COVID-19 case doubling time associated with non-pharmaceutical interventions and vaccination: a global experience

SUPPLEMENTARY DOCUMENT

Appendix S1 Flow chart of the study sample

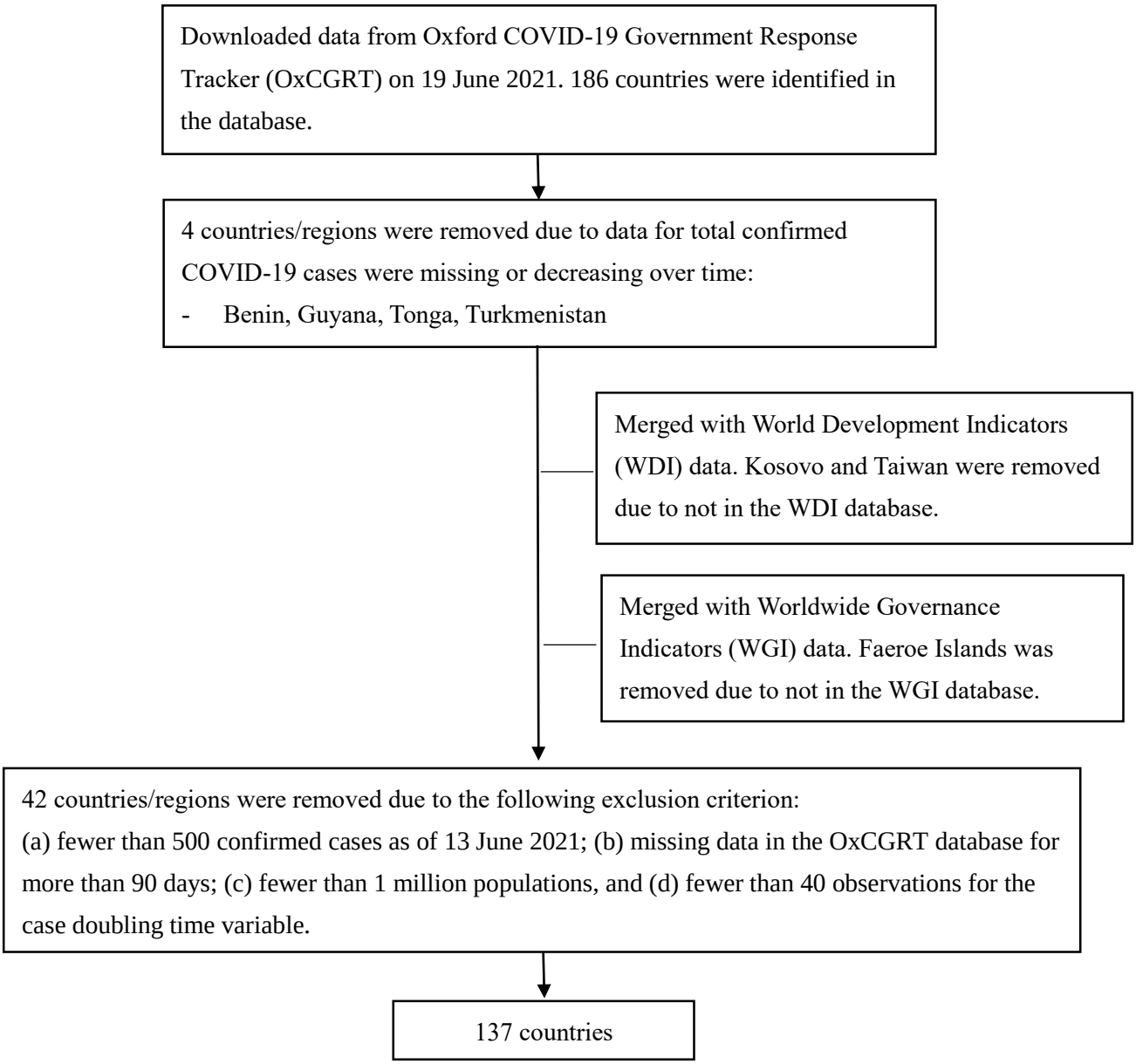


Figure S1. Flow chart of 137 countries analysed in this study

Appendix S2 Sample countries, observed country days and government effectiveness scores

The study sample is composed of 137 countries over the period of 1st January 2020 – 13rd June, 2021. Observed country days refers to days since the first reported COVID-19 case until the last day after which the case doubling time (the outcome variable) could not be calculated. See Methods for calculation of case doubling time. The government effectiveness scores range from -2.5 to 2.5, with a higher value indicating higher government effectiveness. We applied the latest 2019 scores. For subgroup analysis presented in Figure 3 in the main text, we ranked countries according to their effectiveness scores and divided them into three equal-sized groups: low, medium and high, denoted by L, M, and H, respectively in Table S2.

Table S2. Sample countries, observed country days and government effectiveness scores

Country	ISO code	Continent	Observed days	Government effectiveness	
				Score	Level
Afghanistan	AFG	Asia	266	-1.46	L
Angola	AGO	Africa	297	-1.12	L
Albania	ALB	Europe	312	-0.06	M
United Arab Emirates	ARE	Asia	359	1.38	H
Argentina	ARG	South America	356	-0.09	M
Australia	AUS	Oceania	183	1.57	H
Austria	AUT	Europe	293	1.49	H
Azerbaijan	AZE	Asia	286	-0.14	M
Burundi	BDI	Africa	352	-1.33	L
Belgium	BEL	Europe	287	1.03	H
Burkina Faso	BFA	Africa	297	-0.76	L
Bangladesh	BGD	Asia	242	-0.74	L
Bulgaria	BGR	Europe	310	0.34	H
Bahrain	BHR	Asia	368	0.30	M
Bosnia and Herzegovina	BIH	Europe	286	-0.63	L
Belarus	BLR	Europe	313	-0.18	M
Bolivia	BOL	South America	315	-0.70	L
Brazil	BRA	South America	331	-0.19	M
Botswana	BWA	Africa	339	0.43	H
Central African Republic	CAF	Africa	106	-1.75	L
Canada	CAN	North America	356	1.73	H
Switzerland	CHE	Europe	286	1.95	H
Chile	CHL	South America	348	1.06	H
Cote d'Ivoire	CIV	Africa	297	-0.48	M

Cameroon	CMR	Africa	370	-0.81	L
Democratic Republic of Congo	COD	Africa	295	-1.63	L
Congo	COG	Africa	274	-1.39	L
Colombia	COL	South America	316	0.07	M
Costa Rica	CRI	North America	304	0.42	H
Czech Republic	CZE	Europe	316	0.89	H
Germany	DEU	Europe	346	1.59	H
Denmark	DNK	Europe	301	1.94	H
Dominican Republic	DOM	North America	288	-0.36	M
Algeria	DZA	Africa	264	-0.52	M
Ecuador	ECU	South America	314	-0.40	M
Egypt	EGY	Africa	321	-0.42	M
Spain	ESP	Europe	331	1.00	H
Estonia	EST	Europe	367	1.17	H
Ethiopia	ETH	Africa	316	-0.63	L
Finland	FIN	Europe	374	1.93	H
France	FRA	Europe	362	1.38	H
Gabon	GAB	Africa	335	-0.90	L
United Kingdom	GBR	Europe	331	1.44	H
Georgia	GEO	Asia	288	0.83	H
Ghana	GHA	Africa	218	-0.21	M
Guinea	GIN	Africa	228	-0.78	L
Gambia	GMB	Africa	168	-0.63	L
Greece	GRC	Europe	377	0.41	H
Guatemala	GTM	North America	290	-0.68	L
Honduras	HND	North America	301	-0.61	L
Croatia	HRV	Europe	294	0.41	H
Haiti	HTI	North America	169	-2.02	L
Hungary	HUN	Europe	355	0.50	H
Indonesia	IDN	Asia	326	0.18	M
India	IND	Asia	443	0.17	M
Ireland	IRL	Europe	314	1.28	H
Iran	IRN	Asia	362	-0.55	M
Iraq	IRQ	Asia	336	-1.34	L
Israel	ISR	Asia	314	1.33	H
Italy	ITA	Europe	336	0.46	H
Jamaica	JAM	North America	358	0.50	H
Jordan	JOR	Asia	347	0.10	M

Japan	JPN	Asia	374	1.59	H
Kazakhstan	KAZ	Asia	320	0.12	M
Kenya	KEN	Africa	267	-0.38	M
Kyrgyz Republic	KGZ	Asia	221	-0.68	L
Cambodia	KHM	Asia	469	-0.58	L
South Korea	KOR	Asia	366	1.38	H
Kuwait	KWT	Asia	342	0.02	M
Laos	LAO	Asia	406	-0.78	L
Lebanon	LBN	Asia	335	-0.83	L
Liberia	LBR	Africa	161	-1.38	L
Libya	LBY	Africa	272	-1.92	L
Sri Lanka	LKA	Asia	462	-0.11	M
Lesotho	LSO	Africa	242	-0.83	L
Lithuania	LTU	Europe	305	1.04	H
Latvia	LVA	Europe	338	1.11	H
Morocco	MAR	Africa	253	-0.12	M
Moldova	MDA	Europe	282	-0.38	M
Madagascar	MDG	Africa	354	-1.14	L
Mexico	MEX	North America	287	-0.16	M
Mali	MLI	Africa	281	-1.06	L
Myanmar	MMR	Asia	236	-1.15	L
Mongolia	MNG	Asia	418	-0.19	M
Mozambique	MOZ	Africa	312	-0.82	L
Mauritania	MRT	Africa	270	-0.50	L
Mauritius	MUS	Africa	372	0.87	H
Malawi	MWI	Africa	290	-0.75	L
Malaysia	MYS	Asia	420	1.00	H
Namibia	NAM	Africa	311	0.10	M
Niger	NER	Africa	277	-0.80	L
Nigeria	NGA	Africa	302	-1.09	L
Nicaragua	NIC	North America	137	-0.77	L
Netherlands	NLD	Europe	314	1.80	H
Norway	NOR	Europe	344	1.86	H
Nepal	NPL	Asia	407	-1.05	L
New Zealand	NZL	Oceania	46	1.67	H
Oman	OMN	Asia	259	0.26	M
Pakistan	PAK	Asia	305	-0.68	L
Panama	PAN	North America	279	0.07	M

Peru	PER	South America	294	-0.07	M
Philippines	PHL	Asia	416	0.05	M
Papua New Guinea	PNG	Oceania	386	-0.81	L
Poland	POL	Europe	320	0.60	H
Portugal	PRT	Europe	308	1.15	H
Paraguay	PRY	South America	380	-0.53	M
Qatar	QAT	Asia	151	0.71	H
Romania	ROU	Europe	289	-0.28	M
Russia	RUS	Europe	316	0.15	M
Rwanda	RWA	Africa	307	0.19	M
Saudi Arabia	SAU	Asia	133	0.31	M
Senegal	SEN	Africa	303	-0.06	M
Singapore	SGP	Asia	122	2.22	H
Sierra Leone	SLE	Africa	182	-1.13	L
El Salvador	SLV	North America	249	-0.47	M
Serbia	SRB	Europe	310	0.02	M
Slovak Republic	SVK	Europe	306	0.67	H
Slovenia	SVN	Europe	306	1.08	H
Sweden	SWE	Europe	355	1.83	H
Eswatini	SWZ	Africa	293	-0.68	L
Chad	TCD	Africa	296	-1.57	L
Togo	TGO	Africa	358	-0.92	L
Thailand	THA	Asia	467	0.36	H
Tajikistan	TJK	Asia	76	-1.05	L
Timor-Leste	TLS	Asia	413	-0.88	L
Trinidad and Tobago	TTO	North America	425	0.10	M
Tunisia	TUN	Africa	322	-0.10	M
Turkey	TUR	Asia	349	0.05	M
Uganda	UGA	Africa	276	-0.59	L
Ukraine	UKR	Europe	311	-0.30	M
Uruguay	URY	South America	404	0.70	H
United States	USA	North America	328	1.49	H
Uzbekistan	UZB	Asia	190	-0.51	M
Vietnam	VNM	Asia	488	0.04	M
South Africa	ZAF	Africa	286	0.37	H
Zambia	ZMB	Africa	322	-0.68	L
Zimbabwe	ZWE	Africa	295	-1.21	L

Appendix S3 Policy measures based on the Oxford COVID-19 Government Response Tracker (OxCGRT) indicators

Table S3 provides the definition of policy measures used in this study and the corresponding OxCGRT indicators. We focused on interventions that were actually enforced; thus for most OxCGRT indicators, degree of 0 and 1 were treated as the reference group, i.e. no measures. In addition, we combined the highest two degrees for stay-at-home requirements, testing policies, and face covering. For vaccine rollout, we combined degrees of 1−5 into a single category because the number of country-days for individual degrees was relatively small.

Table S3. Policy measures based on Oxford COVID-19 Government Response Tracker (OxCGRT) indicators

OxCGRT indicators		**Policy measures in this study**
Degree	**School closures**	
0	No measures	No measures
1	Recommend closing	No measures
2	Require closing (some levels or categories)	Partial closures
3	Require closing (all levels)	Full closures
Degree	**Workplace closures, or work-from-home**	
0	No measures	No measures
1	Recommend closing	No measures
2	Require closing (some sectors or categories)	Partial closures
3	Require closing (all-but-essential workplaces)	Full closures
Degree	**Cancellation of public events**	
0	No measures	No measures
1	Recommend cancelling	No measures
2	Require cancelling	Requirement of cancellation
Degree	**Restrictions on gathering size**	
0	No restriction	No limits or up to 1000 people
1	Restrictions on gatherings above 1000 people	No limits or up to 1000 people
2	Restrictions on gatherings between 101-1000 people	No limits or up to 1000 people
3	Restrictions on gatherings between 11-100 people	Up to 100 people
4	Restrictions on gatherings of 10 people or less	Up to 10 people

Degree	**Requirements to stay-at-home**	
0	No measures	No measures
1	Recommend not leaving house	No measures
2	Require not leaving house with exceptions for daily exercise, grocery shopping and essential trips	Required, with exceptions
3	Require not leaving house with minimal exceptions	Required, with exceptions
Degree	**Restrictions on international travel**	
0	No measures	No international travel bans
1	Screening	No international travel bans
2	Quarantine arrivals from high-risk regions	No international travel bans
3	Ban on arrivals from some regions	Bans on arrivals from some regions
4	Ban on all regions or total border closure	Bans on arrivals from all regions
Degree	**Public information campaigns**	
0	No campaigns	No or limited campaigns
1	Public officials urging caution about COVID-19	No or limited campaigns
2	Coordinated public information campaign	Coordinated public campaigns
Degree	**Testing policy**	
0	No testing policy	No or limited testing
1	Only those who meet specific criteria and have symptoms	No or limited testing
2	Testing of anyone with COVID-19 symptoms	Widespread testing
3	Open public testing	Widespread testing
Degree	**Contact tracing**	
0	No contact tracing	No or limited contact tracing
1	Contact tracing not done for all cases	No or limited contact tracing
2	Contact tracing done for all identified cases	Comprehensive contact tracing
Degree	**Face covering**	
0	No policy	No measures
1	Recommended	No measures
2	Required in some specified shared/public spaces	Required in some places
3	Required in all shared/public spaces	Required in all places
4	Required outside the home at all times	Required in all places
Degree	**Vaccination policy**	
0	No availability	No vaccination

1	Availability for one of the following: key workers/clinically vulnerable groups/elderly groups	Vaccine rollout
2	Availability for two of the following: key workers/clinically vulnerable groups/elderly groups	Vaccine rollout
3	Availability for all of the following: key workers/clinically vulnerable groups/elderly groups	Vaccine rollout
4	Availability for all three plus partial additional availability	Vaccine rollout
5	Universal availability	Vaccine rollout

Note: Data for OxCGRT indicators were retrieved from https://COVIDtracker.bsg.ox.ac.uk/, on 19 June, 2021. Data source: Hale Thomas, Sam Webster, Anna Petherick, Toby Phillips, and Beatriz Kira (2021). Oxford COVID-19 Government Response Tracker, Blavatnik School of Government.

