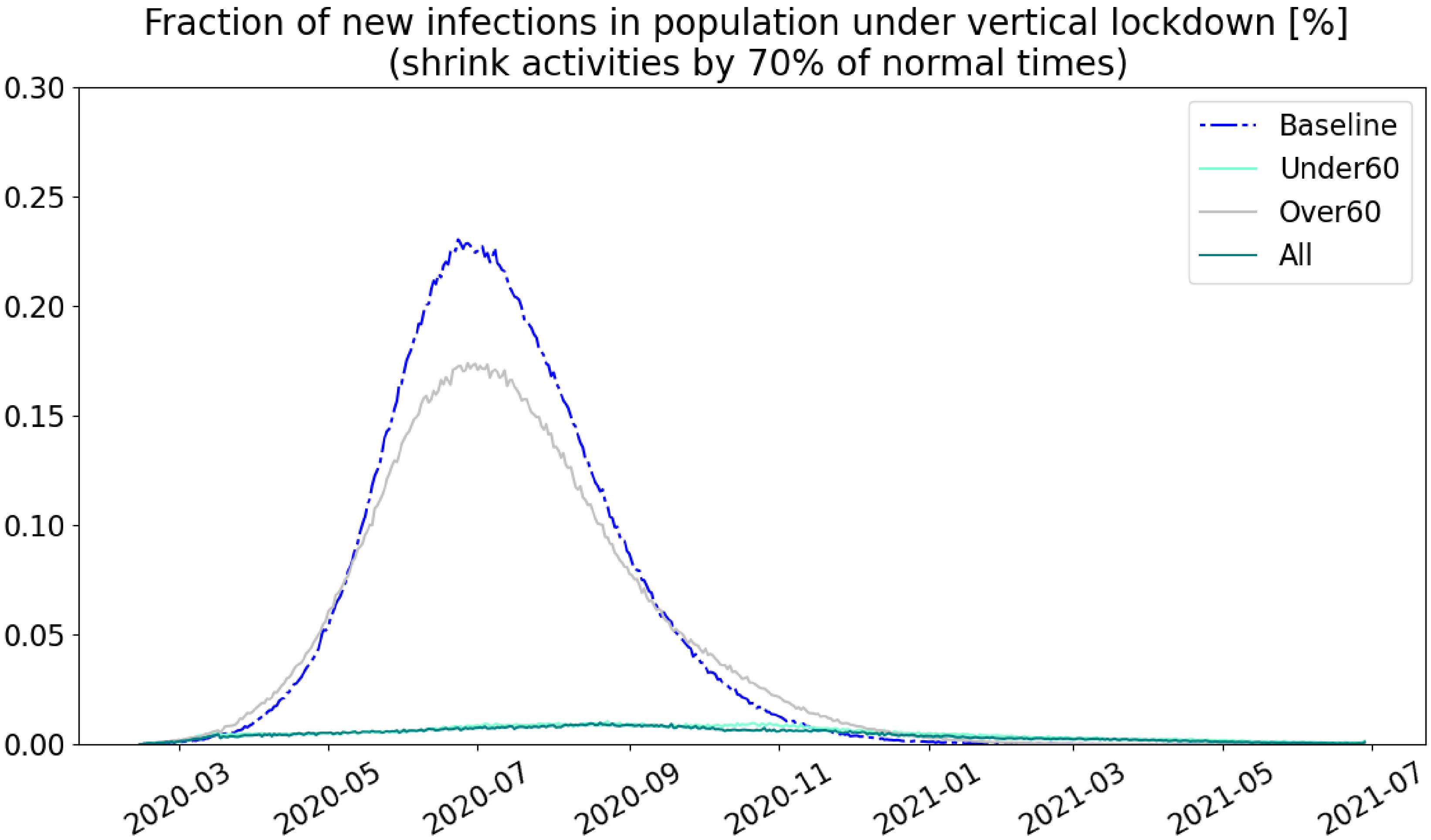
- Other countermeasures
- Characteristics of coronavirus in more detail
- Introduction of economic parameters

Appendix
Effects of lockdown

70%-lockdown have a significant effect.



Vertical lockdown exclusive on the elderly is ineffective.



Severe estimation under homogeneity.