Modelling the impact of interventions on progression of the pandemic

Introduction: In this analysis, we will identify interventions which have had an impact on the trajectory of the epidemic curve. In particular, we will focus on the various interventions which have been adopted in India.

Data Sources: Data on various interventions adopted by national governments was used from the ACAPS government measures database available at https://www.acaps.org/. The following is the breakup of categories of measures and the frequency with which each was enforced by national governments during the course of the pandemic:

Governance and socio-economic measures	Humanitarian exemption	Lockdown
1047	2	236
Movement restrictions	Public health measures	Social distancing
1423	1800	1042

Specific measures considered under these categories were:

- Additional health/documents requirements upon arrival
- Amendments to funeral and burial regulations
- Awareness campaigns
- Border checks
- Border closure
- Changes in prison-related policies
- Checkpoints within the country
- Complete border closure
- Curfews
- Domestic travel restrictions
- Economic measures
- Emergency administrative structures activated or established
- Full lockdown
- General recommendations
- Health screenings in airports and border crossings
- Humanitarian exemptions
- International flights suspension
- Introduction of isolation and quarantine policies
- Limit product imports/exports
- Limit public gatherings
- Lockdown of refugee/idp camps or other minorities
- Mass population testing
- Military deployment
- Obligatory medical tests not related to COVID-19
- Other public health measures enforced
- Partial lockdown
- Psychological assistance and medical social work
- Public services closure

- Requirement to wear protective gear in public
- Schools closure
- State of emergency declared
- Strengthening the public health system
- Surveillance and monitoring
- Testing Policy
- Visa restrictions

Case information was obtained from the Johns Hopkins repository at https://systems.jhu.edu/research/public-health/ncov/. Data on testing rates as well as population values and median age was obtained from Our World in Data.

Preliminary Analysis:

The table below shows some of the earliest responders in some of the popular categories

Border checks	Domestic travel restrictions	Emergency administrative structures established	Health screenings in airports and border crossings
Oman 01-04	China 01-27	Mali 01-04	Russia 01-01
Panama 01-04	Bhutan 01-31	Suda 01-20	Côte d'Ivoire 01-02
Lithuania 01-27	Thailand 02-20	United States 01-21	Barbados 01-22
Afghanistan 02-01	Mongolia 02-23	Italy 01-22	Panama 01-22
Switzerland 02-13	Afghanistan 02-24	Palau 01-22	Palau 01-23
Turkey 02-16	Ecuador 03-02	Thailand 01-22	UAE 01-23
Bosnia 02-24	Estonia 03-1	Israel 01-27	Turkey 01-24
Iran 02-27	Namibia 03-14	Gambia 02-01	India 01-25
Israel 03-05	Yemen 03-14	Sweden 02-01	Kyrgyzstan 01-25
San Marino 03-08	Eq. Guinea 03-15	Canada 02-02	Thailand 01-25
Germany 03-10	Iraq 03-15	Hungary 02-04	Afghanistan 01-26
Austria 03-11	Philippines 03-15	Afghanistan 02-06	Iran 01-31
Honduras 03-11	Albania 03-16	Seychelles 02-07	Hungary 02-03
India 03-11	Brunei 03-16	Pakistan 02-12	Mauritania 02-05
Algeria 03-12	Lithuania 03-16	France 02-13	Gambia 02-07
Burkina Faso 03-12	Maldives 03-16	Australia 02-17	Lao PDR 02-17
Philippines 03-12	Peru 03-16	Saint Lucia 03-01	Sierra Leone 02-19
Hungary 03-13	Slovenia 03-16	Dominica 03-03	South Sudan 02-20
Malaysia 03-15	Eritrea 03-17	Grenada 03-04	Malta 02-23
Norway 03-15	Venezuela 03-17	Cameroon 03-07	Zambia 02-24
Isolation and quarantine	**Limit public gatherings**	**Partial lockdown**	**Schools closure**
Bulgaria 01-03	China 01-29	Iran 01-31	Mongolia 01-27
Thailand 01-18	Brunei 01-30	Thailand 02-22	Italy 02-21
Italy 01-23	Mongolia 02-19	Ecuador 03-02	Bahrain 02-26
Canada 01-25	Japan 02-20	Palestine 03-07	Kuwait 02-26
Brunei 01-30	Italy 02-25	Italy 03-08	Iran 02-27
Afghanistan 02-02	Liechtenstein 02-28	El Salvador 03-11	Korea Republic of 02-27
Bahamas 02-02	Switzerland 02-28	Iraq 03-11	Afghanistan 03-01
Indonesia 02-02	France 02-29	Bulgaria 03-13	Azerbaijan 03-01
Mauritius 02-02	Afghanistan 03-01	Azerbaijan 03-14	Armenia 03-02
Israel 02-03	Kenya 03-03	Ukraine 03-15	Ecuador 03-02
Mauritania 02-05	Spain 03-03	Austria 03-16	Palestine 03-07
Angola 02-06	India 03-05	Bolivia 03-16	UAE 03-08
Japan 02-06	Kazakhstan 03-05	Colombia 03-16	Cyprus 03-09
Lebanon 02-16	Albania 03-08	Czech Republic 03-16	Lebanon 03-09
Turkey 02-16	Rwanda 03-08	India 03-16	Qatar 03-09
Ethiopia 02-22	San Marino 03-08	Luxembourg 03-16	Saudi Arabia 03-09
Sri Lanka 02-24	Hungary 03-09	Peru 03-16	Spain 03-09
Malta 02-27	Austria 03-10	Spain 03-16	Ukraine 03-09
Rwanda 02-27	Germany 03-10	Venezuela 03-16	Albania 03-10
Australia 03-01	Nepal 03-10	Hungary 03-17	Brunei 03-10

