

Más allá del modelo SIR: modelo SCIR, SIR con confinamiento (o cuidadosos)

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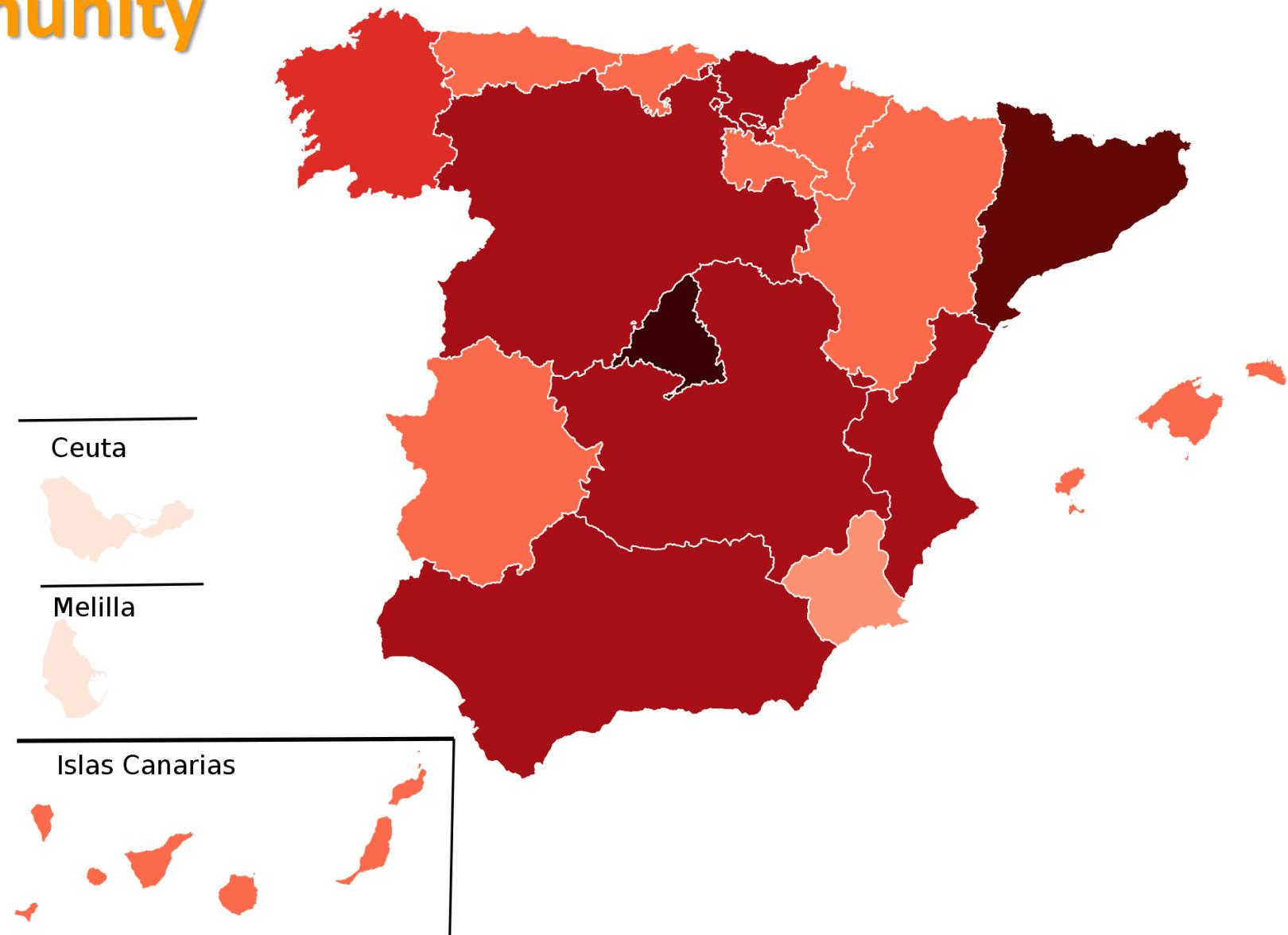
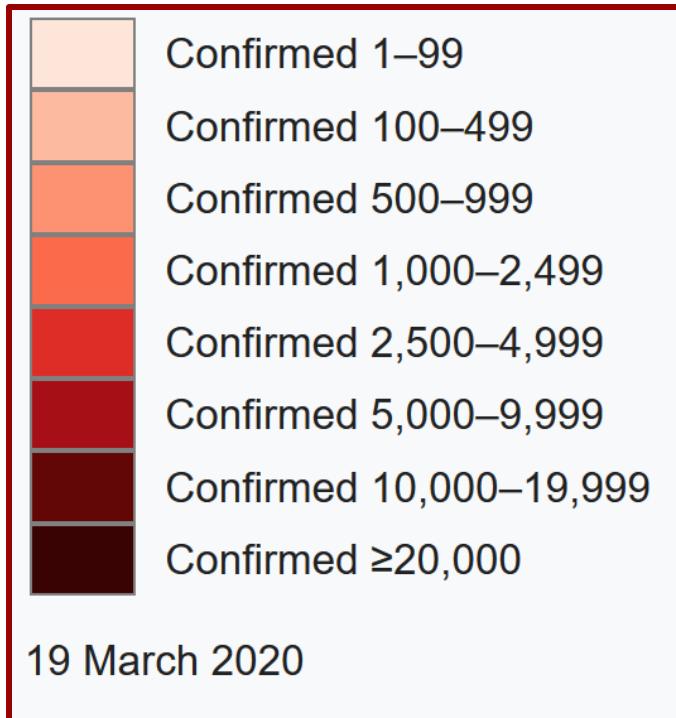
Máster Universitario en Bioinformática y Biología Computacional
Universidad Autónoma de Madrid

