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## Effectiveness of Containment Policies:

## Corona Virus Cases and Death Rates

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Arvind Virmani

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FOUNDATION FOR ECONOMIC GROWTH AND WELFARE

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* Dr. Arvind Virmani is Chairman of Foundation for Economic Growth and Welfare (India). This work is part of a joint research project with Dr Surjit Bhalla, Executive Director, IMF. Author would like to thank Ratan Chand and Charan Singh for suggestions on earlier version of paper.

# 1. Introduction

One of the questions arising from the Pandemic crisis, is the effect of various social and economic containment/lockdown policies adopted by different governments. Only a few studies have used panel data to estimate the impact of specific containment lockdown measures on the growth of Covid 19 cases and of deaths. In this paper we estimate the effect of eight different containment measures using panel regressions, in a formal model based on the S curve of propagation of pandemic.

Section 2 presents a brief literature review, while section 3 presents the formal model used in the estimation. Section 4 presents the results of the estimation of the model, using panel regressions with fixed effects. Section 5 explores the interaction of different containment measures, introduced into estimating equations in the form of dummies. Section 6 explains the reasons for the cross-country differences in spread of cases and deaths and section 7 concludes the paper.

# 2. Literature Review

Dergiades et al (2020) found that the effectiveness of government interventions in slowing or reducing deaths is higher, the earlier and more "stringent" the interventions. They found school closures to be less effective in slowing death rates. Bonardi et al (2020) created four internal and four external containment measures and found that the former is more effective than the latter. They also discovered that the 25 countries, which according to their index took internal lockdown measures, experienced a reduction in the growth rate compared to other countries, with growth rate lowered by 7.5% after 50 days. They also suggested that early lockdowns were more effective than delayed ones, but comprehensive lockdowns were not more effective than partial measures. Deb et all (2020) also found that containment measures are highly effective in flattening the pandemic curve, with several specific containment measures affecting the speed of spread of cases and death rates. They also found that public health interventions reduce growth of cases, with fast interventions having a greater effect than slower ones.

# 3. Model Framework

We use Government response Tracker index (developed by the University of Oxford) lockdown indices to determine the effect of different aspects of the lock down and the Johns Hopkins COVID data for the corona virus cases and deaths.

Author's earlier analysis shows that the logistic (S) curve can be fitted with a high degree of accuracy to the accumulated corona virus cases for most countries. For the dozen or so countries with the highest number of cases and sufficient elapsed period since the first case, the fit has improved as countries move past the inflection point of the logistic (S) curve. The slope of the S curve represents the growth rate of cases at any point in the trajectory of cases. This slope rises from virtually zero at the start, rises to a peak at the inflection point and then starts to decline till it again flattens out at zero. Any estimate that doesn't account for this S curve of corona virus cases is inherently flawed because we know that the growth rate of cases will eventually decline for every country and it is very easy to attribute this to policy intervention or other factors, if not accounted for.

Virmani and Bhalla (2020) showed that the speed of arrival of the Corona Virus from China was related to the degree of connectivity between China and the country. Bhalla and Virmani (2020a,b) used cross-country regressions and a stages approach to account for countries being on different points of the logistic curve at different points of time (measured by daycvc when cvc or its transformation is the LHS variable). The current issue requires a panel regression approach, so the variation in the slope of the curve of (accumulated) cases must be built into the regression analysis. We do this by introducing a time variable in the form of a Gomperts S curve equation.

The logic of using various restrictions on economic and social activity was to "flatten the curve". The assumption was that such measures would slow the rate of growth of cases and thus give more time for medical services, which were needed to deal with the pandemic to gear up. Thus, medical personnel could be trained, equipment procured for testing and treatment, and new facilities for isolation and quarantine can be built. There were however a few commentators who argued that the total number of cases at the end of the pandemic would be lower than if no lockdown measures were taken. Our results show that the curve was flattened by some of these measures, but the effect on the final count of total number of cases remains unclear.

## 3.1 Model

We use the *Gompers Sigmoid curve* to model the evolution of cases and deaths over time, i.e.

(1) y=a*exp[-exp(-g*(t-b))]

where a, b and g are positive constants and t is a time dimension (day, week or month).

Taking the log of this equation and differentiate to get equation (3)

(2) Log(y) = log(a) - exp[-g(t-b)]

(3) m = (1/y)*(dy/dt) = g* exp[-g(t-b)]

where m(t) = (1/y)*(dy/dt) is the rate of growth of cases.

Taking the log of (3) we get,

(4) Log(m) = A -gt ,

where A =log (g)+ b*g and

We start by estimating equation (4) for number of cases cvc as LHS variable y, to obtain the turning point b (see appendix for derivation), and the parameter c, of the Gomperts curve, using panel data. Then we use equation (3) to predict the slope of the S curve and the time at which it reaches its peak level.

To estimate the impact of lockdown variables, we assume

(5) b =bo + b1*z(-n), and

(6) g = g0 + g1* z(-n), where.

where n the lag from introduction of lockdown policy and its effect on number of recorded cases, and z is any lockdown variable like workplace closing or personal confinement, which takes the value zero when containment measure z is off and 1 when the containment measure z is in operation.

Note that, rate of growth m is reduced if $b1 < 0$ and its slope is reduced if $g1 < 0$. If both b1 and g1 are negative and significant, the effect on rate of growth at time t is ambiguous but rate will decline at a faster rate. Substituting equations (5) and (6) in equation (4), we get the equation,

(7) $\log(m0) = A0 - g0 * t$, $A0 = \log(g0) + b0*g0$, when $z(-n) = 0$

(8) $\log(m1) = A1 - (g0+g1) * t$, $A1 = \log(g0+g1) + (b0+b1)*(g0+g1)$, when $z(-n) = 1$.

In this note we estimate the linear equations (7) and (8) for the number of cases, i.e. y = cvc or y= cvd, t = week (from first covid case) and n is 1 or 2 (lag in weeks). The equation is estimated for each of eight different lockdown indices obtained from the Oxford COVID -19 data base. The change in m due to the containment policy is, subtracting (7) from (8) and simplifying,

(9) $\text{Log}\,(m1/m0) = \log(1+g1/g0) + (b0+b1)*(g0+g1) - b0g0 - g1*t \;\; < / > 0$ , as

(9') $m1/mo = (g0+g1)/g0 + \exp(b0*g1+b1*g0)*\exp(-g1(t-b1)) \;\; </> 1$

m, the rate of growth of y (cases or deaths) is slower or faster after interventions as m1 is < or > mo or log (m1/m0) is negative or positive.

If g1 = 0 (non-significant), $A1 = \log(g0) + g0*(b0+b1)$ . In this case we can also estimate the effect of strength of containment measure on rate of growth by substituting $b = bo + b1*z(-n)$ in (4) to get,

(9) $\log(m) = A2 + b1*z(-n) - g*t$, $A2 = \log(g0) + g0*(b0+b1)$ .

