



# Probabilistic Programming on COVID-19

**#coronavirus #covid19 #togetherapart #newnormal**



How **dangerous**  
is COVID-19?

How should  
government **respond**?

## Pandemic & Policy

A Fatal Error

## Approval Wanes for Sweden's Lax Coronavirus Policies

Popular support for Sweden's lax response to the coronavirus is waning and the situation in the country's retirement homes is concerning. The architect of the Swedish approach,

Anders Tegnell, is stand

## How Vietnam Contained COVID-19 and Why its Economy Will Rebound

## China coronavirus: Lockdown measures rise across Hubei province

🕒 23 January 2020



CORONAVIRUS

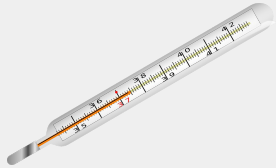
## Coronavirus USA: which states are still on lockdown?

California, North Carolina and a string of U.S. cities mandated or urged mandatory mask use to get a grip on spiralling coronavirus cases as at least six states set daily records.

## Countries responses to COVID-19

# OUR GOAL

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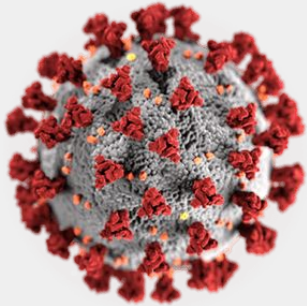


**QUARANTINE**



Best Policy For COVID-19?

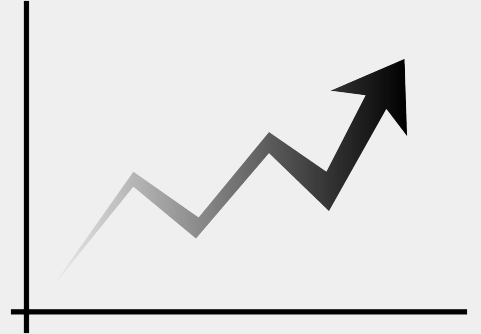
# OUR GOAL



Analyze important **virus**  
**statistics**

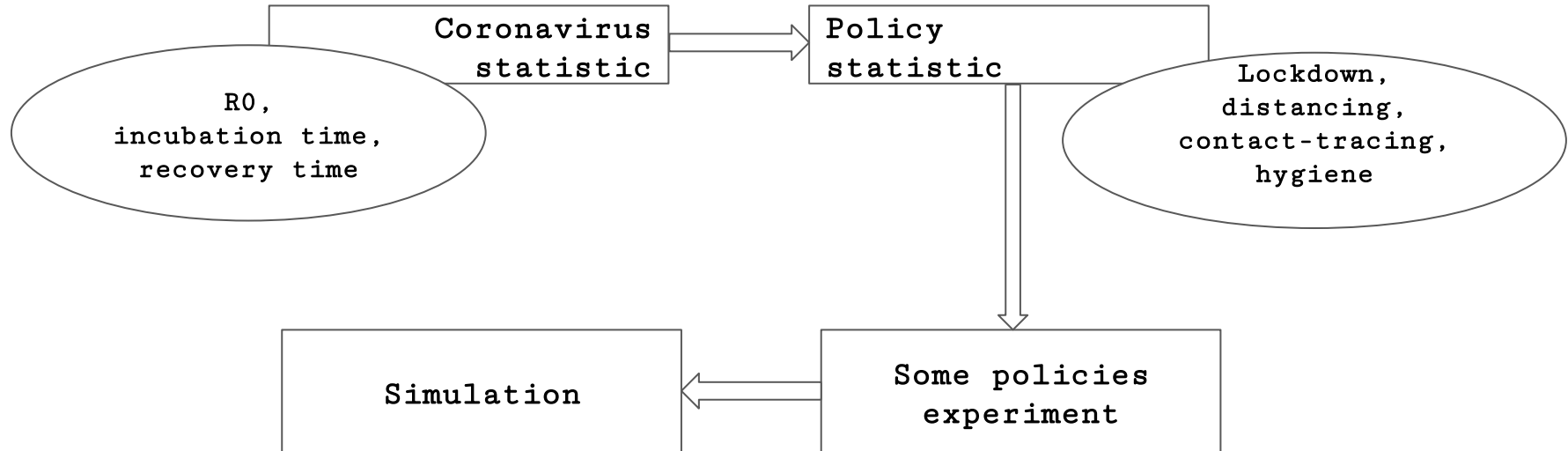


Estimate the **efficiency**  
of the **policies**



**Simulate** some  
policies

# PIPELINE



# DATASET

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## **Dataset from Kaggle: COVID-19 Dataset**

Content: Number of Confirmed, Death and Recovered cases every day across the globe, divided by countries, region, province

Link:

[https://www.kaggle.com/imdevskp/corona-virus-report?select=full\\_grouped.csv&fbclid=IwAR3ZDw5Kc9lo9kbIiw63fyrvSdV1CPSnQUbFAVXgKx9jIIxm6nWce5DFRs0](https://www.kaggle.com/imdevskp/corona-virus-report?select=full_grouped.csv&fbclid=IwAR3ZDw5Kc9lo9kbIiw63fyrvSdV1CPSnQUbFAVXgKx9jIIxm6nWce5DFRs0)