State of emergency declared	Strengthening the public health system	Visa restrictions	Military deployment
China 01-20	Mongolia 01-01	UAE 01-02	Mongolia 02-20
Italy 01-31	Thailand 01-18	Marshall Islands 01-30	Cuba 03-09
United States 01-31	United States 01-22	Iran 01-31	Albania 03-11
Micronesia 02-05	Saint Lucia 01-23	Philippines 01-31	Hungary 03-12
Afghanistan 02-24	Albania 01-24	United States 01-31	Philippines 03-13
Lithuania 02-26	India 01-25	Indonesia 02-02	France 03-16
Palestine 03-05	Bahamas 01-28	Mauritius 02-02	Peru 03-16
Iceland 03-06	Iran 01-28	Saint Lucia 02-04	Sierra Leone 03-16
Philippines 03-09	Japan 01-28	Belize 02-08	Switzerland 03-16
Hungary 03-11	Dominica 01-29	Palau 02-13	Jordan 03-18
Czech Rep 03-12	Bulgaria 01-31	Switzerland 02-13	Chile 03-19
Estonia 03-12	Latvia 01-31	Thailand 02-17	Italy 03-20
Maldives 03-12	Poland 01-31	India 02-26	Ethiopia 03-22
Portugal 03-12	Afghanistan 02-02	Iraq 02-26	United States 03-22
Slovakia 03-12	Palestine 02-03	Canada 02-29	Algeria 03-23
Slovenia 03-12	Israel 02-04	Tuvalu 02-29	Ecuador 03-25
Bulgaria 03-13	Barbados 02-05	Angola 03-01	Moldova 03-25
Poland 03-13	Antigua and Barbuda 02-12	Australia 03-01	Romania 03-25
Spain 03-13	Kyrgyzstan 02-14	Azerbaijan 03-01	Bolivia 03-26
Uruguay 03-13	Marshall Islands 02-15	Bahrain 03-01	Eswatini 03-26

An interesting observation from the above table is that the earliest responders were not necessarily countries with the most resources or access to information but were spread across the spectrum of income categories.