Appendix S4 Frequency and average duration of policy measures

Figures in Table S4 were calculated based on 137 sample countries over the period of 1st January 2020 – 13rd June, 2021. The most frequently adopted policy was "workplace closures for some sectors or categories" (355 times), followed by "requirements to stay-at-home with exceptions for daily exercise, grocery shopping and essential trips" (289 times), and school closures at all levels (272 times). With respect to average duration, coordinated public information campaigns had the longest days (358 days), followed by comprehensive contact tracing (218 days) and cancellation of public events (168 days).

Table S4. Frequency and average duration of COVID-19 policy measures

	OxCGRT policy indicator	Total country days	Frequency of adoption	Average number of days
Degree	**School closures**			
1	Recommend closing	14477	201	72.02
2	Require closing (some levels or categories)	15468	266	58.15
3	Require closing (all levels)	26856	272	98.74
Degree	**Workplace closures, or work-from-home**			
1	Recommend closing	12841	187	68.67
2	Require closing (some sectors or categories)	31102	355	87.61
3	Require closing (all-but-essential workplaces)	9832	216	45.52
Degree	**Cancellation of public events**			
1	Recommend cancelling	12400	202	61.39
2	Require cancelling	44159	263	167.90
Degree	**Restrictions on gathering size**			
1	Restrictions on gatherings above 1000 people	1687	43	39.23
2	Restrictions on gatherings between 101-1000 people	6062	129	46.99
3	Restrictions on gatherings between 11-100 people	19109	264	72.38
4	Restrictions on gatherings of 10 people or less	28992	248	116.90
Degree	**Requirements to stay-at-home**			
1	Recommend not leaving house	18622	256	72.74
2	Require not leaving house with exceptions for daily exercise, grocery shopping and essential trips	24356	289	84.28
3	Require not leaving house with minimal exceptions	3546	84	42.21
Degree	**Restrictions on international travel**			
1	Screening	10674	175	60.99

2	Quarantine arrivals from high-risk regions	13578	226	60.08
3	Ban on arrivals from some regions	21761	257	84.67
4	Ban on all regions or total border closure	18685	169	110.56
Degree	**Public information campaigns**			
1	Public officials urging caution about COVID-19	4448	89	49.98
2	Coordinated public information campaign	61253	171	358.20
Degree	**Testing policy**			
1	Only those who meet specific criteria and have symptoms	21365	163	131.07
2	Testing of anyone with COVID-19 symptoms	26265	163	161.14
3	Open public testing	16210	118	137.37
Degree	**Contact tracing**			
1	Contact tracing not done for all cases	23557	164	143.64
2	Contact tracing done for all identified cases	34397	158	217.70
Degree	**Face covering**			
1	Recommended	4071	65	62.63
2	Required in some specified shared/public spaces	9653	115	83.94
3	Required in all shared/public spaces	27124	199	136.30
4	Required outside the home at all times	13777	112	123.01
Degree	**Vaccination policy**			
1	Availability for one of the following: key workers/clinically vulnerable groups/elderly groups	2639	86	30.69
2	Availability for two of the following: key workers/clinically vulnerable groups/elderly groups	4693	102	46.01
3	Availability for all of the following: key workers/clinically vulnerable groups/elderly groups	5250	114	46.05
4	Availability for all three plus partial additional availability	2533	85	29.80
5	Universal availability	1280	30	42.67

Appendix S5 Summary of model variables

Table S5 summarises model variables based on the full sample, which had 4,2012 country days. The table excludes all the squared terms in the Equation (1) in the main text. The mean log of case doubling time was 3.8. The mean number of weeks from the first reported death to the earliest intervention was −7.26, indicating that countries generally adopted at least one policy measure before the first death was reported.

Table S5. Descriptive statistics of model variables

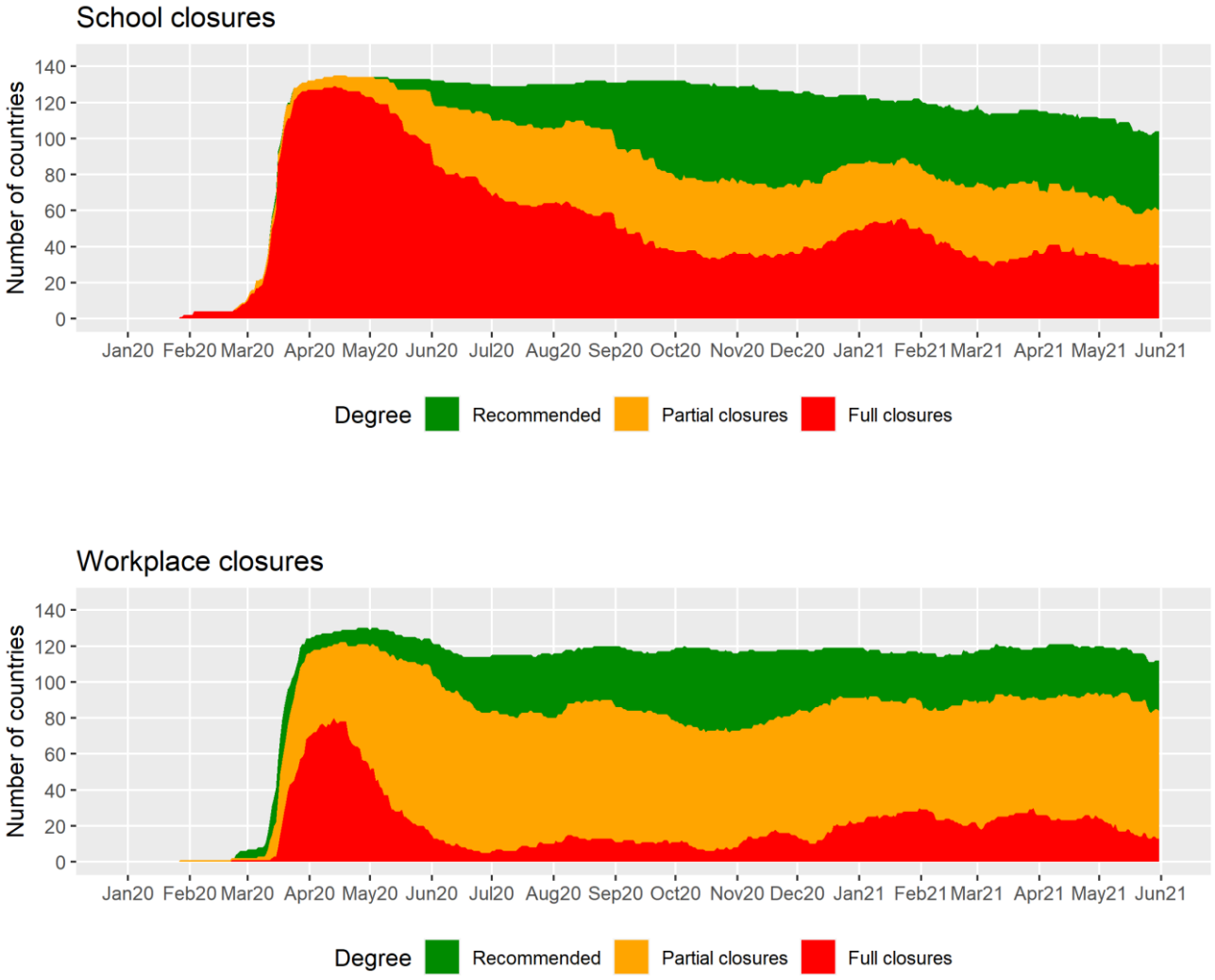
Variables	**Mean**	**SD**	**Min.**	**Max.**
Case doubling time (days, log)	3.80	1.14	0	6.05
Number of days since the first confirmed case	163.50	101.68	1	488
Number of days since the most recent implementation at date *t* (0 if no policy at date *t*)				
Partial school closures	10.61	26.49	0	207
Full school closures	45.00	69.31	0	349
Partial workplace closures	38.55	60.95	0	357
Full workplace closures	5.19	18.50	0	266
Cancellation of public events	77.83	85.93	0	418
Restriction on gatherings to 100 people	21.94	49.53	0	358
Restriction on gatherings to 10 people	35.42	62.81	0	341
Stay-at-home requirements	26.99	50.50	0	328
Bans on arrivals from some regions	25.46	54.39	0	325
Bans on arrivals from all regions	28.56	55.22	0	416
Coordinated public campaigns	151.80	104.21	0	487
Widespread testing	66.34	83.26	0	408
Comprehensive contact tracing	72.61	96.60	0	452
Face covering required in some places	13.48	41.90	0	328
Face covering required in all places	51.42	71.39	0	373
COVID-19 vaccine rollout	0.90	5.79	0	113
Government effectiveness scores (-2.5 – 2.5)	0.04	0.93	-2.02	2.22
Number of weeks from first death to the earliest policy	-7.26	11.29	-61.14	1
Population (log)	16.58	1.41	13.96	21.05
Population aged 65 and above (%)	9.63	6.85	1.16	28.00
Number of people per squared kilometre of land area (hundreds)	1.74	4.82	0.02	79.53
Universal Health Coverage service coverage index (0–100)	65.38	15.09	28	89

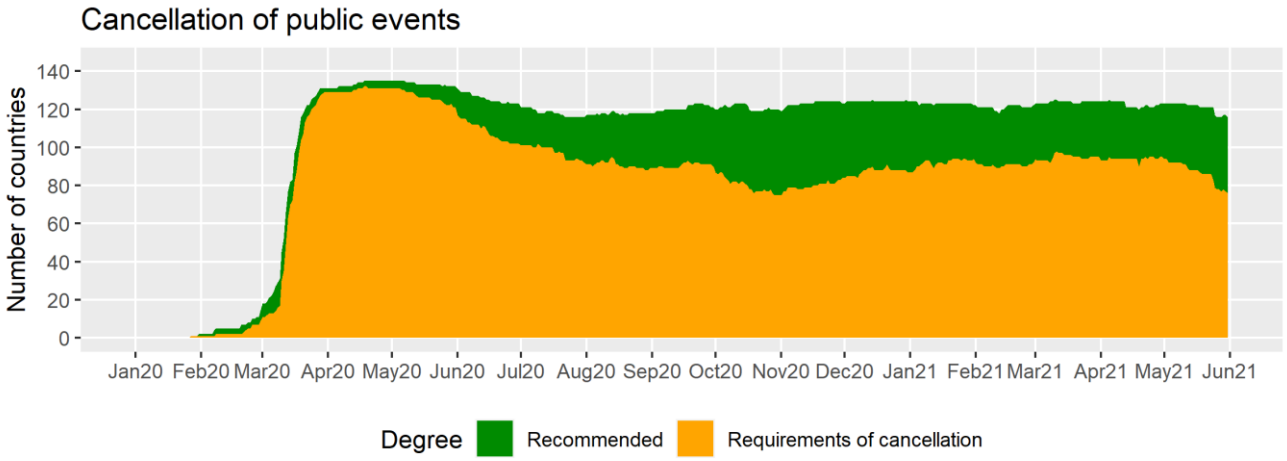
GDP per capita adjusted by purchasing power parity (current international dollars, log)	9.43	1.15	6.62	11.49
Death caused by communicable diseases and maternal/prenatal/nutrition conditions (%)	21.62	20.28	1.3	65.3
Europe (=1)	0.26	0.44	0	1
Africa (=1)	0.28	0.45	0	1
Asia (=1)	0.29	0.45	0	1
North America (=1)	0.09	0.29	0	1
South America (=1)	0.07	0.26	0	1
Oceania (=1)	0.01	0.12	0	1

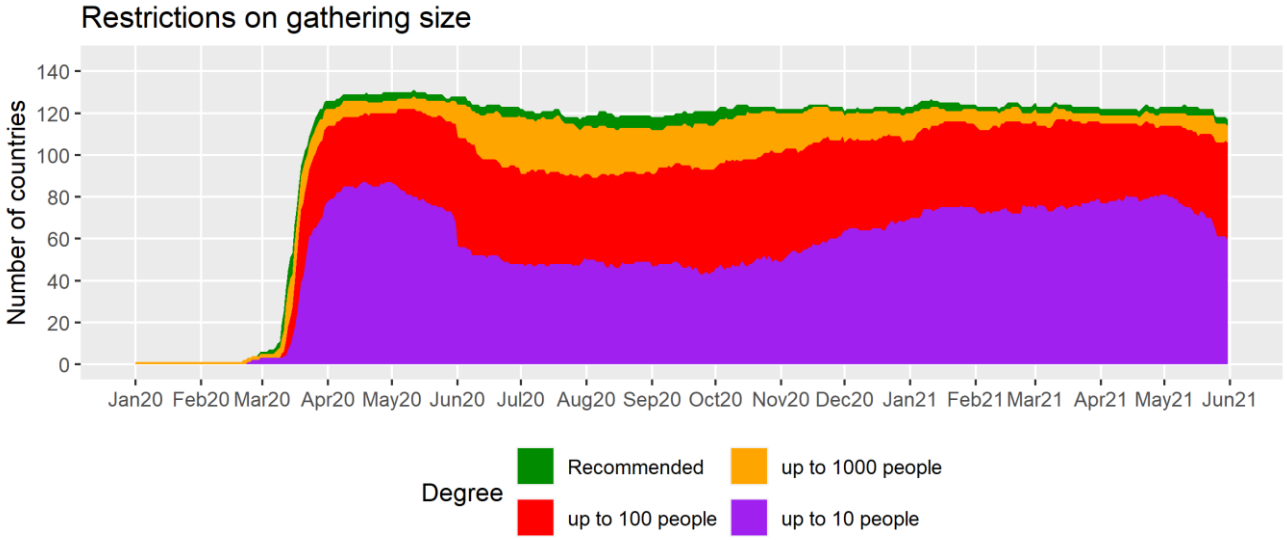
Note: N=42,102 country days. Data for government effectiveness scores were retrieved from Worldwide Governance Indicator Database at http://info.worldbank.org/governance/wgi/#home. Data for country characteristics were collected from World Development Indicators (WDI) at https://datatopics.worldbank.org/world-development-indicators/. The latest year WDI were available for most countries was: year 2019 for population size, percentage of old people, and GDP per capita; year 2018 for population density; year 2017 for University Health Coverage index, and year 2016 for cause of death. When a country had missing data in the designated year, we replaced that missing value with the country's recoded value from the previous one or two years.