# MODELS:

Virus Statistics Model

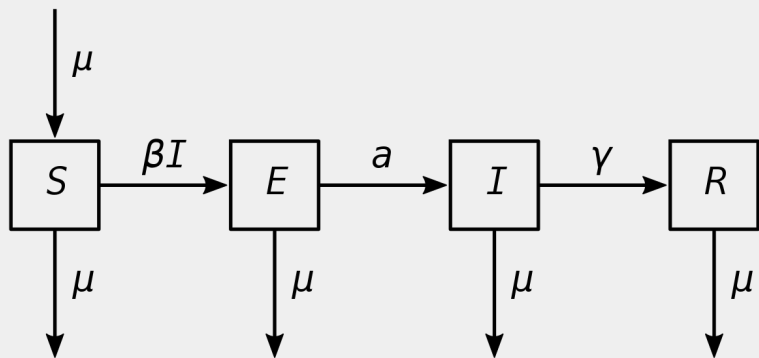
Policy Strength Model

Simulation Model



# 1. VIRUS STATISTICS MODEL

Mathematic Model: SEIR Model



$$\begin{aligned}\frac{dS}{dt} &= \mu N - \frac{\beta SI}{N} + \xi R - \nu S \\ \frac{dE}{dt} &= \frac{\beta SI}{N} - \sigma E - \nu E \\ \frac{dI}{dt} &= \sigma E - \gamma I - \nu I \\ \frac{dR}{dt} &= \gamma I - \xi R - \nu R\end{aligned}$$

Assumptions:

1. recovered are immune for a lifetime
2. population is constant

# 1. VIRUS STATISTICS MODEL

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Probabilistic Programming Model: Epidemiology Model (base model: Compartmental Model) in Pyro

Inference Algorithm: HMC with NUTS (No-U Turns) Kernel

Inferred parameter:  $R_0$ ,  $\tau_e$ ,  $\tau_i$ ,  $\rho$ ,  $\text{mort\_rate}$ ,  $\text{rec\_rate}$   
(basic reproduction numbers, recover time, incubation time, response rate, mortality rate, recover rate)

Flow:

```
state["S"] = state["S"] - S2E
state["E"] = state["E"] + S2E - E2I
state["I"] = state["I"] + E2I - I2R
```

# 1. VIRUS STATISTICS MODEL

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Experiment:

We run data on the initial stage of Sweden (before April 1st)

Reason:

Sweden did not impose strict policies until April. We can assume that virus transmission rate was unaffected.



# 1. VIRUS STATISTICS MODEL: RESULT

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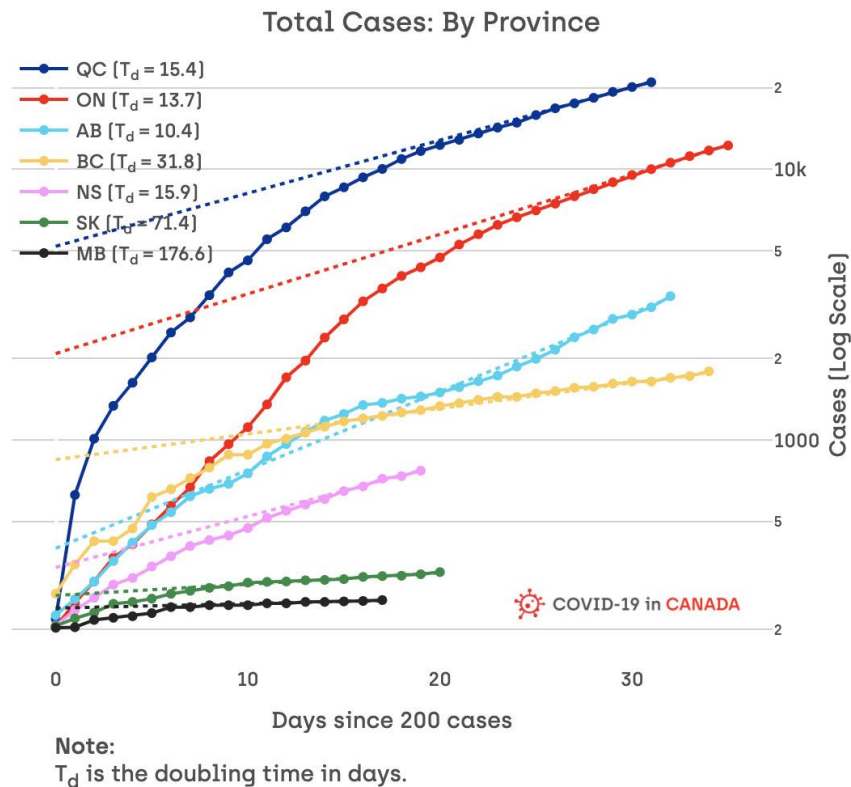
start\_date = "2020-02-01" end\_date = "2020-04-01"

	mean	std	median	5.0%	95.0%	n_eff	r_hat
rec_time	16.33	0.00	16.33	16.33	16.33	2.78	2.28
incub_time	3.83	0.00	3.83	3.83	3.83	7.60	1.42
R0	2.40	0.00	2.40	2.40	2.40	7.69	1.09
rho	0.54	0.03	0.52	0.51	0.58	2.39	4.38
mort_rate	0.02	0.00	0.02	0.01	0.02	2.38	5.53
rec_rate	0.27	0.00	0.27	0.27	0.27	2.38	4.84

