

A Medley of Modelling and Policy Insights on COVID-19

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**Presented at The Centre for Applied Macroeconomic Analysis (CAMA),
Crawford School of Public Policy,
The ANU**

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Medley Overview

- I. Robust estimates of the true (population) infection rate for COVID-19.**
(Phipps, Grafton & Kompas)
<https://royalsocietypublishing.org/doi/pdf/10.1098/rsos.200909>
- II. Health and Economic Costs of Early & Delayed Suppression of COVID-19 in Australia (first wave).** (Kompas, Grafton, Che, Chu & Camac)
<https://www.medrxiv.org/content/10.1101/2020.06.21.20136549v1>
- III. Epidemiological Modelling of the Health and Economic Effects of COVID-19 Controls in Australia's Second Wave.** (Grafton, Parslow, Kompas, Glass and Banks)
<https://www.medrxiv.org/content/10.1101/2020.08.31.20185587v1.full.pdf>
- IV. Statistical Analyses of the Public Health and Economic Performance of Nordic Countries in Response to the COVID-19 Pandemic.** (Gordon, Grafton and Steinshamn)
<https://www.medrxiv.org/content/10.1101/2020.11.23.20236711v1>

I. Robust estimates of the true (population) infection rate for COVID-19: a backcasting approach

(Royal Society Open Science 7: 200909)

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The three parameters used in the backcasting exercise: name, units, and the minimum and maximum values of the uncertainty ranges sampled

Table 1. The three parameters used in the backcasting exercise: name, units, and the minimum and maximum values of the uncertainty ranges sampled.

parameter	units	minimum	maximum
infection fatality rate (IFR)	%	0.37	1.15
mean incubation period	days	4.1	7.0
mean time from symptoms to death	days	12.8	19.2

Statistics for each country as at 28 March 2020 and 31 August 2020

Table 2. Statistics for each country as at 28 March 2020 and 31 August 2020: the estimated true cumulative number of infections (median and 95% confidence interval); the estimated cumulative percentage of the population to be infected (median and 95% confidence interval); the confirmed percentage of the population to have tested positive; and the implied detection rate (median and 95% confidence interval). For 28 March 2020, the estimated true cumulative number of infections according to Flaxman *et al.* [5] (mean and 95% credible interval) is also provided for comparison. The data shown for 'all' represents aggregated statistics for all 15 countries. Population statistics are obtained from the European Centre for Disease Prevention and Control.

country	28 March 2020						31 August 2020			
	population (millions)	estimated cumulative infections (thousands)	% population infected			implied detection rate (%)	estimated cumulative infections (thousands)	% population infected		
			this study	Flaxman <i>et al.</i> [5]	confirmed			this study	confirmed	implied detection rate (%)
Australia	25.203	9 (6–15)	0.03 (0.02–0.06)	—	0.01	38.7 (22.0–56.0)	120 (83–211)	0.48 (0.33–0.84)	0.10	21.4 (12.2–30.8)
Austria	8.859	55 (38–96)	0.62 (0.42–1.09)	1.1 (0.36–3.1)	0.09	14.1 (8.0–20.5)	101 (71–178)	1.14 (0.80–2.01)	0.31	26.9 (15.3–38.6)
Belgium	11.456	736 (504–1301)	6.43 (4.40–11.35)	3.7 (1.3–9.7)	0.11	1.6 (0.9–2.4)	1307 (911–2293)	11.41 (7.95–20.01)	0.75	6.5 (3.7–9.4)
Canada	37.411	201 (125–365)	0.54 (0.33–0.98)	—	0.01	2.3 (1.3–3.7)	1209 (843–2121)	3.23 (2.25–5.67)	0.34	10.6 (6.0–15.2)
Denmark	5.806	43 (30–76)	0.74 (0.51–1.31)	1.1 (0.40–3.1)	0.04	4.7 (2.7–6.9)	83 (58–146)	1.43 (1.00–2.51)	0.29	20.1 (11.5–28.9)
France	67.013	2315 (1588–4087)	3.45 (2.37–6.10)	3.0 (1.1–7.4)	0.05	1.4 (0.8–2.1)	4087 (2849–7167)	6.10 (4.25–10.69)	0.41	6.8 (3.9–9.8)
Germany	83.091	529 (355–935)	0.64 (0.43–1.13)	0.72 (0.28–1.8)	0.06	9.2 (5.2–13.7)	1232 (859–2161)	1.48 (1.03–2.60)	0.29	19.7 (11.2–28.2)
Italy	60.360	2949 (2048–5190)	4.89 (3.39–8.60)	9.8 (3.2–26)	0.14	2.9 (1.7–4.2)	4688 (3269–8226)	7.77 (5.42–13.63)	0.44	5.7 (3.3–8.2)
Norway	5.328	18 (12–32)	0.34 (0.23–0.60)	0.41 (0.09–1.2)	0.07	19.8 (11.2–29.2)	35 (24–61)	0.66 (0.46–1.15)	0.20	30.2 (17.2–43.3)
South Korea	51.225	30 (21–52)	0.06 (0.04–0.10)	—	0.02	31.8 (18.1–45.7)	51 (36–90)	0.10 (0.07–0.17)	0.04	39.1 (22.3–56.2)
Spain	46.937	2548 (1768–4480)	5.43 (3.77–9.54)	15 (3.7–41)	0.18	3.3 (1.9–4.7)	3963 (2763–6956)	8.44 (5.89–14.82)	0.99	11.7 (6.7–16.8)
Sweden	10.230	242 (163–428)	2.36 (1.59–4.18)	3.1 (0.85–8.4)	0.03	1.4 (0.8–2.1)	769 (536–1350)	7.52 (5.24–13.19)	0.82	11.0 (6.2–15.7)
Switzerland	8.545	136 (93–239)	1.59 (1.09–2.80)	3.2 (1.3–7.6)	0.14	8.9 (5.1–13.0)	231 (161–406)	2.71 (1.89–4.75)	0.49	18.1 (10.3–26.0)
UK	66.647	2212 (1485–3912)	3.32 (2.23–5.87)	2.7 (1.2–5.4)	0.03	0.9 (0.5–1.4)	5479 (3820–9614)	8.23 (5.73–14.43)	0.50	6.1 (3.5–8.8)
USA	329.065	4737 (3121–8456)	1.44 (0.95–2.57)	—	0.03	2.2 (1.2–3.4)	26 355 (18 387–46 319)	8.01 (5.59–14.08)	1.82	22.8 (12.9–32.6)
all	817.104	16 758 (11 355–29 664)	2.05 (1.39–3.63)	—	0.05	2.6 (1.5–3.8)	49 710 (34 669–87 297)	6.08 (4.24–10.68)	0.98	16.1 (9.2–23.1)

UK 6.1%

USA 22.8%

ALL 16.1%

A comparison of published seroprevalence studies with our estimated true cumulative infection rates

Table 3. A comparison of published seroprevalence studies with our estimated true cumulative infection rates: the study, the country where the samples were collected, the region where the samples were collected, the dates when the samples were collected, the reported rate of seroprevalence (best estimate and 95% confidence interval), and the estimated true cumulative infection rate according to this study (median and 95% confidence interval).

study	country	location	dates	seroprevalence (%)	this study (%)
Havers <i>et al.</i> [6]	USA	Western Washington State	23 March–1 April 2020	1.1 (0.7–1.9)	1.40 (0.86–2.36)
		New York City metro area	23 March–1 April 2020	6.9 (5.0–8.9)	1.40 (0.86–2.36)
		Louisiana	1–8 April 2020	5.8 (3.9–8.2)	2.07 (1.41–3.66)
		South Florida	6–10 April 2020	1.9 (1.0–3.2)	2.35 (1.61–4.14)
		Philadelphia metro area	13–25 April 2020	3.2 (1.7–5.2)	3.09 (2.15–5.44)
		Missouri	20–26 April 2020	2.7 (1.7–3.9)	3.34 (2.32–5.88)
		Utah	20 April–3 May 2020	2.2 (1.2–3.4)	3.52 (2.45–6.19)
		San Francisco Bay area	23–27 April 2020	1.0 (0.3–2.4)	3.45 (2.40–6.07)
		Connecticut	26 April–3 May 2020	4.9 (3.6–6.5)	3.68 (2.56–6.47)
		Minneapolis–St Paul–St Cloud metro area	30 April–12 May 2020	2.4 (1.0–4.5)	3.97 (2.76–6.97)
Bendavid <i>et al.</i> [2]	USA	Santa Clara County, California	3–4 April 2020	2.8 (1.3–4.7) ^a	1.99 (1.35–3.52)
Pollán <i>et al.</i> [30]	Spain	nationwide	27 April–11 May 2020	6.2 (5.8–6.6) ^b	7.68 (5.35–13.48)
Hicks <i>et al.</i> [7]	Australia	nationwide	May–June 2020	0.28 (0.00–0.71)	0.06 (0.04–0.10) ^c

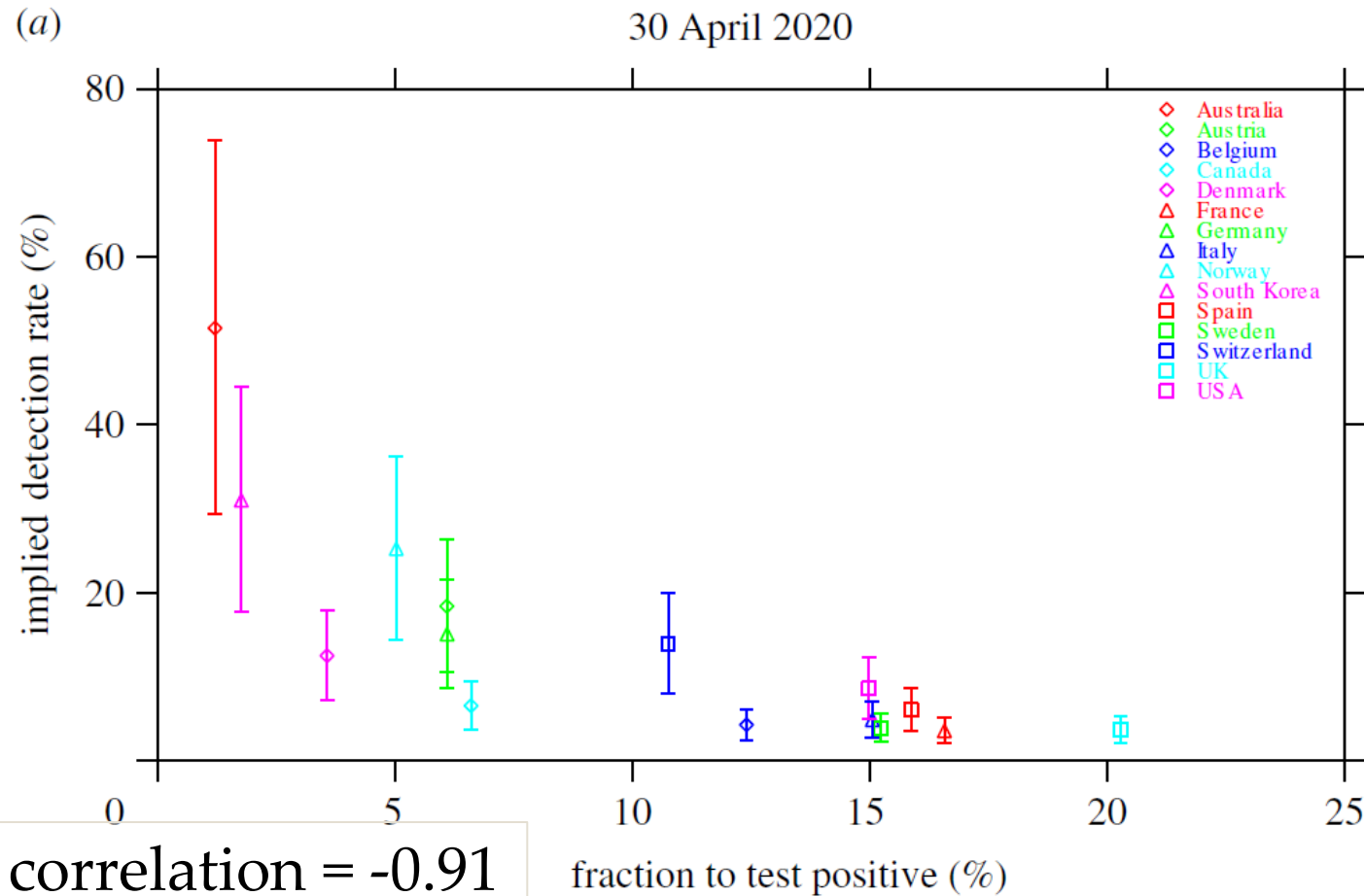
^aWeighted by the authors for the population demographics of Santa Clara County.

^bEither point-of-care test or immunoassay positive.

^cStatistics are calculated for the period 1 May–30 June 2020.