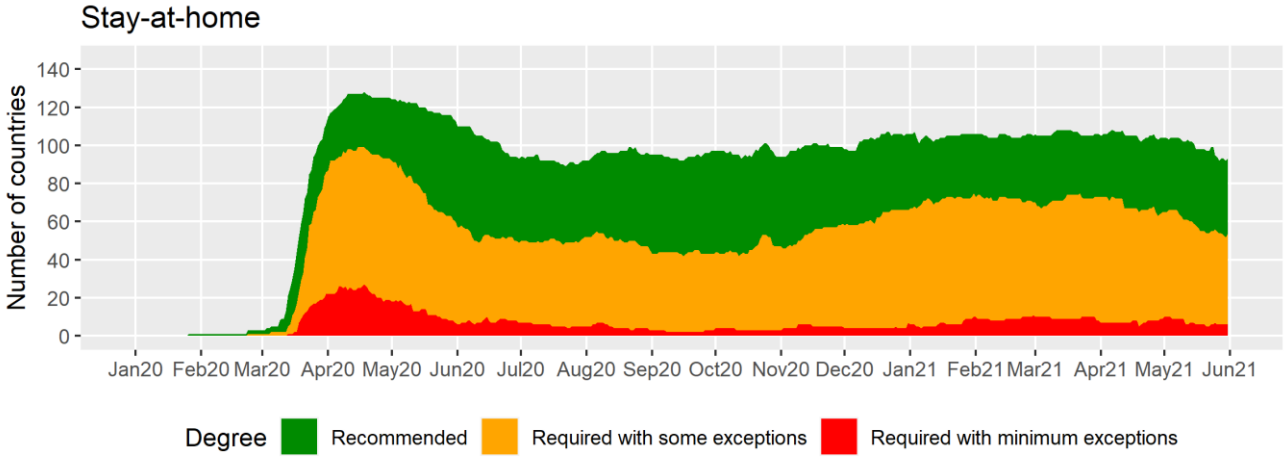
Appendix S6 Number of countries implemented the 11 policy measures by calendar date

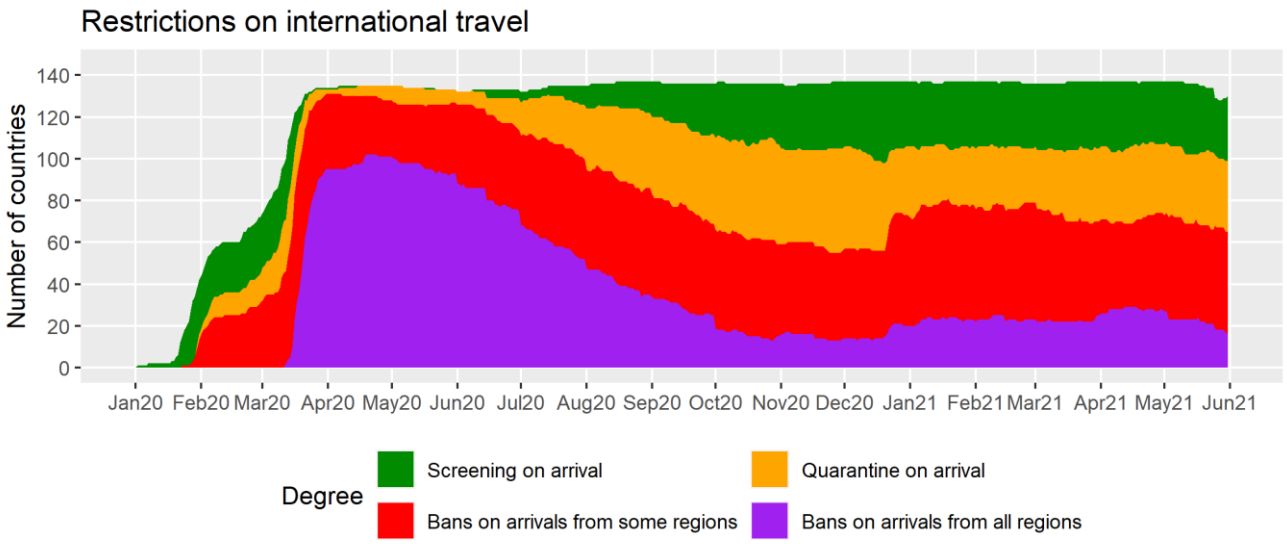
Figure S6 illustrates the number of countries out of 137 sample countries that adopted respective policy measures each day from 1 January 2020 to May 31 2021. The X-axis denotes calendar date. For example, Jan20 refers to January 2020, and May21 refers to May 2021. Data for all policy measures were obtained from Oxford COVID-19 Government Response Tracker (OxCGRT) indicators database.

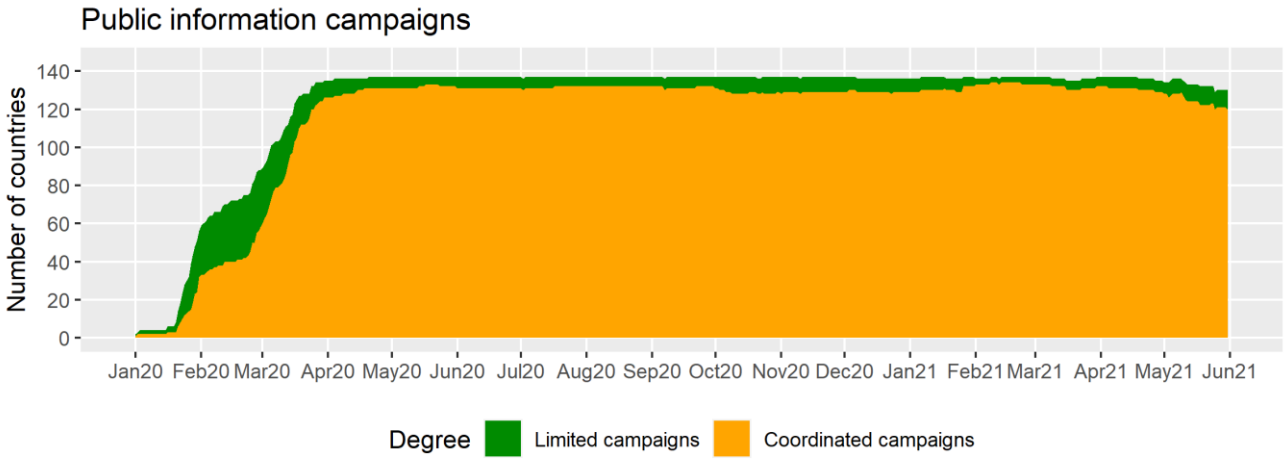


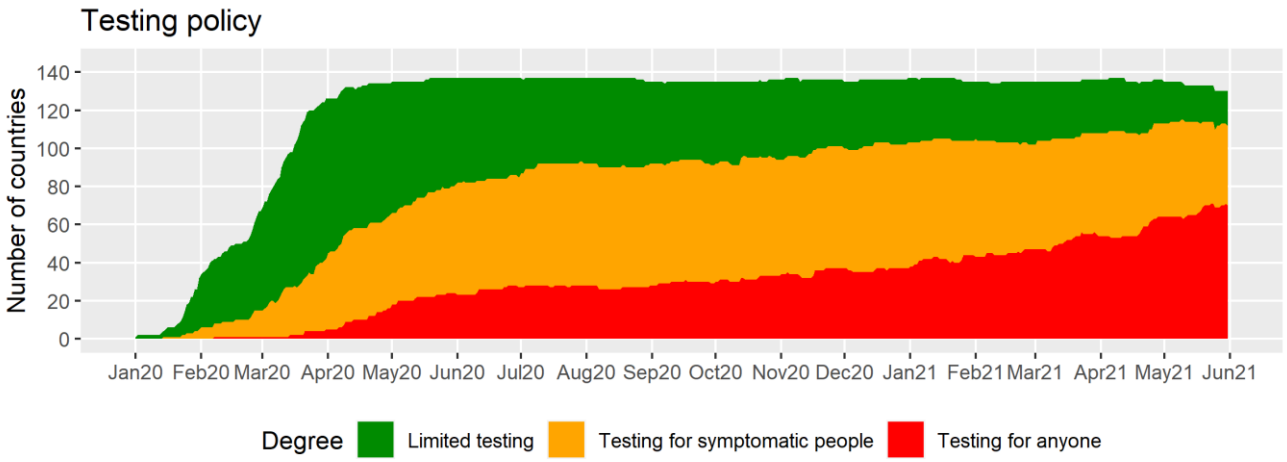

Cancellation of public events
Number of countries
0
20
40
60
80
100
120
140
Jan20 Feb20 Mar20 Apr20 May20 Jun20 Jul20 Aug20 Sep20 Oct20 Nov20 Dec20 Jan21 Feb21 Mar21 Apr21 May21 Jun21
Degree
Recommended
Requirements of cancellation


Restrictions on gathering size
Number of countries
0
20
40
60
80
100
120
140
Jan20 Feb20 Mar20 Apr20 May20 Jun20 Jul20 Aug20 Sep20 Oct20 Nov20 Dec20 Jan21 Feb21 Mar21 Apr21 May21 Jun21
Degree
Recommended
up to 1000 people
up to 100 people
up to 10 people


Stay-at-home
Number of countries
0
20
40
60
80
100
120
140
Jan20 Feb20 Mar20 Apr20 May20 Jun20 Jul20 Aug20 Sep20 Oct20 Nov20 Dec20 Jan21 Feb21 Mar21 Apr21 May21 Jun21
Degree
Recommended
Required with some exceptions
Required with minimum exceptions


Restrictions on international travel
Number of countries
0
20
40
60
80
100
120
140
Jan20 Feb20 Mar20 Apr20 May20 Jun20 Jul20 Aug20 Sep20 Oct20 Nov20 Dec20 Jan21 Feb21 Mar21 Apr21 May21 Jun21
Degree
Screening on arrival
Quarantine on arrival
Bans on arrivals from some regions
Bans on arrivals from all regions


Public information campaigns
Number of countries
0
20
40
60
80
100
120
140
Jan20 Feb20 Mar20 Apr20 May20 Jun20 Jul20 Aug20 Sep20 Oct20 Nov20 Dec20 Jan21 Feb21 Mar21 Apr21 May21 Jun21
Degree
Limited campaigns
Coordinated campaigns


Testing policy
Number of countries
0
20
40
60
80
100
120
140
Jan20 Feb20 Mar20 Apr20 May20 Jun20 Jul20 Aug20 Sep20 Oct20 Nov20 Dec20 Jan21 Feb21 Mar21 Apr21 May21 Jun21
Degree
Limited testing
Testing for symptomatic people
Testing for anyone

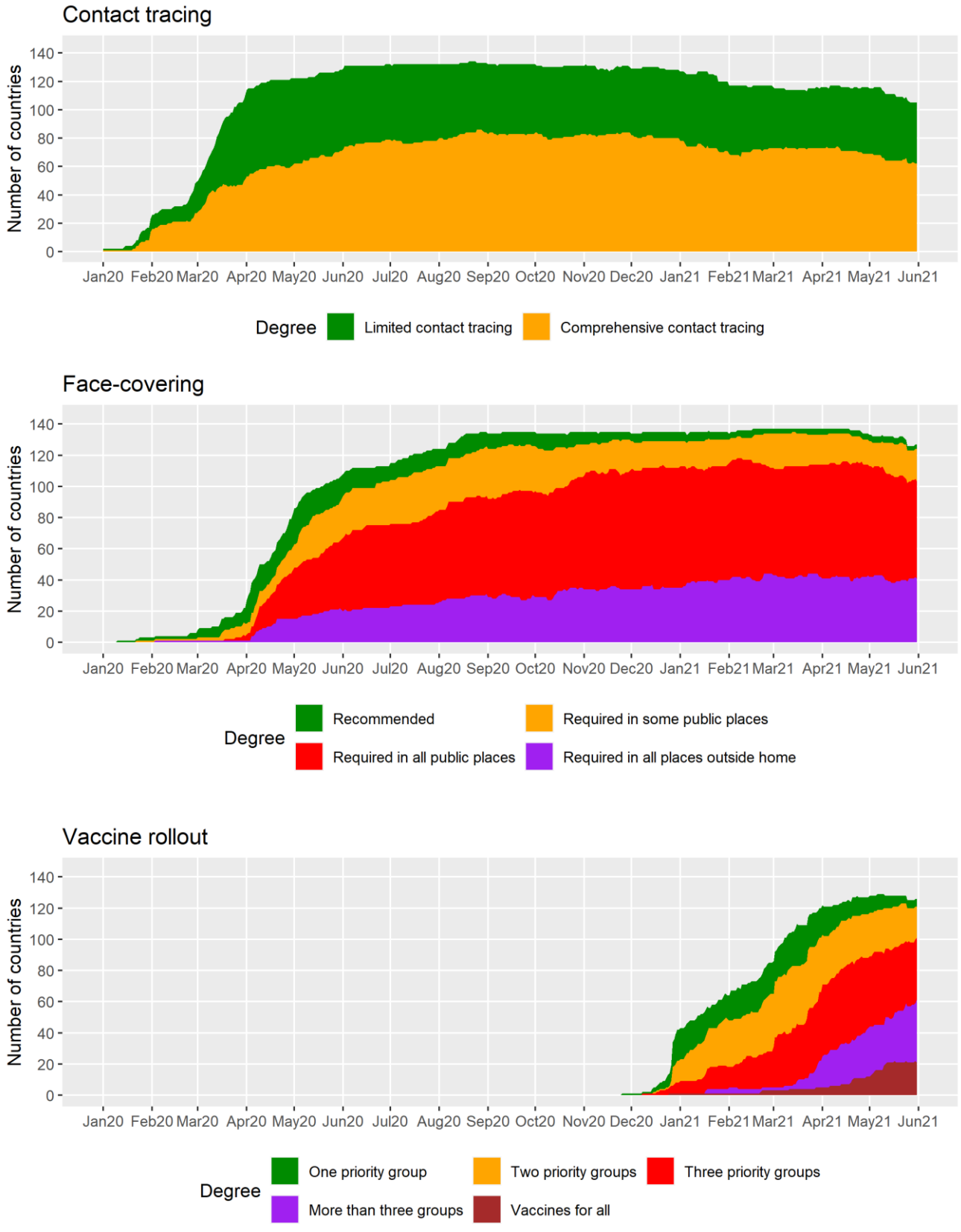


Figure S6. Number of countries implemented the 11 policy measures by calendar date.