## 2. POLICY STRENGTH: CHANGE-POINT MODEL

Adapted from “Detecting Changes in COVID-19 Cases with Bayesian Models” (Jonathan Ramkisson)

**Assumption:** If all statistic of the virus remain the same, the **policy strength** will be reflected in the **rate of transmission** of the virus (**slope in log scale** of cases graph)



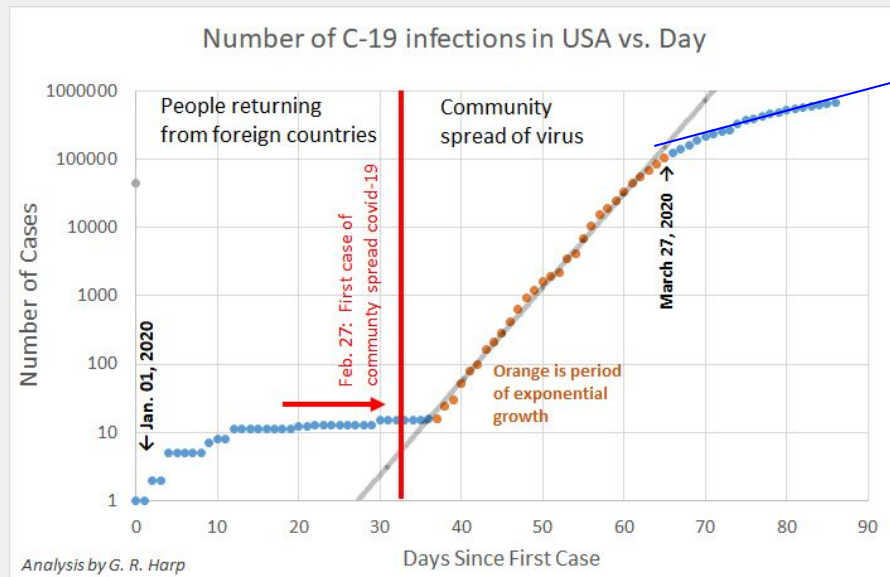
## 2. POLICY STRENGTH: CHANGE-POINT MODEL

Mathematical model: Segmented  
(piece-wise) linear model

Consider the **case count** from the **community spread** onwards in log scale.

The graph is roughly a **segmented linear** with **2 pieces** of different **slopes**,  $w_1$  and  $w_2$ .

**Policy Strength** can be estimated by  $1 - w_2/w_1$



## 2. POLICY STRENGTH: CHANGE-POINT MODEL

Probabilistic model:

Likelihood

$$y = wt + b + \epsilon,$$
$$\epsilon \sim N(0, \sigma^2)$$
$$p(y \mid w, b, \sigma) \sim N(wt, \sigma^2)$$

Where:

$$w = \begin{cases} w_1 & \text{if } \tau \leq t \\ w_2 & \text{if } \tau > t \end{cases}$$
$$b = \begin{cases} b_1 & \text{if } \tau \leq t \\ b_2 & \text{if } \tau > t \end{cases}$$

Prior

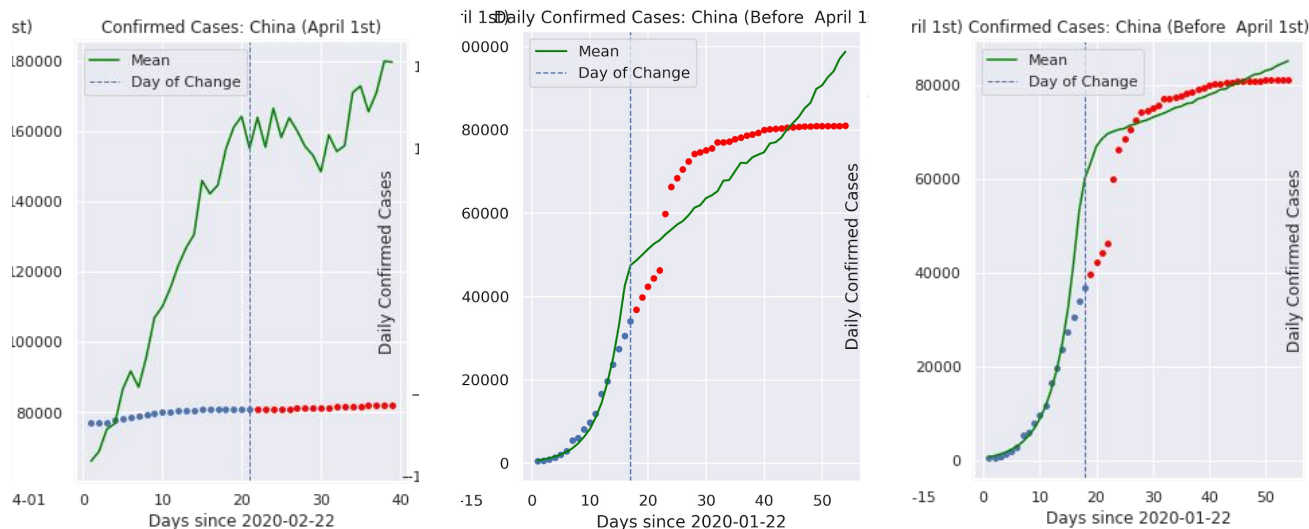
$$w_1 \sim N(\mu_{w_1}, \sigma_{w_1}^2) \quad w_2 \sim N(\mu_{w_2}, \sigma_{w_2}^2)$$
$$b_1 \sim N(\mu_{b_1}, \sigma_{b_1}^2) \quad b_2 \sim N(\mu_{b_2}, \sigma_{b_2}^2)$$
$$\tau \sim \text{Beta}(\alpha, \beta) \quad \sigma \sim U(0, 3)$$