Biología de Sistemas

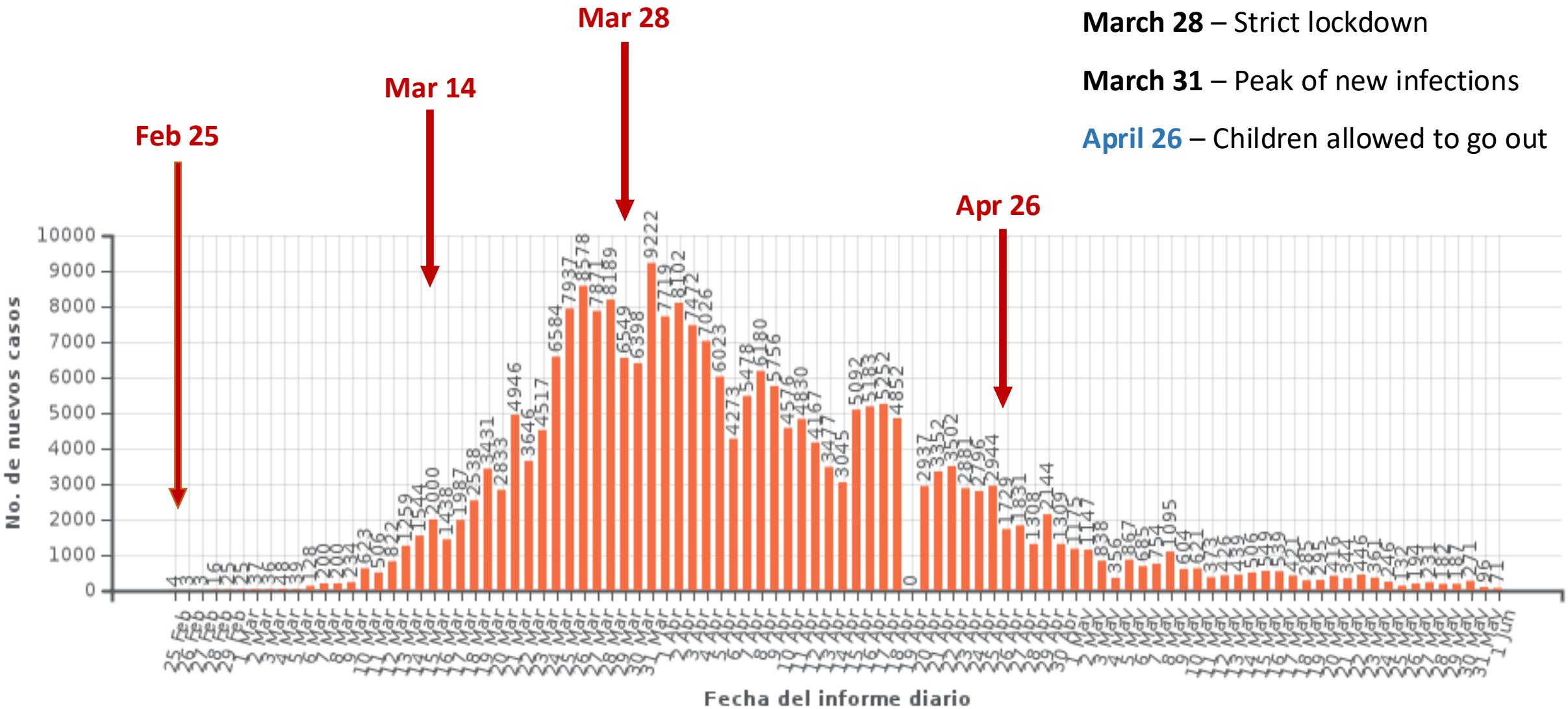
Madrid, 24 de abril de 2025



Number of COVID-19 cases in Spain by autonomous community



Daily cases: infection



February 26 – First local contagion

March 11 – Schools close

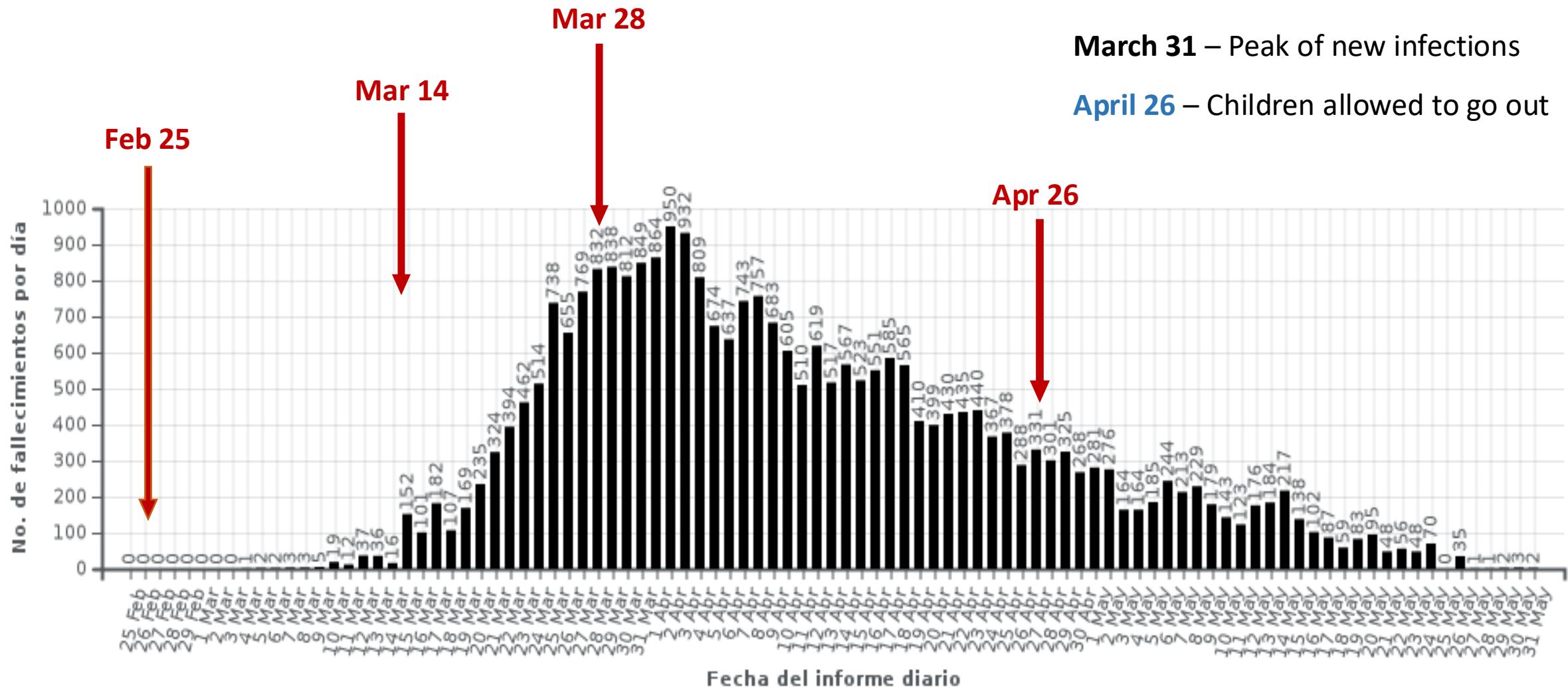
March 14 – State of alarm – Lockdown

March 28 – Strict lockdown

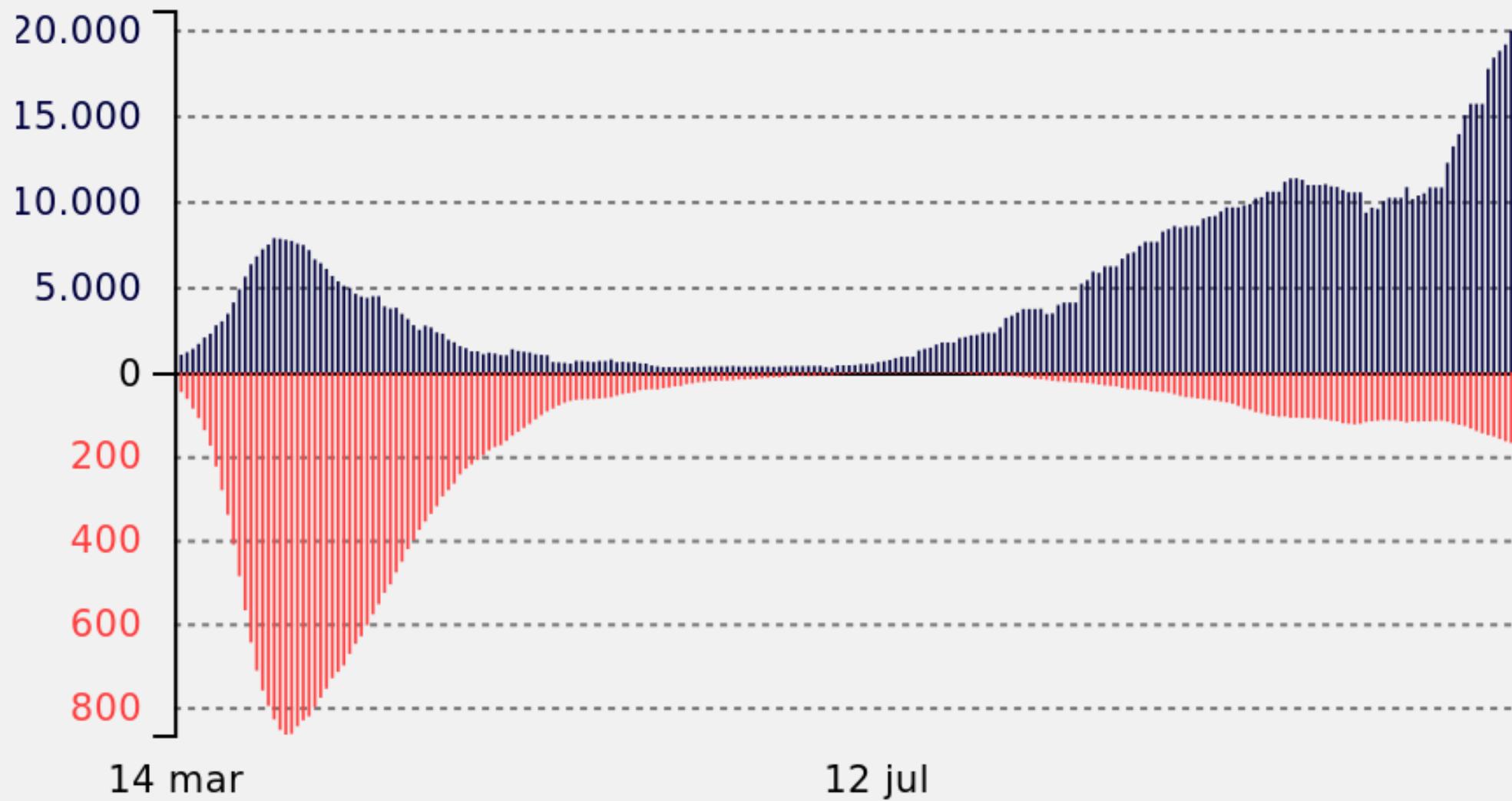
March 31 – Peak of new infections

April 26 – Children allowed to go out

Daily cases: deaths



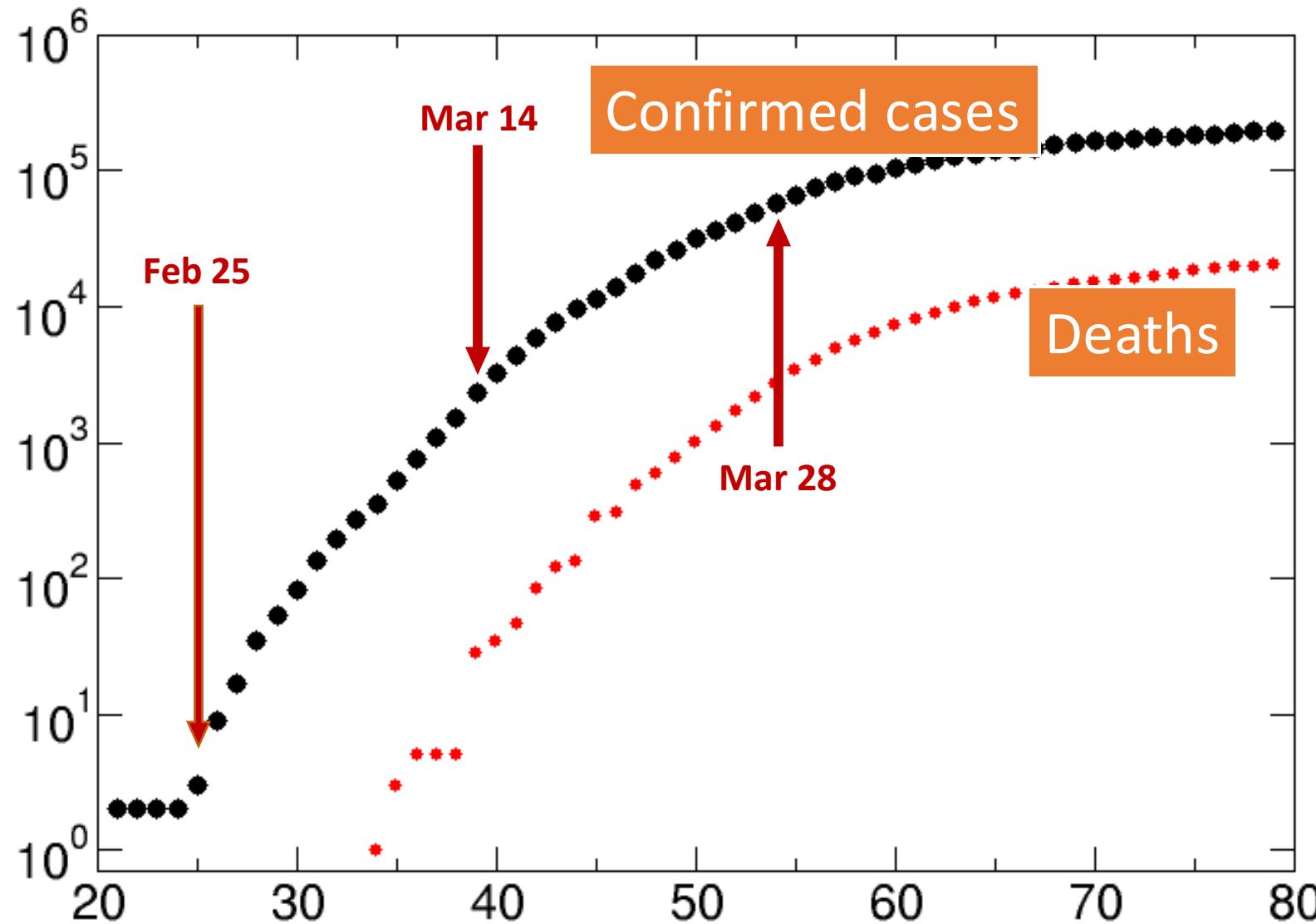
Evolución de casos diagnosticados y muertes (media 7 días)



Fuente: Ministerio de Sanidad e ISCIII

* Últimos datos: 8/11/2020

Our first motivation: a bending curve



- January 31** – First confirmed case
- February 13** – First death
- February 26** – First local contagion
- March 11** – Schools close
- March 14** – State of alarm – Lockdown
- March 28** – Strict lockdown
- March 31** – Peak of new infections
- April 26** – Children allowed to go out
- May 2** – Deescalation begins
- Currently:** Phase 2 in Madrid
- June 20** – End of state of alarm

Our second motivation: future tellers

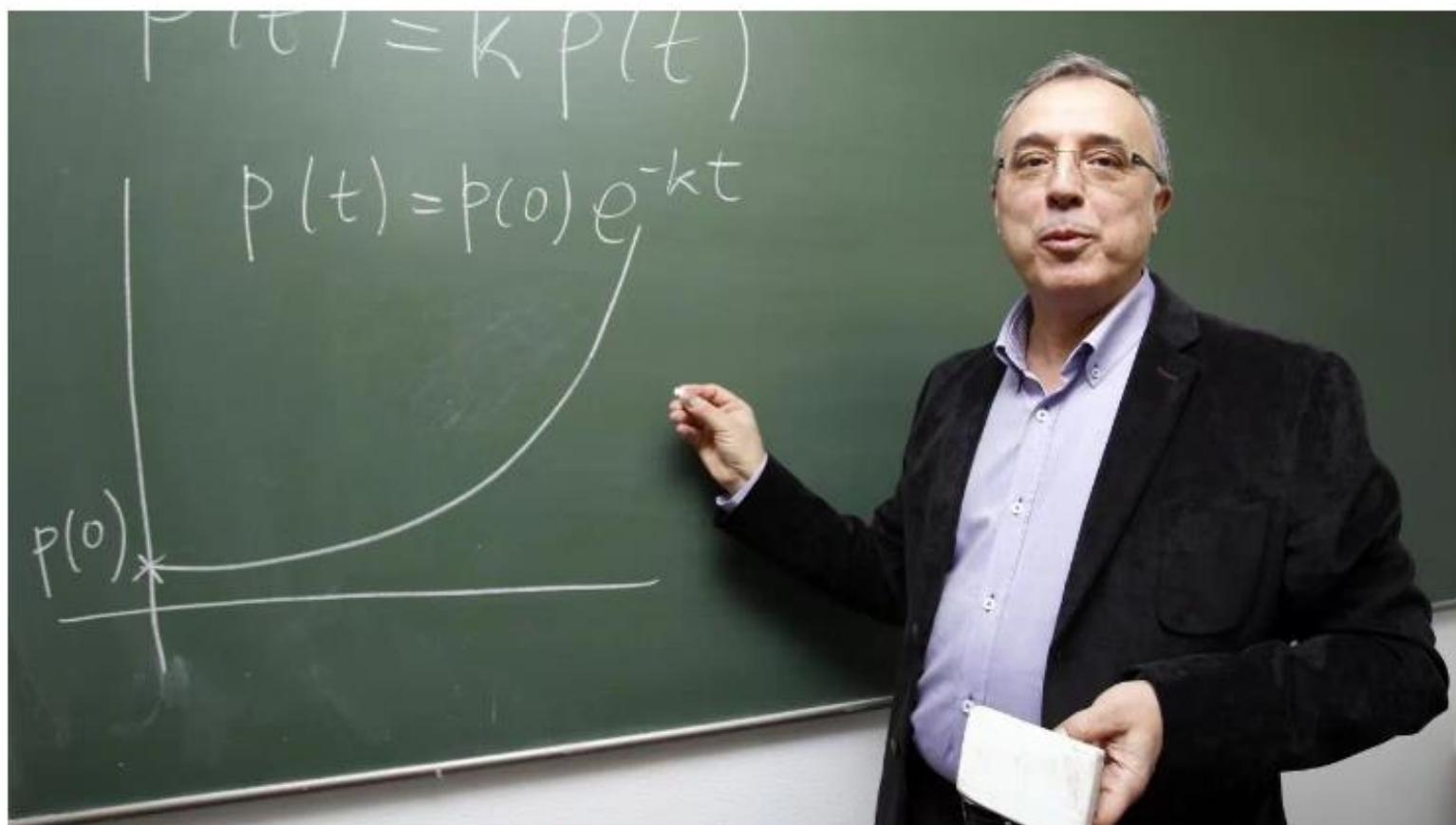


March 19

La crisis del coronavirus

«El pico máximo de contagios se producirá a principios de abril»

Juan José Nieto, catedrático de Análisis Matemático, lidera un grupo de expertos gallegos y lusos que han diseñado un modelo que predice la evolución del virus



Juan José Nieto, catedrático de Análisis Matemático. XOÁN A. SOLER

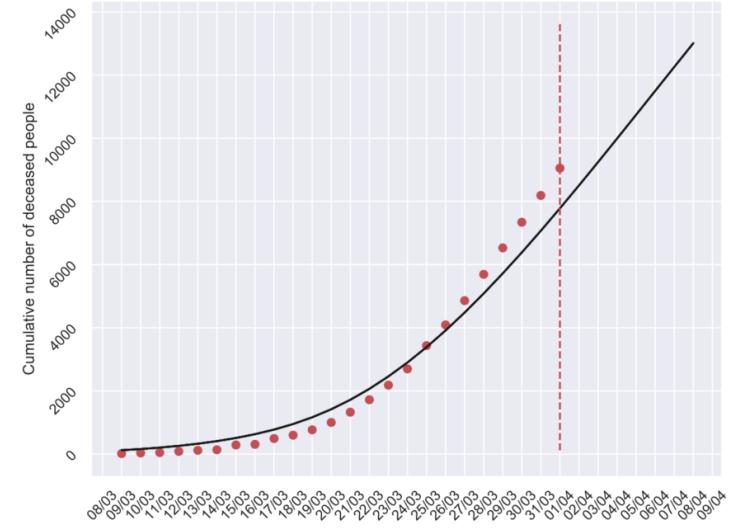


GESTIONA TU PATRIMONIO BOLSA ESPAÑA BOLSA EUROPA BOLSA EEUU MATERIAS PRIMAS

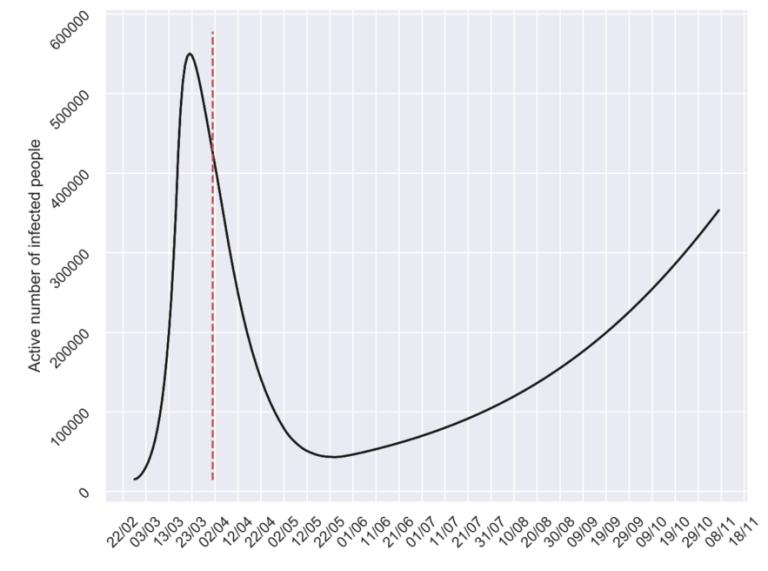
Fallecidos acumulados

¿Cuándo podremos salir de casa?