Appendix S7 Results from regressions for COVID-19 case doubling time

Table S7.1 Results from regressions based on the full sample and by outbreak stages

Y: case doubling time (in log days)	**Full sample**	**Subsample regressions by outbreak stages (cases)**				
		<5,000	**<20,000**	**<80,000**	**<320,000**	**<1,280,000**
Predictors	Coef.	Coef.	Coef.	Coef.	Coef.	Coef.
No. of days since the most recent implementation						
Partial school closures	0.0138***	0.0008	0.0070*	0.0120***	0.0127***	0.0132***
Full school closures	0.0040**	0.0077*	0.0061*	0.0051*	0.0037*	0.0038**
Partial workplace closures	0.0009	0.0011	-0.0008	-0.0012	0.0005	0.0003
Full workplace closures	0.0141***	0.0384***	0.0312***	0.0227***	0.0248***	0.0158***
Cancellation of public events	0.0021	0.0058**	0.0039	0.0019	0.0021	0.0017
Restriction on gatherings to 100 people	0.0028	-0.0039	-0.0021	0.0014	0.0021	0.0023
Restriction on gatherings to 10 people	0.003	0.0074	0.0077*	0.0046	0.0050**	0.0041*
Stay-at-home requirements	0.0015	0.0056*	0.0012	0.0018	0.002	0.0018
Bans on arrivals from some regions	-0.0004	0.0033	0.0022	0.0021	0.0013	0.0002
Bans on arrivals from all regions	0.0018	0.0064*	0.002	0.003	0.0031	0.0021
Coordinated public campaigns	0.0039	0.0086**	0.0037	0.0036	0.0034	0.0038
Widespread testing	-0.0023	-0.0022	-0.0022	-0.0029	-0.002	-0.0021
Comprehensive contact tracing	-0.0019	-0.0017	0.0000	-0.0003	-0.0022	-0.0024
Face covering required in some places	-0.0003	-0.004	0.0001	0.0021	0.0005	0.0000
Face covering required in all places	-0.0001	0.0066*	0.0011	0.0012	0.0019	0.001
COVID-19 vaccine rollout	0.0196**	0.0176	0.019	0.0304**	0.0151*	0.0208**
Government effectiveness scores (-25 – 25)	0.0226*	0.0257*	0.0326**	0.0319**	0.0281**	0.0244*
No. of weeks from 1st death to earliest policy	-0.014	-0.0164*	-0.0125	-0.0129	-0.015	-0.0143
Population (log)	-0.1607***	-0.1031*	-0.1609***	-0.1668***	-0.1634***	-0.1553***
Population aged 65 and above (%)	0.0344	0.0261	0.0325	0.038	0.0384*	0.034
No. of people per km^2 of land area	-0.0083*	-0.0038	-0.0073	-0.0095*	-0.0086*	-0.0081*
UHC service coverage index (0–100)	0.0046	-0.0062	-0.0026	-0.0021	0.0043	0.0044
GDP per capita adjusted by PPP (log)	-0.2255*	-0.1861	-0.3054**	-0.2943**	-0.2716*	-0.2344*
Death caused by communicable diseases (%)	0.0024	-0.0042	-0.0048	-0.0021	0.0026	0.0024
Africa (=1)	0.0468	0.2711	0.2351	0.0913	0.0039	0.0361
Asia (=1)	0.2627	0.3215	0.4012	0.3197	0.2443	0.2534
North America (=1)	-0.3071	0.073	-0.1478	-0.3013	-0.4304	-0.3499
South America (=1)	-0.3705	-0.0528	-0.1231	-0.2351	-0.4141	-0.4043
Oceania (=1)	0.5917*	0.4409*	0.4683*	0.4591*	0.5520*	0.6089*
Number of observations (country days)	42102	17353	24762	31658	37935	40804

Note: UHC=universal health coverage; GDP=gross domestic product. Note: All models included the time trend, quadratic terms of time and policy variables, and country-specific random intercepts and random coefficients of time. Country-clustered robust standard errors were used. Legend: * p<0.05; ** p<0.01; *** p<0.001.

Table S7.2 Results from regressions by levels of government effectiveness

Y: case doubling time (in log days)	**Subsample regressions by government effectiveness**		
	High	**Medium**	**Low**
Predictors	Coef.	Coef.	Coef.
No. of days since the most recent implementation			
Partial school closures	0.0163***	0.0115**	0.007
Full school closures	0.0095*	0.0008	0.0036
Partial workplace closures	0.0026	-0.001	0.0024
Full workplace closures	0.0205***	0.0116*	0.0125*
Cancellation of public events	0.0054**	0.0043	-0.0004
Restriction on gatherings to 100 people	0.0009	0.0028	0.0024
Restriction on gatherings to 10 people	0.0076***	0.0015	-0.0035
Stay-at-home requirements	0.0075*	0.002	0.0004
Bans on arrivals from some regions	0.0022	-0.0028	0.0009
Bans on arrivals from all regions	0.0065*	-0.0002	0.0009
Coordinated public campaigns	0.0042	0.0016	-0.0017
Widespread testing	-0.0036	0.0016	-0.005
Comprehensive contact tracing	-0.0008	0.0006	-0.0021
Face covering required in some places	0.0001	-0.0021	0.0086
Face covering required in all places	0.0000	-0.0008	0.003
COVID-19 vaccine rollout	0.0265*	0.0173	0.0031
Government effectiveness scores (-25 – 25)	0.0041	-0.0295	0.0159
No. of weeks from 1st death to earliest policy	0.0840**	-0.0028	-0.0191*
Population (log)	-0.2616***	-0.0941**	-0.091
Population aged 65 and above (%)	0.0217	0.0435*	-0.0748
No. of people per km^2 of land area	0.0029	-0.0057	-0.0317
UHC service coverage index (0–100)	0.0236	0.0051	0.0032
GDP per capita adjusted by PPP (log)	-0.2078	0.0587	-0.1911
Death caused by communicable diseases (%)	-0.0164	0.0024	0.0064
Africa (=1)	0.796	0.4624	-1.723
Asia (=1)	0.5214*	0.4272	-1.0284
North America (=1)	-0.4599	0.0007	-1.5287
South America (=1)	-0.1965	-0.2	-1.5947
Oceania (=1)	0.621	(omitted)	-1.1063
Number of countries	46	45	46
Number of observations	14661	14294	13147

Note: UHC=universal health coverage; GDP=gross domestic product. PPP=purchasing power parity. Note: All models included the time trend, quadratic terms of time and policy variables, and country-specific random intercepts and random coefficients of time. Country-clustered robust standard errors were used. Legend: * p<0.05; ** p<0.01; *** p<0.001

Appendix S8 Sensitivity analysis: results from alternative specifications

Sensitivity analysis was conducted to check the robustness of the study results. We examined the collinearity by calculating the correlation coefficient (cc) of each pair of policy variables, and excluded those that had a cc greater than 0.4. As Table S8.1 shows (figures in bold), cancellation of public events (ID=5) was highly correlated with full school closures (0.42), partial workplace closures (0.41) and restriction on gatherings to 10 people (0.44). Coordinated public campaigns (ID=11) was highly correlated with widespread testing (0.46), comprehensive contact tracing (0.49), and face covering required in all places (0.46). Therefore, we excluded these two policy measures one by one from the main model. The results are presented under the heading of Model S1 and Model S2 in Table S8.2. We found that results from alternative specifications are generally consistent with those from the main model, except that in Model S1 "Restriction on gatherings to 10 people" became positively associated with prolonged case doubling time.

Table S8.1 Pairwise correlation coefficients between policy variables

Policy measures	**ID**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
Partial school closures	**1**	1.00															
Full school closures	**2**	-0.26	1.00														
Partial workplace closures	**3**	0.14	0.16	1.00													
Full workplace closures	**4**	-0.08	0.23	-0.18	1.00												
Cancellation of public events	**5**	0.09	**0.42**	**0.41**	0.12	1.00											
Restriction on gatherings to 100 people	**6**	0.09	0.00	-0.07	-0.05	0.15	1.00										
Restriction on gatherings to 10 people	**7**	0.00	0.25	0.30	0.08	**0.44**	-0.25	1.00									
Stay-at-home requirements	**8**	-0.01	0.28	0.13	0.25	0.36	0.20	0.21	1.00								
Bans on arrivals from some regions	**9**	0.01	-0.08	0.11	0.00	0.13	-0.07	0.18	-0.01	1.00							
Bans on arrivals from all regions	**10**	-0.03	0.20	0.09	0.04	0.20	0.04	0.12	0.07	-0.24	1.00						
Coordinated public campaigns	**11**	0.15	0.10	0.31	-0.02	0.35	0.15	0.20	0.21	0.23	0.08	1.00					
Widespread testing	**12**	0.06	0.11	0.18	-0.01	0.29	0.01	0.19	0.09	0.25	0.01	**0.46**	1.00				
Comprehensive contact tracing	**13**	0.11	-0.01	0.23	0.02	0.18	-0.03	0.09	0.11	0.07	0.07	**0.49**	0.29	1.00			
Face covering required in some places	**14**	0.06	-0.07	0.13	0.07	0.07	-0.07	-0.03	-0.08	0.19	0.02	0.17	0.17	0.15	1.00		
Face covering required in all places	**15**	0.08	0.20	0.20	-0.03	0.35	0.27	0.24	0.32	0.01	0.02	**0.46**	0.23	0.25	-0.23	1.00	
COVID-19 vaccine rollout	**16**	0.01	-0.01	0.07	0.04	0.10	0.01	0.10	0.04	0.04	0.04	0.31	0.15	0.17	0.00	0.17	1.00

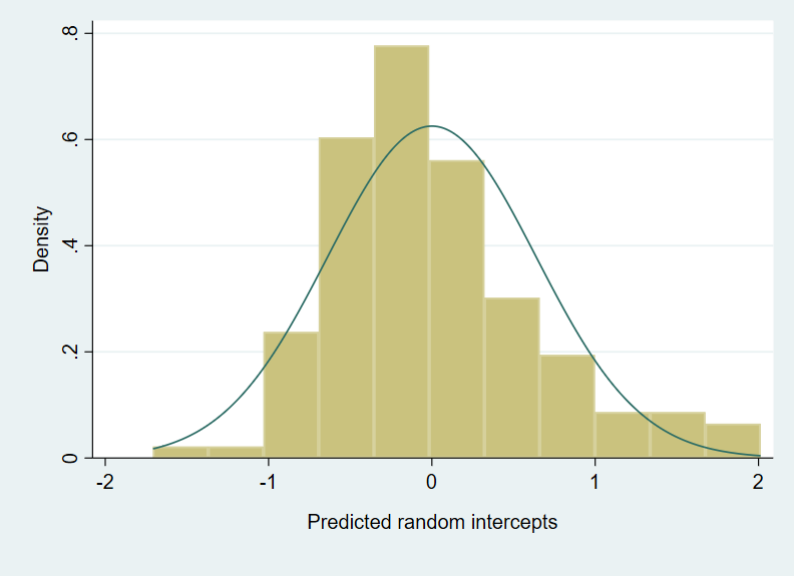
Table S8.2 Results from alternative model specifications

Y: case doubling time (in log days)	**Main model**	**Model S1**	**Model S2**
Predictors	Coef.	Coef.	Coef.
No. of days since the most recent implementation			
Partial school closures	0.0138***	0.0141***	0.0139***
Full school closures	0.0040**	0.0043**	0.0039**
Partial workplace closures	0.0009	0.0015	0.001
Full workplace closures	0.0141***	0.0143***	0.0143***
Cancellation of public events	0.0021		0.0021
Restriction on gatherings to 100 people	0.0028	0.0034	0.0029
Restriction on gatherings to 10 people	0.003	0.0037**	0.0029
Stay-at-home requirements	0.0015	0.002	0.0014
Bans on arrivals from some regions	-0.0004	-0.0004	-0.0002
Bans on arrivals from all regions	0.0018	0.0022	0.0019
Coordinated public campaigns	0.0039	0.0042	
Widespread testing	-0.0023	-0.0021	-0.002
Comprehensive contact tracing	-0.0019	-0.002	-0.0018
Face covering required in some places	-0.0003	-0.0001	-0.0005
Face covering required in all places	-0.0001	0.0002	0.0001
COVID-19 vaccine rollout	0.0196**	0.0209**	0.0196**
Government effectiveness scores (-25 – 25)	0.0226*	0.0232*	0.0244**
Number of weeks from first death to the earliest policy	-0.014	-0.0137	-0.0143*
Population (log)	-0.1607***	-0.1604***	-0.1699***
Population aged 65 and above (%)	0.0344	0.0339	0.0343
Number of people per $km^2$of land area	-0.0083*	-0.0082*	-0.0079*
Universal Health Coverage service coverage index (0–100)	0.0046	0.0044	0.0043
GDP per capita adjusted by purchasing power parity (log)	-0.2255*	-0.2323*	-0.2362*
Death caused by communicable diseases (%)	0.0024	0.002	0.0029
Africa (=1)	0.0468	0.0439	0.0293
Asia (=1)	0.2627	0.2585	0.2781
North America (=1)	-0.3071	-0.3142	-0.2977
South America (=1)	-0.3705	-0.3682	-0.3554
Oceania (=1)	0.5917*	0.5911*	0.5890*
Number of countries	137	137	137
Number of observations (country days)	42102	42103	42103

Note: All models included the time trend, quadratic terms of time and policy variables, and country-specific random intercepts and random coefficients of time. Country-clustered robust standard errors were used. Legend: * p<0.05; ** p<0.01; *** p<0.001.

Appendix S9 Residual diagnostics

a. Distribution of predicted random intercepts for 137 countries



b. Distribution of predicted random slopes for 137 countries

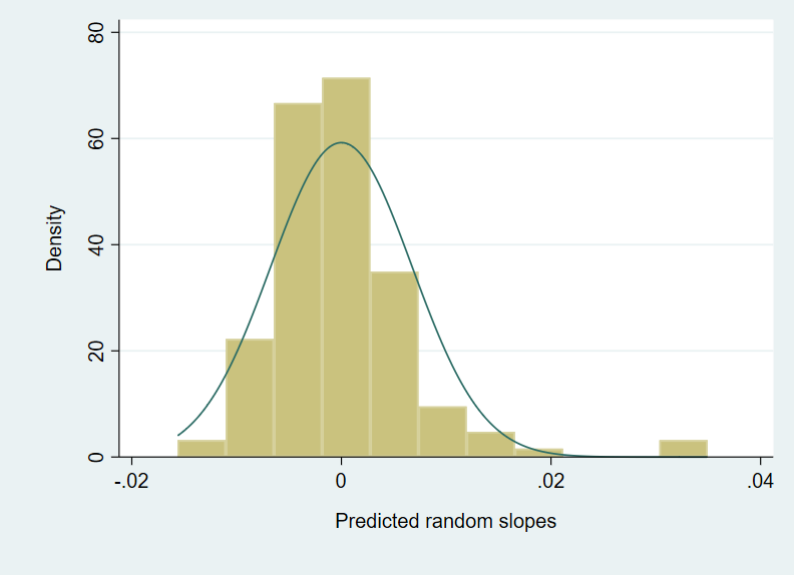


Figure S9. Residual diagnostics. This study used the empirical Bayes prediction method to assign values to country-specific random intercepts and random slopes, and assumed that they have a normal distribution. **a.** Distribution of predicted random intercepts for 137 countries. **b.** Distribution of predicted random slopes for 137 countries. Predicted random slopes are positively skewed, but in general predicted random effects are close to normal distributions.

Appendix S10 Cross validation of the study results

To check the stability and robustness of the study results, a cross-validation method was applied. First, we randomly assigned 50% of the data for individual countries as the training data, and saved the remaining data for testing (validation). Second, we ran the regression (Equation (1) in the main text) using the training data to obtain coefficient estimates and country-specific random intercepts and slopes of time. Third, we predicted the case doubling time (DT) for the testing data using the estimated model and compared the fitted with observed DT (Table S10.1). The equation for prediction is given by Equation (S1) in Appendix S11. Finally, the DT regression was run on the testing data; the results were compared with those from the training data and from the full sample (Table S10.2).

Table S10.1 shows that the root mean squared error (RMSE) calculated was only marginally higher for testing (0.679) than for training (0.657) data. The correlation coefficient between fitted and observed DT was only slightly lower for the testing data (0.802) than for the training data (0.816). These results suggest that the study results seemed robust to different datasets. In addition, Table S10.2 shows that the coefficient estimates were consistent for regressions using the full sample (the main model), the training data and testing data.

We also performed random forest algorithm using Stata command *rforest* and compared the prediction accuracy with that of the random-effect growth-curve model. The RMSE converged prior to100 iterations; thus we set iterations to be 100. The lowest validation RMSE (calculated against the testing data) occurred at 0.22 when the number of randomly selected variables at each split was 7. This result shows that random forest model had a slightly higher prediction accuracy than the empirical model used in this study. For the present study, the goal was to estimate the relative effectiveness of a wide range of policy measures (which increased the RMSE); hence the random forest model was used for validation only.