## 2. POLICY STRENGTH: CHANGE-POINT MODEL

Other design choices

Inference algorithm: MCMC with NUTS (over SVI)

Likelihood: Student Distribution (over Normal distribution)



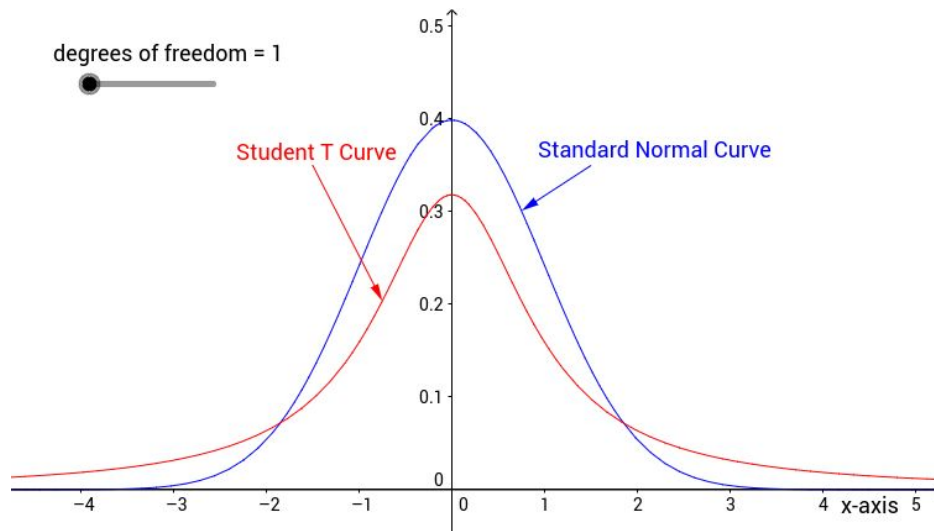


## 2. POLICY STRENGTH: CHANGE-POINT MODEL

Other design choices

Inference algorithm: MCMC with NUTS over SVI

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## 2. POLICY STRENGTH: CHANGE-POINT MODEL

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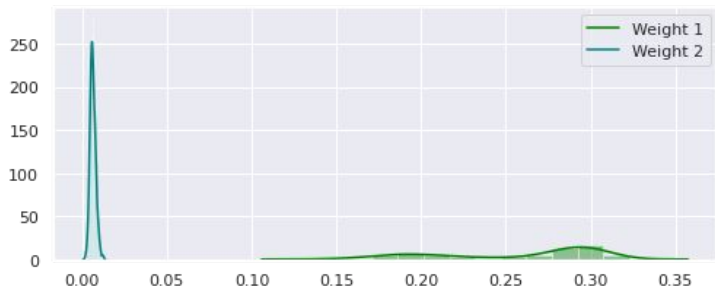
**Experiment:** Run the model on the countries that **strongly impose a policy**. The **full efficacy** of the policy is assumed to be **the policy strength in that country**.