If z is a vector of policy interventions, z =(z1, z2, z3, ….zs), then equation (8') can be written as,

(9') $\log(m) = A2 - g*t + b1.1*z1(-n) + b1.2 * z2(-n) + \ldots\ldots b1.s * zs(-n)$, $A2 = \log(g0) + g0*(b0+b1)$ .

For the set of policy interventions, in which g1 is found to be non-significant in equation (8), we also estimate an integrated equation (9), using both the dummy (0-1) form and the index with integer values 1 to 5.

## 3.2 Derivation of parameters

Once the coefficients in equations (7), (8) or (9) are estimated, we can derive the original parameters and the effect on m. Equation (7) yields estimates of the coefficients *g0* and *A0*, using (7), we can estimate,

(10) $b0 = (A0 - \log(g0))/g0$,

Equation (8) yields estimates of *g*=g0 +g1 and *A1*. Using these in (8) we can derive,

$b = (b0+b1) = (A1 - \log(g0+g1))/(g0+g1)$, or and substituting *bo* from earlier equation, we get,

(11) $b1 = (A1 - \log(g0+g1))/(g0+g1) - (A0 - \log(g0))/g0$ .

### 3.3 Extended Model

We can test for interaction effects arising from the presence of two policies at the same time, by generalizing equations 7 and 8. We expand equations (5) and (6) to,

(5b) b = b0 +b1*dz1(-n) + b2*dz2(-n)

(6b) g = g0 + g1*dz1(-n) + g2*dz2(-n)

where dz1 and dz2 are the dummy variables for the policies z1 and z2, n is the lag with which the policies take effect. In the basic estimation with weekly data we assume n =1. Substituting these in equation (4) of text, we get, four equations dependent on the values of dz1 and dz2, the first of which is identical to (7), i.e.

(7) Ln(m) =ln(g0) +b0*g0 – g0*t , when dz1 =0, dz2 =0

(12) Ln(m) = log(g0+g1) +(b0+b1)*(g0+g1) –(g0+g1)* t , when dz1 = 1, dz2 = 0.

(13) ln(m) = log(g0+g2) +(b0+b2)*(g0+g2) –(g0+g2)* t , when dz1 = 0, dz2 = 1.

(14) ln(m) = log(go+g1+g2) + (bo+b1+b2)*(g0+g1+g2) – (go+g1+g2)*t , when dz1 = 1, dz2 = 1

## 4. Empirical Estimation: Results

### 4.1 Growth of Corona virus cases and deaths

Table 1, reg 1, gives the result of the panel estimation of equation (4). In this equation we have y = Corona virus cases (CVC) in each country at the end of each week, and t weeks from first corona virus case, with week 1 as the week in which the first corona virus case was recorded in the country recorded. It should be cautioned that in a few countries the official recording of cases started weeks into the crisis.

The most significant result is that both the time trend and the constant are significant at the 0.1% level of confidence. This means that any previous analysis which has ignored the S-curve nature of the spread of cases is questionable. At best, they may have got the right results for the wrong reasons, namely if the measures are taken before the inflection point of the S curve for the country, the rate of growth of cases will inevitably decline after the inflection point.

**Table 1: Estimation of Gomperts Curve**

| Dependent variable: | | log(rate of growth of y): y = | | |
|---|---|---|---|---|
| | | CVC | | CVD |
| Independent | | reg 1 | | reg 2 |
| variable | | | | |
| week | | -0.26 | | -0.305 |
| | | (-24)**** | | (-21)**** |
| _cons | | 1.03 | | 1.88 |
| | | (10)**** | | (12)**** |
| | | | | |
| adj. R-sq | | 0.38 | | 0.40 |
| N | | 2480 | | 1570 |

Note: t statistics in parentheses: Confidence level $p < 0.001$ = ***.
Data Source: CVC and CVD data from the Johns Hopkins, COVID data base.

Where,
ycvc=log(m), m= (d(cvc)/dt)/cvc) ,
cvc = cumulative corona virus cases at time t in weeks.
week= weeks from first corona virus case.
Tempave = average temperature during pandemic
Xpopmge = share of population 70 or over to total
Xurb is share of urban population in total
Xpopden = population density.

Table 2 shows the inflection point b (9.1 weeks) and the predicted values of the rate of growth using the parameters shown in table 1. The most noteworthy result is that overall, it took more than 10 weeks for the rate of growth to go below 1 and more than 15 weeks to go below 0.5. But thereafter progress is very slow, with the rate of growth going below 0.3 after 30 weeks (table 2, 1st column).

**Table 2: Predicted Rate of growth (m) of Corona virus cases & deaths**

| *week* | Reg1 | Reg2 |
|---|---|---|
| y = | *cvc* | *cvd* |
| 1 | 8.7 | 16.1 |
| 5 | 3.3 | 5.0 |
| 8 | 1.6 | 2.2 |
| 9 | 1.3 | 1.7 |
| 10 | 1.1 | 1.3 |
| 15 | 0.49 | 0.53 |
| 20 | 0.32 | 0.35 |
| 25 | 0.28 | 0.32 |
| 28 | 0.27 | 0.31 |
| 30 | 0.26 | 0.31 |
| g = | -0.26 | -0.30 |
| b = (A-log(g))/g | 9.3 | 10.1 |

We also apply the same Gomperts model to estimate the evolution of deaths and the impact of country variations in the parameters discussed above. Death rates depend on both the number of cases and on the variable that directly affects the fatality of the disease, such as aged population and the quality of health infrastructure. Regression 2 shows that the Gomperts model we have used fits the progression of deaths at the 0.1% level of significance just like the progression of cases (table 1, reg 2). The inflection point for deaths at 10.1 weeks is about 1.5 weeks after that for cases. The projections in table 2 shows that on average the rate of growth of deaths starts at a much higher level than that of cases, but converges in about 20 weeks (table 2, reg 2).

It should be noted that these estimates of the inflection points (in weeks) of the S curve for corona virus cases and COVID 19 deaths are average values for the World. They may differ considerably for individual countries. As an illustration we fit the model to Indian data, derive the parameters c and b and project the cases and deaths and find that the inflection points for corona cases is >3x and for deaths >2x that of the averages obtained in table 2 (appendix tables A1 & A2).

## 4.2 Effect of Containment measures: Cases

Table 3 presents the results of our analysis of the lockdown measures adopted by various governments. We examine the effect of eight specific lockdown measures incorporated in c1 to c8). All the lockdown measures tested in our model have negative effect on the growth rate of coronavirus cases indicating that they slow the spread of the corona virus (reg 1 to reg 8).

Three specific indices for school closures of public transport (c5), stay at home restrictions (c6) and restrictions on internal movement (c7) show a decline in the rate of growth after a week, but the effect declines over time, with the rate of growth exceeding the no-lockdown trend at some point in the future. i.e. the curve is *flattened* as expected. In the case of the other five lockdown measures, the rate of growth seems to have been permanently reduced below its no-lockdown path. These measures are school closures (c1), workplace closures (c2), cancelation of public events (c3), restrictions on public gatherings (c4) and international travel controls (c8).