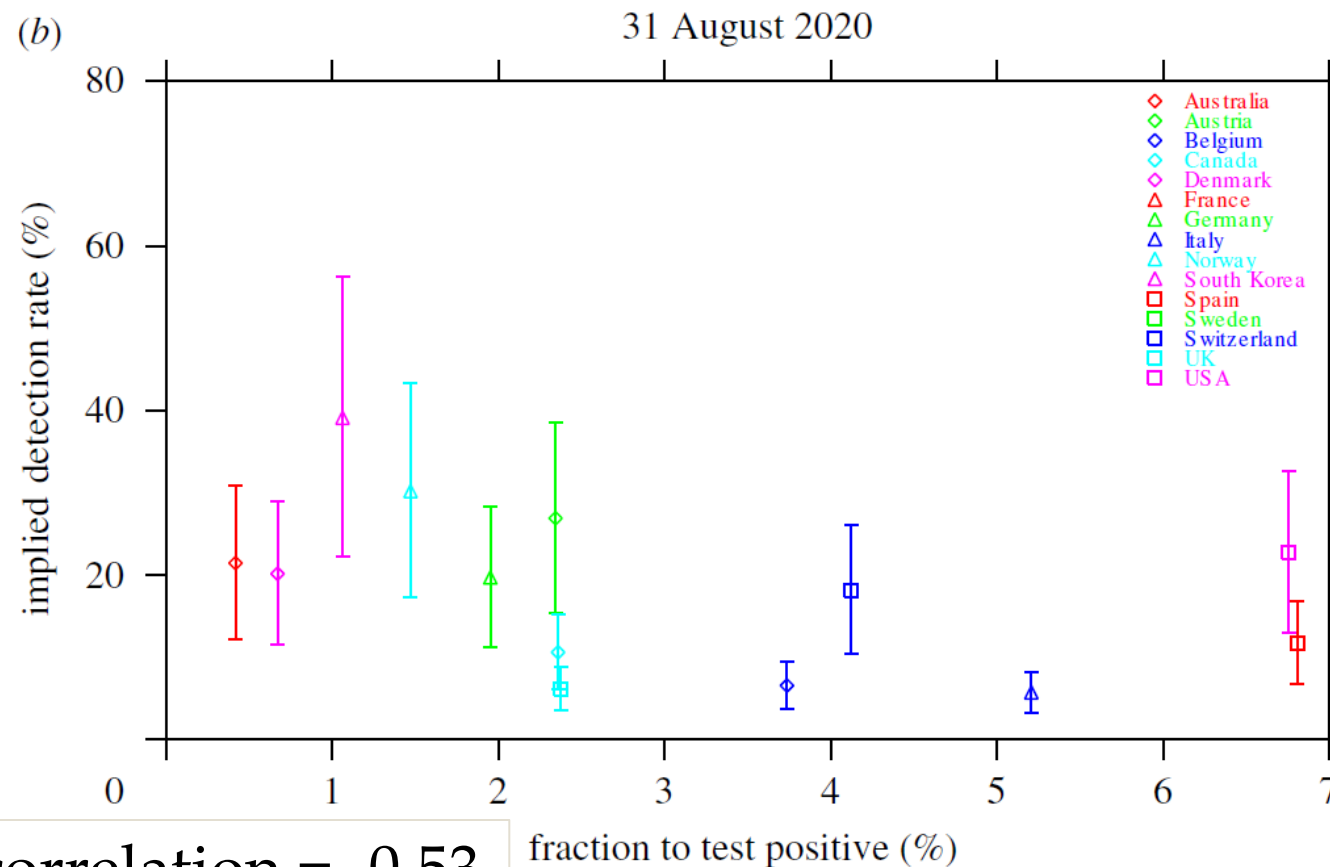
Implied true detection rate for each country versus the fraction of tests to return a positive result: (a) 30 April 2020

Symbols indicate the median estimates and vertical bars indicate the 95% confidence intervals. Note that the horizontal scale is different for each panel.



The implied true detection rate for each country versus the fraction of tests to return a positive result: (b) 31 August 2020.

Symbols indicate the median estimates and vertical bars indicate the 95% confidence intervals. Owing to a lack of available data, values for France and Sweden are not shown in (b). Note that the horizontal scale is different for each panel.



II. Health and Economic Costs of Early and Delayed Suppression and the Unmitigated Spread of COVID-19: The Case of Australia (under review, *PLOSOne*)

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^d Centre of Excellence for Biosecurity Risk Analysis, School of Biosciences, University of Melbourne

Epidemiological model

$$\frac{dS}{dt} = -\frac{R_0}{T_i}[1 - \epsilon] \times I \frac{S}{S + I + Q + R} + \mu^b (S + I + Q + R) - \mu^d S \quad (1)$$

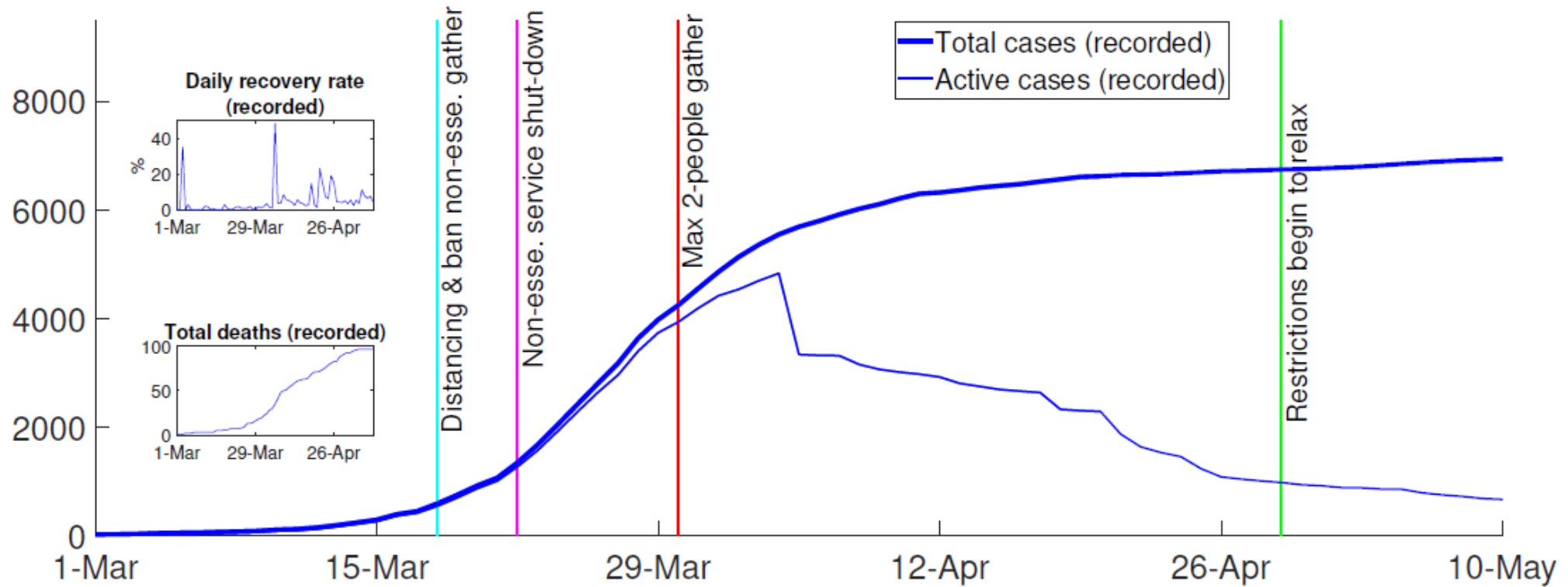
$$\frac{dI}{dt} = \frac{R_0}{T_i}[1 - \epsilon] \times I \frac{S}{S + I + Q + R} - \mu^d I - \frac{1}{T_i} I + W \quad (2)$$

$$\frac{dQ}{dt} = \frac{1}{T_i} I - \chi Q - fQ - \mu^d Q \quad (3)$$

$$\frac{dR}{dt} = \chi Q - \mu^d R \quad (4)$$

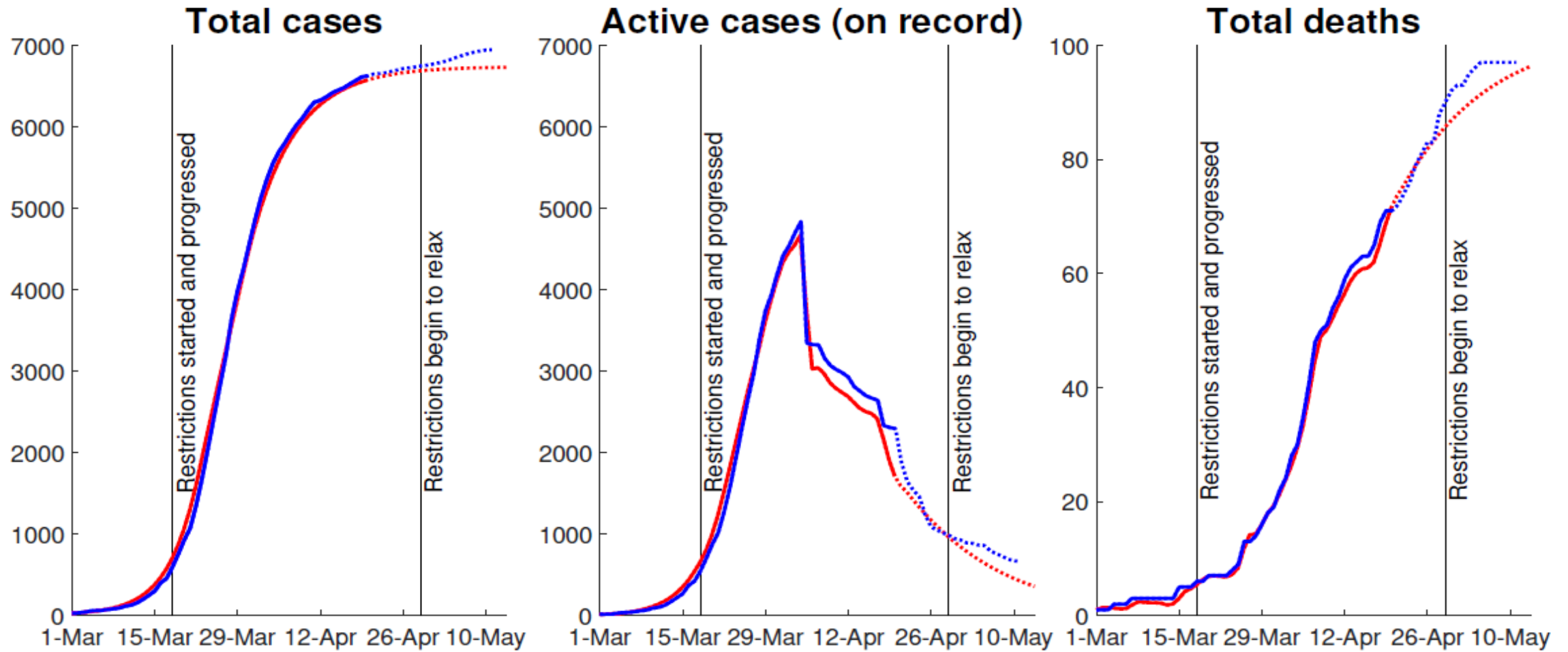
$$\frac{dM}{dt} = fQ \quad (5)$$

Overview of COVID-19 in Australia



Source: Covid19-Data (2020)