Partiendo de esta base, **¿cuándo podemos anticipar una salida del confinamiento?** El modelo de la UPV plantea un levantamiento progresivo y escalonado del aislamiento. Así, el 1 de mayo, el confinamiento concluye para 1 de cada 4 ciudadanos recluidos, mientras que el 8 de mayo se amplía la medida al 50% de los ciudadanos que no pueden salir de casa. El 15 de mayo se daría un nuevo paso, con el levantamiento del confinamiento para 3 de cada 4 personas, mientras que **el 22 de mayo se produciría una normalización**, pero no absoluta sino relativa, puesto que es de asumir que se seguirán imponiendo ciertas restricciones y limitaciones orientadas a mantener ciertos niveles de aislamiento social.



Fallecidos acumulados



Escenario desfavorable

La predicción del matemático Santiago García sobre el coronavirus: "Si las condiciones no cambian, todo acabaría entre el 10 y el 12 de mayo"

#LiarlaPardo82

DIRECTO



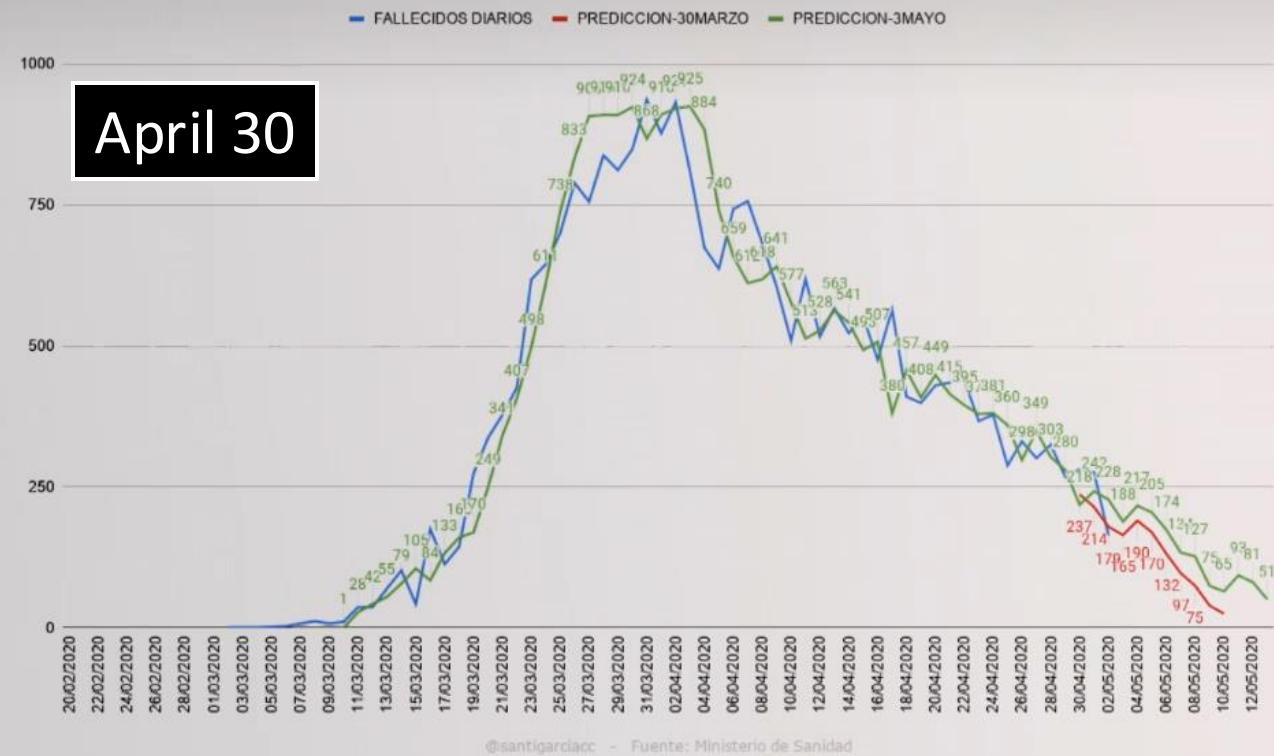
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CRISIS DEL CORONAVIRUS

LIARLA
PARDO

Hablamos con Santiago García, un matemático que ha desarrollado un modelo capaz de predecir la evolución del coronavirus en nuestro país

PREDICCIÓN EVOLUCIÓN DE COVID-19

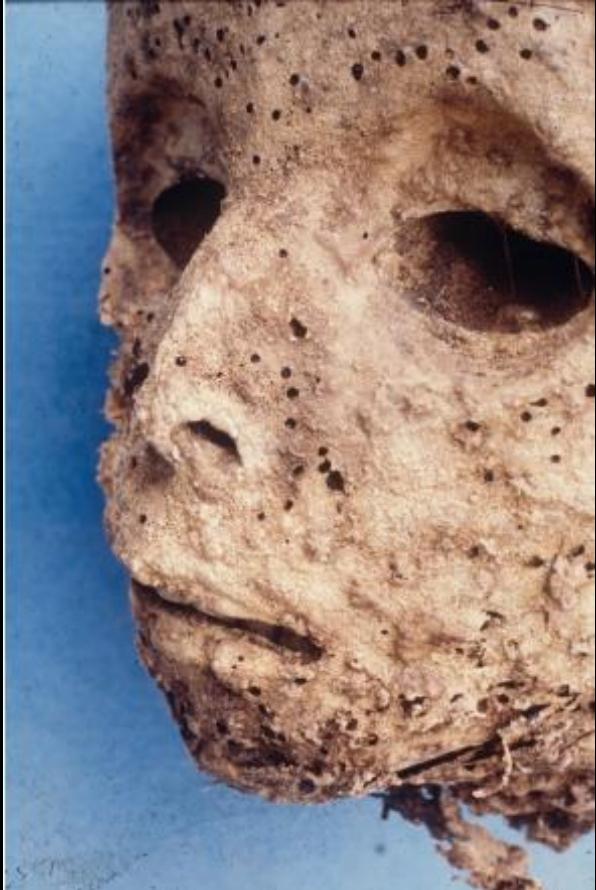


@santigarciacc - Fuente: Ministerio de Sanidad



A small history of epidemic modeling

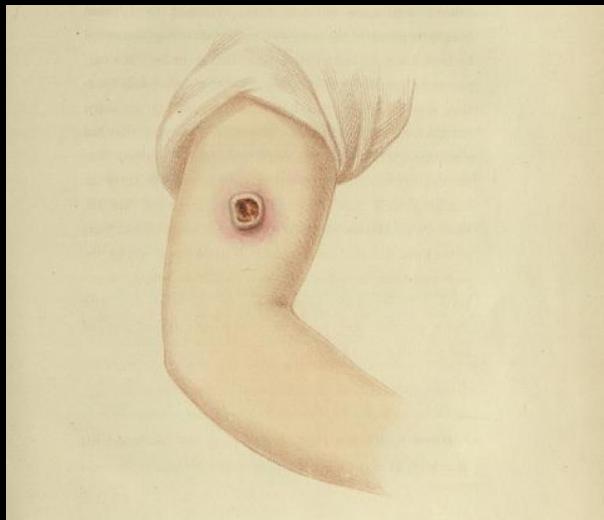
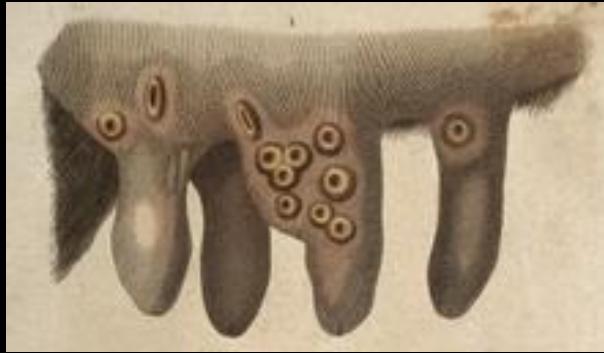
Smallpox



Mummy, III c. BC

Only in the XX century, it caused 300 million deaths before its eradication (1980)

Europe, XVIII century: inoculation (variolation)



The Cow-Pock — or — the Wonderful Effects of the New Inoculation! — Vide. the Publications of the Anti-Vaccine Society.

Is variolation a good idea?

- An infected individual dies with probability p
- An individual gets infected with rate q
- Once recovered, an individual is never infected again

$m(t)$ is the probability of dying for causes other than smallpox

$S(t)$ is the number of susceptible individuals
 $R(t)$ is the number of recovered individuals



Daniel Bernoulli (1700-1782)

Is variolation a good idea?

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$m(t)$ is the probability of dying for causes other than smallpox

$S(t)$ is the number of susceptible individuals
 $R(t)$ is the number of recovered individuals

$$\dot{S} = -qS - m(t)S$$

$$\dot{R} = q(1 - p)S - m(t)R$$

Is variolation a good idea?

Age.	Per- sons.	Age.	Per- sons	Age.	Per- sons	Age.	Per- sons	Age.	Per- sons	Age.	Per- sons	Age.	Per- sons.
Curt.		Curt.		Curt.		Curt.		Curt.		Curt.		Curt.	
1	1000	8	680	15	628	22	585	29	539	36	481	7	5547
2	855	9	670	16	622	23	579	30	531	37	472	14	4584
3	798	10	661	17	616	24	573	31	523	38	463	21	4270
4	760	11	653	18	610	25	567	32	515	39	454	28	3964
5	732	12	646	19	604	26	560	33	507	40	445	35	3604
6	710	13	640	20	598	27	553	34	499	41	436	42	3178
7	692	14	634	21	592	28	546	35	490	42	427	49	2709
												56	2194
Age.	Per- sons.	Age.	Per- sons	Age.	Per- sons	Age.	Per- sons	Age.	Per- sons	Age.	Per- sons	Age.	Per- sons.
Curt.	<th>Curt.</th> <td><th>Curt.</th><td><th>Curt.</th><td><th>Curt.</th><td><th>Curt.</th><td><th>Curt.</th><td></td></td></td></td></td></td>	Curt.	<th>Curt.</th> <td><th>Curt.</th><td><th>Curt.</th><td><th>Curt.</th><td><th>Curt.</th><td></td></td></td></td></td>	Curt.	<th>Curt.</th> <td><th>Curt.</th><td><th>Curt.</th><td><th>Curt.</th><td></td></td></td></td>	Curt.	<th>Curt.</th> <td><th>Curt.</th><td><th>Curt.</th><td></td></td></td>	Curt.	<th>Curt.</th> <td><th>Curt.</th><td></td></td>	Curt.	<th>Curt.</th> <td></td>	Curt.	
43	417	50	346	57	272	64	202	71	131	78	58	77	692
44	407	51	335	58	262	65	192	72	120	79	49	84	253
45	397	52	324	59	252	65	182	73	109	80	41	100	107
46	387	53	313	60	242	67	172	74	98	81	34		
47	377	54	302	61	232	68	162	75	88	82	28		34000
48	367	55	292	62	222	69	152	76	78	83	23		
49	357	56	282	63	212	70	142	77	68	84	20		Sum Total.

$$\dot{S} = -qS - m(t)S$$

$$\dot{R} = q(1-p)S - m(t)R$$

$$p=1/8$$

$$q=1/8 \text{ yr}^{-1}$$

A fraction 1/13 dies from smallpox

Births and deaths in Wrocław between 1687 y 1691

Is variolation a good idea?