**Table 3: Effect of Lockdown on the speed of spread of Corona Virus cases (cvc)**

| | Dependent Variable = log(m); m=rate of growth of cvc | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Reg 1 | Reg 2 | Reg 3 | Reg 4 | Reg 5 | Reg 6 | Reg 7 | Reg 8 |
| **dz =** | **dc1** | **dc2** | **dc3** | **dc4** | **dc5** | **dc6** | **dc7** | **dc8** |
| Indipendent Variables | | | | | | | | |
| Constant | 1.38 | 1.27 | 1.25 | 1.39 | 1.38 | 1.31 | 1.41 | 1.79 |
| | (7)**** | (10)**** | (7)**** | (9)**** | (11)**** | (12)**** | (10)**** | (8)**** |
| l.dz | -0.46 | -0.46 | -0.29 | -0.63 | -0.79 | -0.80 | -0.69 | -0.92 |
| | (-2.0)** | (-3)*** | (-1.4) | (-3.4)**** | (-5)**** | (-5)**** | (-4)**** | (-3.7)**** |
| week | -0.26 | -0.25 | -0.25 | -0.26 | -0.27 | -0.27 | -0.27 | -0.27 |
| | (-16)**** | (-20)**** | (-18)**** | (-20)**** | (-21)**** | (-24)**** | (-20)**** | (-17)**** |
| l.week*dz | 0.004 | 0.003 | -0.007 | -0.012 | 0.043 | 0.059 | 0.036 | -0.016 |
| | (0.21) | (0.21) | (-0.46) | (0.8) | (2.8)*** | (4)**** | (2.5)*** | (0.9) |
| R square | 0.38 | 0.38 | 0.38 | 0.38 | 0.38 | 0.38 | 0.37 | 0.37 |
| N | 2480 | 2480 | 2480 | 2480 | 2480 | 2480 | 2480 | 2480 |

Note: t statistics are given below each coefficient and marked with asterisk(s) if significant. Level: * = 10%; ** = 5%; *** = 1% ; **** = 0.1%. Data Sources: Johns Hopkins, Oxford University COVID 19 data base.

Where,
l. indicates one-week lag

dz = dl1 in reg1, dc5 in reg 2, dc6 in reg 3, dc7 in reg 4, dc1 in reg 5, dc2 in reg6, dc3 in reg 7, dc4 in reg 8, dc8 in reg 9. dz is = to ds1 in reg 10 and dr2 in reg 11.
dc1 = dummy for School closing index
dc2 = dummy for Workplace closure index
dc3 = dummy for cancelation of Public events index
dc4 = dummy restrictions on public gatherings index
dc5 = dummy closure of public transport index
dc6 = dummy for stay at home restrictions index
dc7 = dummy restrictions on Internal movement index

dc8 = dummy for international travel controls index.
m = rate of growth of cvc = (1/cvc)*(dcvc/dt)

For the five containment/confinement measures in which the coefficient on the variable weekdz, is not significant, we can use equation (9) to estimate the individual effect of the containment measures. All these measures reduce the rate of growth of cases (reg 1 to reg 5 of table 3b). The marginal effect of containment policies are shown in column headed reg 6 (table 3b). The co-efficient on three of the five confinement measures, workplace closure (c2), restrictions on public gatherings (c4) and international travel control (c8) remain negative and significant. On one of the five confinement measures, school closing (c1), it becomes non-significant; In one containment measure, cancellation of public events (c3), where it was not-significant in the original equation(table 3),it flips significance from negative to positive (reg 3 & reg 6, table 3b). Thus the effect of cancellation of public events seems to be highly unstable and dependent on what other measures are in place.

**Table 3b: Effect of Lockdown on the speed of spread of Corona Virus cases (cvc)**

| Dependent Var | y = log(m); m=rate of growth of cvc | | | | | |
|---|---|---|---|---|---|---|
| | Reg 1 | Reg 2 | Reg 3 | Reg 4 | Reg 5 | Reg 6 |
| Indipendent Var | | | | | | |
| Constant | 1.36 | 1.25 | 1.29 | 1.33 | 1.68 | 1.59 |
| | (9)**** | (11)**** | (9)**** | (10)**** | (11)**** | (10)**** |
| week | -0.26 | -0.25 | -0.26 | -0.26 | -0.26 | -0.25 |
| | (-23)**** | (-23)**** | (-23)**** | (-35)**** | (-24)**** | (-23)**** |
| I.dc1 | -0.46 | | | | | 0.10 |
| | (-4)**** | | | | | (0.5) |
| I.dc2 | | -0.44 | | | | -0.22 |
| | | (-5)**** | | | | (-2.0)* |
| I.dc3 | | | -0.36 | | | 0.46 |
| | | | (-3.2)*** | | | (2.3)* |
| I.dc4 | | | | -0.53 | | -0.35 |
| | | | | (-5)**** | | (-2.2)* |
| I.dc8 | | | | | -0.77 | -0.78 |
| | | | | | (-6)**** | (-4)**** |
| | | | | | | |
| R square | 0.38 | 0.38 | 0.38 | 0.38 | 0.37 | 0.38 |
| N | 2480 | 2480 | 2480 | 2480 | 2480 | 2480 |

Note: t statistics are given below each coefficient and marked with asterisk(s) if significant.
Level: * = 10%; ** = 5%; *** = 1% ; **** = 0.1%.

Table 4 for calculates the parameters (b and g) in equations (7) and (8) and also projects the impact of each containment variable on the growth rate of cases, using the results of table 3 and table 3b. The most significant result is that the greatest impact of three containment measure in which the curve of cases is flattened (c5, c6 & c7), the impact on growth rates lasts a maximum of 24 weeks, before reversing.