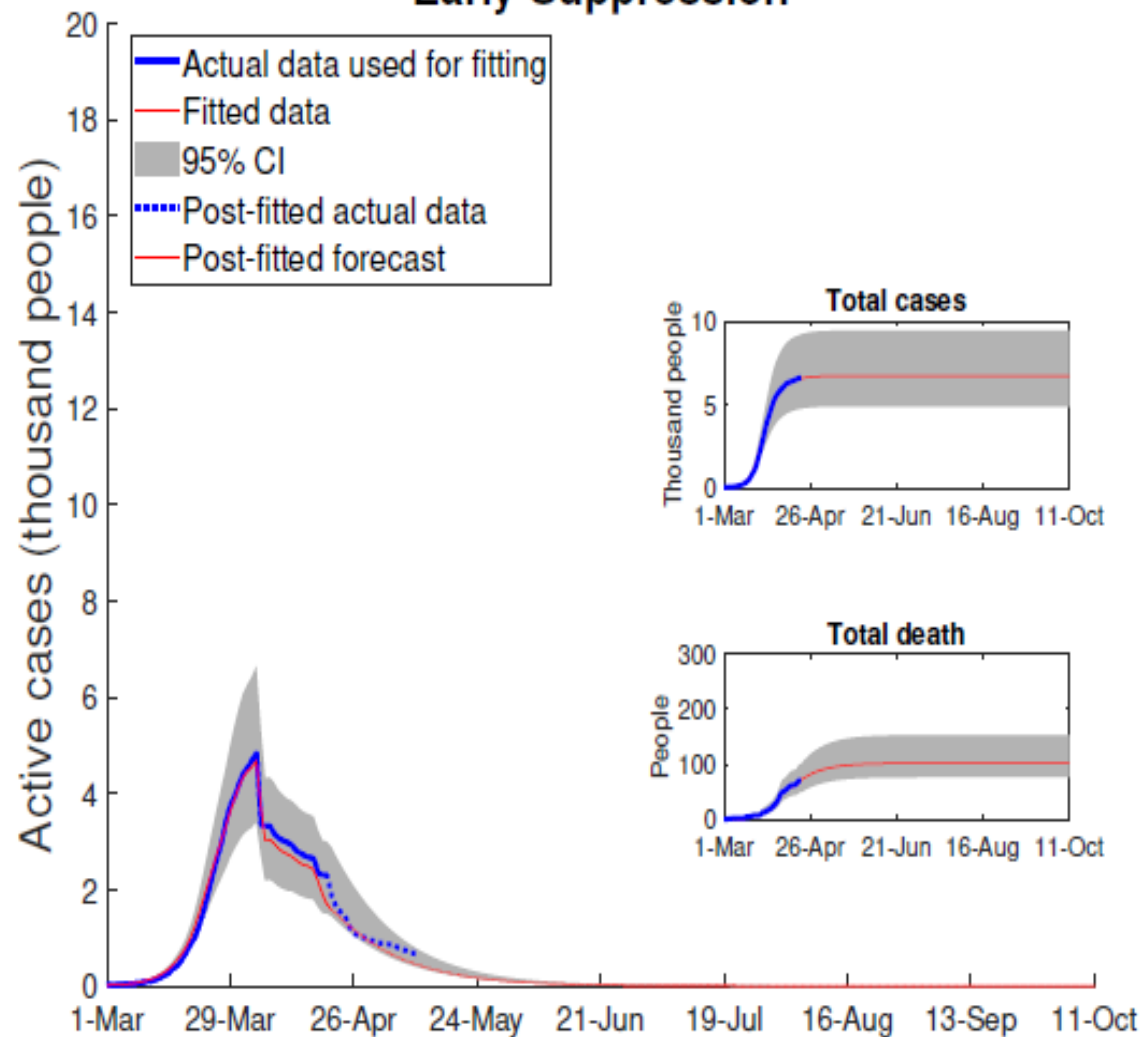
Projected versus Actual Data



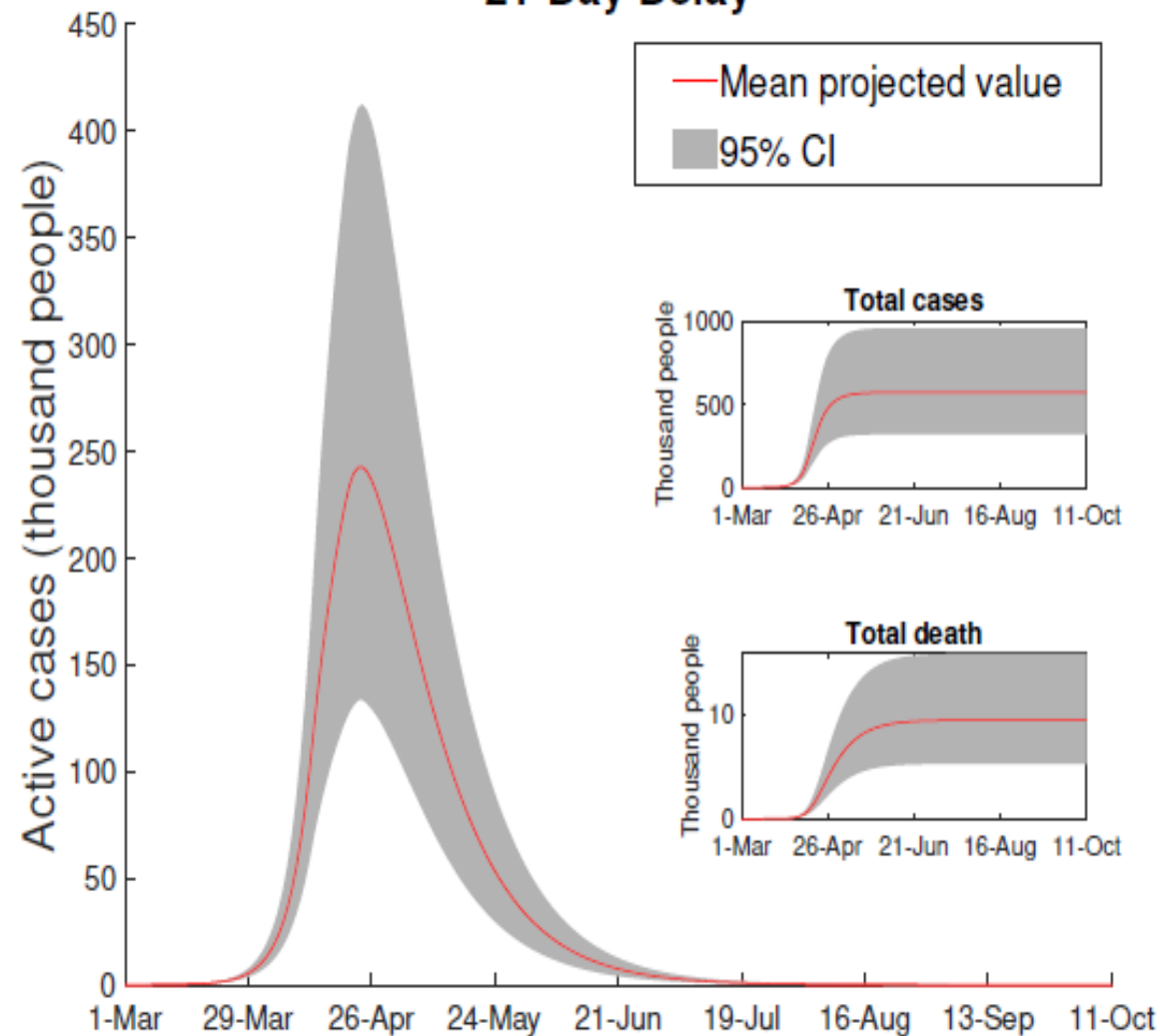
— Actual data used for fitting — Fitted data Post-fitted actual data Post-fitted forecast

Australian COVID-19 Dynamics: Early and Delayed (21 days) Suppression

Early Suppression

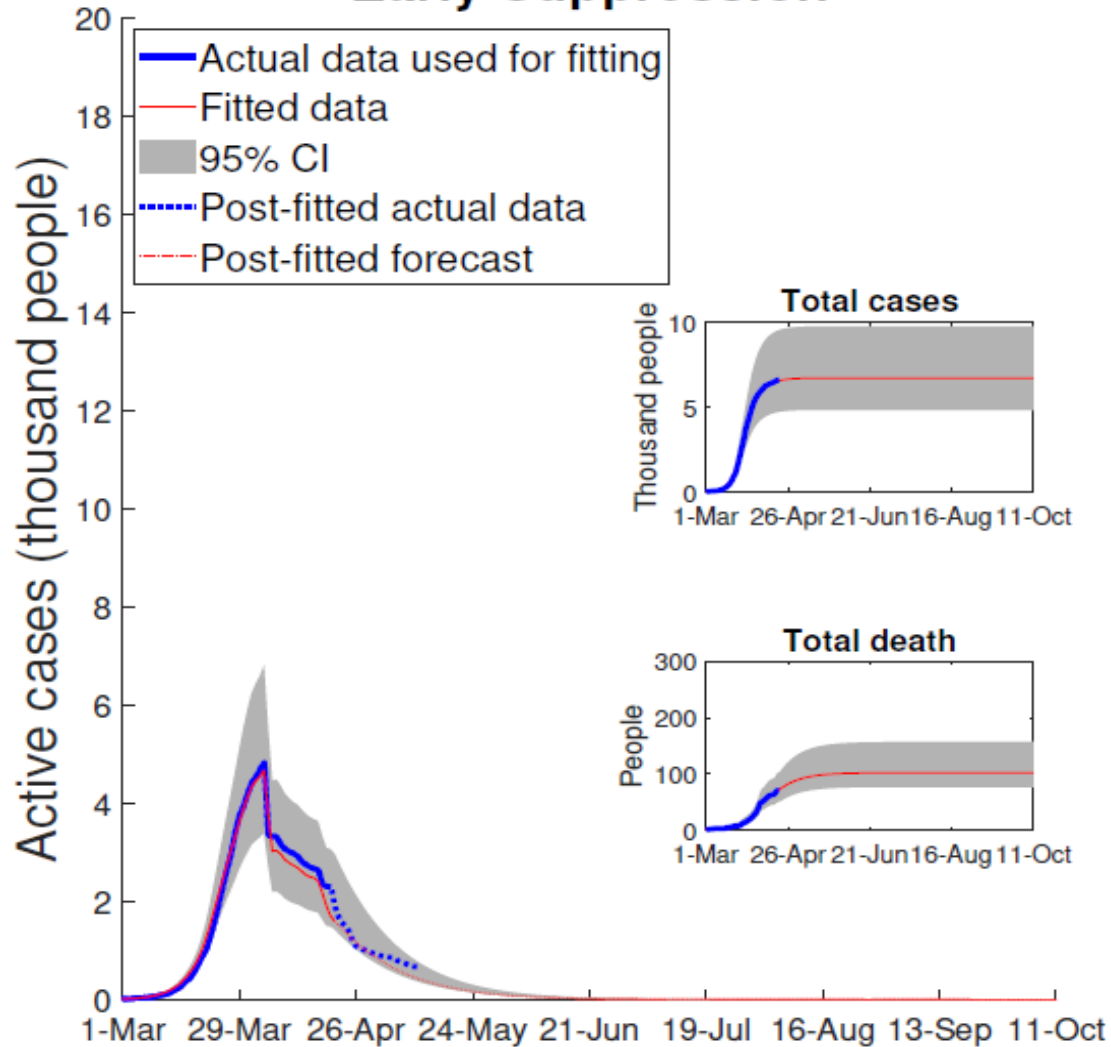


21-Day Delay

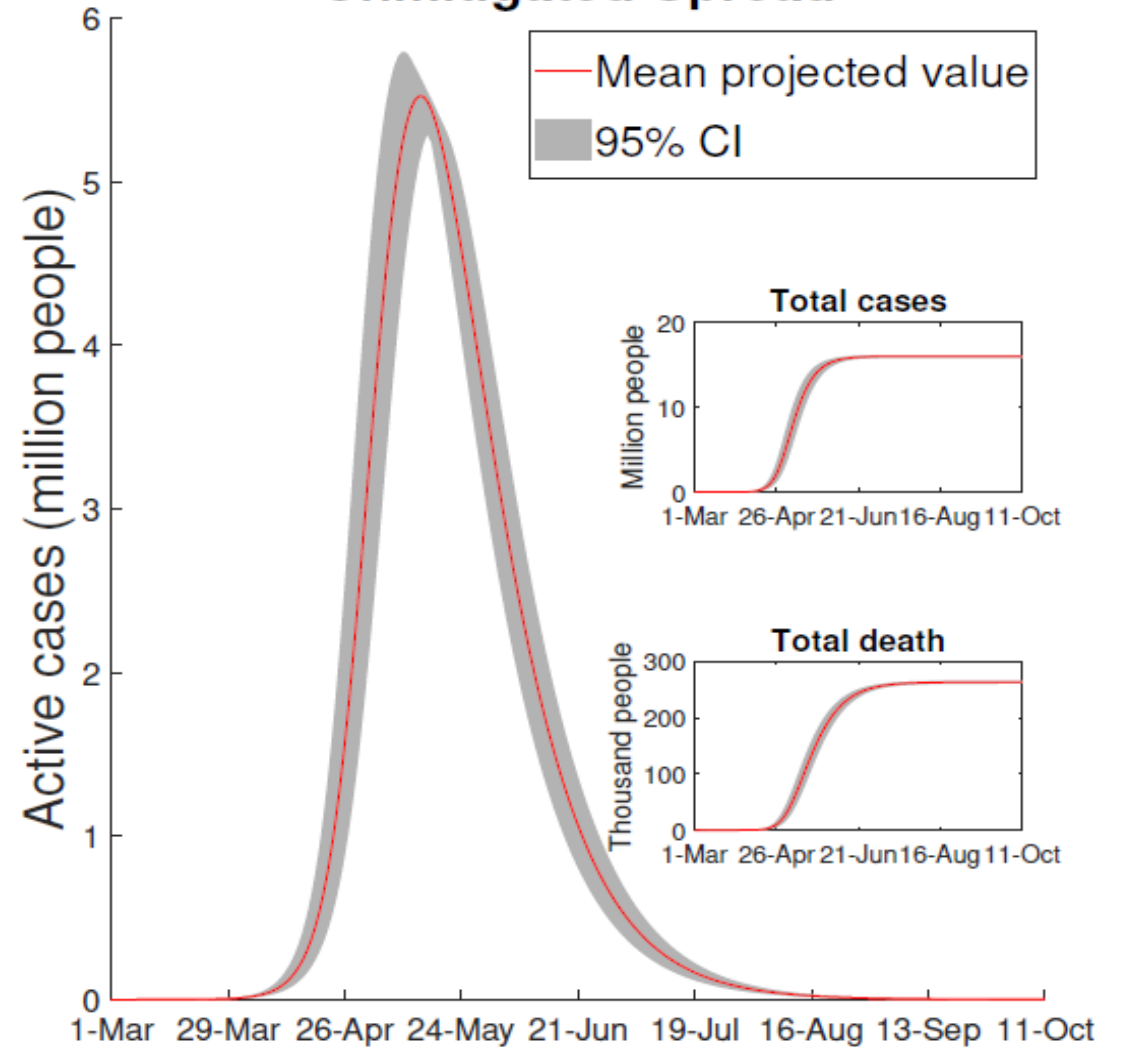


Australian COVID-19 Dynamics: Early and Unmitigated Spread

Early Suppression



Unmitigated Spread



Direct Economic Costs with Early Suppression in \$ billions and GDP loss, and Health and Welfare Losses

	Recovery (months)	Costs (\$ billion AUD)			Economy Costs (% annual GDP)
		Lock-down	Recovery	Total	Annual Loss GDP (%)
Early Suppression Measures for 8 Weeks from March 30th					
Transition 1	1	51.98	14.39	66.37	3.33
Transition 2	2	51.98	30.39	82.37	4.13
Transition 3	3	51.98	48.27	100.26	5.03
Transition 4	4	51.98	68.59	120.57	6.04
Welfare Losses, Hospitalization Costs and Fatality Equivalents of Unmitigated Spread					
		Welfare	Hospital	Total	Annual Loss GDP (%)
VSLY		572.8	23.3	596.1	29.8
VSLY*		240.0	23.3	263.3	13.1
A-VSL		956.2		956.2	47.9
A-VSL*		401.6		401.6	20.1
Fatality equivalent at % GDP**		30,491 (3.3%)	37,816 (4.13%)	46,057 (5.03%)	55,305 (6.04%)
Fatality equivalent at %GDP*		12,808 (3.3%)	15,882 (4.13%)	19,343 (5.03%)	23,228 (6.04%)

*VSLY, A-VSL and fatality equivalent measures using the fatality ratio in Verity et al. (2020). **Fatality equivalent is the VSLY-measured number of fatalities under the unmitigated spread scenario that equals the direct economy cost associated with an early 8-weeks lock-down (early suppression) for each % GDP loss (3.33, 4.13, 5.03, and 6.04). N.B. The estimated early suppression model fatalities are 100.