Table S10.1 Prediction accuracy based on RMSE and correlation coefficient

	Root mean squared error	Correlation coefficient between fitted and observed DT
Own prediction from training data (50% of the sample)	0.657	0.816
Prediction for testing data (50% of the sample)	0.679	0.802

Table S10.2 Results from regressions using training and testing data

Y: case doubling time (in log days)	**Main model**	**From training data**	**From testing data**
Predictors	Coef.	Coef.	Coef.
No. of days since the most recent implementation			
Partial school closures	0.0138***	0.0141***	0.0135***
Full school closures	0.0040**	0.0039**	0.0040**
Partial workplace closures	0.0009	0.0008	0.001
Full workplace closures	0.0141***	0.0135***	0.0146***
Cancellation of public events	0.0021	0.0021	0.0022
Restriction on gatherings to 100 people	0.0028	0.0034	0.002
Restriction on gatherings to 10 people	0.003	0.0029	0.003
Stay-at-home requirements	0.0015	0.0017	0.0014
Bans on arrivals from some regions	-0.0004	-0.0015	0.0008
Bans on arrivals from all regions	0.0018	0.0017	0.0017
Coordinated public campaigns	0.0039	0.0031	0.0043
Widespread testing	-0.0023	-0.0019	-0.0026
Comprehensive contact tracing	-0.0019	-0.0019	-0.0018
Face covering required in some places	-0.0003	0.0002	-0.0011
Face covering required in all places	-0.0001	-0.0002	0.0002
COVID-19 vaccine rollout	0.0196**	0.0195**	0.0203**
Government effectiveness scores (-25 – 25)	0.0226*	0.0229*	0.0202*
Number of weeks from first death to the earliest policy	-0.014	-0.0126	-0.0116
Population (log)	-0.1607***	-0.1485***	-0.1564***
Population aged 65 and above (%)	0.0344	0.0279	0.0289
Number of people per $km^2$of land area	-0.0083*	-0.0066	-0.0077*
Universal Health Coverage service coverage index (0–100)	0.0046	0.0023	0.0033
GDP per capita adjusted by purchasing power parity (log)	-0.2255*	-0.1998	-0.1962
Death caused by communicable diseases (%)	0.0024	0.0032	0.0017
Africa (=1)	0.0468	-0.0648	0.0686
Asia (=1)	0.2627	0.2155	0.2541
North America (=1)	-0.3071	-0.2842	-0.2881
South America (=1)	-0.3705	-0.3754	-0.3365
Oceania (=1)	0.5917*	0.5	0.3409
Number of countries	137	137	137
Number of observations (country days)	42102	20959	21143

Note: All models included the time trend, quadratic terms of time and policy variables, and country-specific random intercepts and random coefficients of time. Country-clustered robust standard errors were used. Legend: * p<0.05; ** p<0.01; *** p<0.001.

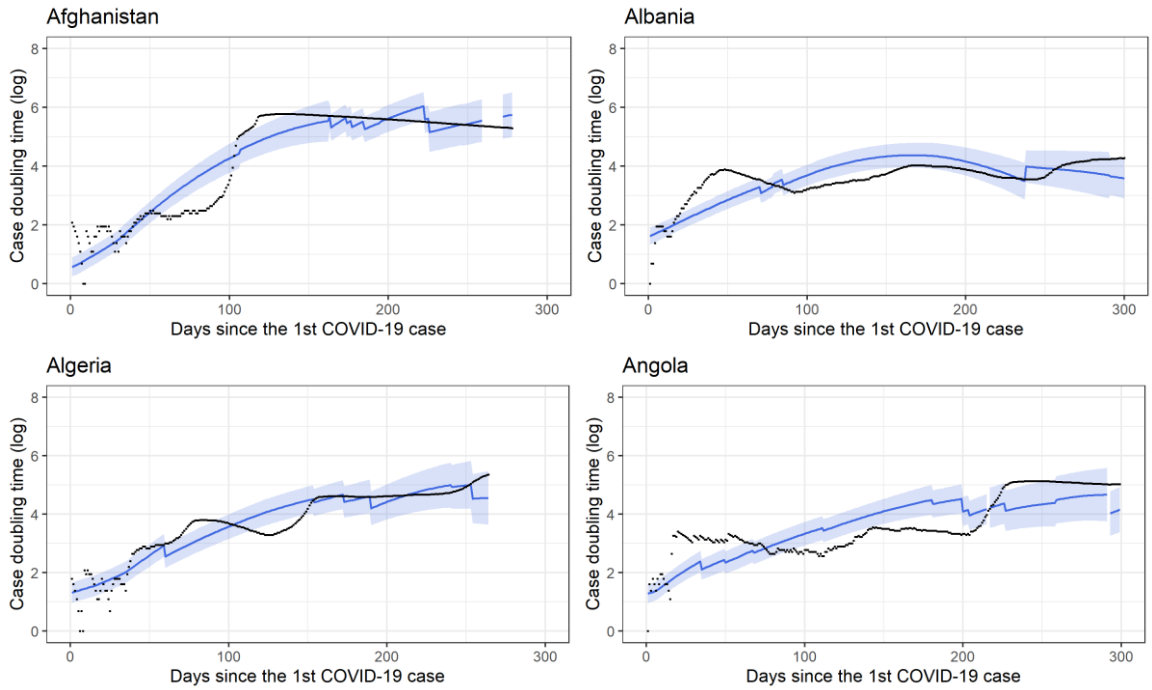
Appendix S11 Predicted versus observed trends of case doubling time for 137 countries

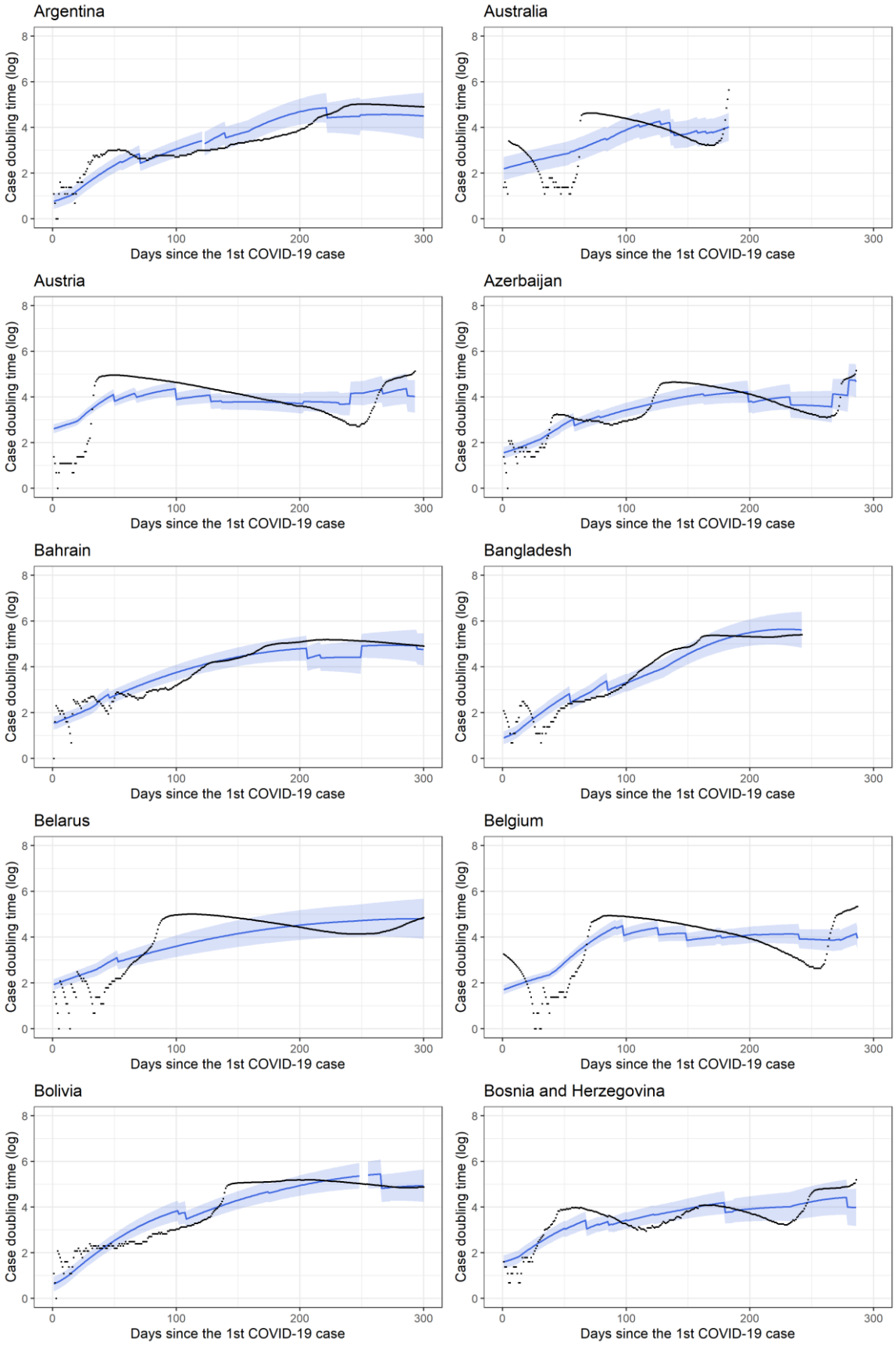
To examine the validity of the model, we predicted the case doubling time (DT) for individual countries over time, and compared country-specific fitted regression lines with the real data, as shown by figures below. Based on Equation (1) in the main text, the fitted DT was calculated as follows:

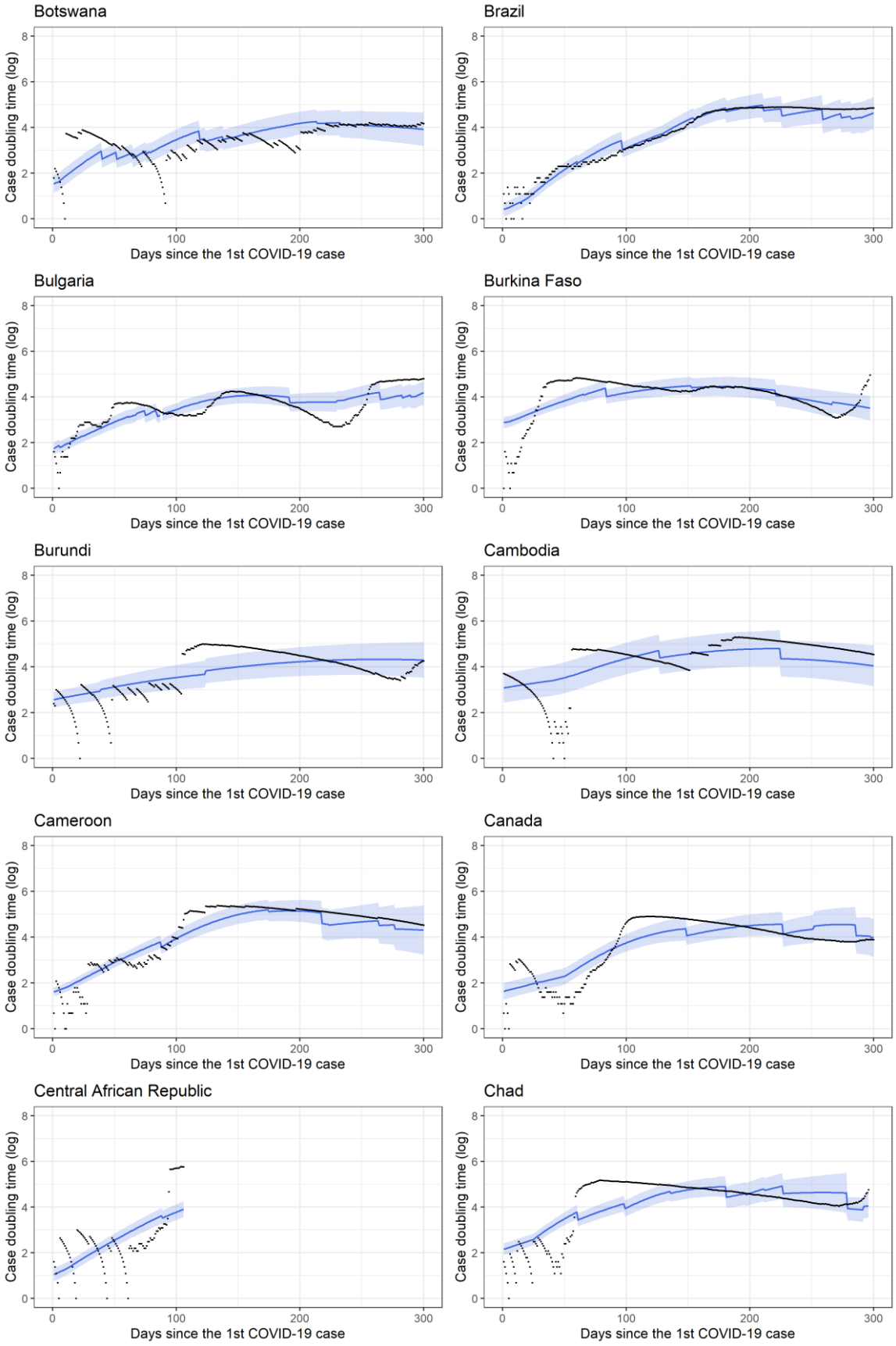
$$\hat{Y}_{it} = \widehat{\alpha_0} + \widehat{\alpha_1} T_{it} + \widehat{\alpha_2} T_{it}^2 + \sum_{j=1}^{6} (\widetilde{\boldsymbol{C}}_j' \widetilde{\boldsymbol{\beta}}_j + \widetilde{\boldsymbol{D}}_j' \widetilde{\boldsymbol{\gamma}}_j) + \sum_{k=1}^{5} (\widetilde{\boldsymbol{H}}_k' \widetilde{\boldsymbol{\delta}}_k + \widetilde{\boldsymbol{G}}_k' \widetilde{\boldsymbol{\theta}}_k) + \widetilde{\boldsymbol{X}}' \widetilde{\boldsymbol{\zeta}} + \widehat{\eta_{1i}} + \widehat{\eta_{2i}} T_{it} \quad . \qquad \text{(S1)}$$