**Table 4: Effect of Containment measure dcm on growth rate of cases m**

| | Reg 1 | Reg 2 | Reg 3 | Reg 4 | Reg 5 | Reg 6 | Reg 7 | Reg 8 | Reg 9 | Reg 10 | Reg 11 | Reg 12 | Reg 13 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | dc1 | dc2 | dc3 | dc4 | dc5 | dc6 | dc7 | dc8 | dc1 | dc2 | dc3 | dc4 | dc8 |
| b0 | 10.5 | 10.4 | 10.4 | 10.7 | 9.9 | 9.6 | 10.0 | 11.4 | 10.5 | 10.5 | 10.3 | 10.5 | 11.6 |
| b0+b1 | 8.6 | 8.5 | 9.6 | 8.8 | 5.6 | 4.9 | 6.2 | 8.8 | 8.7 | 8.7 | 8.9 | 8.4 | 8.6 |
| g0 | 0.26 | 0.25 | 0.25 | 0.26 | 0.27 | 0.27 | 0.27 | 0.27 | 0.26 | 0.25 | 0.26 | 0.26 | 0.26 |
| g0+g1 | 0.26 | 0.26 | 0.25 | 0.25 | 0.31 | 0.33 | 0.31 | 0.26 | 0.26 | 0.25 | 0.26 | 0.26 | 0.26 |
| week | m/m0 =exp(A-A0 -g1*t) | | | | | | | | | | | | |
| 1 | 0.6 | 0.6 | 0.8 | 0.5 | 0.47 | 0.48 | 0.52 | 0.4 | 0.63 | 0.65 | 0.70 | 0.59 | 0.46 |
| 2 | 0.6 | 0.6 | 0.8 | 0.5 | 0.49 | 0.51 | 0.54 | 0.4 | 0.63 | 0.65 | 0.70 | 0.59 | 0.46 |
| 3 | 0.6 | 0.6 | 0.8 | 0.6 | 0.51 | 0.54 | 0.56 | 0.4 | 0.63 | 0.65 | 0.70 | 0.59 | 0.46 |
| 4 | 0.6 | 0.6 | 0.8 | 0.6 | 0.54 | 0.57 | 0.58 | 0.4 | 0.63 | 0.65 | 0.70 | 0.59 | 0.46 |
| 5 | 0.6 | 0.6 | 0.8 | 0.6 | 0.56 | 0.60 | 0.60 | 0.4 | 0.63 | 0.65 | 0.70 | 0.59 | 0.46 |
| 6 | 0.6 | 0.6 | 0.8 | 0.6 | 0.58 | 0.64 | 0.62 | 0.4 | 0.63 | 0.65 | 0.70 | 0.59 | 0.46 |
| 7 | 0.6 | 0.6 | 0.8 | 0.6 | 0.61 | 0.68 | 0.64 | 0.4 | 0.63 | 0.65 | 0.70 | 0.59 | 0.46 |
| 8 | 0.6 | 0.6 | 0.8 | 0.6 | 0.64 | 0.72 | 0.66 | 0.5 | 0.63 | 0.65 | 0.70 | 0.59 | 0.46 |
| 9 | 0.6 | 0.6 | 0.8 | 0.6 | 0.66 | 0.77 | 0.69 | 0.5 | 0.63 | 0.65 | 0.70 | 0.59 | 0.46 |
| 10 | 0.6 | 0.6 | 0.8 | 0.6 | 0.69 | 0.81 | 0.71 | 0.5 | 0.63 | 0.65 | 0.70 | 0.59 | 0.46 |
| 11 | 0.6 | 0.6 | 0.8 | 0.6 | 0.72 | 0.86 | 0.74 | 0.5 | 0.63 | 0.65 | 0.70 | 0.59 | 0.46 |
| 12 | 0.6 | 0.6 | 0.8 | 0.6 | 0.75 | 0.91 | 0.77 | 0.5 | 0.63 | 0.65 | 0.70 | 0.59 | 0.46 |
| 18 | 0.6 | 0.6 | 0.8 | 0.7 | 0.97 | 1.30 | 0.95 | 0.5 | 0.63 | 0.65 | 0.70 | 0.59 | 0.46 |
| 24 | 0.6 | 0.6 | 0.9 | 0.7 | 1.26 | 1.85 | 1.17 | 0.6 | 0.63 | 0.65 | 0.70 | 0.59 | 0.46 |

The ranking of different measures which emerges is as follows: (1) International travel controls (c8), (2) Restrictions on public gatherings (c4), (3) School closures (c1), (4) Workplace closure (c2), (5) cancellation of public events (c3), (6) Restrictions on internal movement (c7), (7) Closure of public transport (c5), (8) Stay at home restrictions (c6), .

For the five containment/confinement measures in which the coefficient on the variable weekdz is not significant in table 3, we can also use equations (9) and (9') to test whether degree/strength of these measures has a significant effect on the rate of growth of corona virus cases. The results of estimation of equation (9), using the actual index (instead of the off-on dummy) are shown in Reg 1 to Reg 5 of table 5. The effect is not significant for c1 and c3, but is negative and significant for c2, c4 and c8, i.e. workplace closure (c2), restrictions on public gatherings (c4) and International travel restrictions (c8) reduce the rate of growth of the virus (table 5) to a larger extent the more comprehensive they are. Reg 6 shows the results from the estimation of equation 9'; The co-efficient of the two containment polices (c1 and c3), which were insignificant in the individual equations, are now found to be significant and positive. In other words, school closure and cancellation of public events increase the speed of spread of cases as their intensity/comprehensiveness increases (table 5). Comparing with the results in reg 6, table 3b, this suggests that school closure have not slowed the rate of growth of deaths, but beyond some level of stringency they may have perverse effect. Similarly, the cancellation of public events may be dependent on other factors such as social consciousness about wearing of face masks/covering and physical distancing.

**Table 5: Effect of containment intensity on speed of spread of Corona Virus cases**

| Dependent Var | y = log(m); m=rate of growth of cvc | | | | | |
|---|---|---|---|---|---|---|
| | Reg 1 | Reg 2 | Reg 3 | Reg 4 | Reg 5 | Reg 6 |
| Indipendent Var | | | | | | |
| Constant | 1.15 | 1.28 | 1.16 | 1.30 | 1.57 | 1.40 |
| | (7)**** | (10)**** | (7)**** | (10)**** | (8)**** | (7)**** |
| week | -0.27 | -0.27 | -0.27 | -0.26 | -0.26 | -0.26 |
| | (-23)**** | (-22)**** | (-23)**** | (-21)**** | (-21)**** | (-20)**** |
| l.c1 | 0.003 | | | | | 0.128 |
| | (0.07) | | | | | (1.9)** |
| l.c2 | | -0.09 | | | | -0.09 |
| | | (-2.2)** | | | | (-2.0)** |
| l.c3 | | | -0.003 | | | 0.19 |
| | | | (-0.04) | | | (1.8)* |
| l.c4 | | | | -0.08 | | -0.09 |
| | | | | (-2.1)** | | (-2.2)** |
| l.c8 | | | | | -0.16 | -0.19 |
| | | | | | (-2.8)*** | (-2.6)*** |
| | | | | | | |
| R square | 0.39 | 0.40 | 0.39 | 0.40 | 0.39 | 0.39 |
| N | 2171 | 2171 | 2169 | 2163 | 2170 | 2159 |

Note: t statistics are given below each coefficient and marked with asterisk(s) if significant.
Level: * = 10%; ** = 5%; *** = 1% ; **** = 0.1%.

Where,
c1 = school closure index,
c2=workplace closure index
c3 = index of cancellation of public events
c4 = index of restrictions on public gatherings
c5 = index of closure of public transport
c6 = index of restrictions on internal movement
c7 = index of restrictions on internal movement
c8 = index of international travel controls
each index has integer values 1 to 5 where 1 is lowest and 5 is highest.