III. Epidemiological Modelling of the Health and Economic Effects of COVID-19 control in Australia's Second Wave *(Under review, Journal of Public Health)*

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¹ Crawford School of Public Policy, The Australian National University, Canberra, Australian Capital Territory, Australia

² Hobart, Tasmania, Australia

³ Centre of Excellence for Biosecurity Risk Analysis, University of Melbourne, Melbourne, Victoria, Australia

⁴ College of Health and Medicine, The Australian National University, Canberra, Australian Capital Territory, Australia

⁵ College of Health and Medicine, The Australian National University, Canberra, Australian Capital Territory, Australia

ELIMINATION: Median (2.5%-97.5 CI) values of additional Elimination Days and Social Distancing Days (sum of social distancing level each day for 365 days) and number of COVID-19 deaths and associated (based on median values) Economy Costs of Social Distancing, Value of Statistical Lives Lost and Hospitalisation Costs for Social Distancing Levels from 0.5 to 1.0 for 365 days after implementation of Social Distancing when average daily cases over the preceding 7 days exceeds 100.

Social Distancing Level	0.5	0.6	0.7	0.8	0.9	1.0
Elimination Days (#)	360 (279-366)	366 (366-366)	249 (134-366)	118 (66-190)	73 (50-107)	51 (37-75)
Social Distancing Days (#)	183 (155-183)	220 (220-220)	196 (116-256)	117 (78-177)	94 (75-125)	83 (71-107)
Economy Costs of Social Distancing (billion \$)	38.43	46.2	41.16	24.57	19.74	17.43
COVID-19 Deaths (#)	77,020 (53,822-104,277)	28,058 (448-69,931)	267 (135-1,151)	135 (80-216)	101 (68-139)	86 (61-115)
Value of Statistical Lives Lost (\$ billion)	377.40	137.48	1.31	0.66	0.49	0.42

Notes:

1. Economy costs of social distancing = \$210 million per social distance day.
2. Value of statistical life = \$4.9 million.
3. **Elimination days** is the number of days until zero community transmission (elimination) is achieved. Elimination days = 366 means the strategy fails to achieve no community transmission after 365 days.

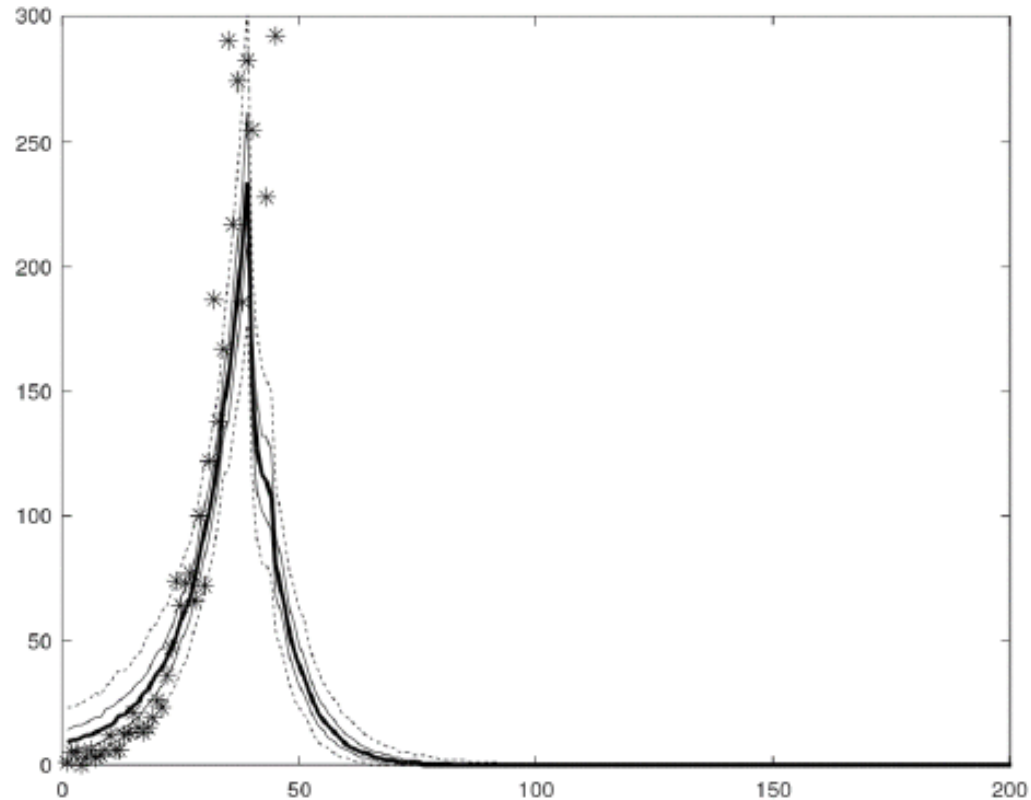
SUPPRESSION: Median (2.5%-97.5 CI) values of additional Social Distancing Days (sum of social distancing level each day for 365 days) and number of COVID-19 deaths and associated (based on median values) Economy Costs of Social Distancing, Value of Statistical Lives Lost and Hospitalisation Costs for Social Distancing Level = 1.0 for 365 days after implementation of Social Distancing.

	Suppression Scenario A ³	Suppression Scenario B ⁴
Social Distancing Days (#)	101 (71-210)	115 (52-225)
Economy Costs of Social Distancing (billion \$)	21.21	24.15
COVID-19 Deaths (#)	124 (66-261)	190 (67-411)
Value of Statistical Lives Lost (\$ billion)	0.61	0.93

Notes:

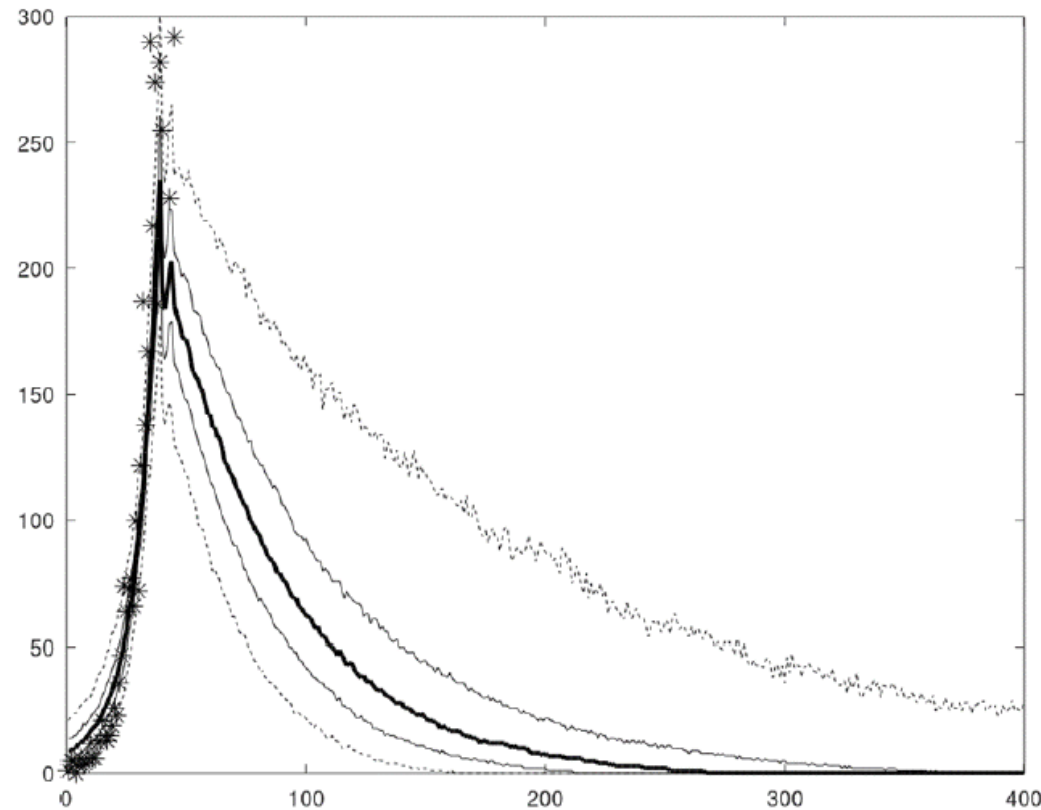
1. Economy costs of social distancing = \$210 million per social distance day.
2. Value of statistical life = \$4.9 million.
3. Social distancing is implemented for 40 days after which gradual relaxation over 60 days occurs once the weekly average of new daily recorded cases declines to 20.
4. No minimum of 40 days of social distancing; gradual relaxation over 60 days occurs once the weekly average of new daily recorded cases declines to 20.

ELIMINATION: SD = 1.0 (day 35), trigger = 100 daily cases, PQ = 0



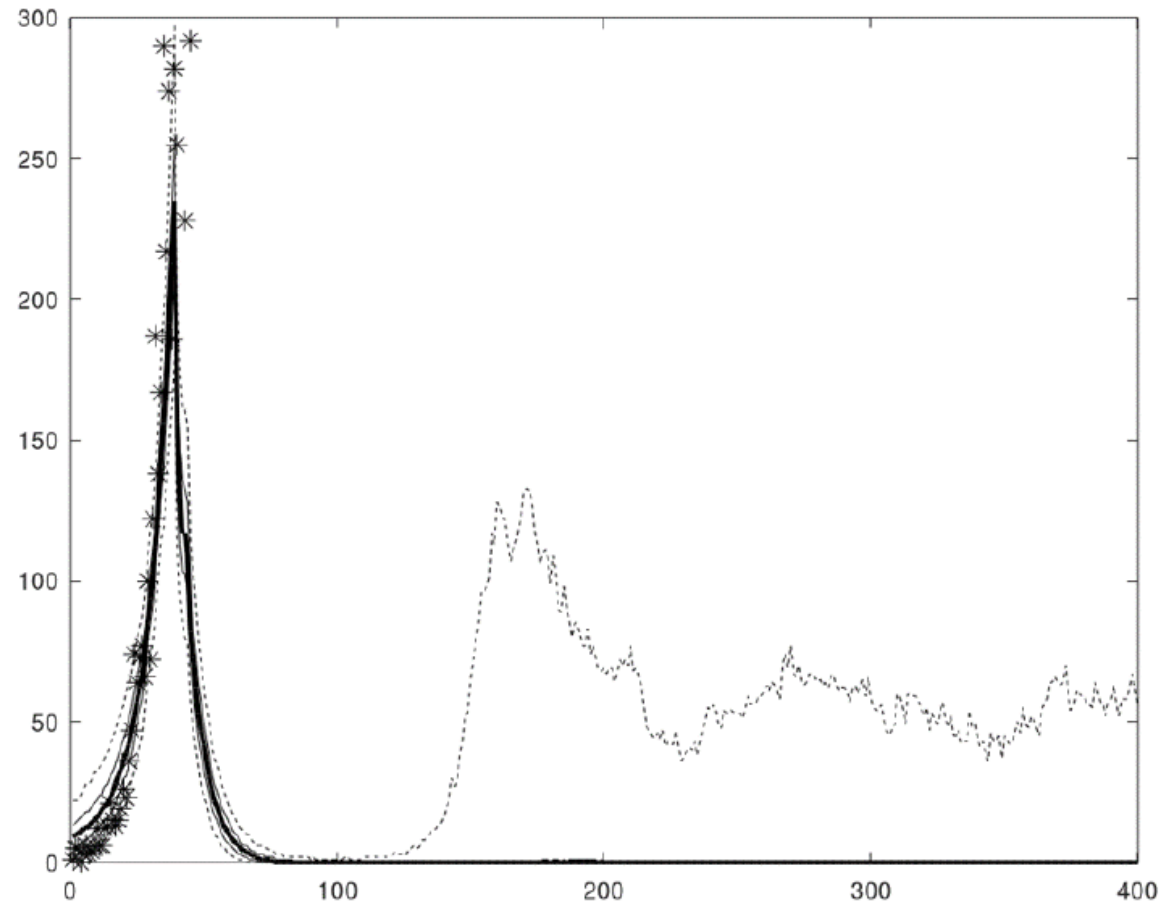
N.B: Simulations (median, quartiles, 5-95 percentiles) are from a 1,000 members ensemble and observed daily new local Australian cases for SD levels. Median (thick line), quartiles (thin lines), 5-95 percentiles (dashed lines), observed daily new Australian local cases, June 6 to 15 July 2020 (*).