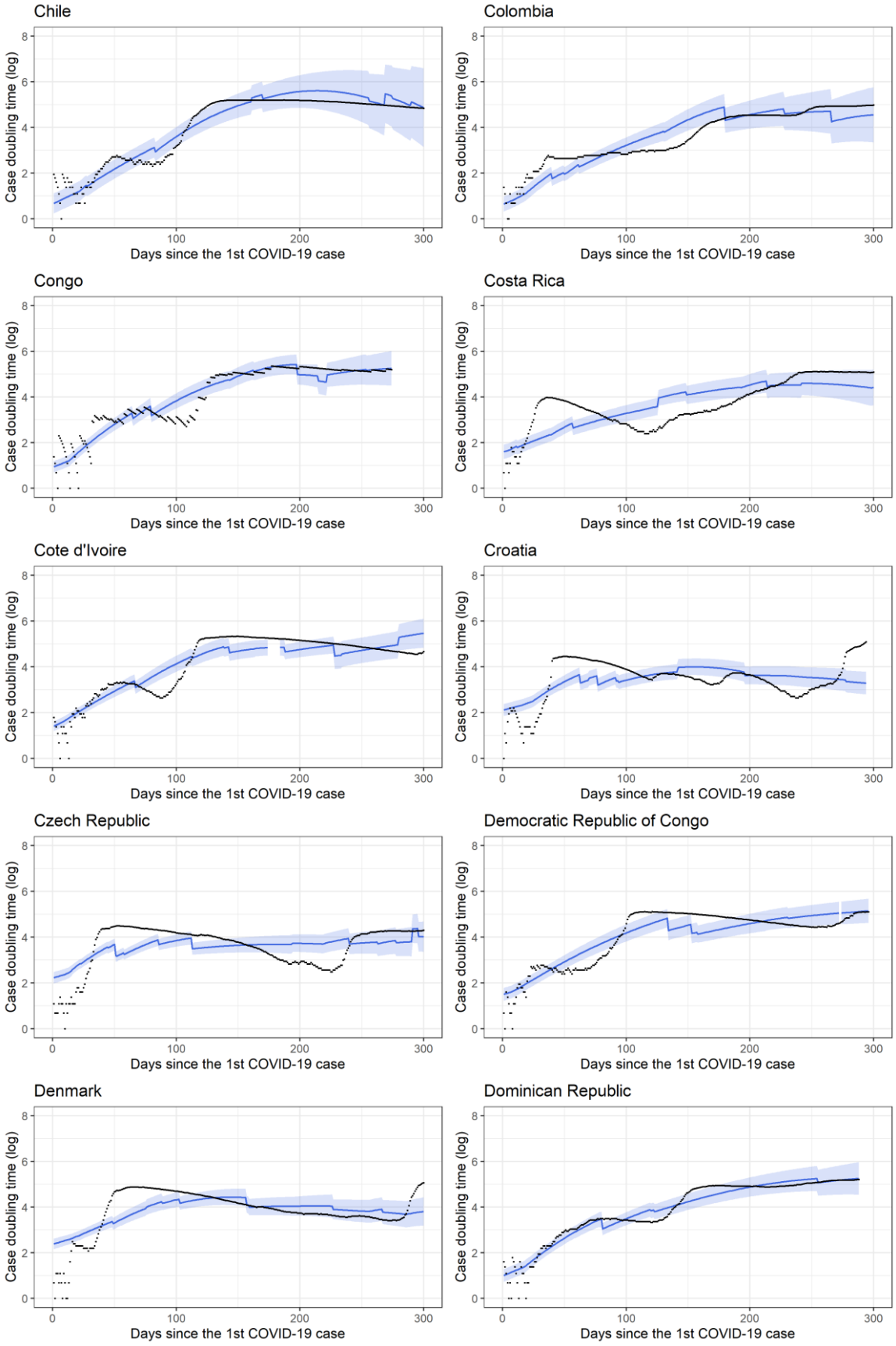
Random intercepts and random slopes for individual countries were not estimated with other model parameters. Instead, we assigned them values by using empirical Bayes predictions. The standard practice is to assume that η_{1i} and η_{2i} have a normal prior distribution with a mean of zero and the variance previously estimated by the maximum likelihood method. The normality assumption was verified by residual diagnostics, as described in Appendix S9.

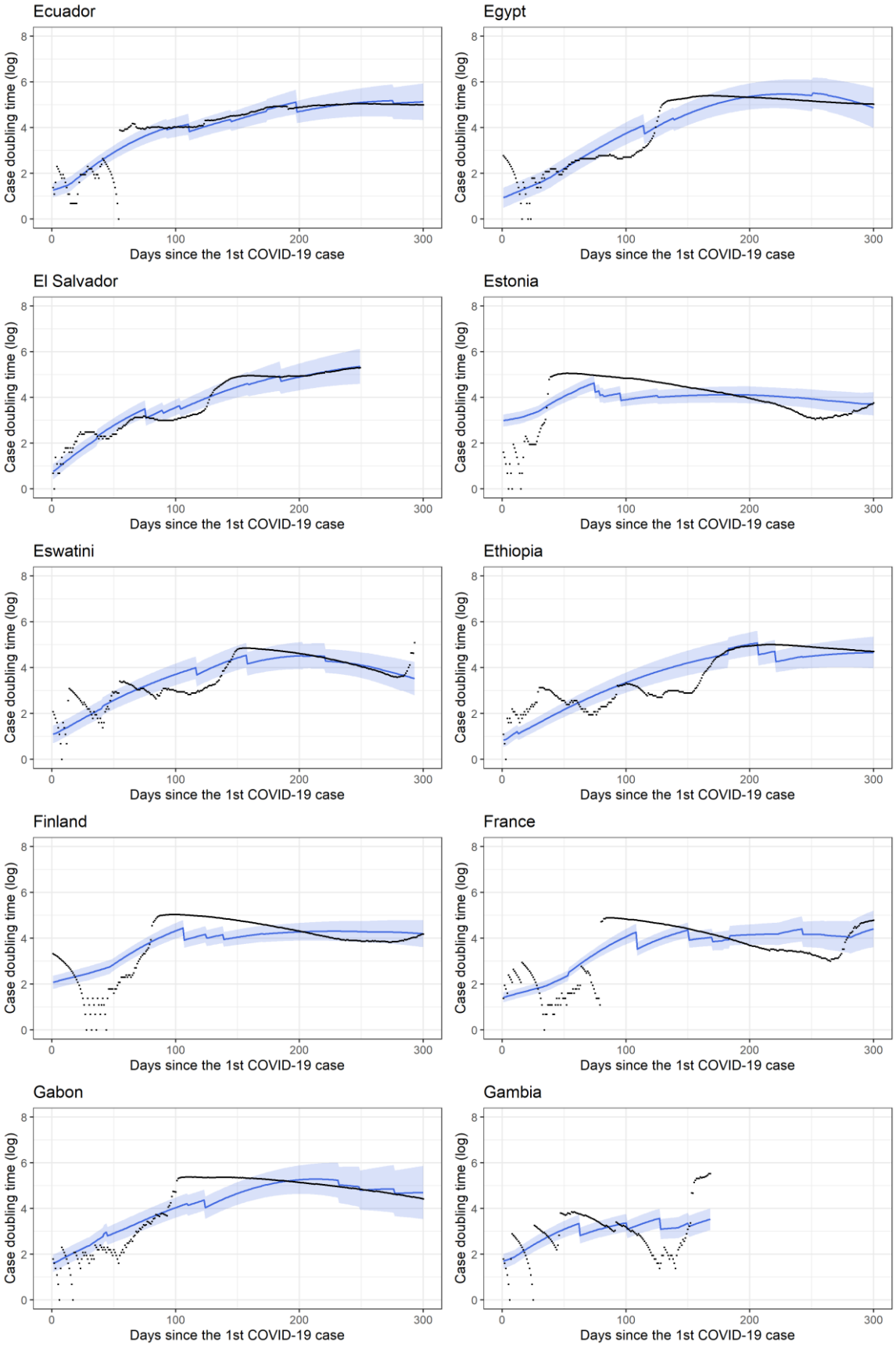
The following figures are displayed in the countries' alphabetic order. The scattered black dots represent observed data. The solid blue line is the predicted case doubling time (log). The shaded area is the 95% confidence interval for the fixed part of the model.

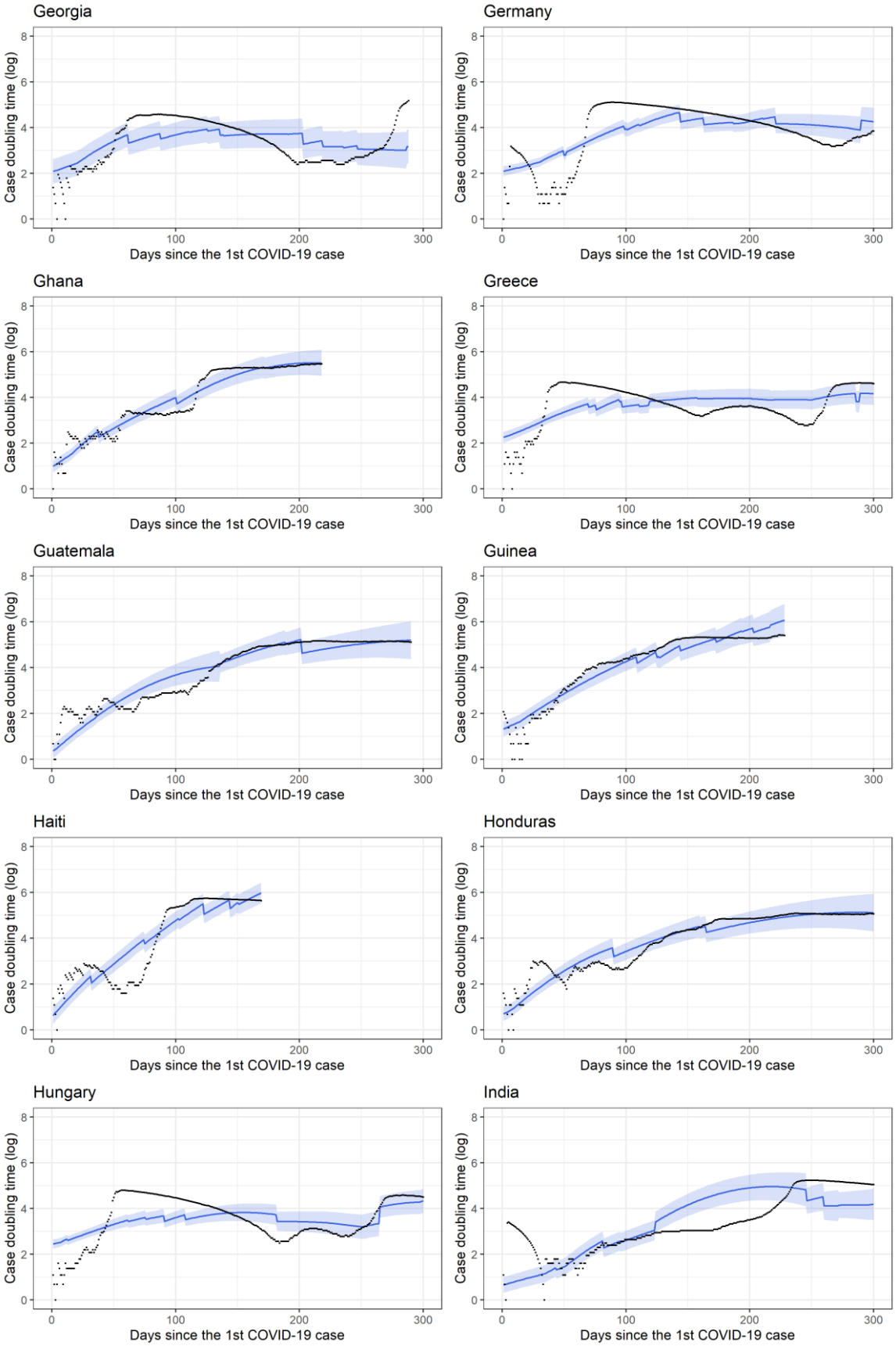


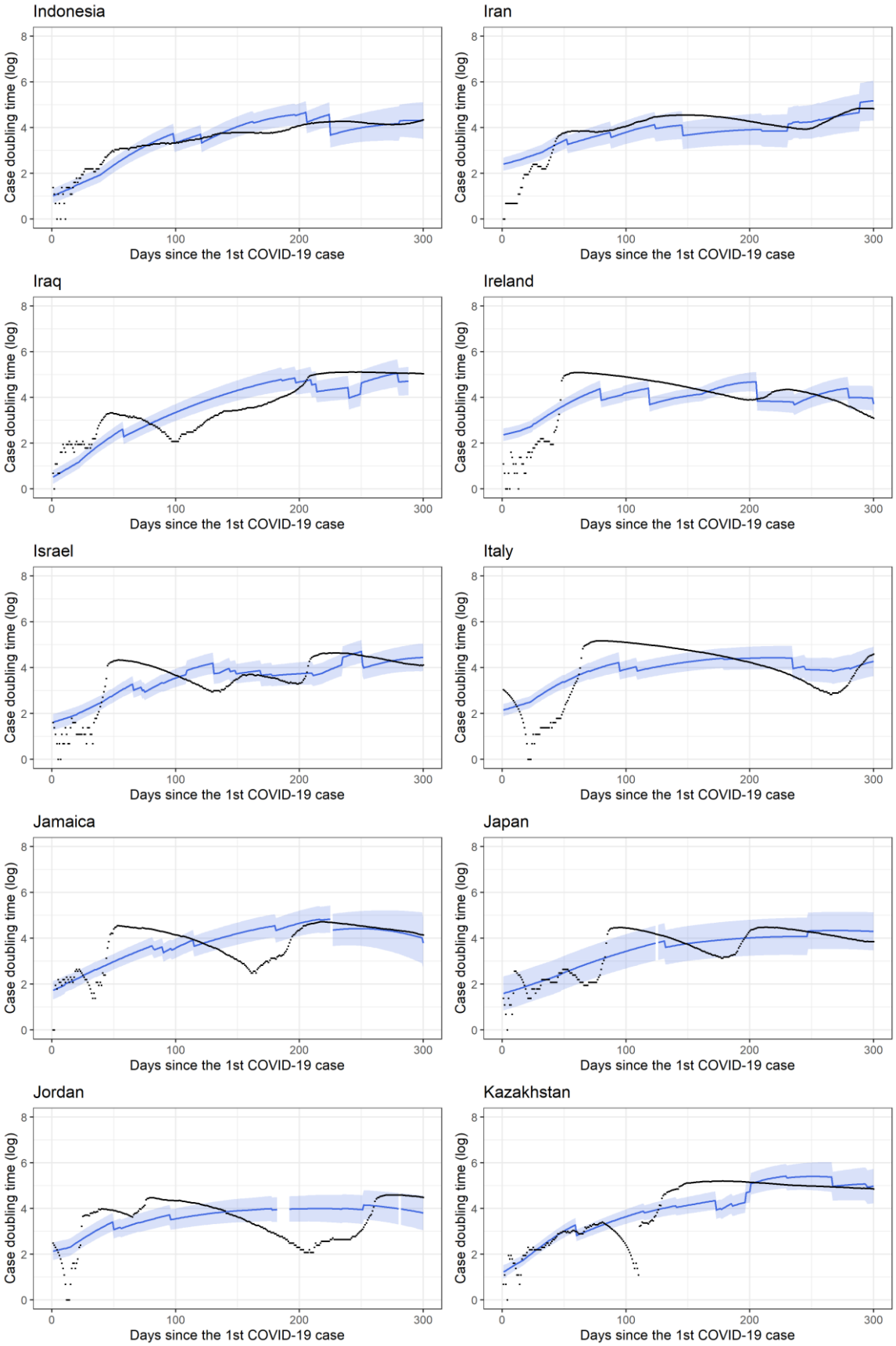

Argentina
Australia
Austria
Azerbaijan
Bahrain
Bangladesh
Belarus
Belgium
Bolivia
Bosnia and Herzegovina
Case doubling time (log)
Days since the 1st COVID-19 case
0
2
4
6
8
0
100
200
300