## 4.3 Effect of Confinement on Covid19 deaths

We next analyze the effect of confinement polices on Covid 19 deaths. Table 6 presents the results of the effect of lockdown on the rate of growth of death rates. Four measures have a statistically insignificant effect on the rate of growth of deaths. These are, School closings (c1), the cancellation of public events (c3), stay at home restrictions (c6) and restrictions on internal movement (c7). One lockdown measure, workplace closing (c2) accelerates the decline in the rate of growth of deaths, without affecting the current death rate (table 6). In other words, the effect of this measure on deaths increases over time (starting at nil). Three containment measures, restrictions on public gatherings (c4), closure of public transport (c5) and controls on international travel (c8) reduced the rate of growth of deaths, without having a significant effect on its declining slope i.e. a parallel reduction in the growth rate (table 6).

**Table 6: Effect of confinement measures on rate of growth of COVID-19 deaths (cvd)**

| | Dependent Variable = log(m), m = rate of growth of cvd | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Reg 1 | Reg 2 | Reg 3 | Reg 4 | Reg 5 | Reg 6 | Reg 7 | Reg 8 |
| **dz =** | dc1 | dc2 | dc3 | dc4 | dc5 | dc6 | dc7 | dc8 |
| Indipendent Var | | | | | | | | |
| Constant | 2.29 | 2.14 | 2.19 | 2.35 | 2.37 | 2.06 | 2.18 | 2.91 |
| | (7)**** | (10)**** | (7)**** | (9)**** | (11)**** | (12)**** | (10)**** | (8)**** |
| | | | | | | | | |
| l.dz | -0.35 | -0.26 | -0.24 | -0.52 | -0.70 | -0.27 | -0.26 | -1.00 |
| | (-1.0) | (-1.2) | (-0.8) | (-1.8)* | (-3)*** | (-1.3) | (-1.2) | (-2.8)*** |
| | | | | | | | | |
| week | -0.30 | -0.29 | -0.29 | -0.30 | -0.32 | -0.31 | -0.30 | -0.33 |
| | (-12)**** | (-17)**** | (-14)**** | (-16)**** | (-17)**** | (-20)**** | (-16)**** | (-13)**** |
| | | | | | | | | |
| l.week*dz | -0.021 | -0.039 | -0.030 | -0.014 | 0.020 | 0.008 | 0.020 | 0.006 |
| | (-0.8) | (-2.2)** | (-1.3) | (-0.6) | (0.9) | (0.4) | (1.6) | (0.2) |
| | | | | | | | | |
| R square | 0.41 | 0.41 | 0.41 | 0.41 | 0.41 | 0.40 | 0.40 | 0.40 |
| Obs | 1570 | 1570 | 1570 | 1570 | 1570 | 1570 | 1570 | 1570 |

Note: numbers in brackets are t statistics. Significance level: * = 10%; ** = 5%; *** = 1% ; **** = 0.1%.
Where m = rate of growth of cvd = (1/cvd)*(d(cvd)/dt).

For the seven containment/confinement measures in which the coefficient on the variable weekdz is not significant in table 6, we can use equations (9) to estimate the individual effect of the containment measures, and (9') to determine the simultaneous effect of these measures on the growth rate of Covid 19 deaths. Results are presented in table 6b. Each of these containment variables is significant and negative when included alone (reg 1 to reg 7). However, when all 7 are included together, the three containment measures (dc4, dc5, dc8), which were separately significant in the full model remain significant, while the four containment measures (dc1, dc3, dc6, dc7) which were non-significant in the full model remain non-significant (table 6 and reg 8, table 6b).

Table 7 uses the results in tables 6 and 6b, to calculate the parameters (b and c) in equations (7) and (12) and to project the impact of each containment variable on the growth rate of deaths. The most significant result is that for the only containment measures which results in a flattening of the curve, workplace closure (c2), the positive effect lasts only for 6 weeks. This is a clear example of the flattening of the curve of deaths, without reducing ultimate total deaths.

In the case of all other measures there has been a permanent reduction in the rate of growth of Covid 19 deaths. We can also use these projections to rank the effectiveness of the different measures in reducing deaths as follows: (1) Restrictions on international travel (c8). This result differs from that of Bonardi et all (2020). (2) Restrictions on public gatherings (c4), (3) Cancellation of public events (c3), (4) school closure (c1), (5) Closure of public transport (c5), (6) restrictions on internal movement (c7). (7) stay at home restrictions, (8) Workplace closure (c2) (last row of table 7).

**Table 6b: Effect of confinement measures on rate of growth of COVID-19 deaths (cvd)**

| | Dependent Variable = log(m), m = rate of growth of cvd | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Reg 1 | Reg 2 | Reg 3 | Reg 4 | Reg 5 | Reg 6 | Reg 7 | Reg 8 | Reg 9 | Reg 10 |
| Ind var | dc1 | dc3 | dc4 | dc5 | dc6 | dc7 | dc8 | all7c | all8c | all8c |
| Constant | 2.54 | 2.52 | 2.47 | 2.25 | 2.03 | 2.36 | 2.85 | 2.77 | 2.58 | 2.73 |
| | (13)**** | (13)**** | (13)**** | (14)**** | (13)**** | (13)**** | (14)**** | (13)**** | (9)**** | (13)**** |
| week | -0.32 | -0.32 | -0.31 | -0.31 | -0.31 | -0.32 | -0.32 | -0.32 | -0.30 | -0.31 |
| | (-21)**** | (-21)**** | (-21)**** | (-21)**** | (-21)**** | (-21)**** | (-22)**** | (-22)**** | (-15)**** | (-21)**** |
| l.dc1 | -0.61 | | | | | | | 0.17 | 0.27 | 0.25 |
| | (-5)**** | | | | | | | (0.2) | (1.2) | (1.2) |
| l.dc3 | | -0.62 | | | | | | 0.030 | 0.35 | 0.32 |
| | | (-6)**** | | | | | | (1.3) | (1.6)* | (1.5) |
| l.dc4 | | | -0.67 | | | | | -0.35 | -0.29 | -0.30 |
| | | | (-6)**** | | | | | (2.0)** | (-1.6) | (-1.7)* |
| l.dc5 | | | | -0.50 | | | | -0.27 | -0.22 | -0.23 |
| | | | | (-5)**** | | | | (2.0)** | (-1.6) | (-1.6) |
| l.dc6 | | | | | -0.20 | | | 0.17 | 0.20 | 0.22 |
| | | | | | (-2.2)** | | | (1.4) | (1.7)* | (1.9)* |
| l.dc7 | | | | | | -0.49 | | -0.08 | -0.004 | 0.01 |
| | | | | | | (-5)**** | | (0.5) | (-0.03) | (0.04) |
| l.dc8 | | | | | | | -0.93 | -0.88 | -0.80 | -0.83 |
| | | | | | | | (-8)**** | (-3.6)**** | (-3.3)**** | (-3.5)**** |
| l.dc2 | | | | | | | | | -0.28 | -0.41 |
| | | | | | | | | | (-1.2) | (-3)*** |
| l.week*dz | | | | | | | | | -0.02 | |
| | | | | | | | | | (-0.7) | |
| R square | 0.41 | 0.41 | 0.41 | 0.41 | 0.40 | 0.40 | 0.40 | 0.41 | 0.41 | 0.41 |
| Obs | 1570 | 1570 | 1570 | 1570 | 1570 | 1570 | 1570 | 1570 | 1570 | 1570 |

As there is only one containment measure(c2) in which the effect on slope was significant, we can introduce this in equation (9') to test what happens. Reg 9 shows that the interactive time coefficient is insignificant when included along with all the other variable (table 8). Re-estimating the equation without this interactive term, the co-efficient on workplace closure (c2) is significant in reducing the rate of growth of deaths, while stay at home restrictions(c6) increase the rate of growth of deaths. The latter is probably because these restrictions reduce access to medical practitioners and hospitals.