ELIMINATION: $SD = 0.7$ (day 35), trigger = 100 daily cases, $PQ = 0$



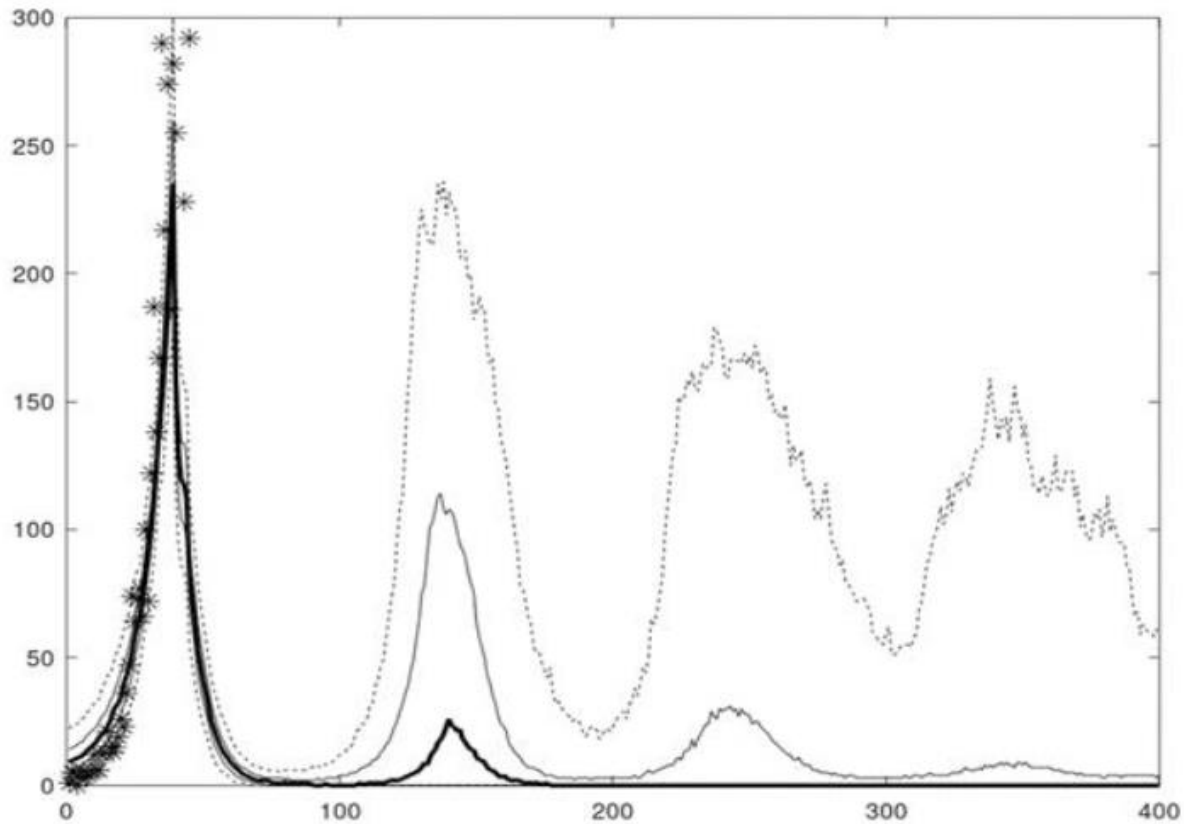
N.B: Simulations (median, quartiles, 5-95 percentiles) are from a 1,000 members ensemble and observed daily new local Australian cases for SD levels. Median (thick line), quartiles (thin lines), 5-95 percentiles (dashed lines), observed daily new Australian local cases, June 6 to 15 July 2020 (*).

SUPPRESSION A: SD = 1.0. suppression (40 days minimum) & relaxation triggers 100 & 20



N.B. Ensemble percentiles: median (thick line), quartiles (thin lines), 5-95 percentiles (dashed lines), observed daily new Australian local cases, June 6 to 15 July 2020 (*). Triggers defined by daily cases. SD begins at day 35. Quarantine leakage, PQ = 0.002.

SUPPRESSION B: SD = 1.0 (day 35), suppression & relaxation triggers 100 & 20



N.B. Ensemble percentiles: median (thick line), quartiles (thin lines), 5-95 percentiles (dashed lines), observed daily new Australian local cases, June 6 to 15 July 2020 (*). Triggers defined by daily cases. SD begins at day 35. Quarantine leakage, $PQ = 0.002$.

IV. Statistical Analyses of the Public Health and Economic Performance of Nordic Countries in Response to the COVID-19 Pandemic

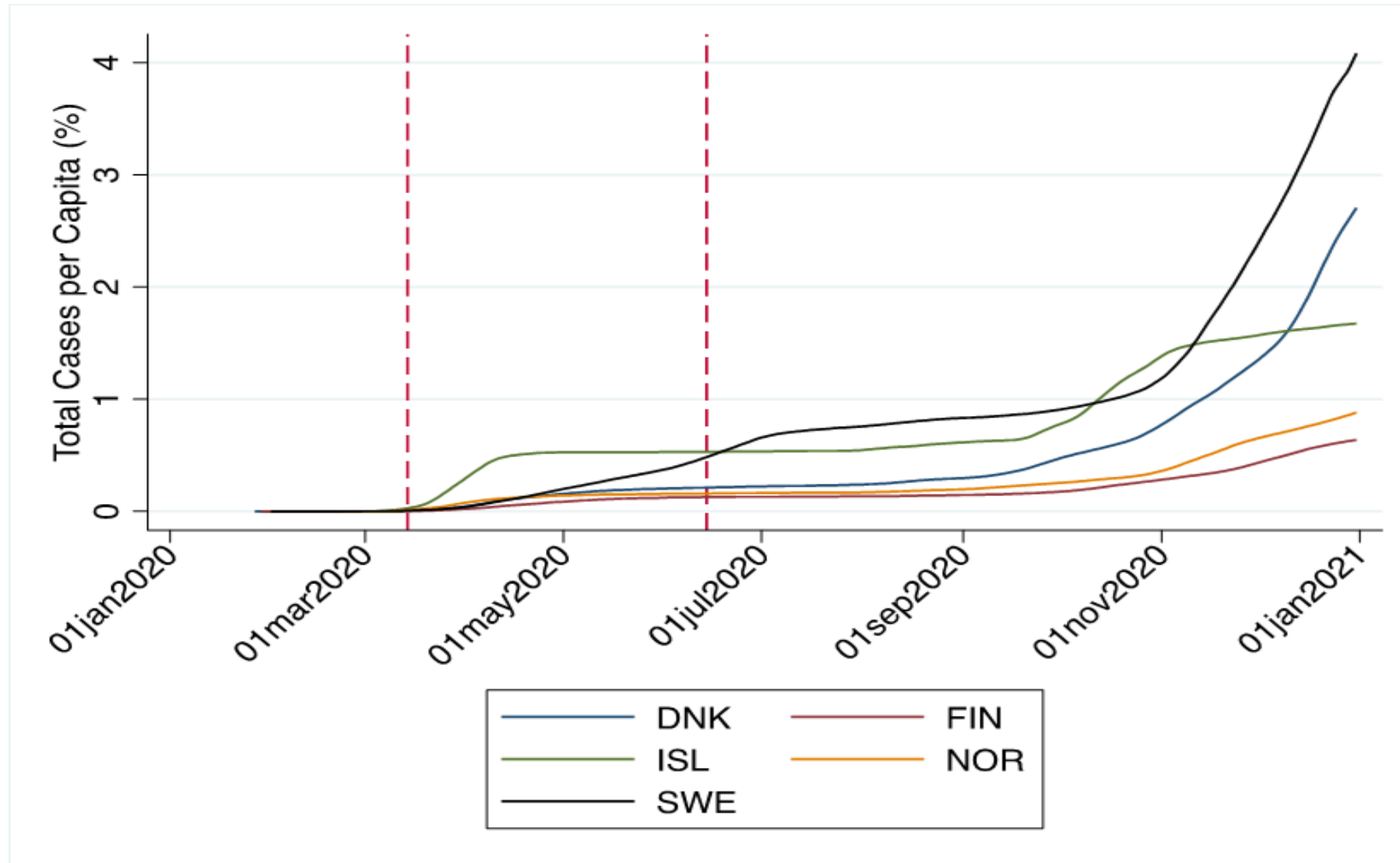
Daniel V.Gordon¹ , R. Quentin Grafton² , Stein Ivar SteinShamn^{3*}

¹ University of Calgary, University of Stavanger

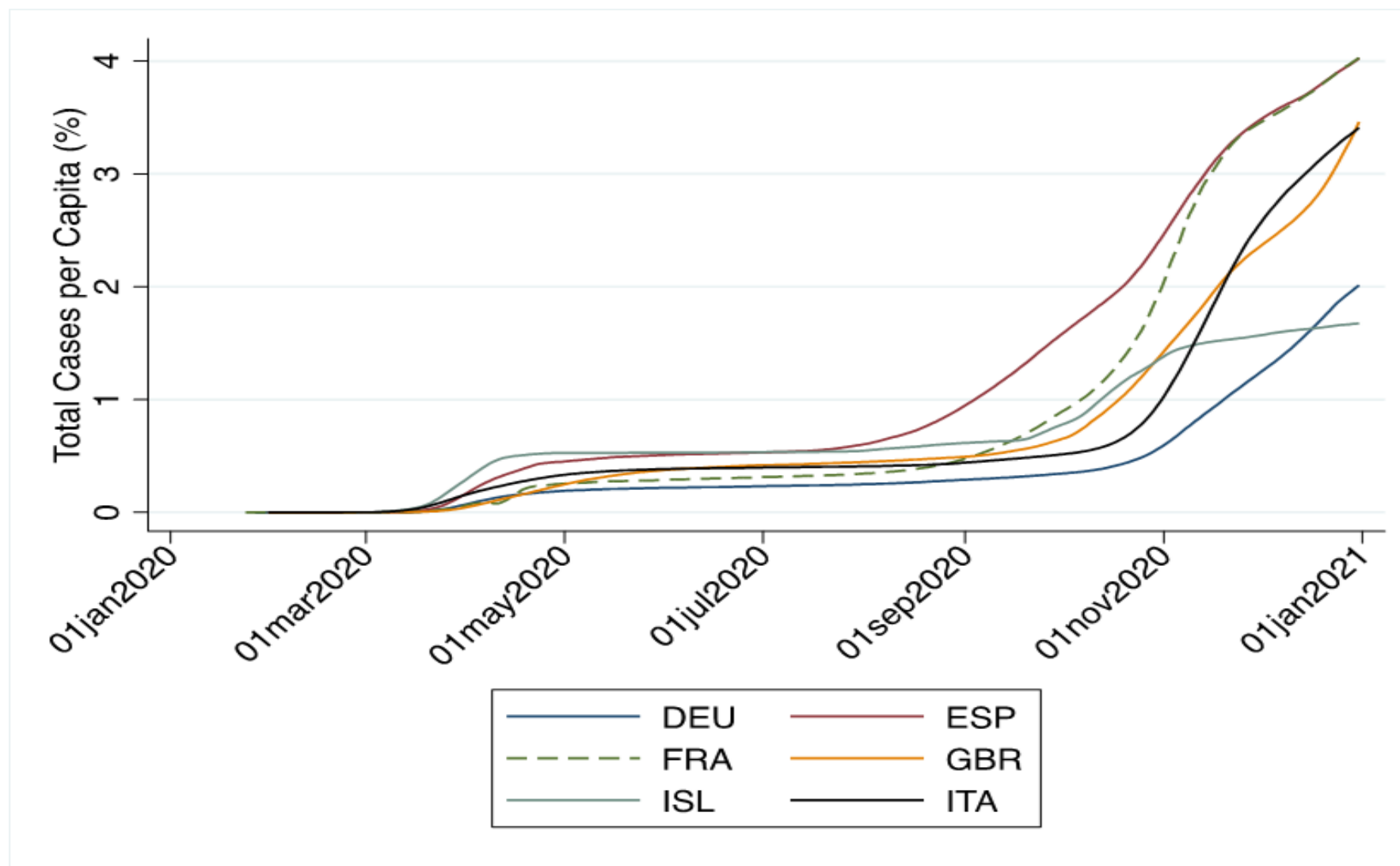
² The Australian National University

³ Department of Business and Management Science/Centre for Applied Research at NHH Norwegian School of Economics (NHH)

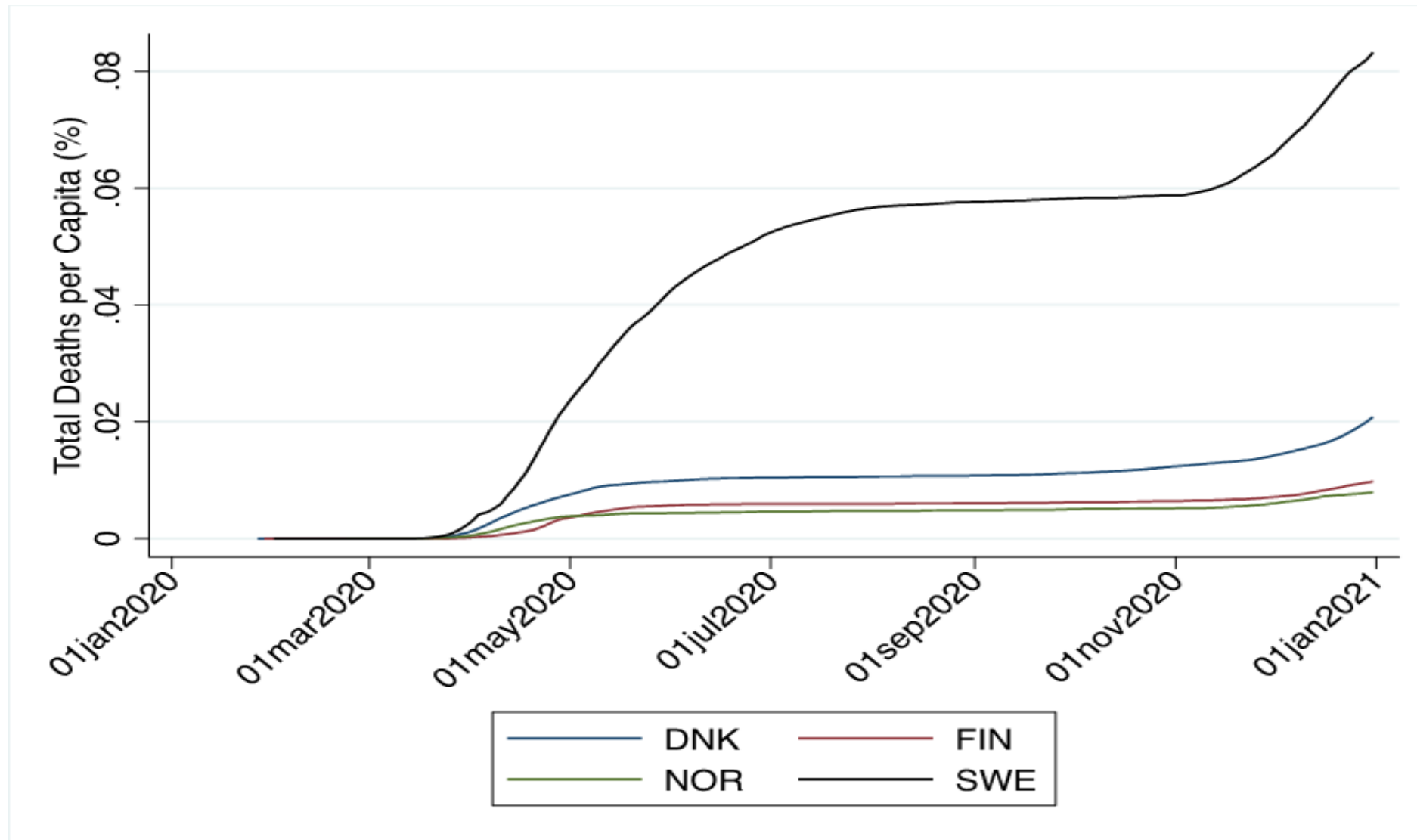
Nordic Countries: Total Cases per capita