- Lockdown: **China, New Zealand**
- Contact tracing and quarantine: **South Korea**
- Social distancing: **Canada**
- Mask and hygiene efficiency: Stay tuned ^^

**How to know our model works well:**

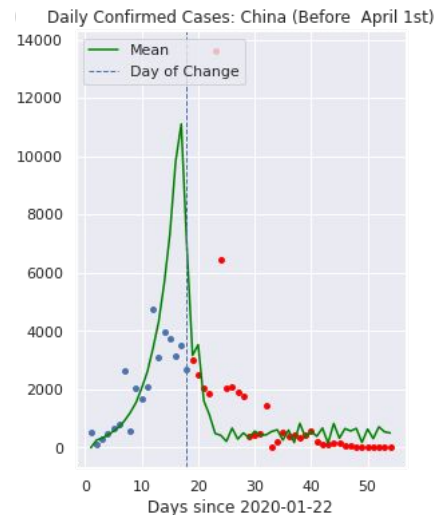
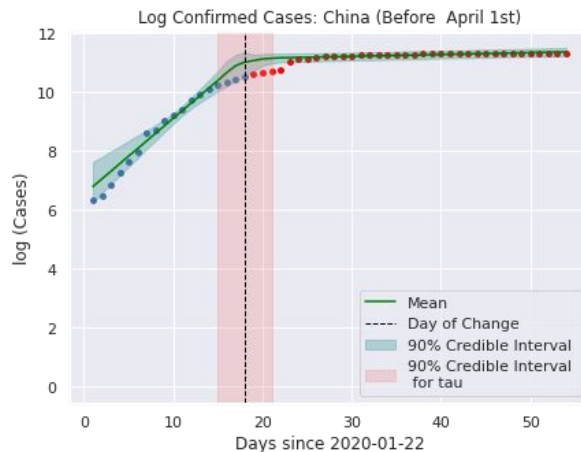
- The date of change should be around 14 days (recommended incubation time by WHO) after the policy establishment
- Strong convergence of the algorithm and the fitness to real data
- Prior: Lockdown has very high strength ...

## 2. RESULT: LOCKDOWN - CHINA

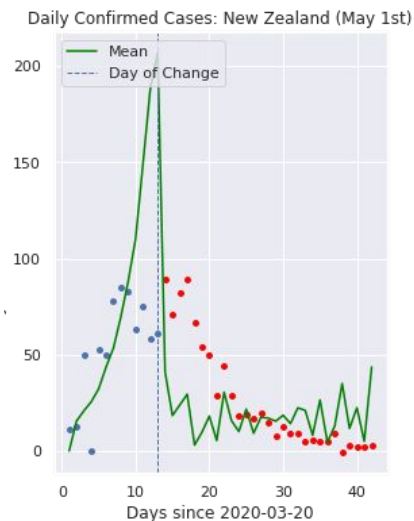
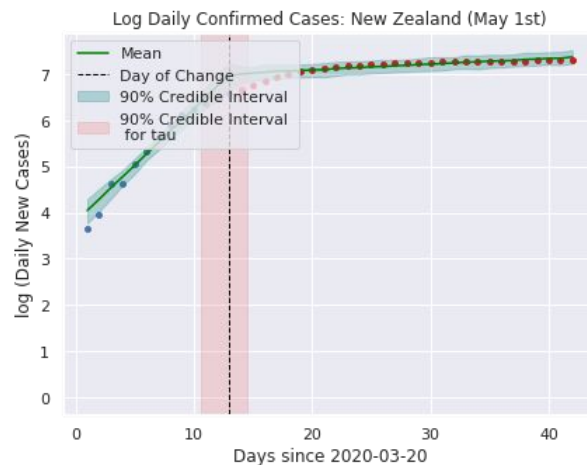
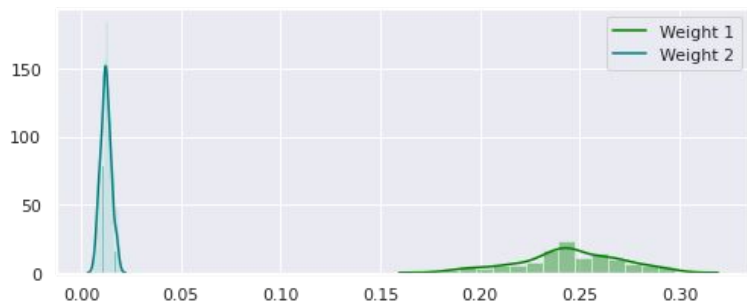