**Table 7: Effect of Containment measures on growth rate of deaths**

| | dc1 | **dc2** | dc3 | dc4 | dc5 | dc6 | dc7 | dc8 |
|---|---|---|---|---|---|---|---|---|
| b0 | 11.6 | 11.8 | 11.5 | 11.6 | 11.0 | 10.3 | 11.1 | 12.3 |
| b0+b1 | 9.6 | 13.2 | 9.6 | 9.5 | 9.4 | 9.7 | 9.6 | 9.5 |
| g0 | 0.32 | 0.29 | 0.32 | 0.31 | 0.31 | 0.31 | 0.32 | 0.32 |
| g0+g1 | | 0.25 | | | | | | |
| | **m/m0 =exp(A-A0 -g1*t)** | | | | | | | |
| 1 | 0.54 | 0.80 | 0.54 | 0.51 | 0.61 | 0.82 | 0.62 | 0.40 |
| 2 | 0.54 | 0.83 | 0.54 | 0.51 | 0.61 | 0.82 | 0.62 | 0.40 |
| 3 | 0.54 | 0.87 | 0.54 | 0.51 | 0.61 | 0.82 | 0.62 | 0.40 |
| 4 | 0.54 | 0.90 | 0.54 | 0.51 | 0.61 | 0.82 | 0.62 | 0.40 |
| 5 | 0.54 | 0.93 | 0.54 | 0.51 | 0.61 | 0.82 | 0.62 | 0.40 |
| 6 | 0.54 | 0.97 | 0.54 | 0.51 | 0.61 | 0.82 | 0.62 | 0.40 |
| 7 | 0.54 | 1.01 | 0.54 | 0.51 | 0.61 | 0.82 | 0.62 | 0.40 |
| 8 | 0.54 | 1.05 | 0.54 | 0.51 | 0.61 | 0.82 | 0.62 | 0.40 |
| 9 | 0.54 | 1.09 | 0.54 | 0.51 | 0.61 | 0.82 | 0.62 | 0.40 |
| 10 | 0.54 | 1.13 | 0.54 | 0.51 | 0.61 | 0.82 | 0.62 | 0.40 |
| 11 | 0.54 | 1.18 | 0.54 | 0.51 | 0.61 | 0.82 | 0.62 | 0.40 |
| 12 | 0.54 | 1.23 | 0.54 | 0.51 | 0.61 | 0.82 | 0.62 | 0.40 |
| 18 | 0.54 | 1.54 | 0.54 | 0.51 | 0.61 | 0.82 | 0.62 | 0.40 |
| 24 | 0.54 | 1.95 | 0.54 | 0.51 | 0.61 | 0.82 | 0.62 | 0.40 |
| Rank | 4 | 8 | 3 | 2 | 6 | 7 | 6 | 1 |

Equations (9) and (9') can also be used to determine whether degree/strength of these measures has a significant effect on the growth rate of COVID 19 deaths. Considering each containment measure c1 and c3 to c8 in turn and simultaneously none is found to have a significant effect on rate of growth of deaths. However, if we introduce c2 into the equation (9') it has a significant negative effect on the rate of growth of deaths (reg 4, table 8). Thus, only the strength/comprehensiveness of workplace closure (c2) seems to affect the rate of growth of deaths(table 8).

**Table 8: Effect of containment intensity on growth of Corona Virus deaths**

| | Dependent Variable = log(m), m = rate of growth of cvd | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Reg 1 | Reg 2 | Reg 3 | Reg 4 | Reg 5 | Reg 6 | Reg 7 | Reg 8 |
| Constant | 1.94 | 2.05 | 2.13 | 2.15 | 2.11 | 2.11 | 2.32 | 2.16 |
| | (7)**** | (9)**** | (11)**** | (7)**** | (13)**** | (12)**** | (7)**** | (6)**** |
| week | -0.33 | -0.33 | -0.33 | -0.33 | -0.33 | -0.33 | -0.33 | -0.33 |
| | (-21)**** | (-21)**** | (-21)**** | (-21)**** | (-21)**** | (-21)**** | (-21)**** | (-21)**** |
| l.c1 | 0.052 | | | | | | | 0.12 |
| | (0.7) | | | | | | | (2.4)** |
| l.c3 | | 0.02 | | | | | | 0.06 |
| | | (0.3) | | | | | | (0.6) |
| l.c4 | | | 0.01 | | | | | 0.01 |
| | | | (0.3) | | | | | (0.1) |
| l.c5 | | | | -0.053 | | | | -0.01 |
| | | | | (-0.7) | | | | (-0.2) |
| l.c6 | | | | | -0.012 | | | 0.05 |
| | | | | | (-0.3) | | | (0.9) |
| l.c7 | | | | | | -0.031 | | -0.02 |
| | | | | | | (-0.5) | | (-0.3) |
| l.c8 | | | | | | | -0.07 | -0.09 |
| | | | | | | | (-0.9) | (-1.0) |
| l.c2 | | | | | | | | -0.13 |
| | | | | | | | | (-2.5)*** |
| R square | 0.41 | 0.41 | 0.41 | 0.41 | 0.41 | 0.41 | 0.41 | 0.41 |
| Obs | 1415 | 1415 | 1410 | 1413 | 1413 | 1414 | 1414 | 1407 |

Note: numbers in brackets are t statistics. Significance level: * = 10%; ** = 5%; *** = 1% ; **** = 0.1%

## 5. Interaction of Containment Measures

There were only three containment measures (c5, c6 and c7) which had a significant effect on the slope variable (g=g0+g1) in the regressions reported in table 5. Consequently, these three variables had to be left out in the estimation using equations (9) and (9'), which assume that g1 is zero. In this section we explore the question as to whether multicollinearity among these three containment measures confounds the results obtained for the effect of lockdown measures on the rate of growth of Corona virus cases (tables 3 & 4). We estimate the extended model given in equations 12 through equations 14, to take account the of the simultaneous presence of two different containment measures.

One noteworthy feature of the results of this exercise is that the co-efficient of the time variable (week), remains completely unaffected by the varying combination of variables (table 9). The second result is that the effect of containment measures on co-efficient of the time variable is significant and positive in three out of nine coefficients, all relating to the interacting term (reg 1 to reg 3, table 9). This suggests that the effect of these three containment measures is not additive, marginal effect is less than when no other containment measure is present. That is the effect of closure of public transport and workplace closure cannot be separated, probably because the bulk of workers use public transport, and closure of either one virtually leads to closure of the other.