Model building

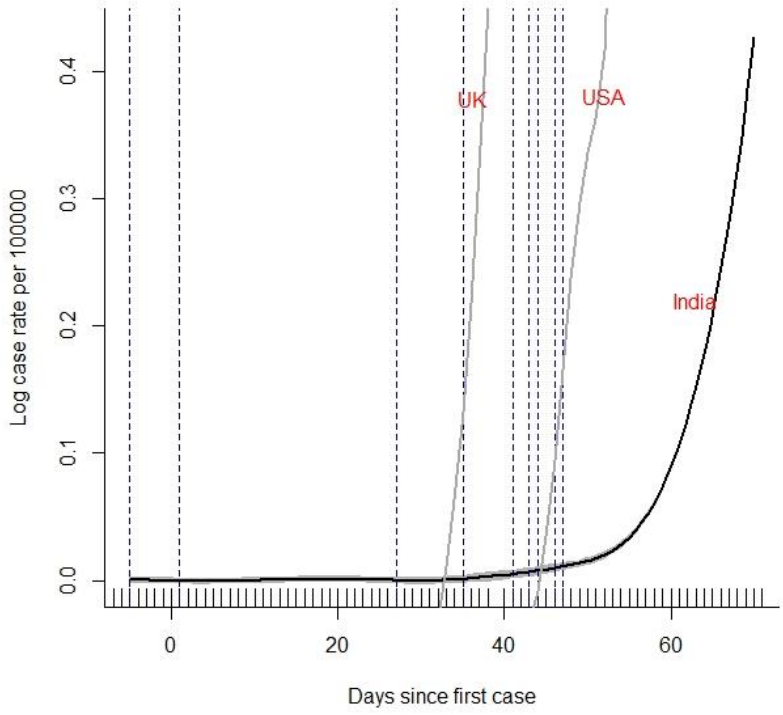
An information theoretic approach was used to rank and select covariates which appeared to have the most impact on the trajectory of the epidemic curve. For this purpose, a regression was fitted to the log case rate per 100,000 population for each country on the time since the first confirmed case. Interventions and some country specific covariates such as median age, population density and HDI values were screened for inclusion in the model, allowing for pairwise interactions and interaction with the time metric. This was done by ranking models via an information theoretic criterion (in this case, the AIC) but using a genetic algorithm which does not require explicit fitting of every model in the candidate model space but has an efficient way of restricting its movement to the better fitting models. Using this approach, the following interventions were found to be of the greatest impact on the trajectory:

1. Median age
2. Introduction of isolation and quarantine policies
3. Border closure
4. Visa restrictions
5. Emergency administrative structures activated or established

Median age had a significant positive interaction with the slope of the curve while border closure, visa restrictions and establishment of emergency administrative structures were found to significantly “flatten the curve”. Introduction of isolation and quarantine had a positive association with the case rate indicating that this led to better case identification. Note, however, that some of the interventions tended to be implemented simultaneously leading to a collinear design matrix and making alternative choices of effective interventions possible. This is true, in particular, for lockdown strategies which were implemented typically alongside border closure and visa restrictions.

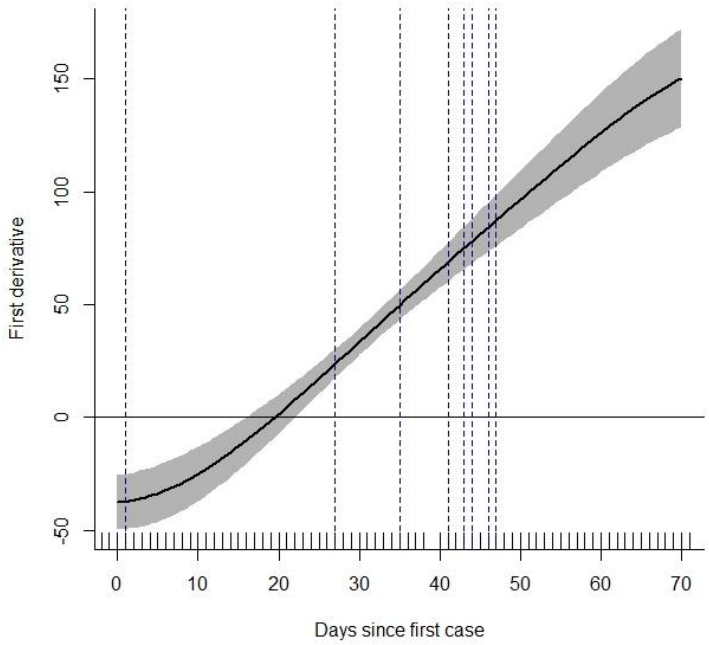
A model for India

We next fit a flexible semiparametric regression model to the log case rate per 100000 on time since identification of the first case, using the data for India. The results are as shown below:



The vertical dotted lines correspond to the timings of the various interventions adopted by the Indian government. The figure indicates that interventions were adopted early on in the course of the pandemic and in fact even before detection of the first Indian case. The curve is substantially flat for an extended period of time and the growth rate of the curve is substantially lower than those of the US and the UK, indicated by grey solid lines for reference.