Date of change: 2020-02-09  
Lockdown applied: 2020-01-23

Policy strength:  $1 - 0.01/0.26 = 0.96$



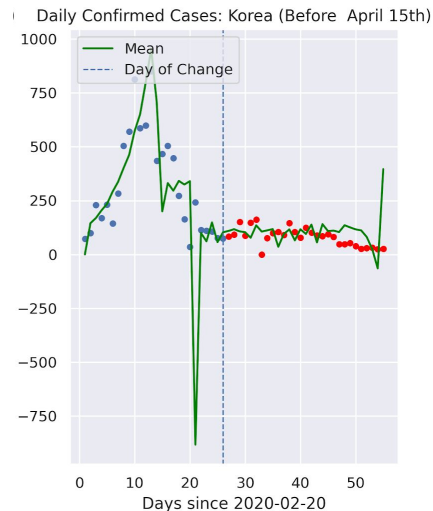
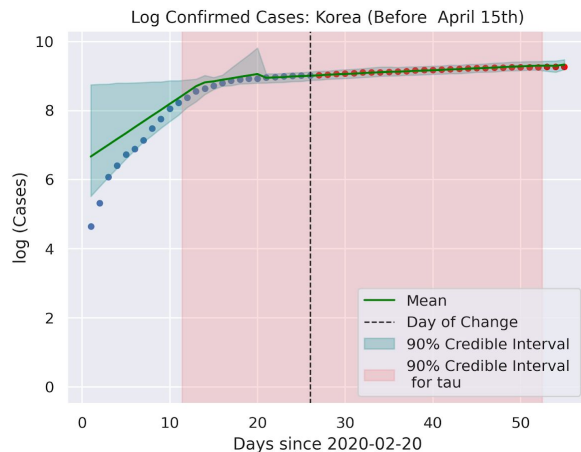
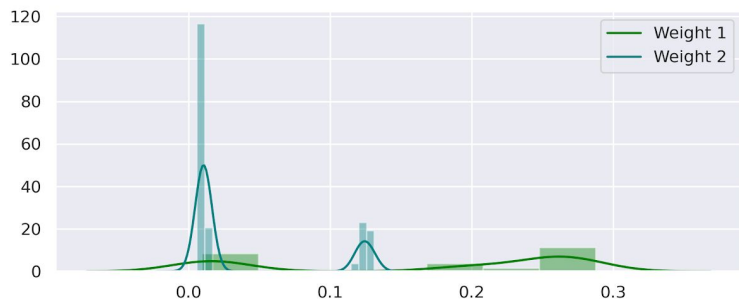
## 2. RESULT: LOCKDOWN - NEW ZEALAND



Date of change: 2020-04-02  
Lockdown applied: 2020-03-25

Policy strength:  $1 - 0.01/0.25 = 0.96$

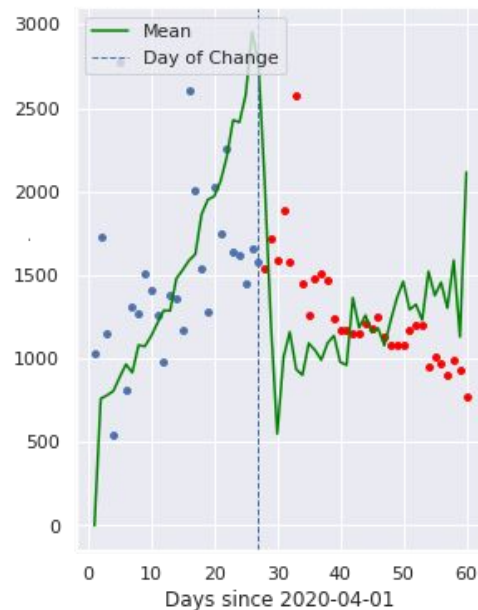
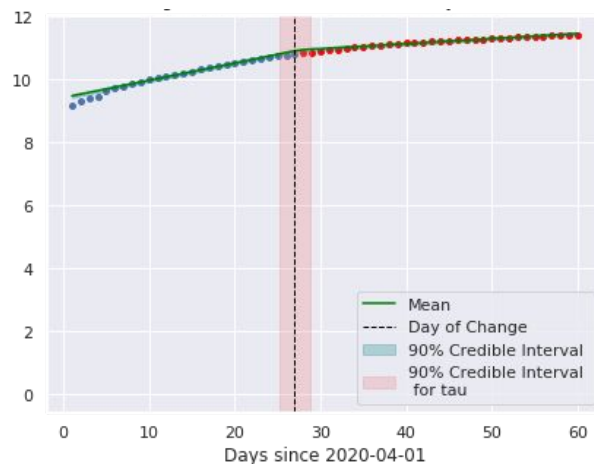
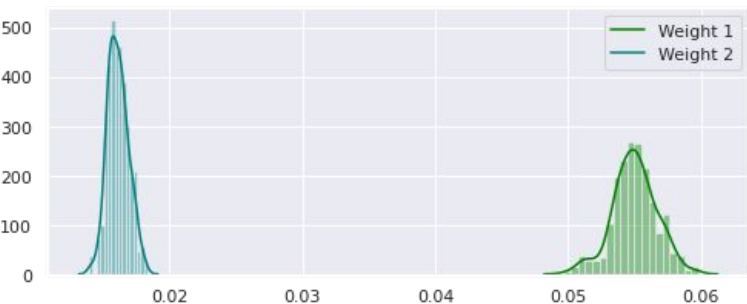
## 2. RESULT: TRACING - SOUTH KOREA



Date of change: 2020-03-17  
Testing increase: 2020-02-25

Policy strength:  $1 - 0.04/0.17 = 0.76$

## 2. RESULT: DISTANCING - CANADA



Date of change: 2020-04-28

Policy applied: March-April

Policy strength:  $1 - 0.02/0.05 = 0.60$

## 2. RESULT: MASKS & HYGIENE- JAPAN

Note: R0 for Sweden is 2.40

	mean	std	median	5.0%	95.0%	n_eff	r_hat
rec_time	16.00	0.00	16.00	15.99	16.00	3.09	1.92
incub_time	6.53	0.00	6.54	6.53	6.54	7.69	1.00
R0	1.58	0.01	1.57	1.56	1.60	2.48	2.73
rho	0.29	0.01	0.29	0.28	0.30	2.58	2.46
mort_rate	0.02	0.00	0.02	0.02	0.02	2.50	2.79
rec_rate	0.14	0.01	0.14	0.13	0.14	2.57	2.51

Assumption:

Japanese people were custom to wear masks even before any policy was applied.