Re-estimating the equations after dropping the non-significant interactive time coefficients, confirms that all three containment measures (c5, c6, c7) reduce the rate of growth of deaths.

**Table 9: Interaction of containment measures**

| dependent Var | log (m), m= growth rate of cvc | | | | | |
|---|---|---|---|---|---|---|
| | Reg 1 | Reg 2 | Reg 3 | Reg 4 | Reg 5 | Reg 6 |
| **dzn & dcm =** | n=5,m=6 | n=6,m=7 | n=5,m=7 | n=5,m=6 | n=6,m=7 | n=5,m=7 |
| Indipendent Var | | | | | | |
| Constant | 1.43 | 1.46 | 1.46 | 1.39 | 1.48 | 1.42 |
| | (11)**** | (10)**** | (10)**** | (11)**** | (10)**** | (11)**** |
| l.dcnm_01 | -0.55 | -0.49 | -0.28 | -0.28 | -0.28 | -0.39 |
| | (-1.2) | (-2.5)*** | (-1.2) | (-1.6) | (-2.6)*** | (-4)**** |
| l.dcnm_10 | -0.57 | -1.37 | -0.27 | -0.45 | -0.45 | -1.06 |
| | (-3)*** | (-2.4)** | (-0.7) | (-4)**** | (-2.1)** | (-4)**** |
| l.dcnm_11 | -1.00 | -0.95 | -0.93 | -0.96 | -0.95 | -0.91 |
| | (-6)**** | (-5)**** | (-5)**** | (-6)**** | (-6)**** | (-6)**** |
| | | | | | | |
| week | -0.27 | -0.27 | -0.27 | -0.27 | -0.27 | -0.27 |
| | (-22)**** | (-20)**** | (-21)**** | (-23)**** | (-21)**** | (-24)**** |
| l.weekdcnm_01 | 0.03 | 0.01 | -0.001 | | | |
| | (0.7) | (0.6) | (-0.04) | | | |
| l.weekdcnm_10 | -0.01 | 0.04 | -0.05 | | | |
| | (-0.7) | (0.8) | (-0.9) | | | |
| l.weekdcnm_11 | 0.07 | 0.06 | 0.05 | 0.06 | 0.05 | 0.06 |
| | (4)**** | (4)**** | (3)*** | (4)**** | (3)**** | (4)**** |
| | | | | | | |
| R square | 0.38 | 0.38 | 0.38 | 0.38 | 0.38 | 0.38 |
| Obs | 2480 | 2480 | 2480 | 2480 | 2480 | 2480 |

Note: numbers in brackets are t statistics.
Significance level: * = 10%; ** = 5%; *** = 1% ; **** = 0.1%

Where,
Dcnm_01 = 1 when dcn = 0 and dcm =1, and = 0 otherwise.
Dcnm_10 = 1, when dcn =1 and dcm = 0, and = 0 otherwise.
Dcnm_11 = 1, when dcn =1 and dcm = 1, and = 0 otherwise.

## 6. Country Specific Factors[1]

In this section we analyse the determinants of the differential spread of cases and death across countries. Virmani and Bhalla (2020 a, b) used cross-country regressions and a stages approach to account for countries being on different points of the logistic curve at different points of time. One of the factors which was speculated early in the life and times of Covid19 was the effect of temperature on its diffusion. It was suggested that cold dry weather accelerated the spread of the disease. An alternative view drew on the experience of seasonality of influenza during winter months. Both explanations point to temperature being an important factor. IMF study finds a negative effect of temperature on number of cases. It is unclear whether temperature affects corona virus diffusion or the incidence of COVID 19 deaths, or both.

Italian Covid19 cases and deaths exploded onto the world stage in March, and since then old age men have been believed to be a strong factor behind the spread of the disease. However, it is important to determine whether age affects virus diffusion or the incidence of death (with

[1] This sub-section is based on joint work with Surjit Bhalla.

Covid19 as the cause), or both. To test this hypothesis, and using country level population data published by the UN, we have extracted the male population in each country over the age of 60, 70 and 80.

The spread of the Spanish Flu in England, a century ago, was attributed by a few studies to the slums in London. Casual inference based on within country data suggests that cases are largely concentrated in Metros and large cities, with noticeably fewer rural cases. Thus, the degree of urbanization in a country may be a factor. A parallel explanation is offered using a population density variable (population size divided by inhabitable area).

The quality of tertiary can directly affect the growth of covid deaths. This is not true of corona virus cases. We us the number of hospital beds for 100,000 population as an indicator of the quality of the system.

Table 10 presents the results of the effects of these factors on the rate of growth of corona virus cases and the rate of growth of COVID 19 deaths, with the fixed effects for selected countries. The coefficient on the time variable, week are unaffected by the introduction of country specific variables. Thus, the underlying model of the S shaped spread of the virus over time, is found to be robust to different specifications. Table 10 also confirms the negative effect of temperature and the positive effect of urban population and aged male population on the speed of spread of virus cases (reg 1). The results are unchanged for different definitions of the aged male population share. The effect of these factors on the trajectory of deaths is very similar, except that the temperature variable is only significant in the absence of the hospital quality variable (reg 3, table 10). When the model is correctly specified, the death rate is found to be significantly determined by the aged population and the quality of tertiary health services. The effect of urban population on death rates is borderline significant, probably because urban areas generally have more effective tertiary health care, which is offsetting the faster spread of cases (reg 3, table 10).

**Table 10: Cross-country differences in spread of cases & deaths**

| Dependent variable: | | log(rate of growth of y): y = | | |
|---|---|---|---|---|
| | | CVC | CVD | CVD |
| Independent | | reg 1 | reg 2 | reg 3 |
| variable | | | | |
| tempave | | -0.07 | -0.09 | -0.08 |
| | | (-1.7)* | (-1.9)* | (-1.6) |
| xurb | | 0.69 | 0.59 | 0.02 |
| | | (10)**** | (3.1)*** | (-1.9)* |
| xpopmge60 | | 22.5 | 19.4 | 0.36 |
| | | (13)**** | (3.2)*** | (2.6)*** |
| hbeds100k | | | | -0.71 |
| | | | | (3.1)*** |
| week | | -0.24 | -0.28 | -0.29 |
| | | (-19)**** | (-17)**** | (-15)**** |
| _cons | | -59 | -49 | 3.1 |
| | | (13)**** | (2.9)*** | (3.2)*** |
| China | | -166 | -144 | -5.2 |
| India | | -69 | -59 | 0.3 |
| USA | | -227 | -195 | -2.9 |
| Russia | | -167 | -144 | 1.4 |
| Japan | | -345 | -296 | 2.3 |
| Brazil | | -132 | -114 | -0.9 |
| | | | | |
| adj. R-sq | | 0.66 | 0.71 | 0.71 |
| No. of obs | | 2360 | 1515 | 1405 |

Note: Numbers in brackets are t statistics
Significance levels are: *=10%, **=5%, ***=1%, ****=0.1%
All country constants are significant at 0.1% level

Where,
tempave =average temperature during spread of virus,
xurb is percent of urban population,
xpopmge60 = percent of male population, 60 years or over,
hbeds100k = hospital beds per 100,000 of population.