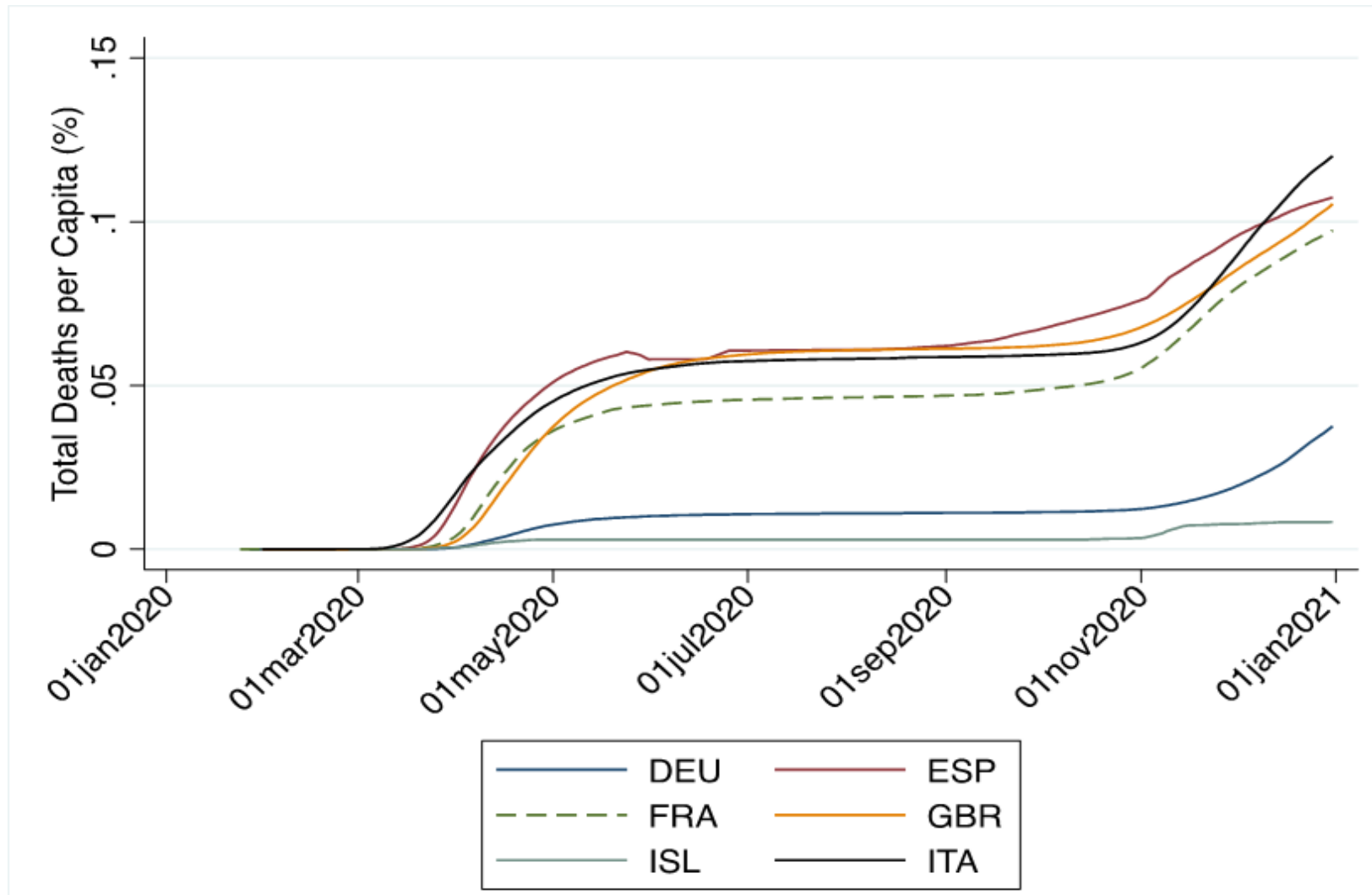
Big Western European Countries: Total Cases per Capita



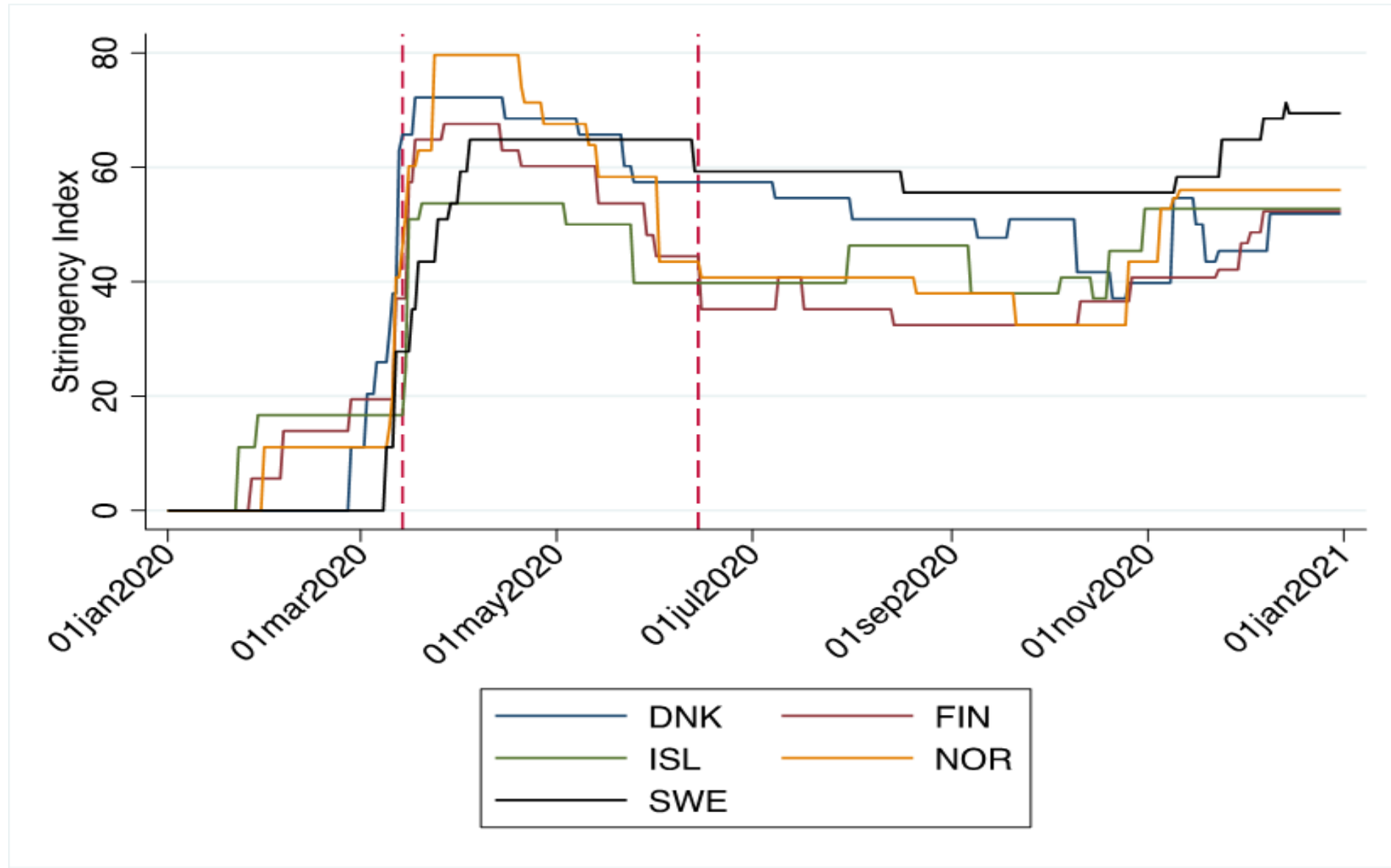
Nordic Countries: Fatalities per Capita



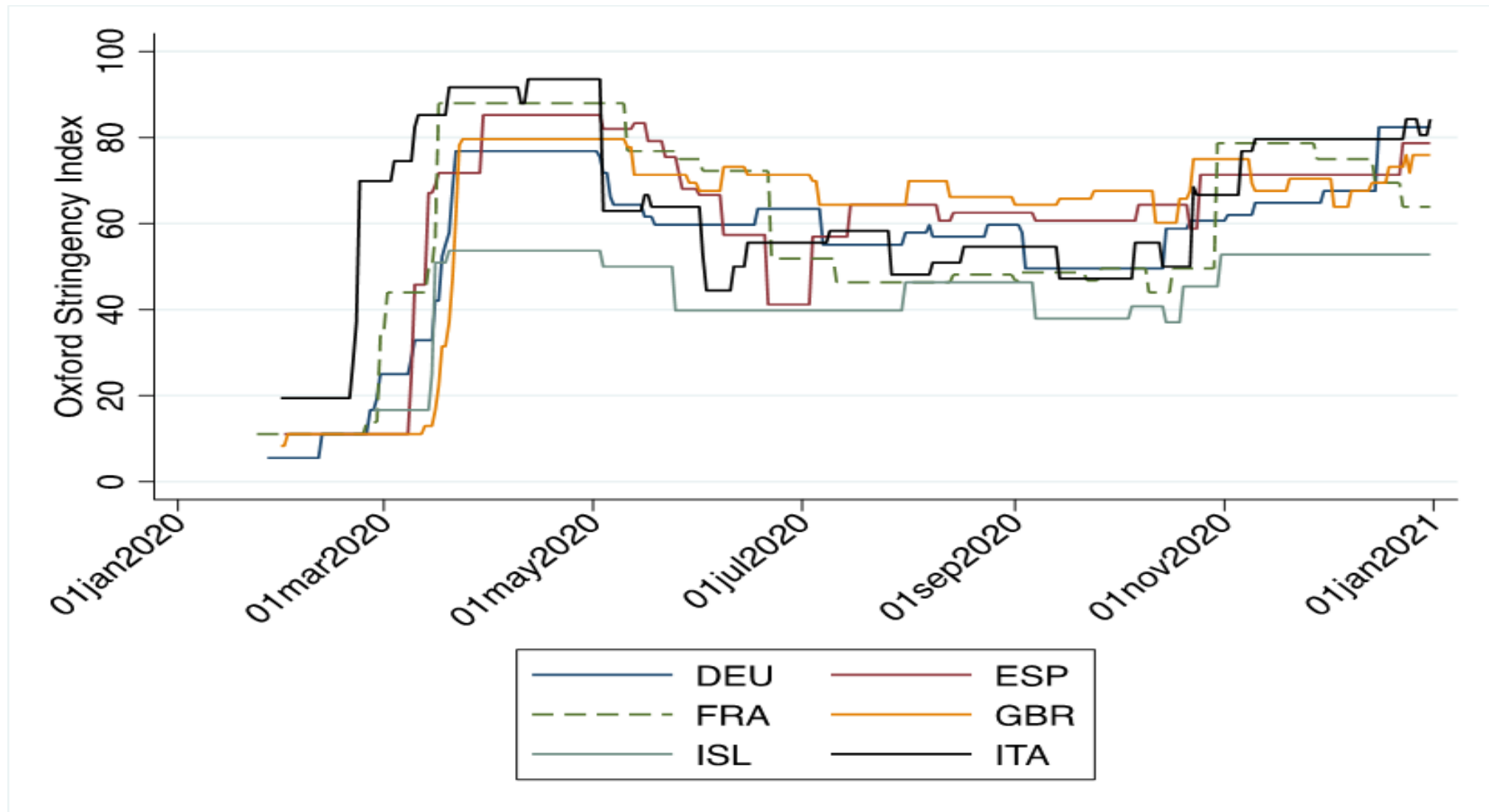
Big Western European Countries: Fatalities per Capita