Policy strength:  $1 - 1.58/2.40 = 0.34$

## 2. RESULT: SUMMARY

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Policy	Strength
Lockdown	0.96
Distancing	0.60
Tracing	0.76
Masks / Hygiene	0.34



# 3. SIMULATION: SIMPLE GENERATIVE MODEL

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## Inferred parameters:

- `R0 : 2.40`
- `incubation_days : 3.83 days`
- `recovery_days : 16.33 days`
- `transmission_days : 8 days`
- `Mortality rate with hospitalization: 2%`
- `hygiene : 0.34`
- `distancing : 0.6`
- `lockdown : 0.96`
- `quarantine : 0.76`

## Assumptions:

- `Population : 1 million ppl`
- `Hospital Cap : 0.06%`
- `Immunity: infinite`
- `Serious cases: 15%`
- `Mortality rate without hospitalization: 90%`

# 3. SIMULATION: SIMPLE GENERATIVE MODEL

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For S, E, I, R: The same with SEIR model

Death tolls estimation:

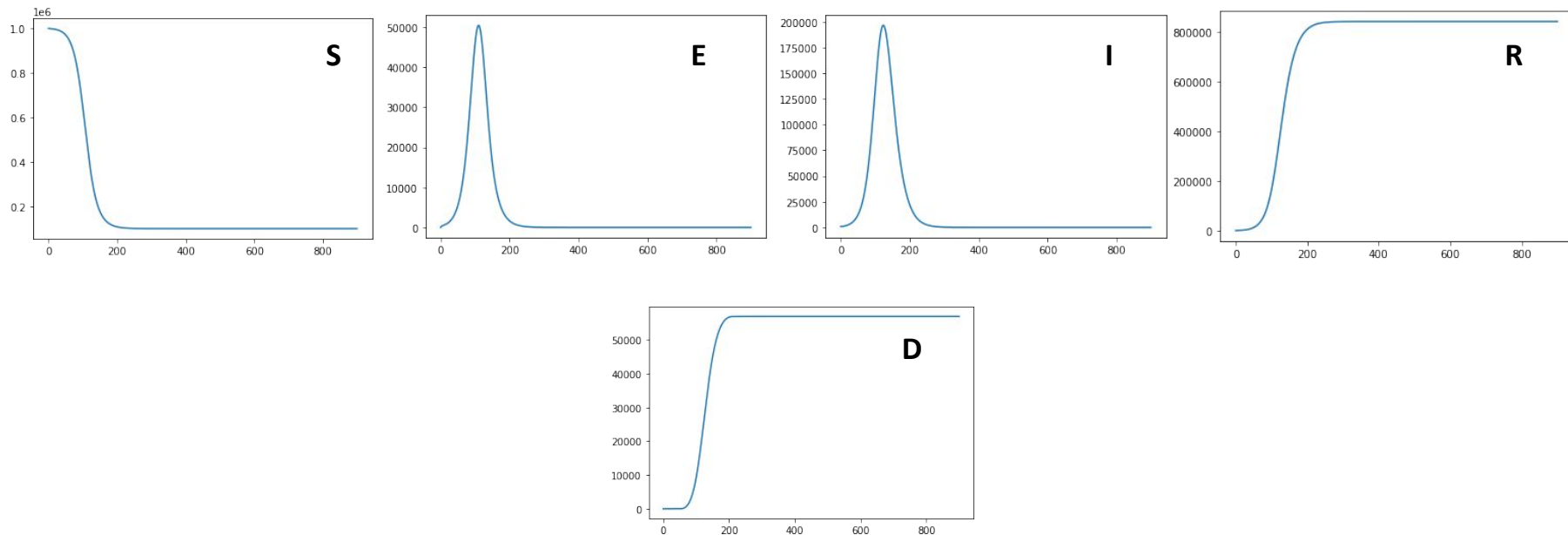
Using hospital capacity .06%, critical case rate of 15%

For critical case:

- Death rate without medical treatment: 90%
- Death rate with medical treatment: 2%