Life expectancy without variolation:
26 years and 7 months

Life expectancy with variolation:
29 years and 8 months

$$\begin{aligned}\dot{S} &= -qS - m(t)S \\ \dot{R} &= q(1 - p)S - m(t)R\end{aligned}$$

$$\begin{aligned}p &= 1/8 \\ q &= 1/8 \text{ yr}^{-1}\end{aligned}$$

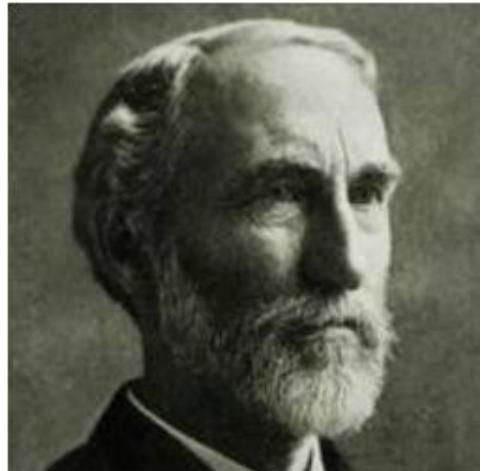
A fraction 1/13 dies from smallpox

“I simply wish that, in a matter which so closely concerns the wellbeing of the human race, no decision shall be made without all the knowledge which a little analysis and calculation can provide”

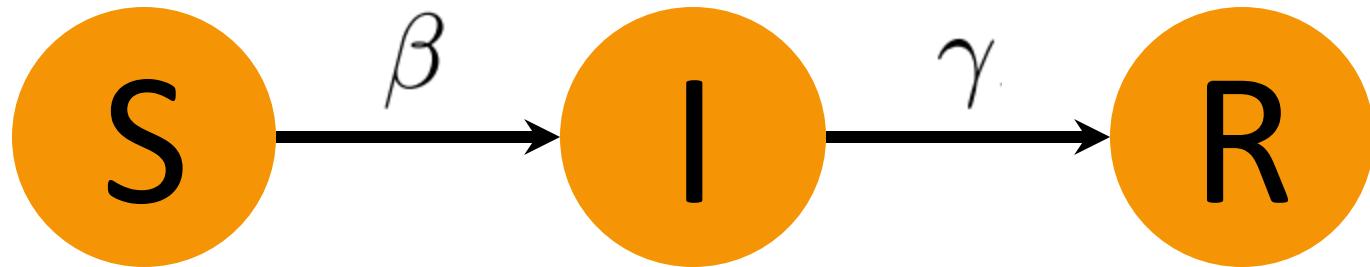
The SIR model, 1927



W. O. Kermack

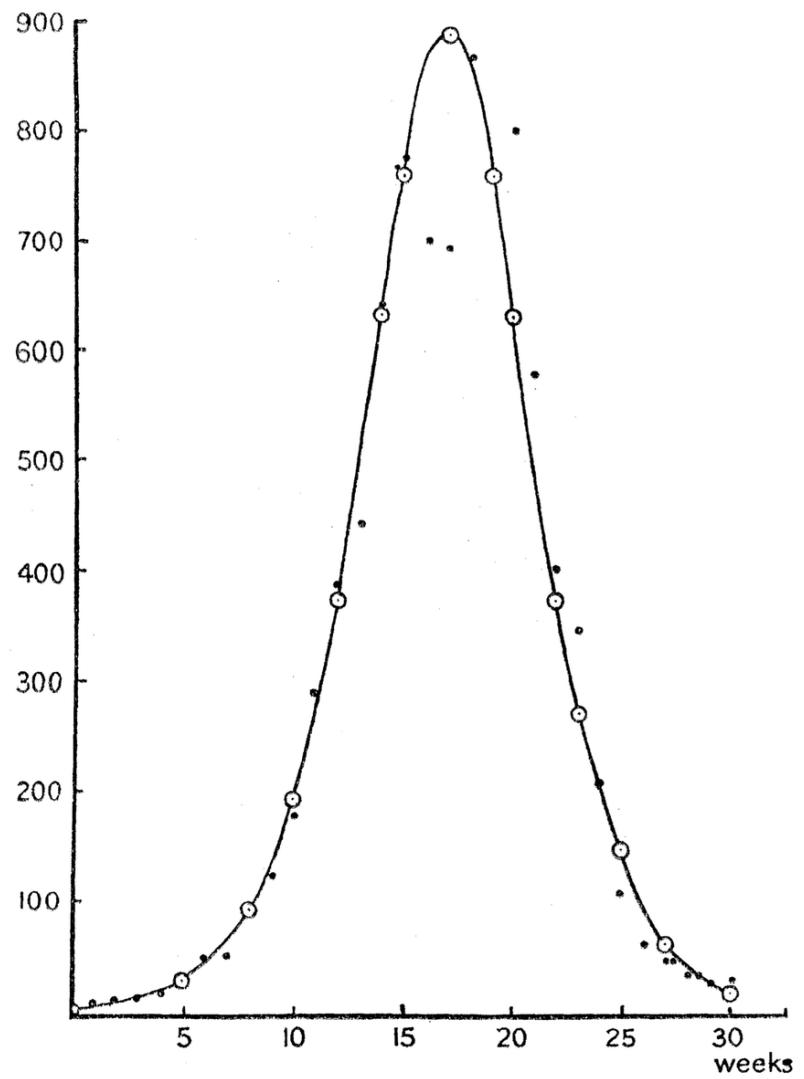


A. G. McKendrick



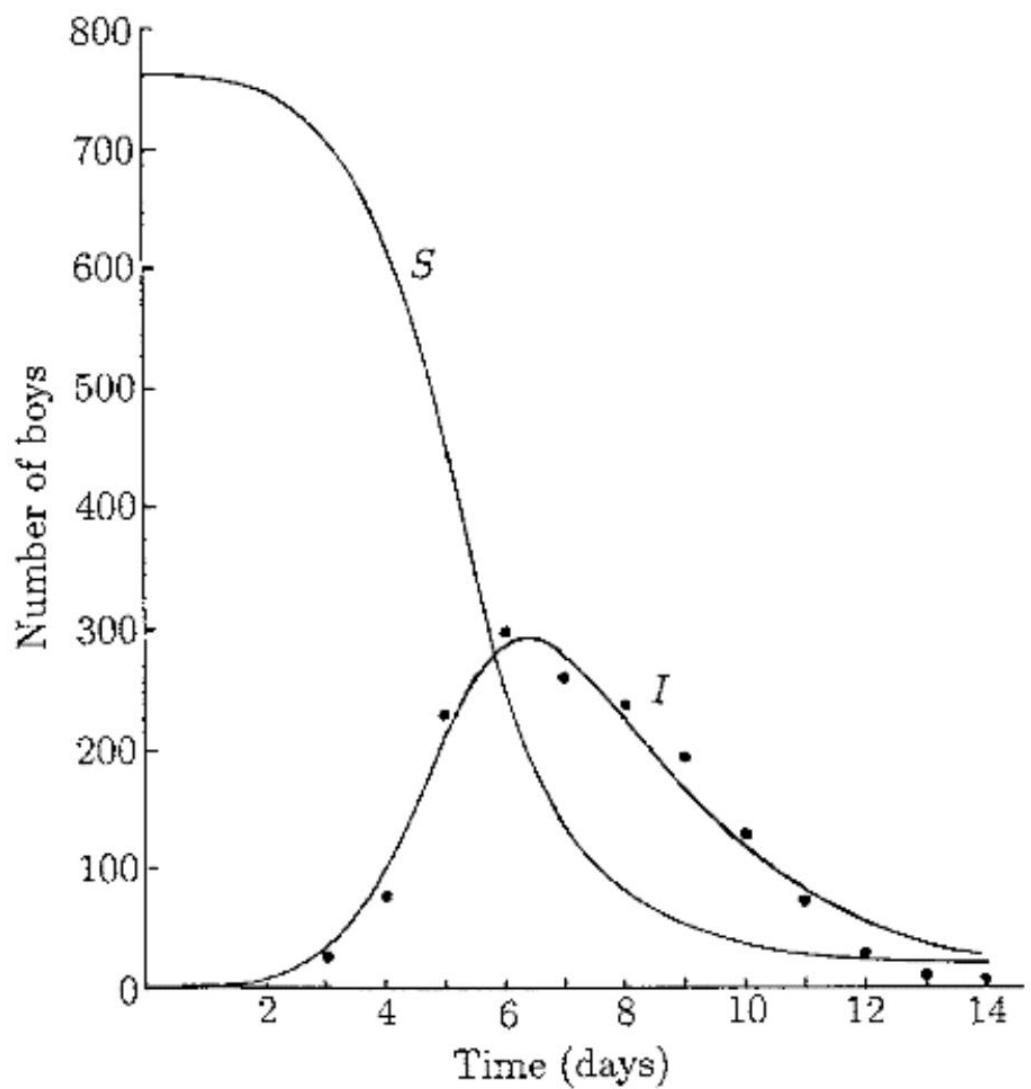
$$\begin{aligned}\dot{S} &= -\beta \left(\frac{I}{N} \right) S \\ \dot{I} &= \beta \left(\frac{I}{N} \right) S - \gamma I \\ \dot{R} &= \gamma I\end{aligned}$$

$$R_0 \equiv \frac{\beta}{\gamma}$$



fit of the SIR model to the data of the 1905-1906
plague at Bombay

kermack & mckendrick, Proc. Royal Soc. 1927

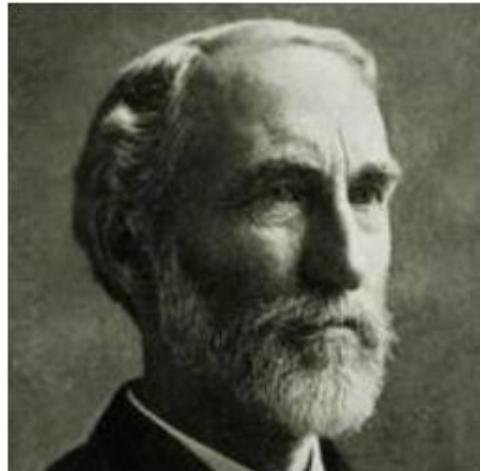


influenza epidemic in a british boy's school, as reported
in *the lancet* on march 4 1978

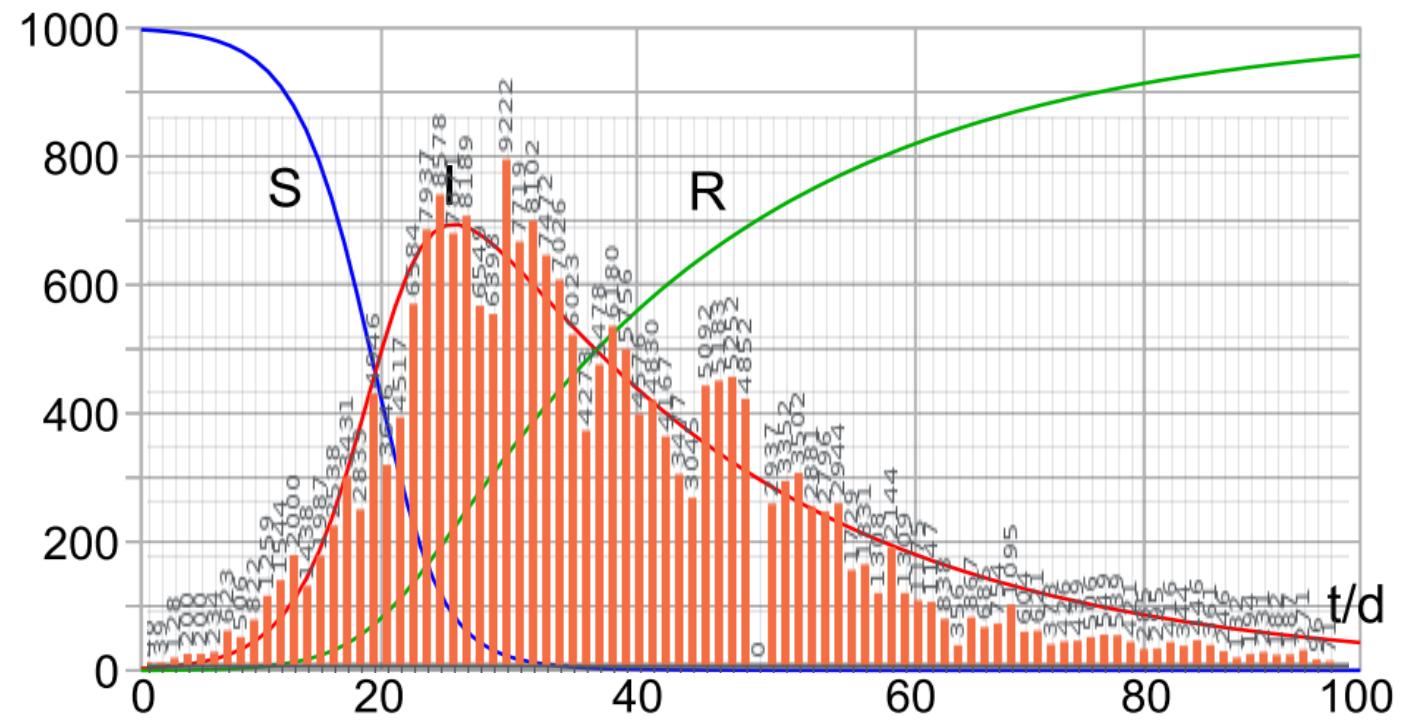
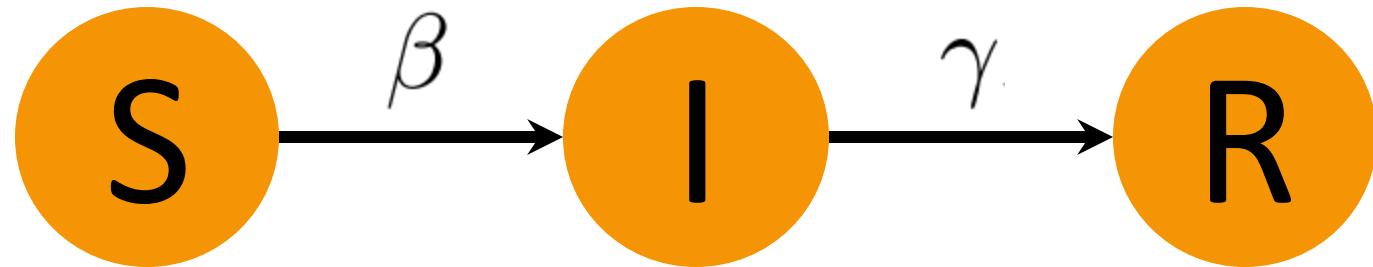
The SIR model, 1927



W. O. Kermack



A. G. McKendrick



Checklist for the epidemics modeller (especially with predictive ambitions)

- Is my model able to capture the past dynamics of the pandemic?
If yes, I have to show it unambiguously
- Can data be fit with suitably chosen effective parameters?
If so, can I assign a precise meaning to fitting values?
- What is the error associated to those parameters? *Because there IS an error*
- Can the fit be projected into the future? *Before drawing too confident responses:*
 - What is the error associated to the prediction? *This exercise HAS to be done*
 - Can effective parameters be mapped to actual empirical values?
 - Are other models any better, or any worse? Why?