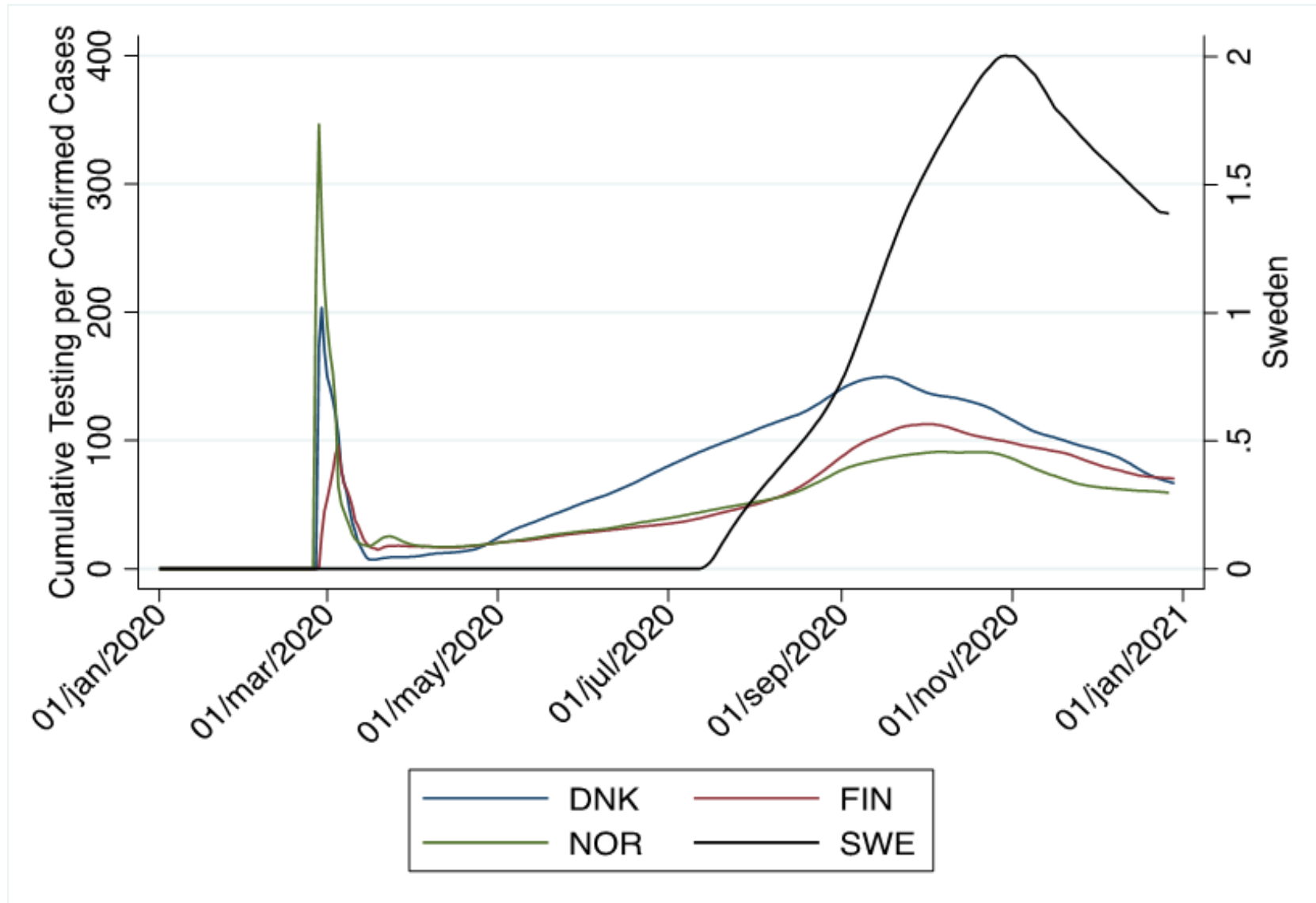
Nordic Countries: Stringency Index



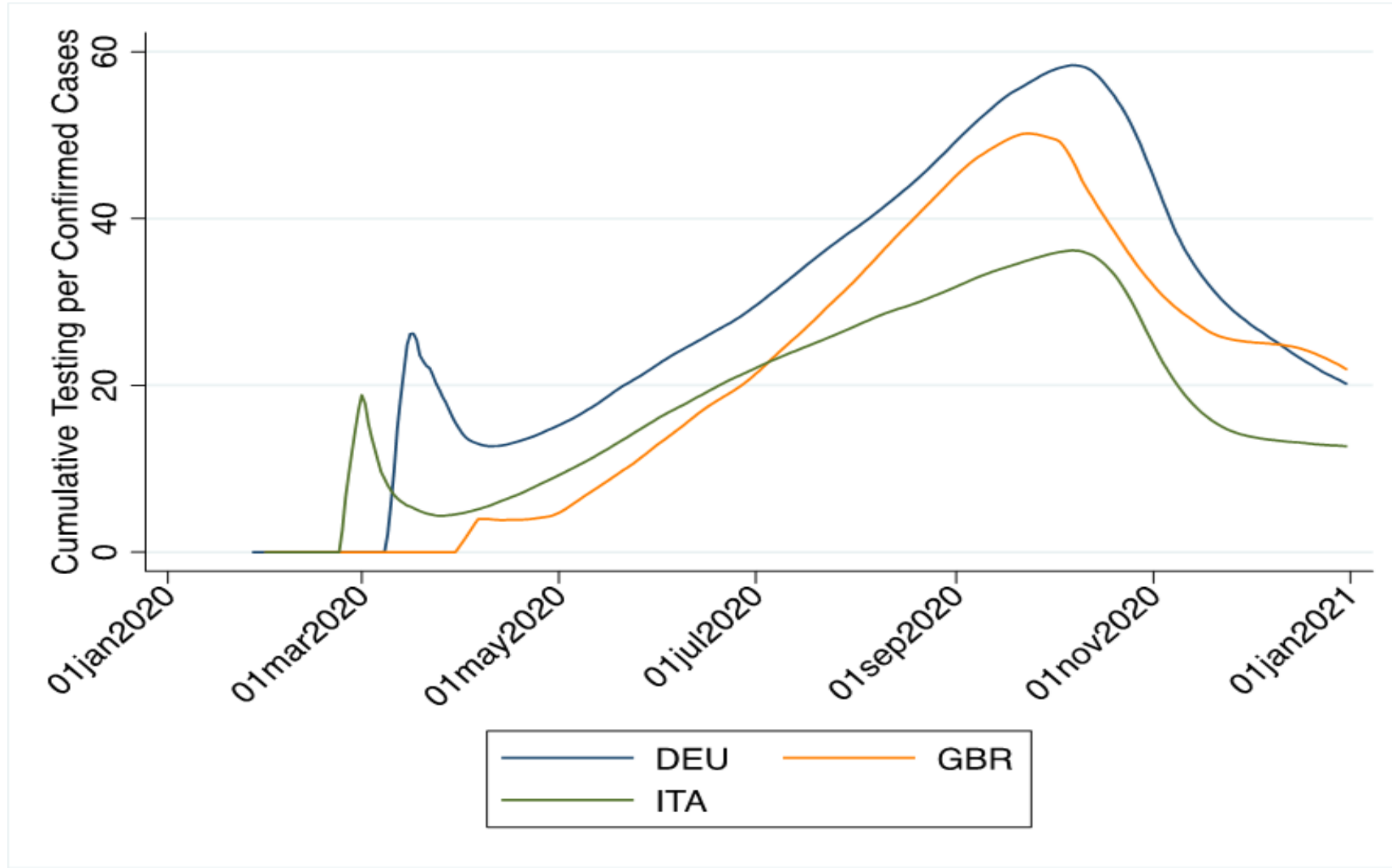
Big Western European Countries: Stringency Index



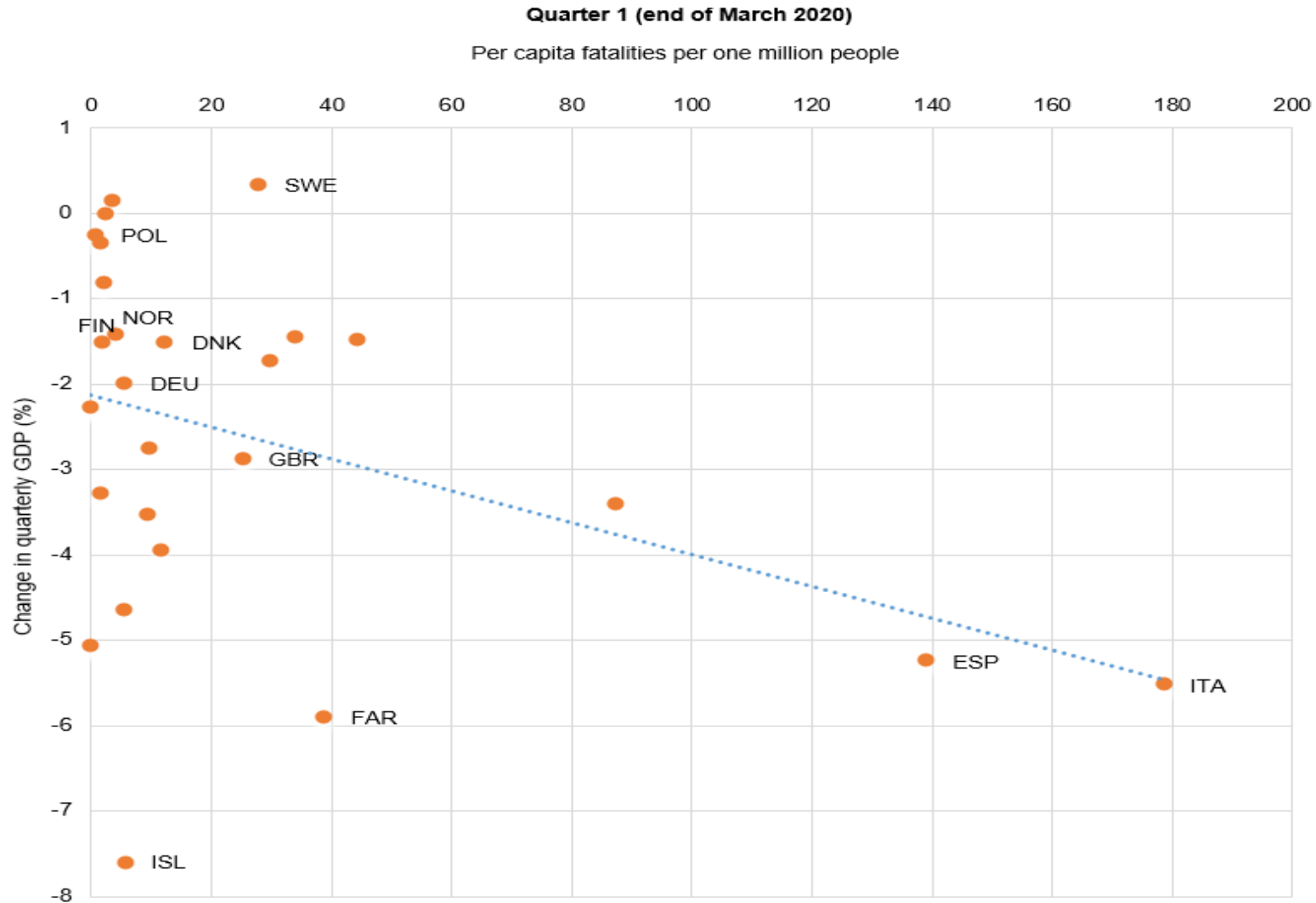
Nordic Countries: Number Tests per Confirmed Case (past week)



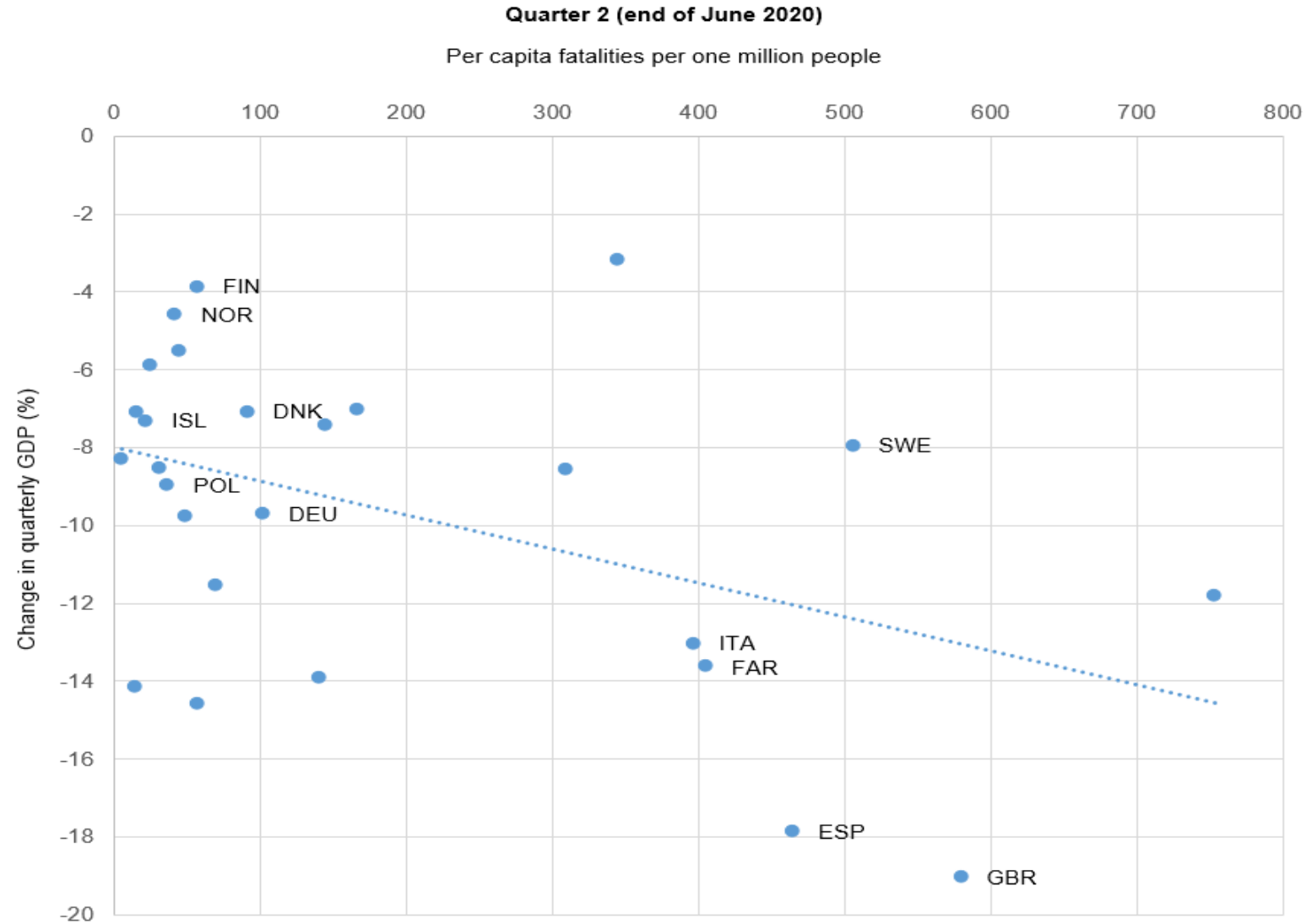
Big European Countries: Number Tests per Confirmed Case (past week)