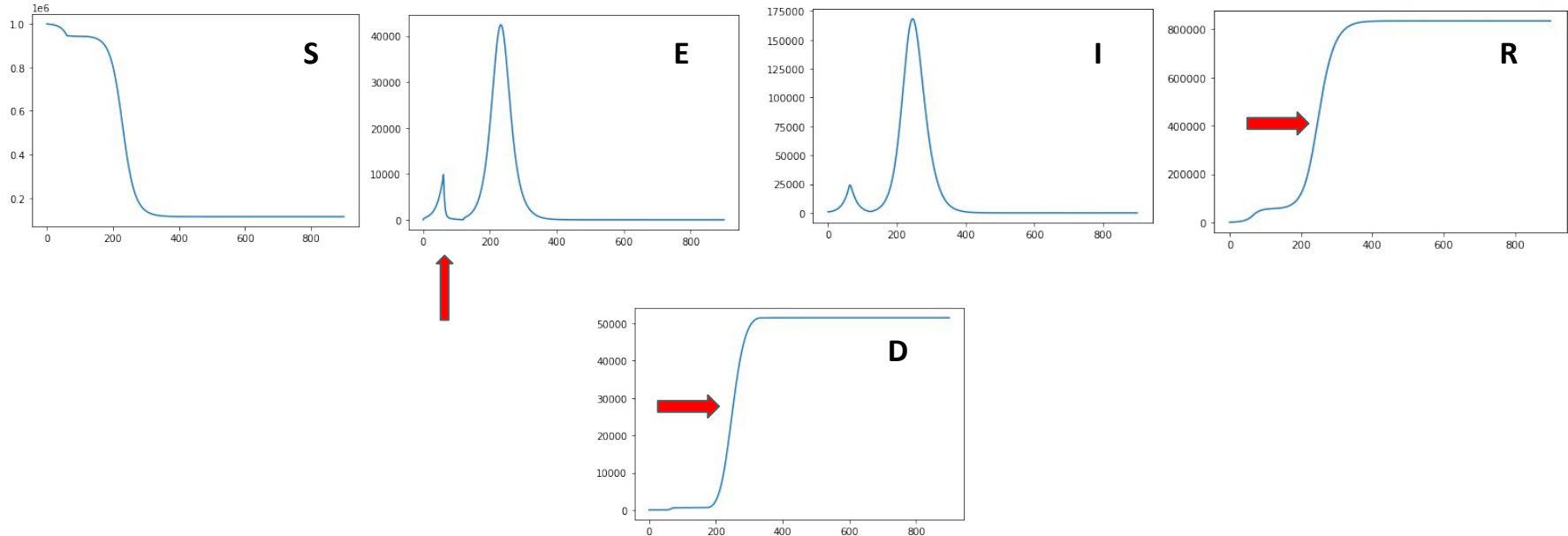
# 3. SIMULATION: SOME EXPERIMENT

No policies:



# 3. SIMULATION: SOME EXPERIMENT

Lockdown starting from day 60 to day 120:



# 3. SIMULATION GAME: ADDING REWARD

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- We estimate the economic cost for each policy and give negative rewards:
  - + Lockdowns: 10% of GDP per year (GDP per capita: 30k\$)
  - + Distancing: 5% of GDP per year
  - + Hygiene: 2\$ per day per capita
  - + Quarantine: 100\$ per day per infected
  - + Infection: 300\$ per infection per day (until recovered)
  - + Death: 4.9 million per death
- We tried to calculate the policy with least loss / highest reward
- Assumption:  
Initially infected: 1%

# 3. SIMULATION GAME: EXPERIMENT

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- Game mission: Derive a policy in **3 month** with **1-month interval** policy. Each policy can be applied at **x%** of its full efficacy
- **Goal: Minimize the loss**
- Original plan: **Generative modeling**, observe the score with mean 0
- **We have issue: NaN**

# 3. SIMULATION GAME: EXPERIMENT

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- Game mission: Derive a policy in 3 month with 1-month interval policy. Each policy can be applied at x% of its full efficacy
  - **Discretize** the game: 3 levels for x: full (100%), partially (50%) and none (0%)
  - Goal: Minimize the loss
  - Result:
    - + Best policy: **Full contact tracing + quarantine in all 3 months**
    - + Loss: - 65 108 814\$
    - + Loss without doing anything: - 7 592 712 053\$
- (Scale up for USA: 9 trillion \$ per year)

# Conclusion

- Policy affects virus a lot
- We must act early
- We must act efficiently
- We should consider health/economy trade off



# References

- Simulation with JS:  
[https://ncase.me/covid-19/?fbclid=IwAR02Xo2w7C9EAqhUchfkvt8Di0BLSapejPgltU5iuR13Q1zm\\_RJD28hXT-0](https://ncase.me/covid-19/?fbclid=IwAR02Xo2w7C9EAqhUchfkvt8Di0BLSapejPgltU5iuR13Q1zm_RJD28hXT-0)
- Simulation with R:  
[https://rviews.rstudio.com/2020/03/19/simulating-covid-19-interventions-with-r/?fbclid=IwAR3bgZRGxLqNhx8G4xQ-sU0DR-oy97gOK-MILX1Urpt2fp\\_iZDupLWbUa\\_I](https://rviews.rstudio.com/2020/03/19/simulating-covid-19-interventions-with-r/?fbclid=IwAR3bgZRGxLqNhx8G4xQ-sU0DR-oy97gOK-MILX1Urpt2fp_iZDupLWbUa_I)
- Change-point Model  
<https://towardsdatascience.com/detecting-changes-in-covid-19-cases-with-bayesian-models-1b628214e8b1?gi=8f422aec39f7>
- Epidemiology Model  
<http://docs.pyro.ai/en/dev/contrib.epidemiology.html>