Factors affecting predictability

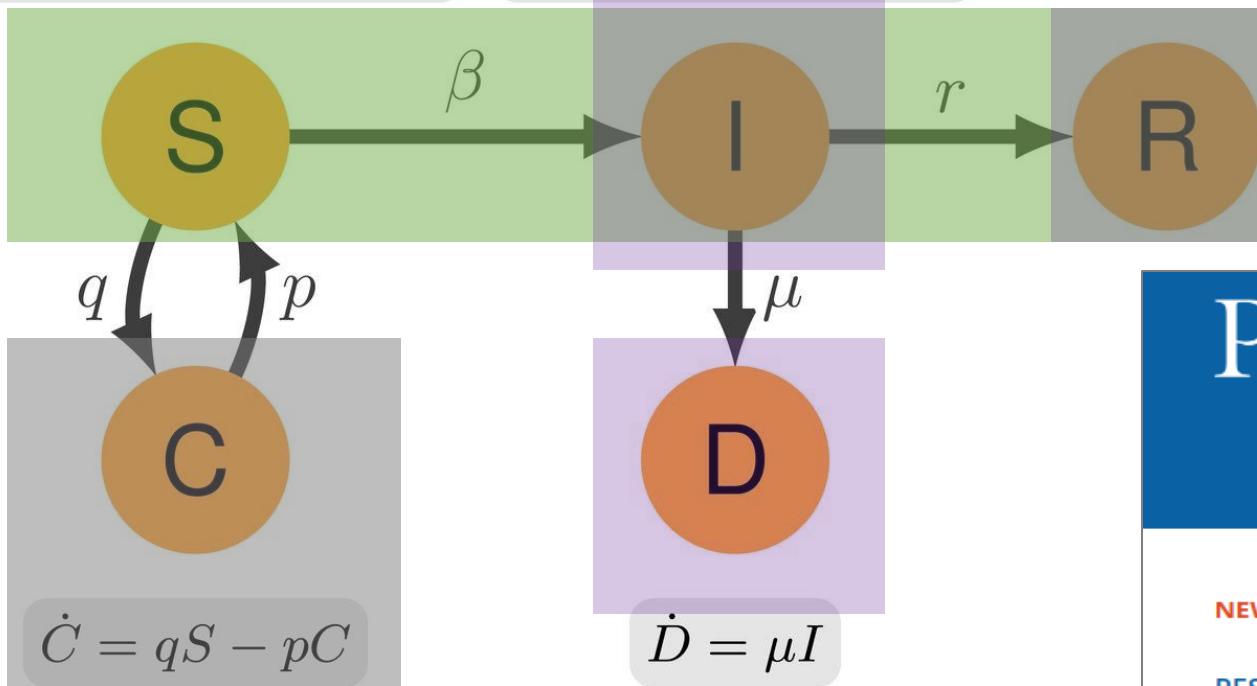
1. The quality of data – *Amendable*
2. Suitability of models – *Improvable*
3. Intrinsic uncertainty of models – *Unavoidable*

SCIR: a minimal model with confinement

$$\dot{S} = -\frac{\beta SI}{N} - qS + pC$$

$$\dot{I} = \frac{\beta SI}{N} - (r + \mu)I$$

$$\dot{R} = rI$$



Reversible!

Go to the root of the problem:
Keep it simple

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NEW RESEARCH IN Physical Sciences Social Sciences

RESEARCH ARTICLE

The turning point and end of an expanding epidemic cannot be precisely forecast

Mario Castro, Saúl Ares, José A. Cuesta, and Susanna Manrubia

PNAS first published October 1, 2020; <https://doi.org/10.1073/pnas.2007868117>

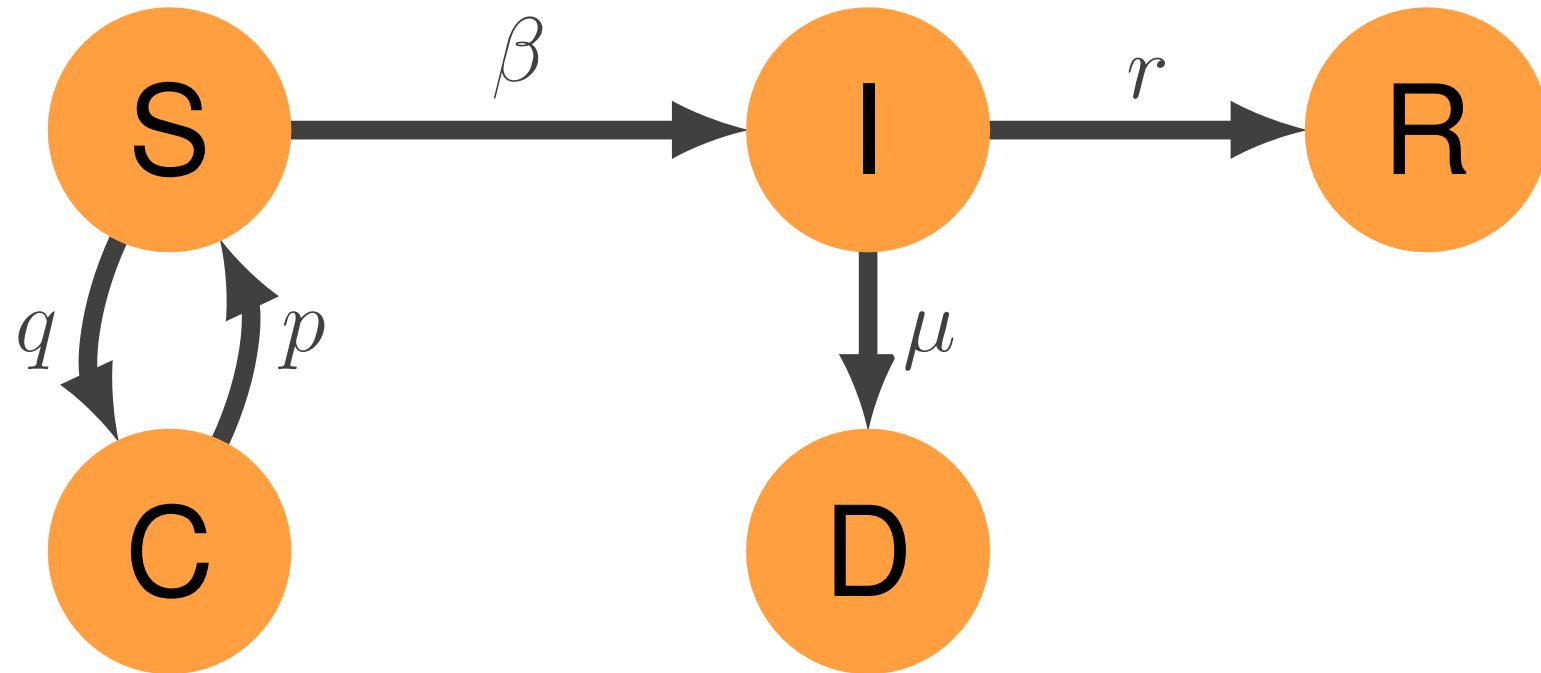
Edited by Eugene V. Koonin, National Institutes of Health, Bethesda, MD, and approved September 11, 2020
(received for review April 23, 2020)

A minimal SIR model with confinement: SCIR

$$\dot{S} = -\frac{\beta SI}{N} - qS + pC$$

$$\dot{I} = \frac{\beta SI}{N} - (r + \mu)I$$

$$\dot{R} = rI$$



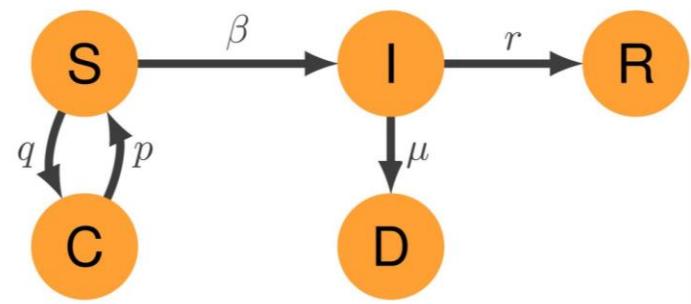
$$\dot{C} = qS - pC$$

$$\dot{D} = \mu I$$

$$\dot{S} = -\frac{\beta S I}{N} - qS + pC$$

$$\dot{C} = qS - pC$$

$$\dot{I} = \frac{\beta S I}{N} - (r + \mu)I$$

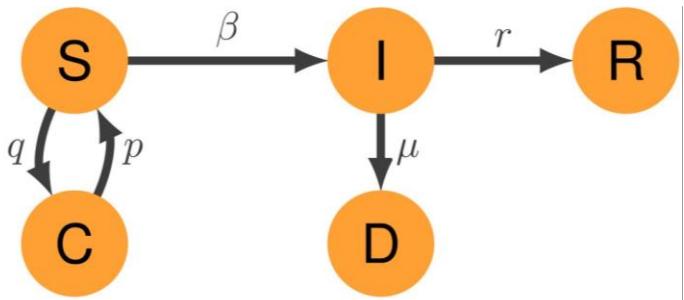


assumption: $I(t) \ll N$

$$\dot{S} = -\frac{\cancel{\beta SI}}{N} - qS + pC$$

$$\dot{C} = qS - pC$$

$$\dot{I} = \frac{\beta SI}{N} - (r + \mu)I$$



assumption: $I(t) \ll N$

Published in August 2020

THE LANCET

ARTICLES | VOLUME 396, ISSUE 10250, P535-544, AUGUST 22, 2020

Prevalence of SARS-CoV-2 in Spain (ENE-COVID): a nationwide, population-based seroepidemiological study

Prof Marina Pollán, MD • Beatriz Pérez-Gómez, MD • Roberto Pastor-Barriuso, PhD • Jesús Oteo, PhD •

Miguel A Hernán, MD • Mayte Pérez-Olmeda, PhD • et al. Show all authors • Show footnotes

Methods

35 883 households were selected from municipal rolls using two-stage random sampling stratified by province and municipality size, with all residents invited to participate. From April 27 to May 11, 2020, 61 075 participants (75·1% of all contacted individuals within selected households) answered a questionnaire on history of symptoms compatible with COVID-19 and risk factors, received a point-of-care antibody test, and, if agreed, donated a blood sample for additional testing with a chemiluminescent microparticle immunoassay. Prevalences of IgG antibodies were adjusted using sampling weights and post-stratification to allow for differences in non-response rates based on age group, sex, and census-tract income. Using results for both tests, we calculated a seroprevalence range maximising either specificity (positive for both tests) or sensitivity (positive for either test).