Δ Quarterly GDP versus COVID-19 Fatality Rate (Q1 only)



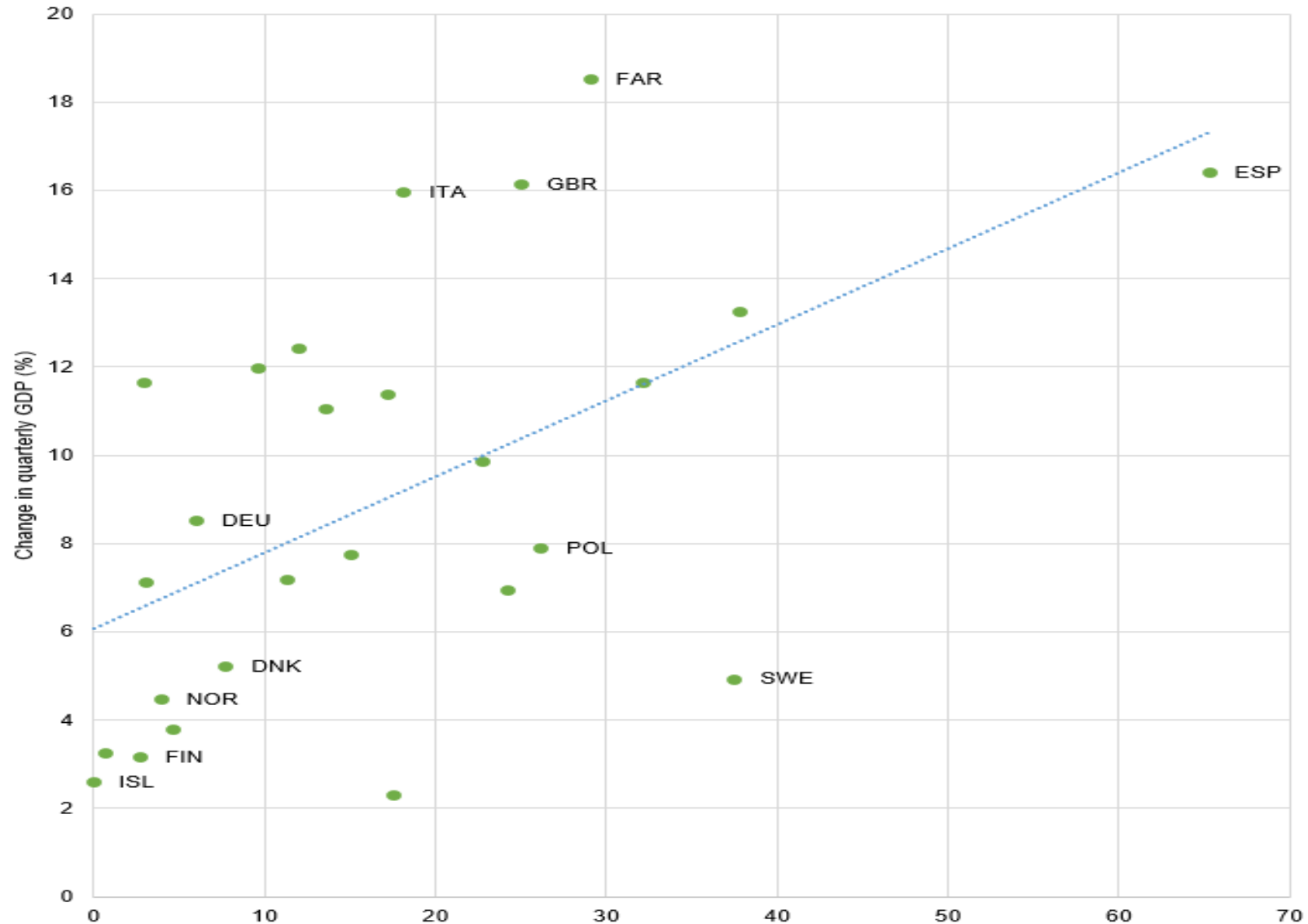
△ Quarterly GDP versus COVID-19 Fatality Rate (Q2 only)



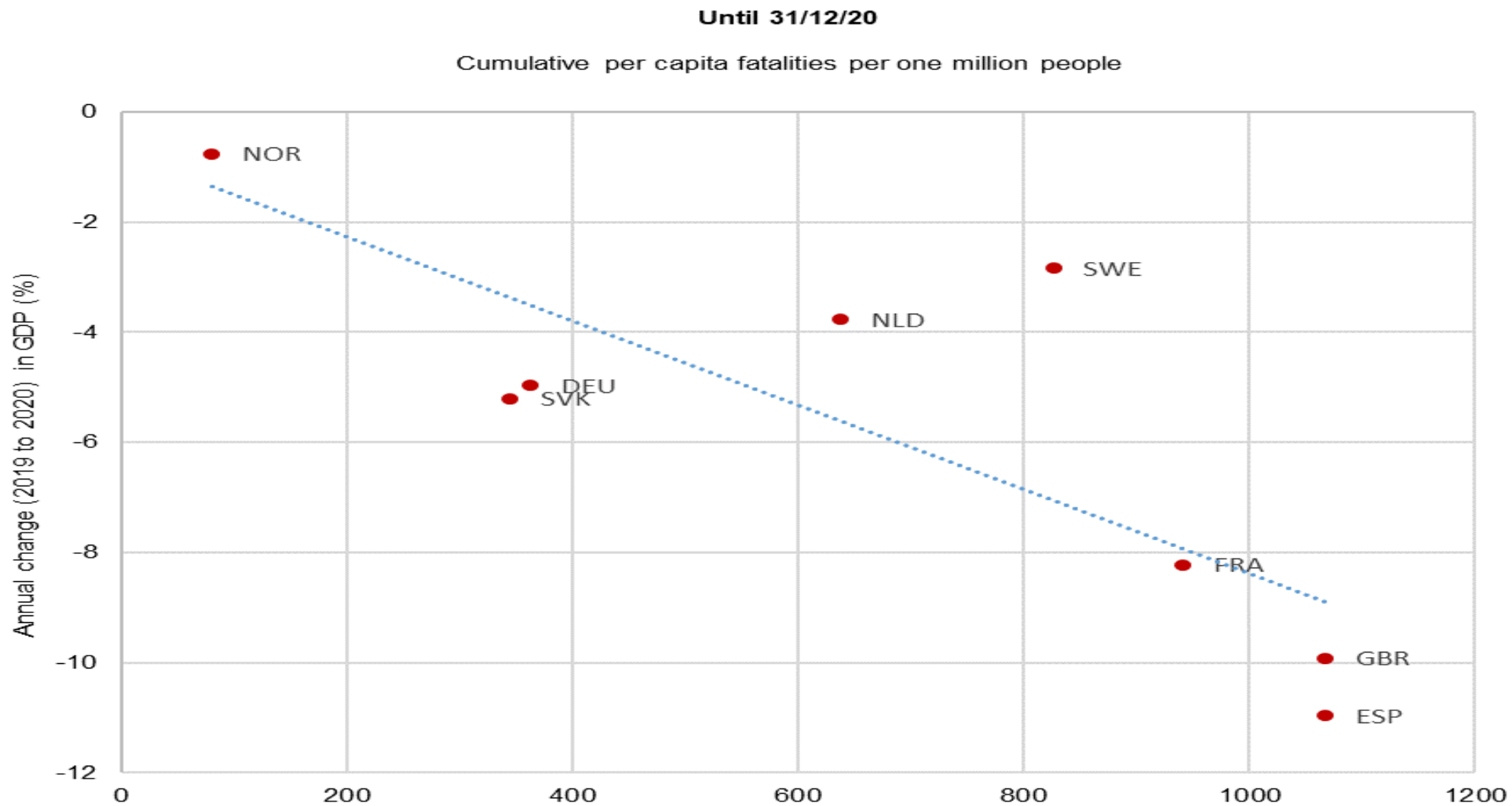
Δ Quarterly GDP versus COVID-19 Fatality Rate (Q3 only)

Quarters 3 (end of September 2020)

Per capita fatalities per one million people



△ Annual GDP versus Cumulative COVID-19 Fatality Rate (to 31/12/20)



Nordic Border Closures and Per Capita Cases (weekly average) TO 31/12/20

	A	B	C	D	E
DDen	0.638 (0.000)	0.689 (0.000)	0.637 (0.000)	0.703 (0.000)	0.719 (0.000)
Dfin	-0.003 (0.922)	0.0129 (0.677)	-0.002 (0.949)	0.016 (0.686)	-0.0003 (0.994)
Dnor	0.425 (0.000)	0.438 (0.000)	0.421 (0.000)	0.442 (0.000)	0.551 (0.000)
Dice	0.307 (0.000)	0.324 (0.000)	-	-	-
Dtreated	0.032 (0.000)	-	0.029 (0.000)	-	-
trend	-	-0.0004 (0.014)	-	-0.0005 (0.032)	-0.003 (0.023)
Trend squared	-	-	-	--	0.00001 (0.026)
IC Den	-0.091 (0.007)	-0.117 (0.006)	-0.082 (0.036)	-0.131 (0.028)	-0.136 (0.029)
IC Nor	-0.041 (0.004)	-0.068 (0.012)	-0.037 (0.001)	-0.082 (0.037)	-0.099 (0.031)
IC Fin	-0.099 (0.002)	-0.141 (0.003)	-0.091 (0.018)	-0.159 (0.017)	-0.181 (0.017)
IC 3	-0.130 (0.000)	-0.135 (0.000)	-0.125 (0.000)	-0.136 (0.000)	-0.085 (0.002)
SD	-0.01 (0.000)	-0.011 (0.000)	-0.01 (0.000)	-0.010 (0.000)	-0.009 (0.000)
SF	-0.001 (0.000)	0.001 (0.275)	-0.001 (0.000)	0.001 (0.250)	0.004 (0.076)
SN	-0.009 (0.000)	-0.009 (0.000)	-0.009 (0.000)	-0.008 (0.000)	-0.008 (0.000)
SI	-0.006 (0.000)	-0.005 (0.000)	-	-	-
SS	-0.001 (0.224)	-0.001 (0.389)	-0.001 (0.212)	0.001 (0.377)	-0.003 (0.156)
intercept	0.192 (0.000)	0.187 (0.000)	0.194 (0.000)	0.185 (0.000)	0.277 (0.000)
Obs.	1,595	1595	1,288	1,288	1,288
p-values in parentheses					

Nordic Border Closures and Per Capita Cases (weekly average): TO 31/08/20

	Aa	Bb	Cc	Dd	Ee
DDen	0.067 (0.000)	0.971 (0.000)	0.809 (0.000)	0.80 (0.000)	0.083 (0.000)
Dfin	0.026 (0.078)	0.019 (0.145)	-0.058 (0.357)	-0.029 (0.625)	0.042 (0.022)
Dnor	0.032 (0.000)	0.083 (0.000)	0.607 (0.000)	0.559 (0.000)	0.045 (0.001)
Dice	0.024 (0.011)	0.027 (0.013)	0.384 (0.000)	0.323 (0.000)	0.023 (0.015)
Dtreated	-	-	-	0.040 (0.000)	0.033 (0.210)
trend	-	-0.001 (0.012)	-0.001 (0.000)	-	-
IC Den	-0.306 (0.000)	-0.286 (0.000)	-0.101 (0.104)	-0.098 (0.076)	-0.345 (0.000)
IC Nor	-0.291 (0.000)	-0.282 (0.000)	-0.028 (0.648)	-0.008 (0.886)	-0.329 (0.000)
IC Fin	-0.247 (0.003)	-0.195 (0.006)	-0.110 (0.106)	-0.076 (0.189)	-0.286 (0.001)
IC 3	-0.293 (0.001)	-0.192 (0.003)	-0.053 (0.372)	-0.098 (0.086)	-0.30 (0.000)
SD	-	-	-0.012 (0.000)	-0.014 (0.000)	-
SF	-	-	0.002 (0.034)	-0.001 (0.000)	-
SN	-	-	-0.012 (0.000)	-0.014 (0.000)	-
SI	-	-	-0.006 (0.000)	-0.007 (0.000)	-
SS	-	-	0.0004 (0.739)	-0.002 (0.186)	-
intercept	0.291 (0.000)	0.354 (0.000)	0.227 (0.000)	0.203 (0.000)	0.281 (0.000)
Obs.	985	985	985	985	985
p-values in parentheses					

Insights

- True (population) infection rate of COVID-19 is MUCH higher than reported cases (6.2 times higher for 15 country sample, 31 August 2020)
- NEGATIVE relationship between % positive viral cases and true infection rate.
- 'Go Early, Go Hard', and for sufficient duration (& WITH strict border controls on arrivals) offers very large economic and public health benefits relative to delayed suppression or unmitigated suppression.
- Stringent border controls for arrivals coupled with supervised quarantine is highly effective at reducing COVID-19 cases (and fatalities).
- Testing and contact tracing fails to suppress growth in COVID-19 cases at relatively low new daily cases; even 'moderate' new daily cases (100+) effective suppression requires mandated social distancing.
- Higher COVID-19 fatalities per capita is correlated with lower GDP growth.
- 'Swedish Model' of suppression has generated MUCH higher per capita cases & fatalities than its Nordic neighbours and no better economic performance.