Semiparametric regression can also be used to estimate the derivative curve which is shown in the following figure:



Translated into cases (rather than the log case rate), this means approximately that the growth rare is minimal upto day 30, around 15 new cases per day between days 30-50 and increasing from 15 new cases per day to 800 new cases per day between days 30-50. For comparison, the corresponding rate for the US at day 50 was estimated to be around 3000 new cases per day.

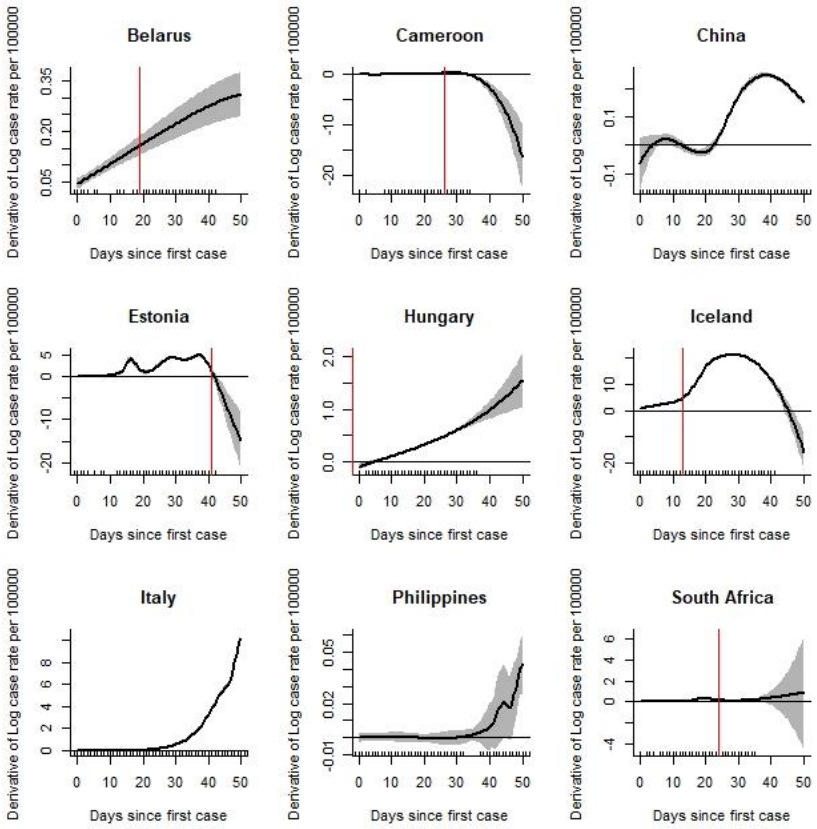
The derivative curve can also be used to estimate the doubling time for cases which was found to be around 7 upto day 35, increase up to 2 at the time of lockdown and then stabilise at around 4.

Impact of testing policy

While the above results indicate that swift action taken by the Indian government has had a significant impact in flattening the curve, a key criticism which has been levelled at India is that testing has not been widespread and the low figures could instead be an artefact of this.

The ACAPS dataset indicated that the countries which had adopted mass testing policies in course of the pandemic were Belarus, Cameroon, China, Estonia, Hungary, Iceland, Italy, Philippines, and South Africa

Semiparametric regression models were fitted to the data from these countries and the following figure shows the derivative plots from these fits:



The red line on the figure corresponds to the day of the pandemic since identification of the first case on which a mass testing policy was adopted. Note that while the impact of this can clearly be seen for Estonia and Cameroon, we fail to make any general observations about the impact of mass testing.

Earlier, we had estimated the SIR curves for the various Indian states and this analysis, featured elsewhere on the website does appear to show some general features of the curves when grouped by the degree of testing. Currently, this remains a grey area requiring further analysis.