Findings

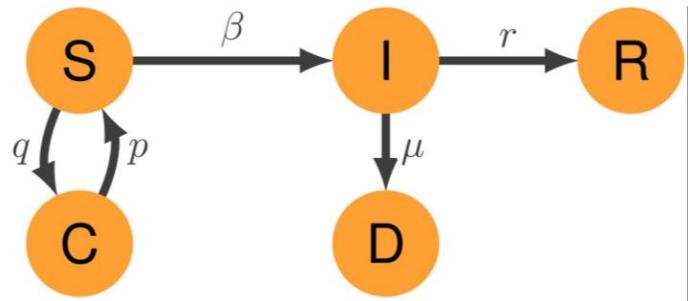
Seroprevalence was 5·0% (95% CI 4·7–5·4) by the point-of-care test and 4·6% (4·3–5·0) by immunoassay, with a specificity–sensitivity range of 3·7% (3·3–4·0; both tests positive) to 6·2% (5·8–6·6; either test positive), with no differences by sex and lower seroprevalence in children younger than 10 years (<3·1% by the point-of-care test). There was substantial geographical variability, with higher prevalence around Madrid (>10%) and lower in coastal areas (<3%). Seroprevalence among 195 participants with positive PCR more

assumption: $I(t) \ll N$

$$\dot{S} = -\frac{\beta S I}{N} - qS + pC$$

$$\dot{C} = qS - pC$$

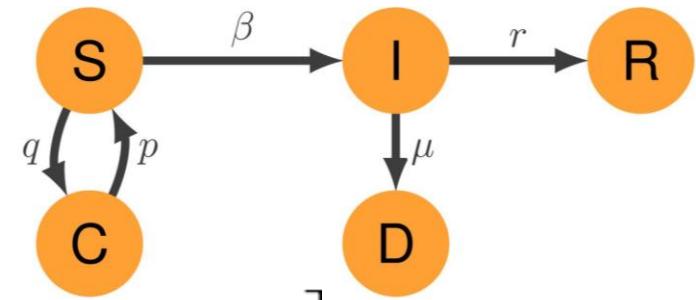
$$\dot{I} = \frac{\beta S I}{N} - (r + \mu)I$$



assumption: $I(t) \ll N$

$$\left. \begin{array}{l} \dot{S} = -\frac{\beta S I}{N} - qS + pC \\ \dot{C} = qS - pC \end{array} \right\}$$

$$S(t) = \frac{N}{q+p} \left[p + q e^{-(q+p)t} \right]$$



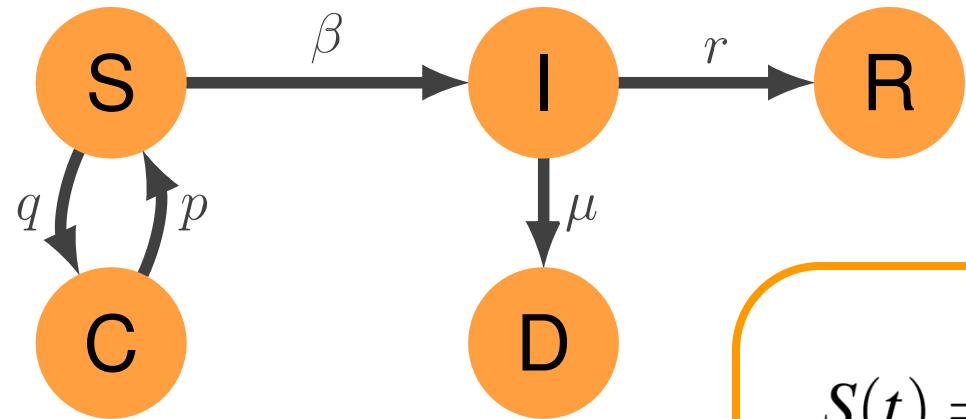
$$\dot{I} = \frac{\beta S I}{N} - (r + \mu)I$$

$$R_0 = \frac{\beta}{r + \mu}$$



$$I = I_0 e^{[R_0^*(t) - 1](r + \mu)t}, \quad R_0^*(t) = \frac{R_0}{q + p} \left[p + q \frac{1 - e^{-(q+p)t}}{(q + p)t} \right]$$

Solution in the limit $I(t) \ll N$



$$S + C = N$$

$$\begin{aligned}\dot{S} &= -(q+p)S + pN, \\ \dot{I} &= \frac{\beta}{N}IS - (r+\mu)I.\end{aligned}$$

$$S(t) = \frac{N}{q+p} \left[p + q e^{-(q+p)t} \right]$$

$$R(t) = r \int_0^t I(u) du,$$

$$I(t) = I_0 e^{[R_0^*(t)-1](r+\mu)t}$$

$$D(t) = \mu \int_0^t I(u) du$$

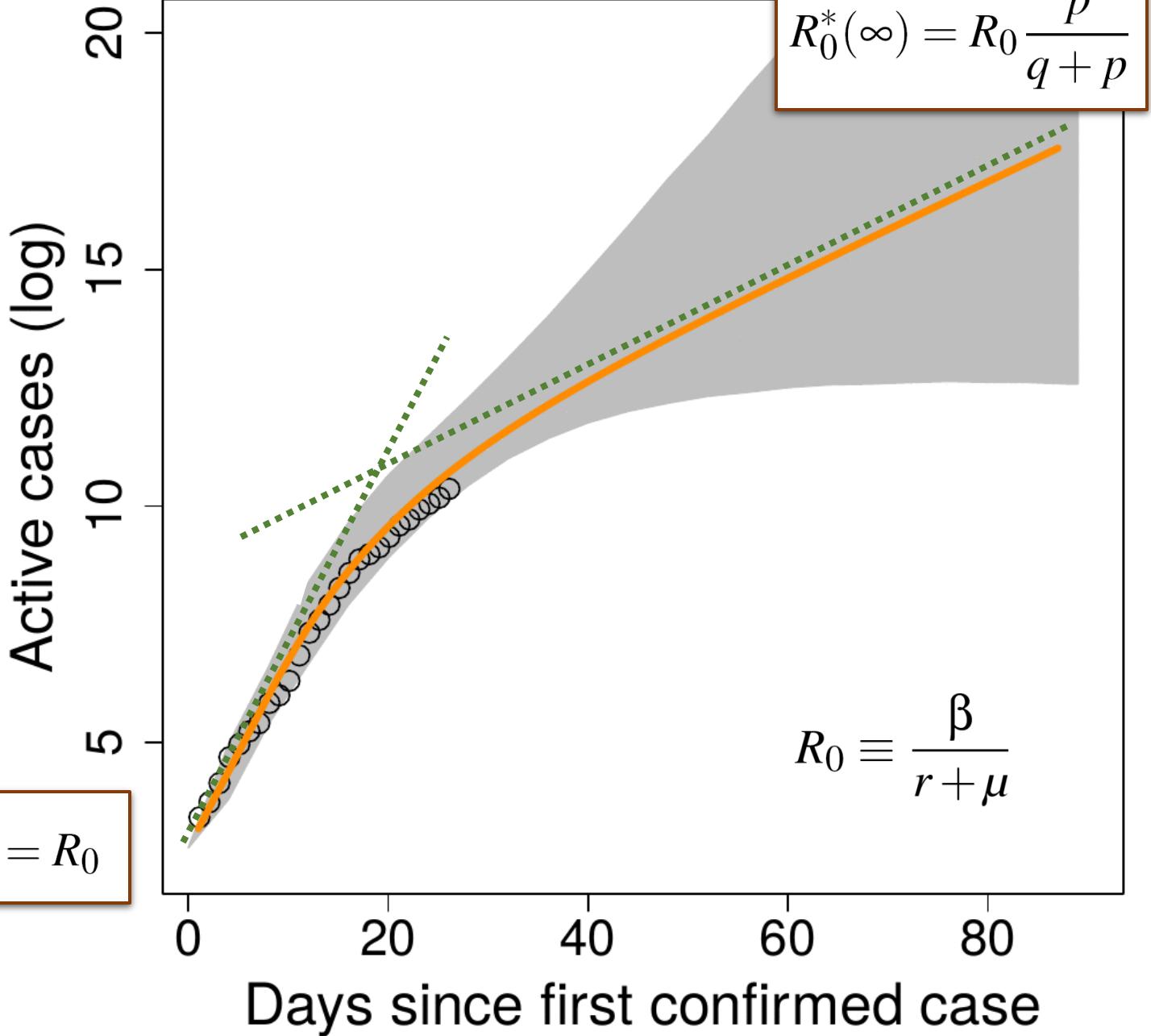
$$R_0^*(t) \equiv \frac{R_0}{q+p} \left[p + q \frac{1 - e^{-(q+p)t}}{(q+p)t} \right] \quad R_0 \equiv \frac{\beta}{r+\mu}$$

A threshold for the effectiveness of containment

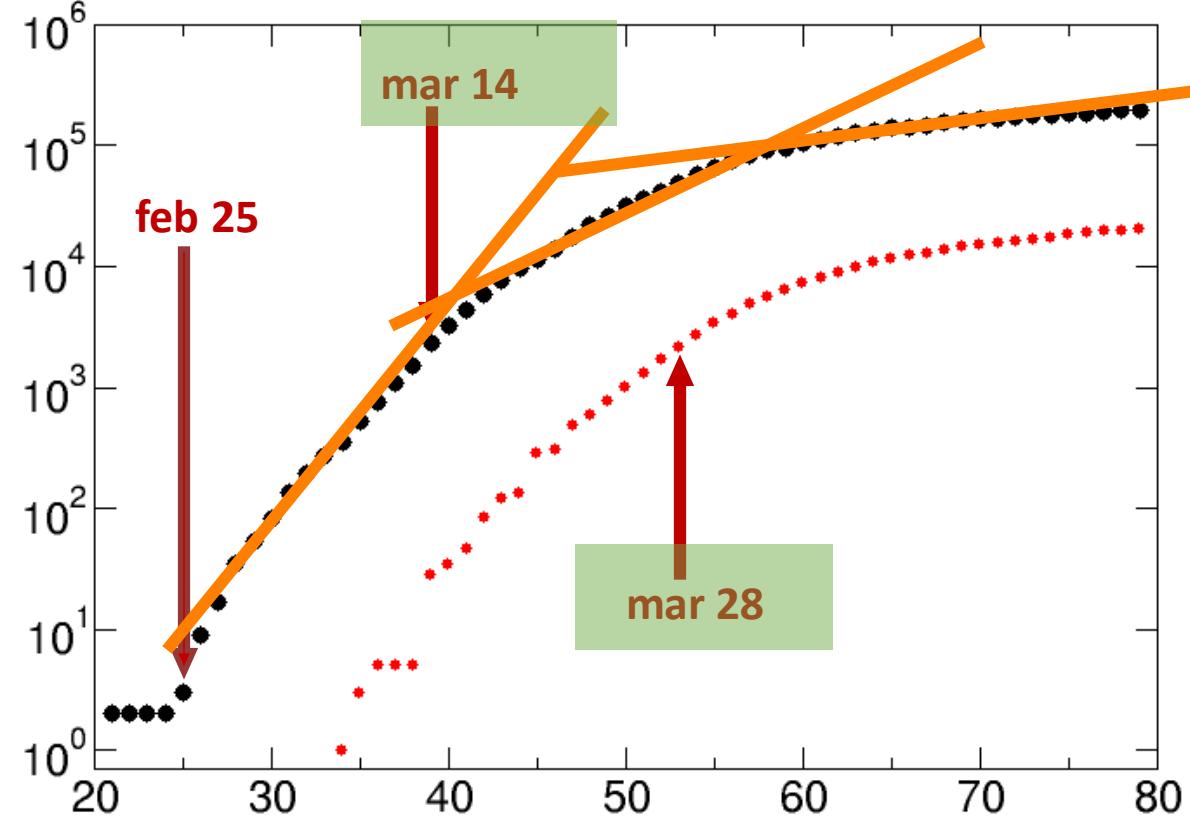
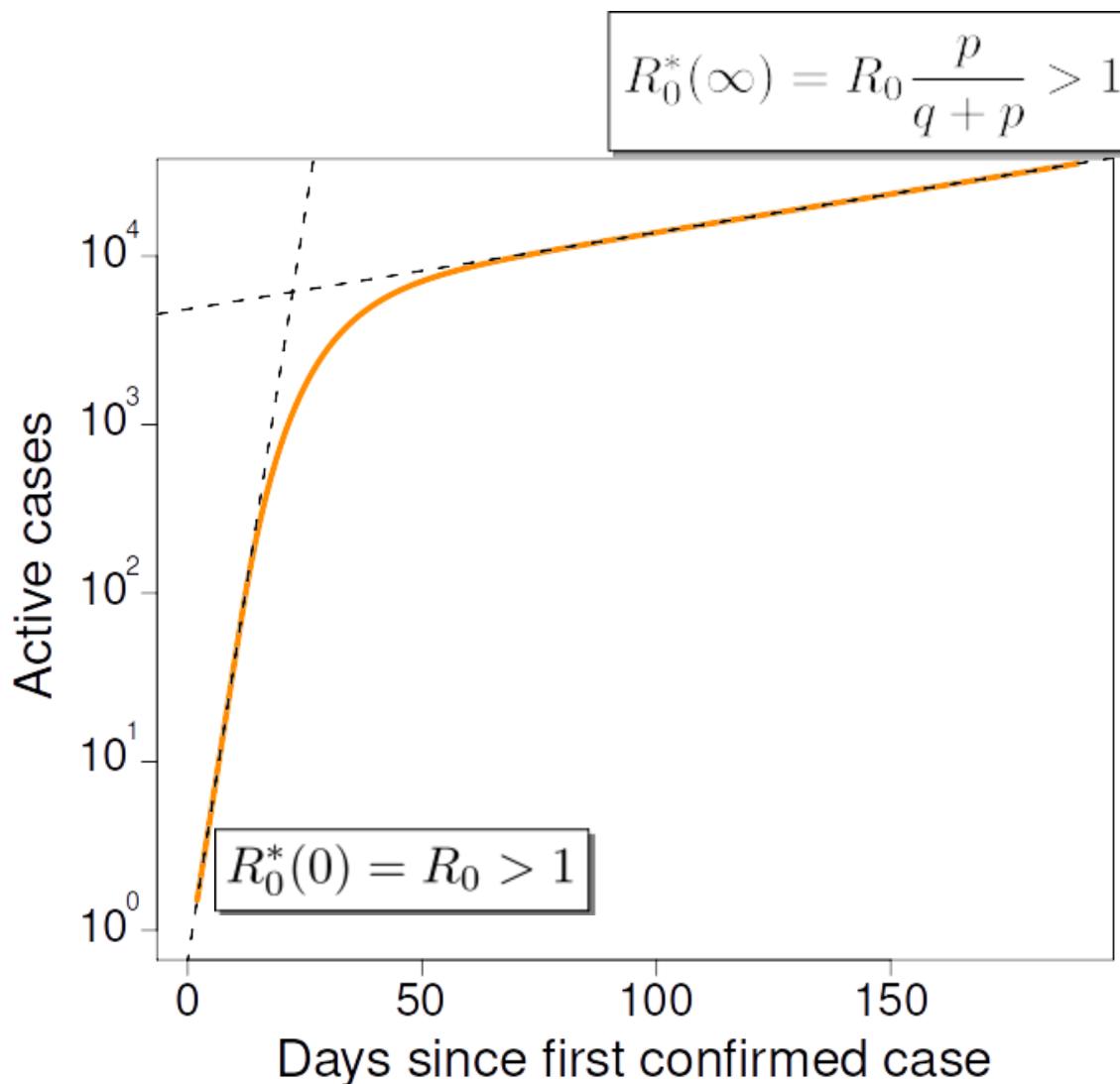
$$I(t) = I_0 e^{[R_0^*(t)-1](r+\mu)t}$$

$$R_0^*(t) \equiv \frac{R_0}{q+p} \left[p + q \frac{1 - e^{-(q+p)t}}{(q+p)t} \right]$$