## 7. Conclusion

We build a rigorous model for the spread of corona virus cases and Covid deaths, based on a mathematical version of the S curve used historically to model the spread of viral epidemics and infectious diseases. This model is then developed to allow its formal use in estimating the effect of confinement/lockdown measures. It is first estimated without confinement/lockdown measures. Introduction of confinement measures allows us to rigorously test for the effect of these confinement measures using cross-country panel regressions. We find that lockdown measures have significant effect on the rate of growth of SARS Corona Virus 2 cases and Covid19 deaths.

For the sub-set of containment measures, which do not affect the coefficient of the time variable (week), we can estimate the joint/marginal effect of these measures. This shows that only school closing does not have a significant effect on the rate of growth of corona virus cases and intensely imposed it may reduce the initial impact on the rate of growth. The effect of cancellation of public events also appears to be related to the intensity with which it was applied.

For the sub-set of three confinement measures which affect the time coefficient on the rate of spread of cases. For these we use the extended model to do pairwise estimates to evaluate the robustness of the results to collinearity among the measures. This confirms the effectiveness of these tree confinement policies in slowing the spread of corona virus cases.

Our methodology also allows us to rank the effectiveness of the specific lockdown/containment polices. The ranking of policies in slowing the spread of the corona virus cases are, (1) International travel controls, (2) Restrictions on public gatherings, (3) School closures, (4) Workplace closure, (5) Cancellation of public event, (6) Restrictions on internal movement, (7) Closure of public transport, (8) Stay at home restrictions.

We also find that for international travel restrictions, workplace closure and restrictions on public gatherings, the degree of slowdown is related to the strength of the clampdown. In contrast intensity seems to reduce the effectiveness of the containment for school closing and cancellation of public events

All eight confinement measures are found to reduce the rate of growth of Covid 19 deaths. Only one of these eight affects the co-efficient of the time variable. The ranking of policies in slowing the rate of growth of COVID19 deaths are: (1) Restrictions on international travel, (2) Restrictions on public gatherings, (3) Cancellation of public events, (4) school closure, (5) Closure of public transport, (6) restrictions on internal movement. (7) stay at home restrictions, (8) Workplace closure.

However, only the controls on international travel, restrictions on public gatherings and stay at home restrictions have a significant incremental effect in reducing the growth of deaths in the presence of other policies. We also find that only for workplace closure is the degree of slowdown affected by the strength of the closure.

We also analyse the effect of factors explaining the differential spread of corona virus cases and death rates among countries. We find that the share of aged male population (over 60, 70 or 80), has a positive and highly significant effect on the spread of cases and death rates. Next in significance is the share of urban population and the average temperature, with the significance reducing when we move from explaining differences in spread of cases to differences in growth of deaths. The quality of the tertiary health system as measured by number of hospital beds has a highly significant effect on deaths, but makes temperature irrelevant and reduces the significance of the share of urban population.

The appendix presents some preliminary results on Indian trajectory of cases and deaths relative to the world. The inflection point for growth of deaths occurs at 22 weeks from start of epidemic, more than two times the average of 10 weeks for all countries A comparison of the projections in table A2 for India with those in table 2 for the world, suggests that decline in Indian growth rate of corona virus cases is lagging the average world trajectory by about 15 weeks, but the decline in the rate of growth of covid 19 deaths is only a few weeks behind the world’s average growth rate trajectory.

# 8. Appendix: Indian S curve

We also ran the basic model separately for India, using the same data set, to determine the turning point b predicted by the Gomperts curve for India(table A1), and the projections of corona virus cases and death rate based on these estimates(table A2). There are several noteworthy results. First, the Gomperts curve fits perfectly for the Covid 19 death rates with an R-square of 0.8 and both coefficients significant at the 0.1% level of significance. The fit is still good for the curve of corona virus cases, at an R square of 0.4, but the constant term is not significant at the 10% level (table A1). Second the inflection point for growth of deaths occurs at 22 weeks from start of epidemic, more than two times the average of 10 weeks for all countries (table A2 & table 2). Third the inflection point for the growth of corona virus cases is more than 3 x that of the average for all countries, but is much more uncertain (with the constant A not-significant).

**Table A1: Estimation of Rate of growth of cases and deaths in India**

| Dependent variable: | | log(rate of growth of y): y = | | |
|---|---|---|---|---|
| | | CVC | | CVD |
| Independent | | reg 1 | | reg 2 |
| variable | | | | |
| week | | -0.12 | | -0.18 |
| | | (-2.6)** | | (-6.8)**** |
| | | | | |
| _cons | | 1.21 | | 2.18 |
| | | (1.7) | | (5.6)**** |
| | | | | |
| adj. R-sq | | 0.50 | | 0.80 |
| N | | 18 | | 15 |

Note: numbers in brackets are t statistics.
Significance level: * = 10%; ** = 5%; *** = 1% ; **** = 0.1%

**Table A2: Predicted Rate of growth (m) of Corona virus cases & deaths**

| *week* | | Reg1 | | Reg2 | |
|---|---|---|---|---|---|
| | y = | *cvc* | | *cvd* | |
| 1 | | 25.4 | | 42.2 | |
| 10 | | 8.9 | | 8.7 | |
| 15 | | 5.0 | | 3.7 | |
| 20 | | 2.8 | | 1.6 | |
| 22 | | 2.3 | | 1.2 | |
| 23 | | 2.0 | | 1.0 | |
| 25 | | 1.6 | | 0.8 | |
| 28 | | 1.2 | | 0.5 | |
| 29 | | 1.1 | | 0.5 | |
| 30 | | 1.0 | | 0.4 | |
| 35 | | 0.6 | | 0.3 | |
| 40 | | 0.4 | | 0.22 | |
| 50 | | 0.20 | | 0.18 | |
| 60 | | 0.14 | | 0.18 | |
| g = | | -0.12 | | -0.18 | |
| b = (A-log(g))/g | | 28.5 | | 22.2 | |

A comparison of the projections in table A2 for India with those in table 2 for the world, suggests that decline in Indian growth rate of corona virus cases is lagging the average world trajectory by about 15 weeks, but the decline in the rate of growth of covid 19 deaths is only a few weeks behind the world's average growth rate trajectory.

## Technical Appendix: Inflection point in Gomperts function

(1) y=a*exp(-exp(-c*(t-b)))
(2) Log(y) = log(a) – exp[(-c(t-b)]
(3) s= dy/dt = y*(c*exp(-c(t-b)] > 0
(4) ds/dt = dy/dt (c*exp[-c(t-b)] – y * (c^2)exp[-(c(t-b)] = 0 at inflection point, ie
(5) c = (1/y)*( dy/dt) = c*exp[-c(t-b)] =>
(6) 1 = exp[-c(t-b)] => t = b

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