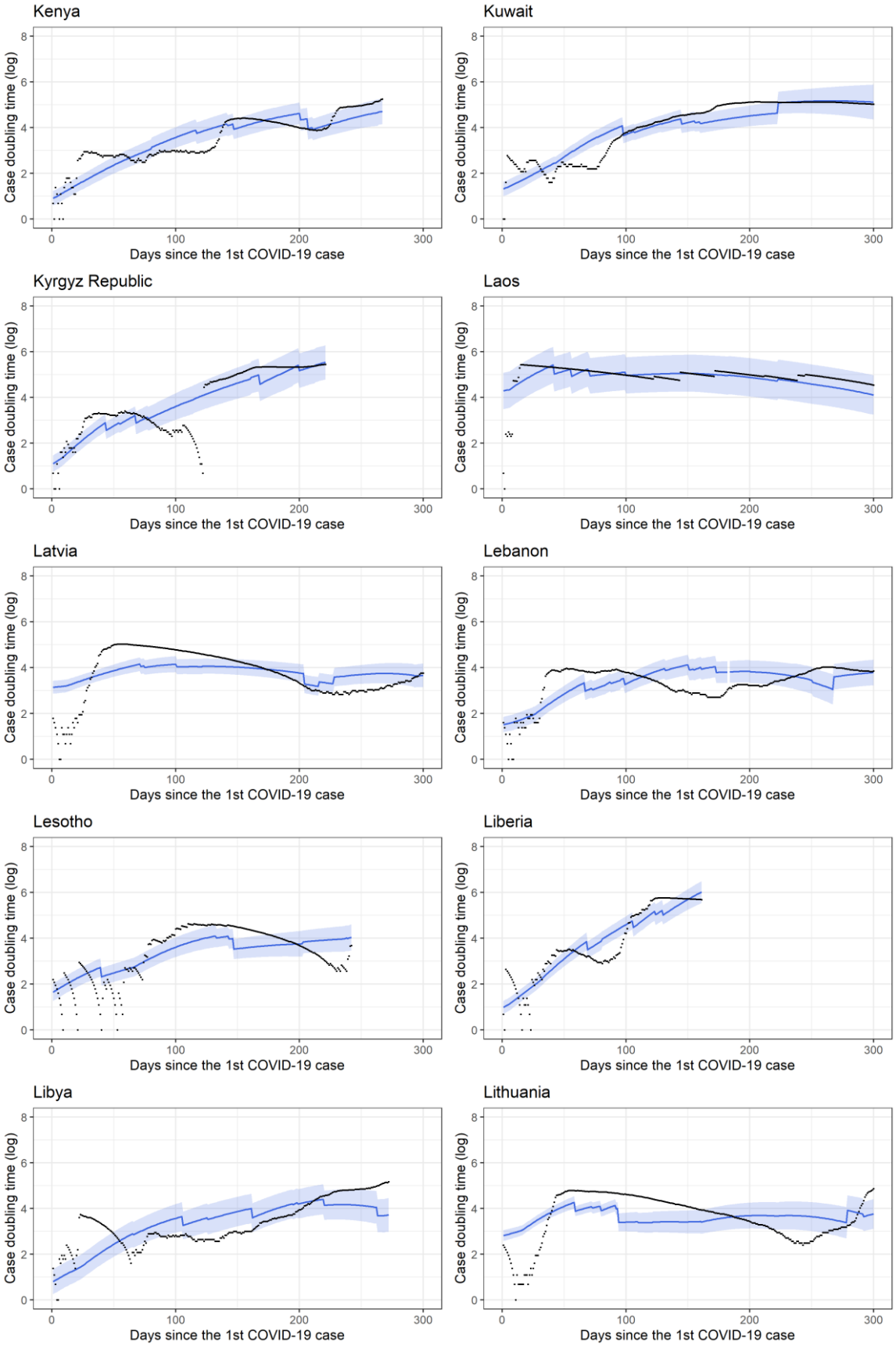

Botswana
Brazil
Bulgaria
Burkina Faso
Burundi
Cambodia
Cameroon
Canada
Central African Republic
Chad
Case doubling time (log)
Days since the 1st COVID-19 case
0
2
4
6
8
0
100
200
300

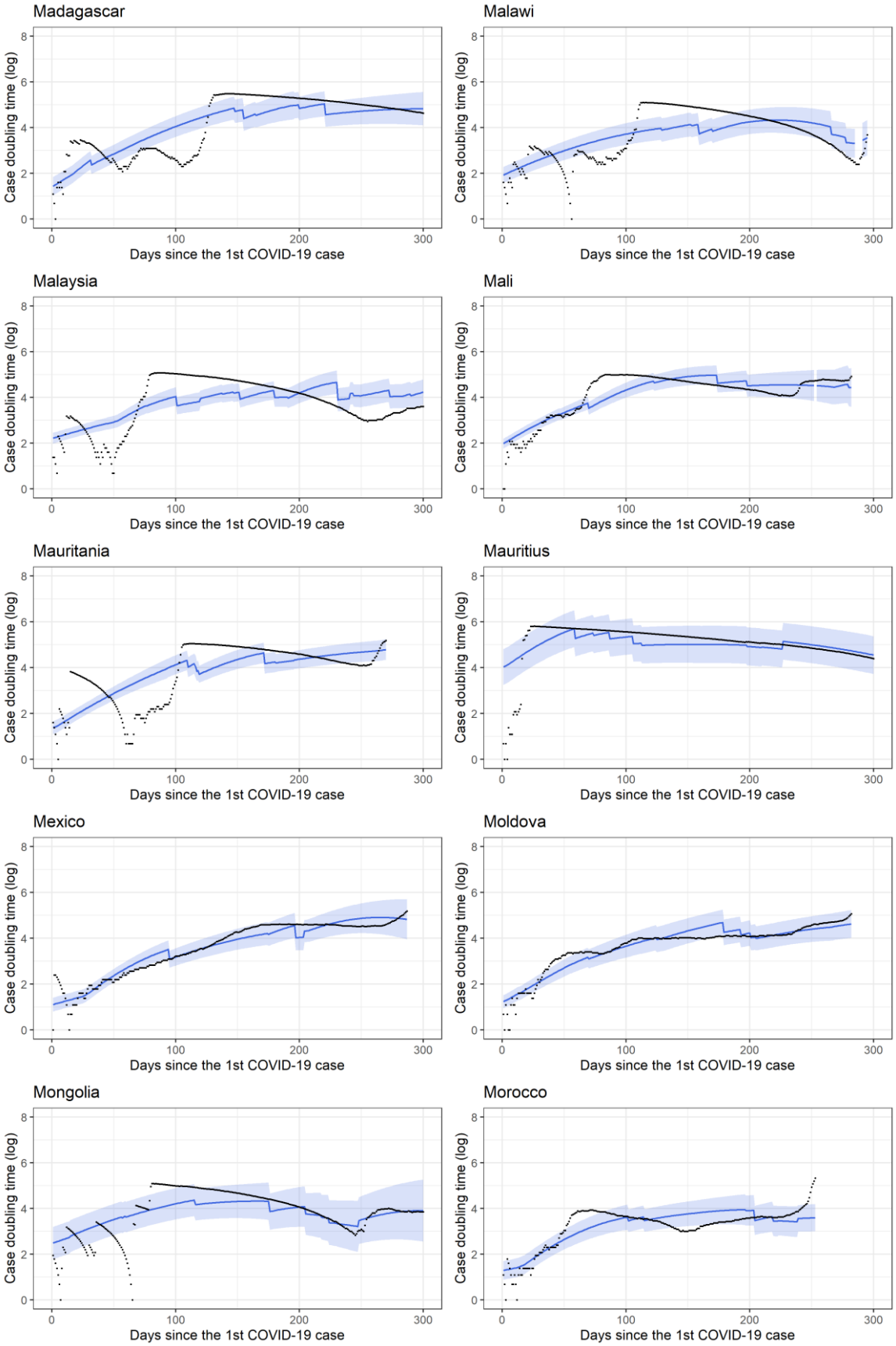

Chile
Colombia
Congo
Costa Rica
Cote d'Ivoire
Croatia
Czech Republic
Democratic Republic of Congo
Denmark
Dominican Republic
Case doubling time (log)
Days since the 1st COVID-19 case

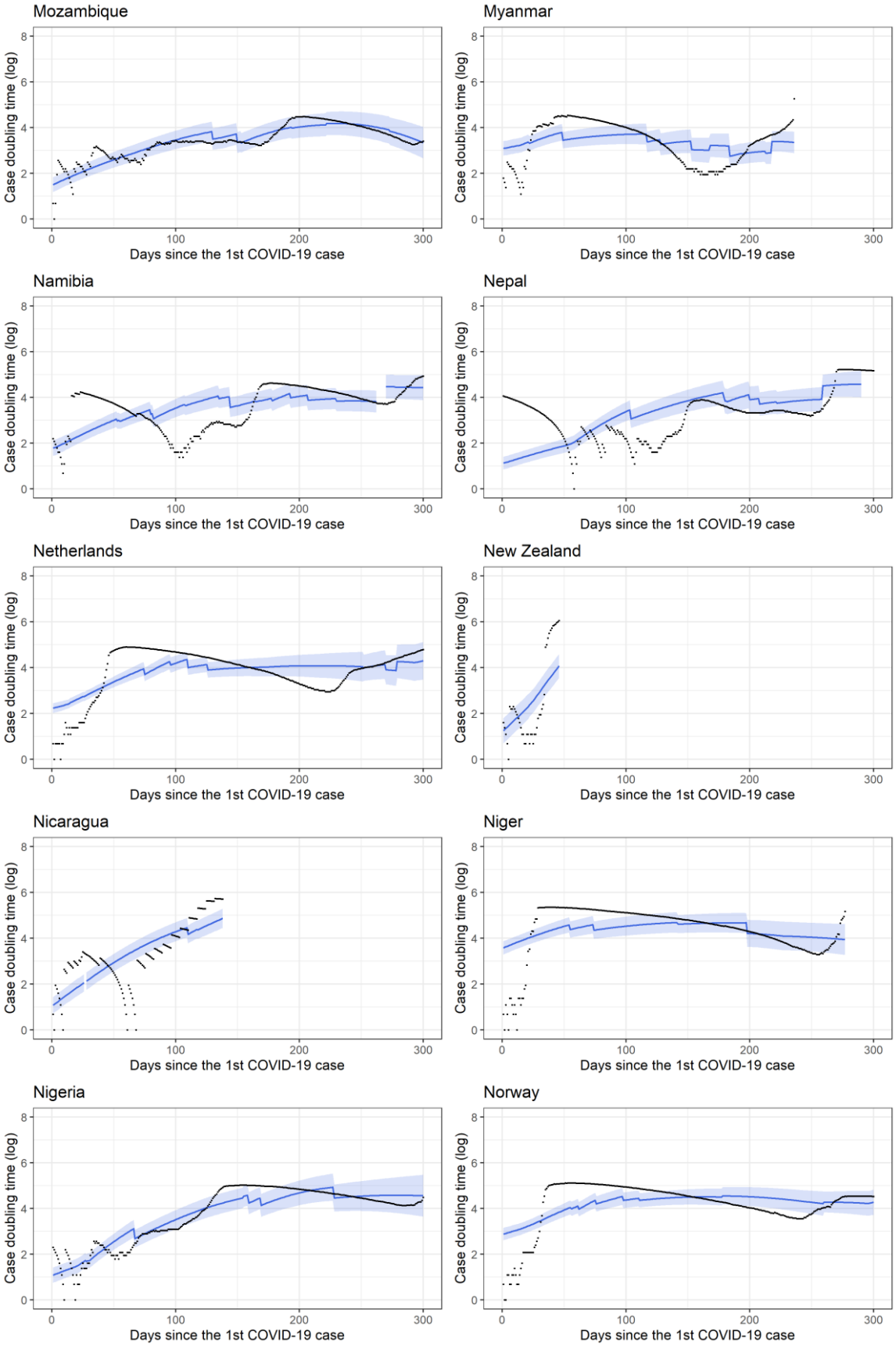

Ecuador
Egypt
El Salvador
Estonia
Eswatini
Ethiopia
Finland
France
Gabon
Gambia
Case doubling time (log)
Days since the 1st COVID-19 case
0
2
4
6
8
0
100
200
300

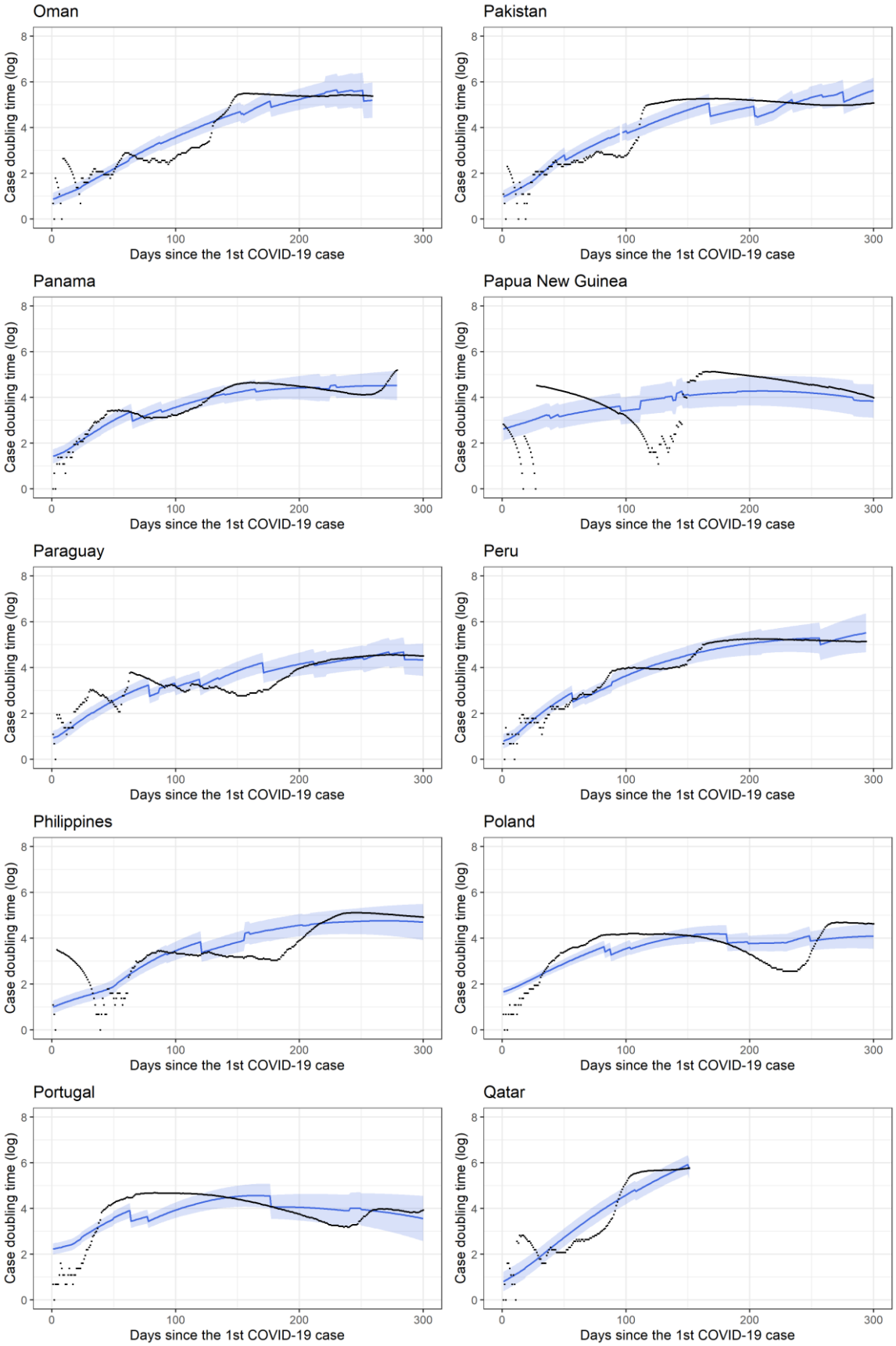

Georgia
Germany
Ghana
Greece
Guatemala
Guinea
Haiti
Honduras
Hungary
India
Case doubling time (log)
Days since the 1st COVID-19 case
0
2
4
6
8
0
100
200
300