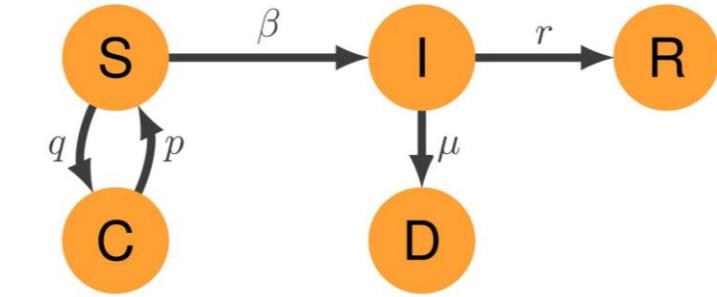
$$R_0^*(0) = R_0$$



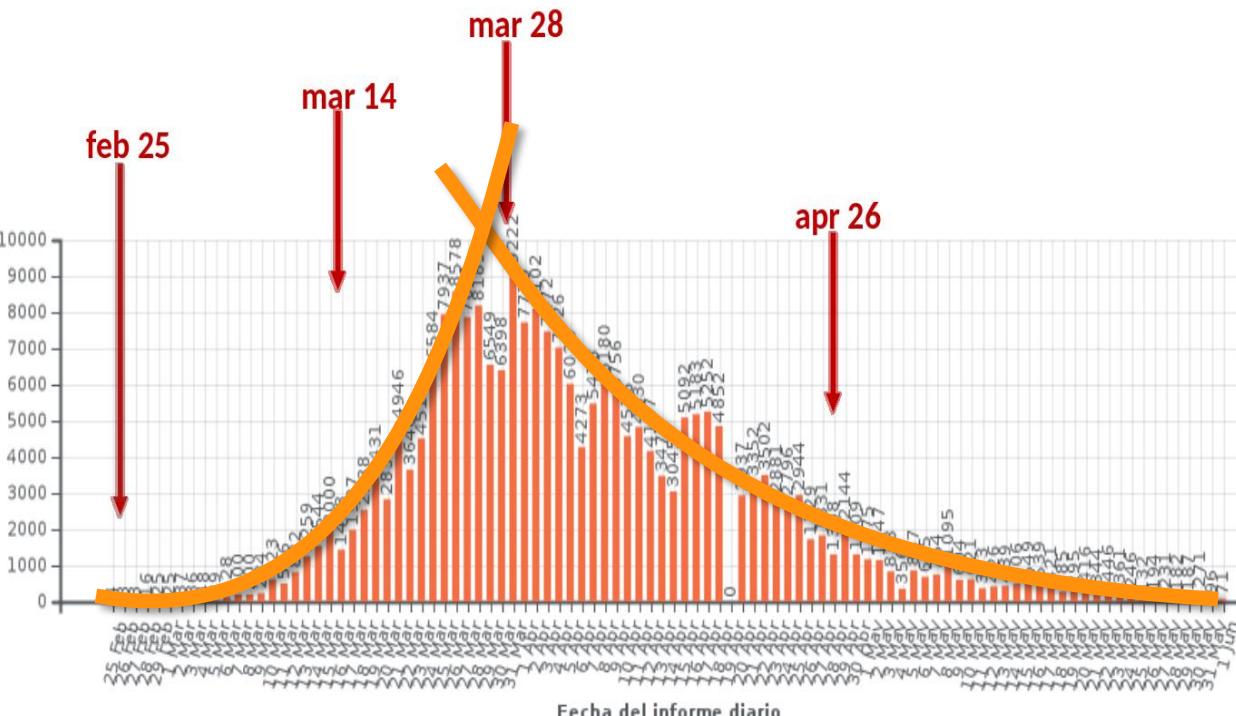
a NEW threshold for lockdown effectiveness



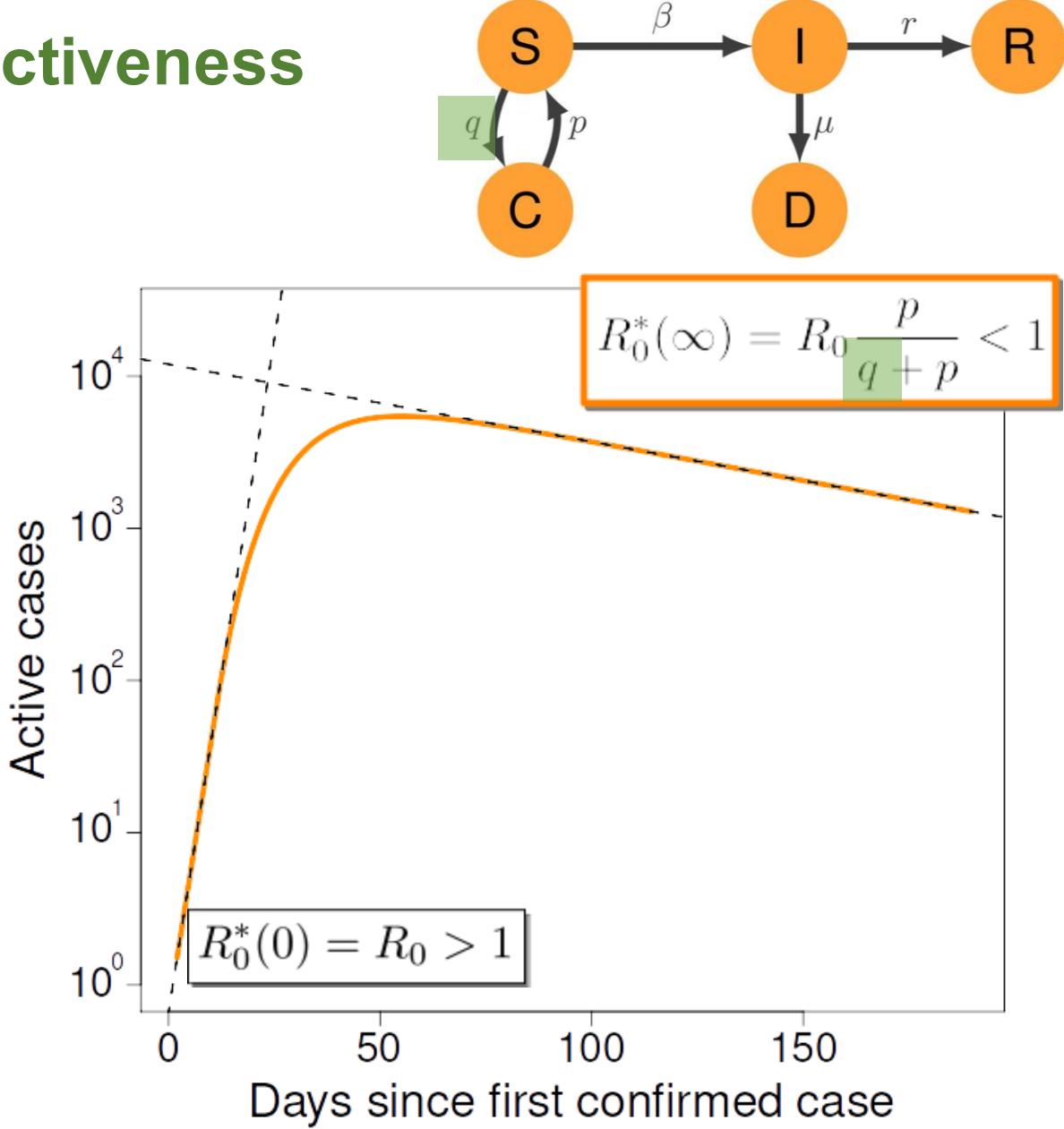
Crossover between exponential regimes
(of course we were still far from herd immunity)



a NEW threshold for lockdown effectiveness



Data from Spain



May 15

Cite as: B. F. Maier and D. Brockmann,
Science 10.1126/science.abb4557 (2020).

Effective containment explains subexponential growth in recent confirmed COVID-19 cases in China

Benjamin F. Maier^{1*} and Dirk Brockmann^{1,2}

¹Robert Koch Institute, Nordufer 20, D-13353 Berlin, Germany. ²Institute for Theoretical Biology, Humboldt-University of Berlin, Philippstr. 13, D-10115 Berlin, Germany.

*Corresponding author. E-mail: bfmaier@physik.hu-berlin.de

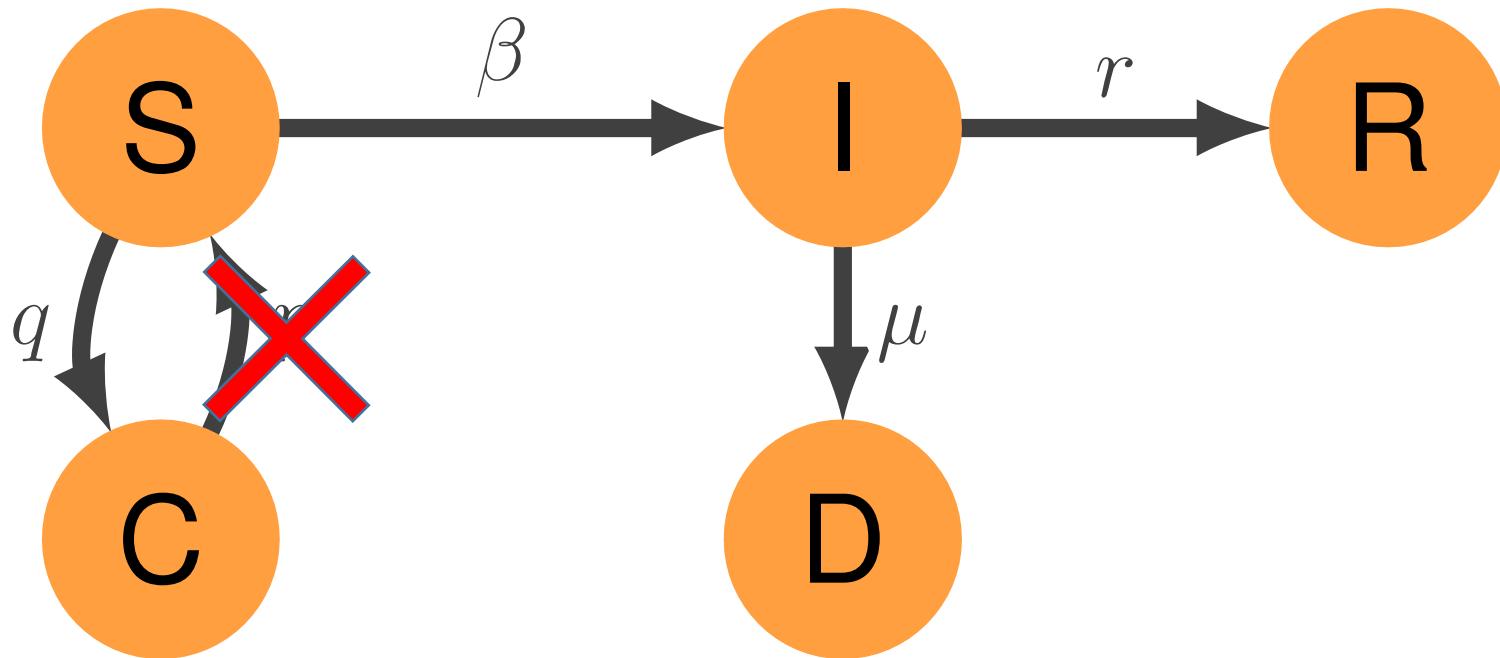
The recent outbreak of COVID-19 in Mainland China was characterized by a distinctive subexponential increase of confirmed cases during the early phase of the epidemic, contrasting an initial exponential growth expected for an unconstrained outbreak. We show that this effect can be explained as a direct consequence of containment policies that effectively deplete the susceptible population. To this end, we introduce a parsimonious model that captures both, quarantine of symptomatic infected individuals as well as population-wide isolation practices in response to containment policies or behavioral changes and show that the model captures the observed growth behavior accurately. The insights provided here may aid the careful implementation of containment strategies for ongoing secondary outbreaks of COVID-19 or similar future outbreaks of other emergent infectious diseases.