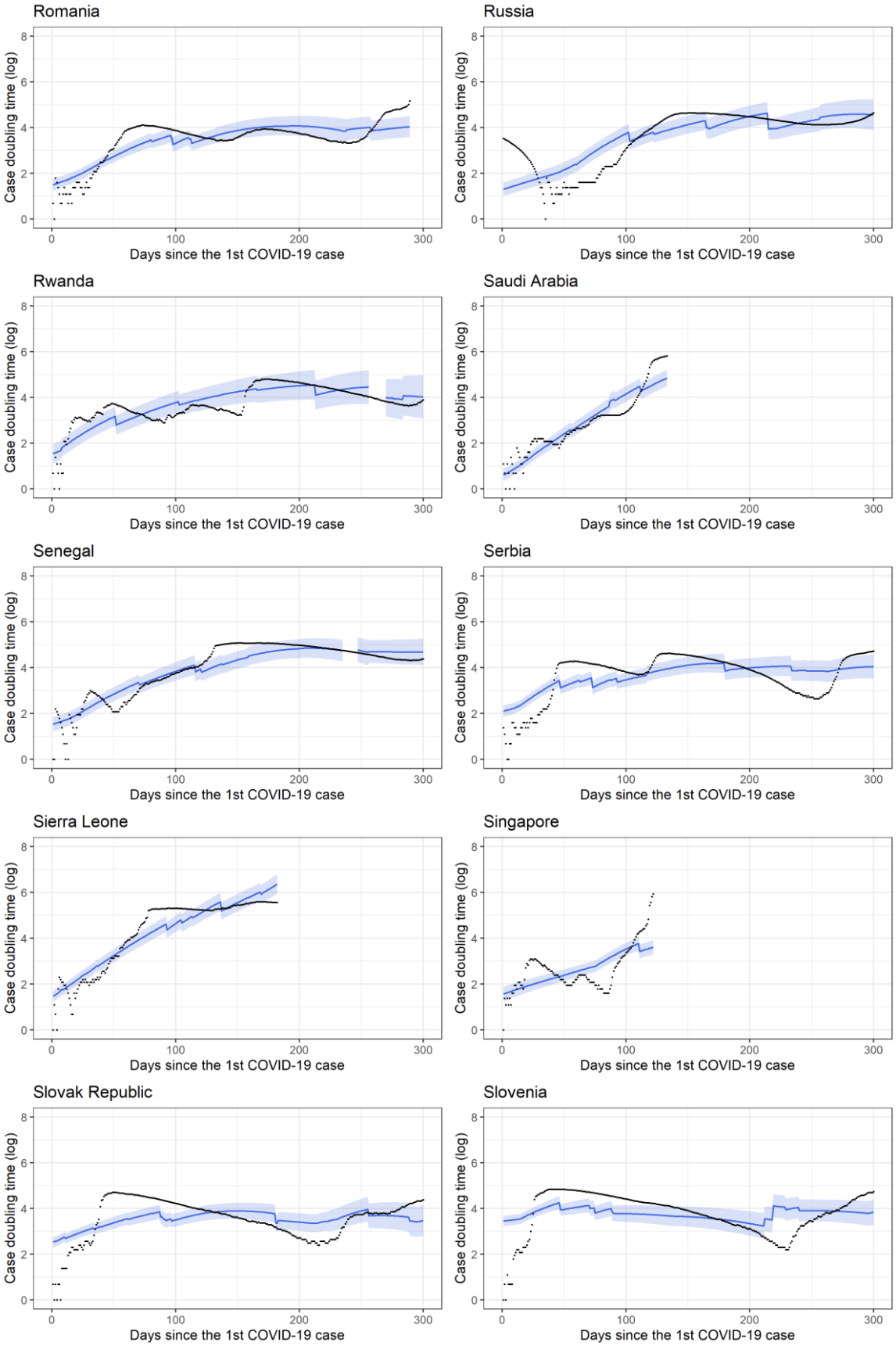

Indonesia
Iran
Iraq
Ireland
Israel
Italy
Jamaica
Japan
Jordan
Kazakhstan
Case doubling time (log)
Days since the 1st COVID-19 case
0
2
4
6
8
0
100
200
300

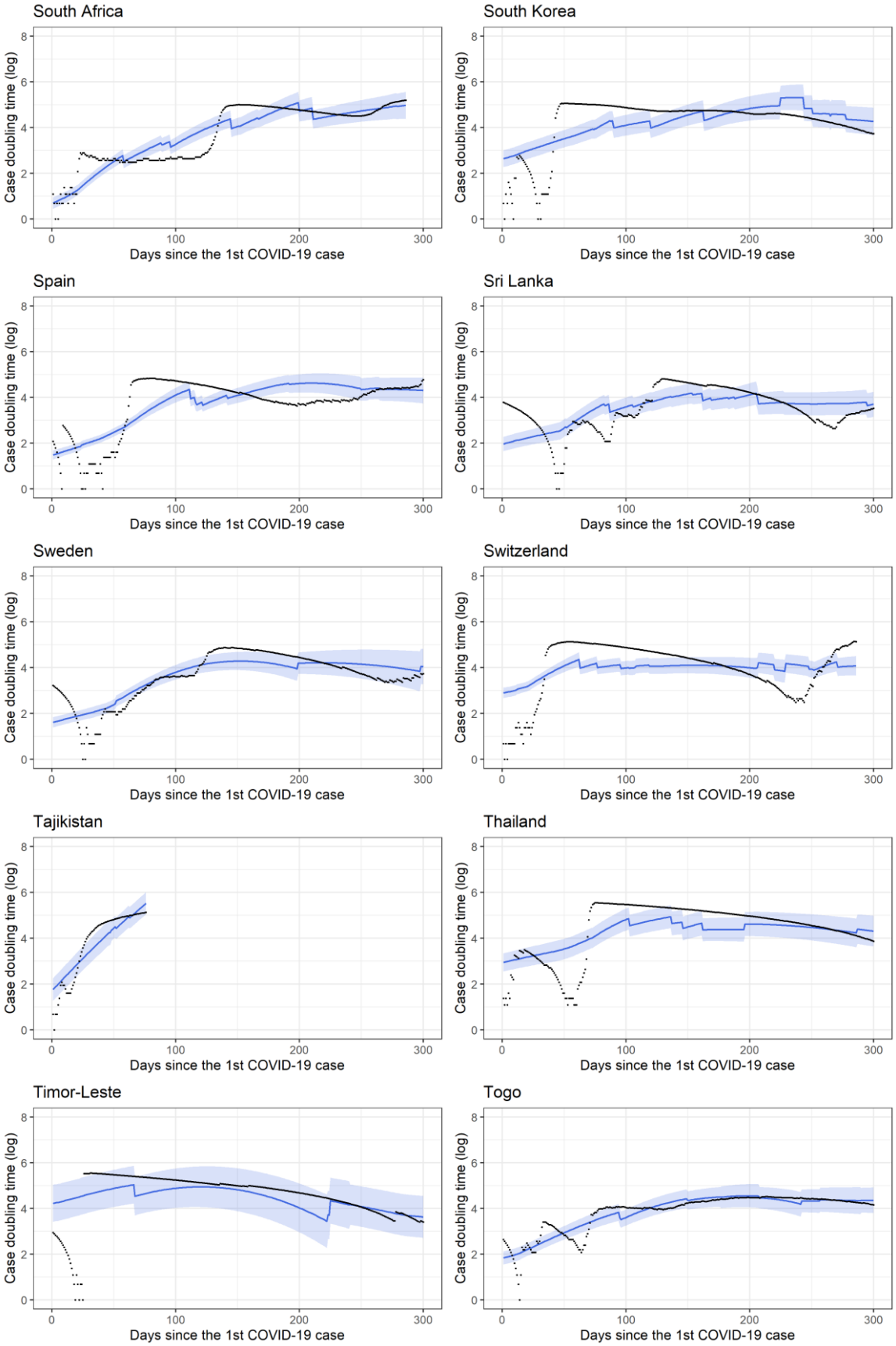

Kenya
Kuwait
Kyrgyz Republic
Laos
Latvia
Lebanon
Lesotho
Liberia
Libya
Lithuania
Case doubling time (log)
Days since the 1st COVID-19 case
0
2
4
6
8
0
100
200
300

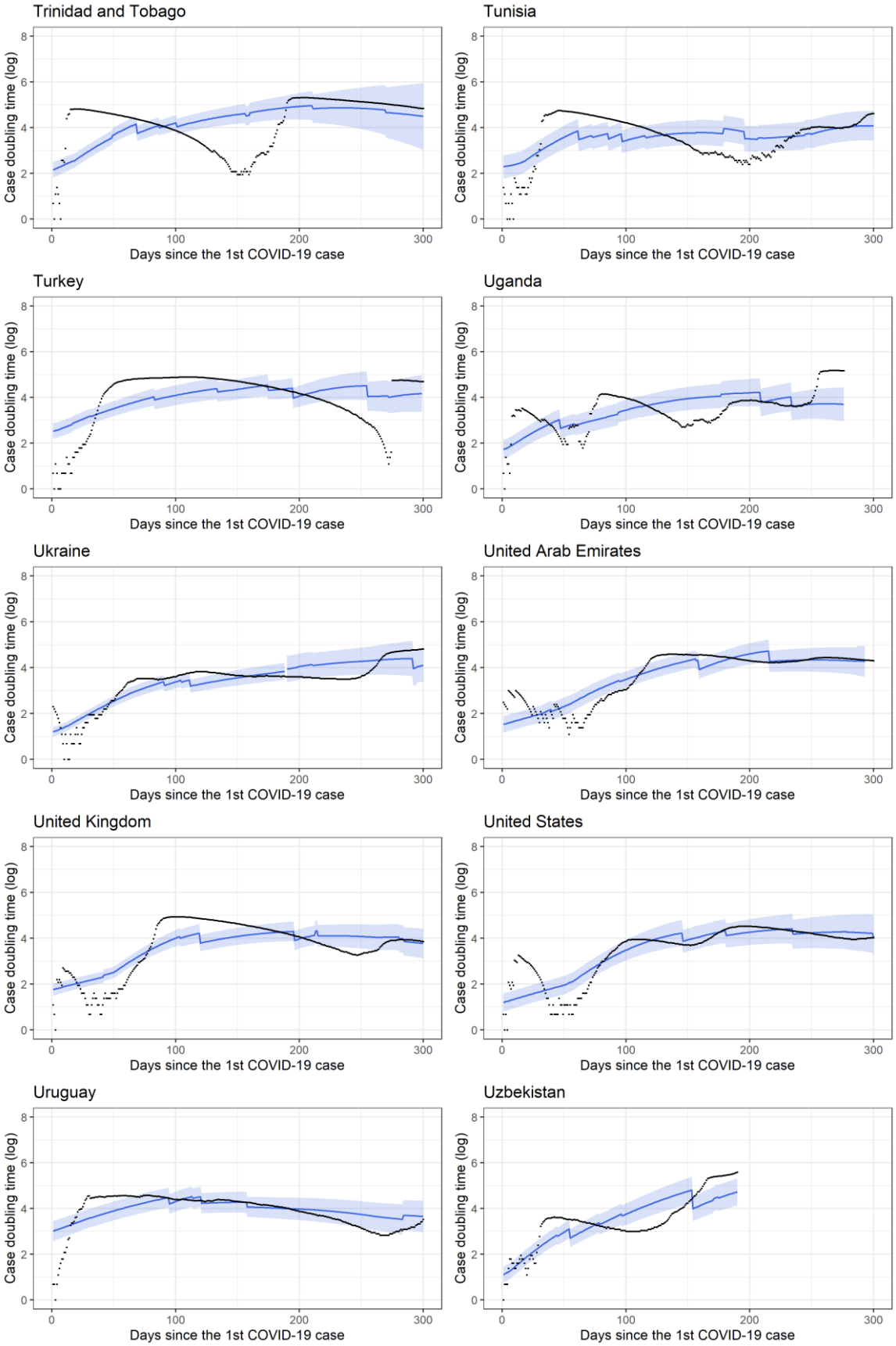

Madagascar
Malawi
Malaysia
Mali
Mauritania
Mauritius
Mexico
Moldova
Mongolia
Morocco
Case doubling time (log)
Days since the 1st COVID-19 case
0
2
4
6
8
0
100
200
300


Mozambique
Myanmar
Namibia
Nepal
Netherlands
New Zealand
Nicaragua
Niger
Nigeria
Norway
Case doubling time (log)
Days since the 1st COVID-19 case
0
2
4
6
8
0
100
200
300


Oman
Pakistan
Panama
Papua New Guinea
Paraguay
Peru
Philippines
Poland
Portugal
Qatar
Case doubling time (log)
Days since the 1st COVID-19 case


Romania
Russia
Rwanda
Saudi Arabia
Senegal
Serbia
Sierra Leone
Singapore
Slovak Republic
Slovenia
Case doubling time (log)
Days since the 1st COVID-19 case
0
2
4
6
8
0
100
200
300


South Africa
South Korea
Spain
Sri Lanka
Sweden
Switzerland
Tajikistan
Thailand
Timor-Leste
Togo
Case doubling time (log)
Days since the 1st COVID-19 case
0
2
4
6
8
0
100
200
300


Trinidad and Tobago
Tunisia
Turkey
Uganda
Ukraine
United Arab Emirates
United Kingdom
United States
Uruguay
Uzbekistan
Case doubling time (log)
Days since the 1st COVID-19 case
0
2
4
6
8
0
100
200
300

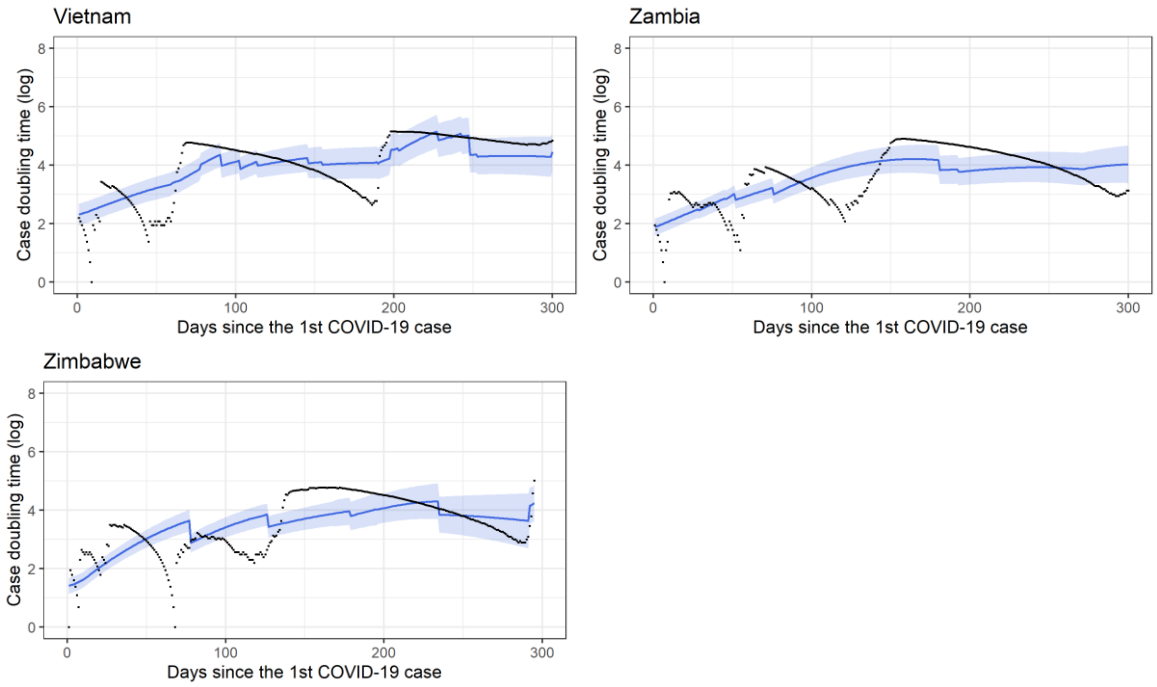


Figure S11 Predicted versus observed trends of case doubling time for 137 countries