Maier and Borckmann's model: **Irreversible confinement inhibits the epidemic at any rate**

$$\dot{S} = -\frac{\beta SI}{N} - qS + \cancel{pC}$$

$$\dot{I} = \frac{\beta SI}{N} - (r + \mu)I$$

$$\dot{R} = rI$$

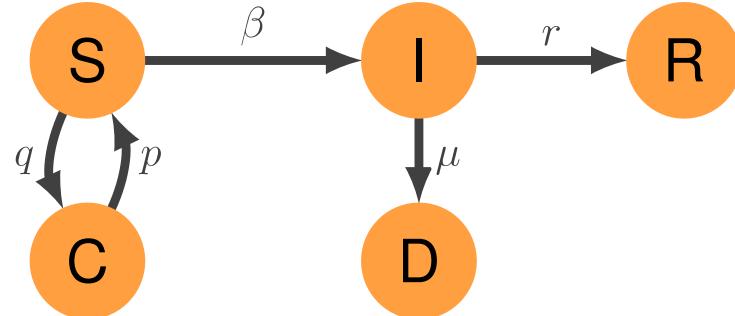


$$\dot{C} = qS - \cancel{pC}$$

$$\dot{D} = \mu I$$

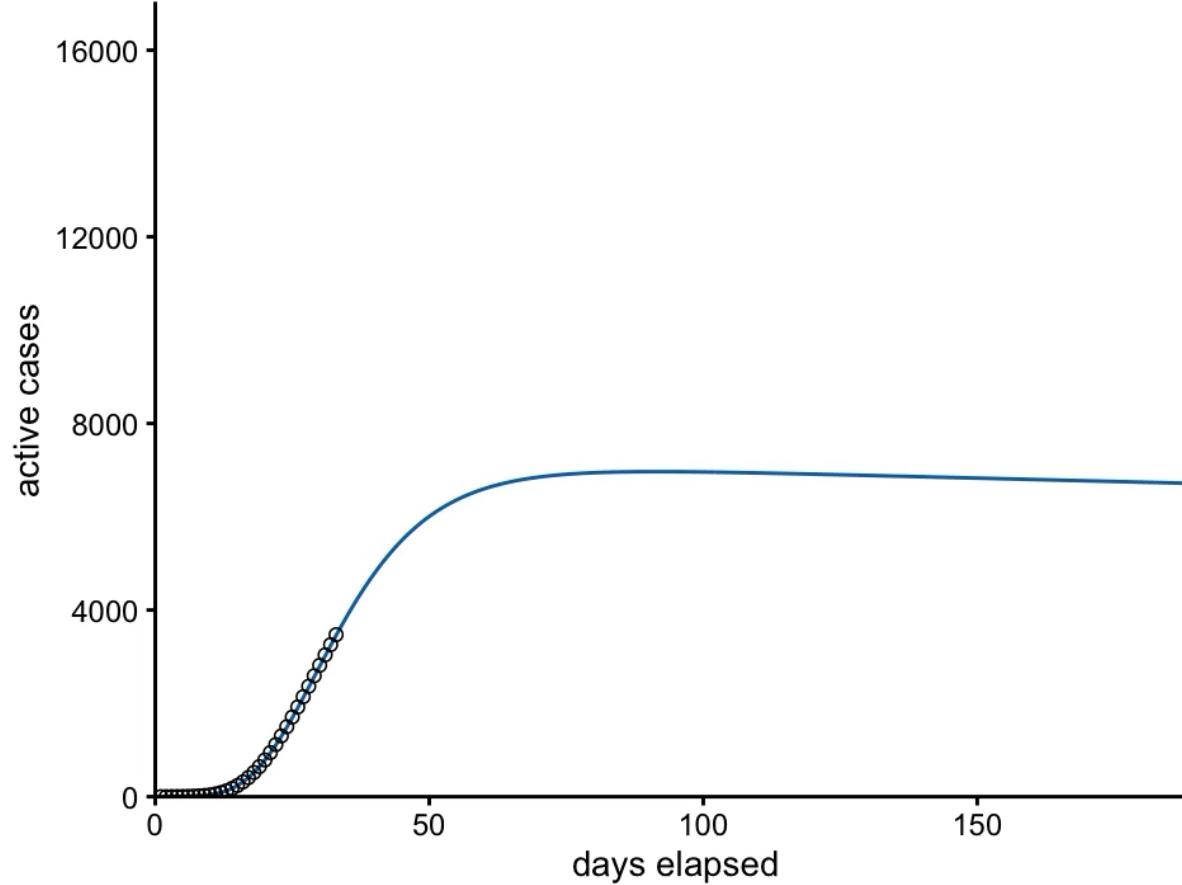
We tried fitting parameters to SCIR model

$$\dot{S} = -\frac{\beta SI}{N} - qS + pC \quad \dot{I} = \frac{\beta SI}{N} - (r + \mu)I \quad \dot{R} = rI$$



$$\dot{C} = qS - pC$$

$$\dot{D} = \mu I$$



Parameters

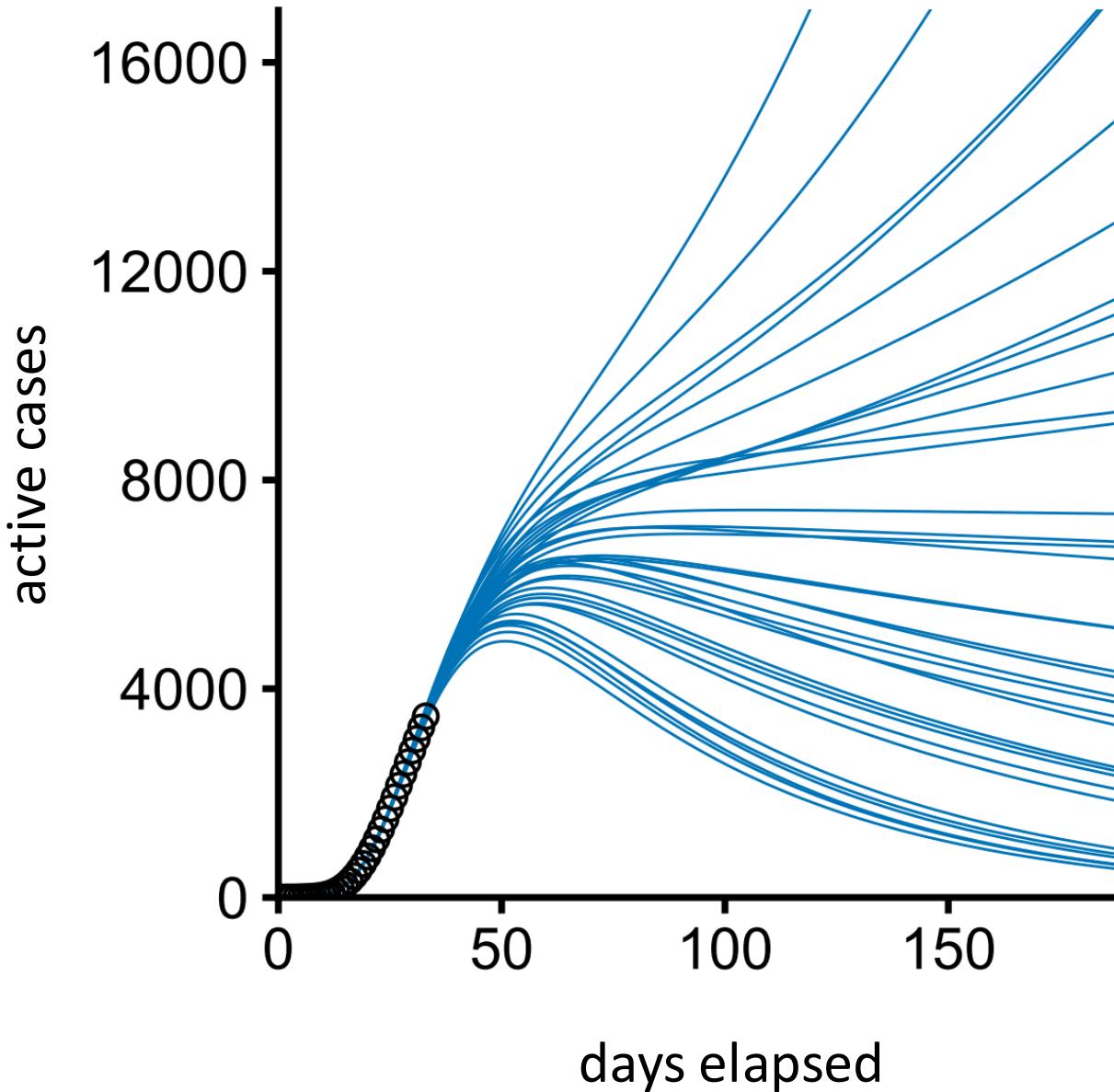
$$\begin{aligned}\dot{S} &= -(q + p)S + pN, \\ \dot{I} &= \frac{\beta}{N}IS - (r + \mu)I.\end{aligned}$$

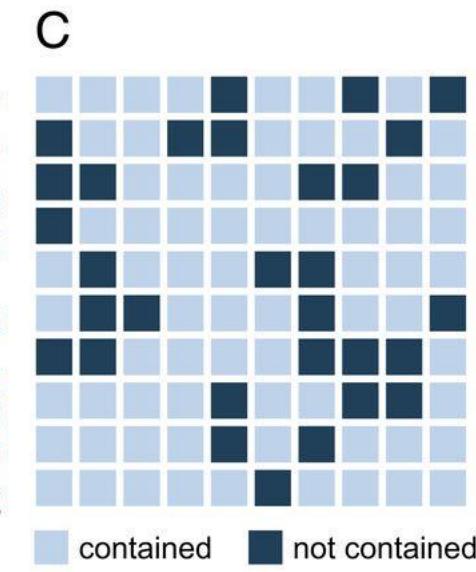
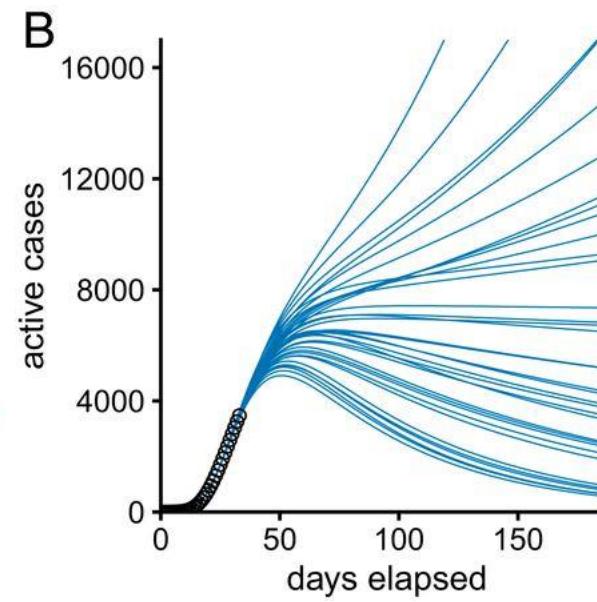
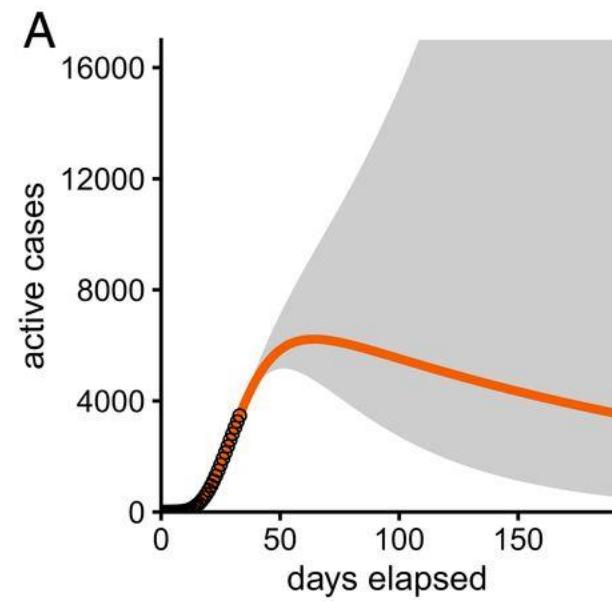


Data



Probabilistic data
fitting





We have fitted a parametric Bayesian model with variables

$$\log I(t) \sim \mathcal{N}(\log I(t_0) + (\beta - \lambda)(t - t_0), \sigma_I), \quad t_0 < t \leq t_2,$$

$t_2 = \text{March 14}$

$$\log I(t) \sim \mathcal{N}(\log I(t_2) + [R_0^*(t - t_2) - 1]\lambda(t - t_2), \sigma_I), \quad t_2 < t,$$

$$\log X(t) \sim \mathcal{N}(\log(r + \mu) + \log I(t), \sigma_X), \quad t_1 < t,$$

$$X(t) = \Delta R(t) + \Delta D(t)$$

and priors

$$\beta \sim \mathcal{U}(0, 1),$$

$$1/\sigma_I^2 \sim \Gamma(0.01, 0.01),$$

$$r + \mu \sim \mathcal{U}(0, 1),$$

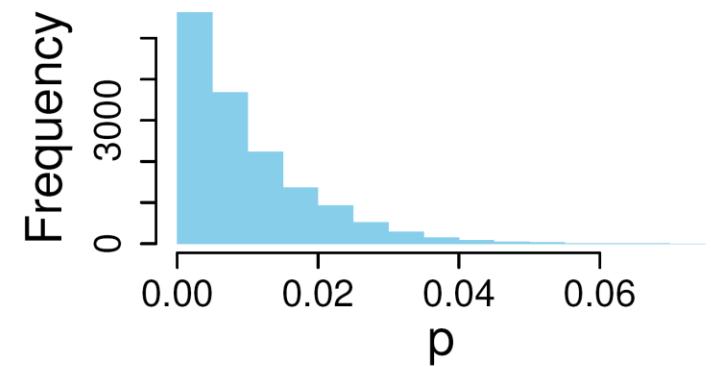
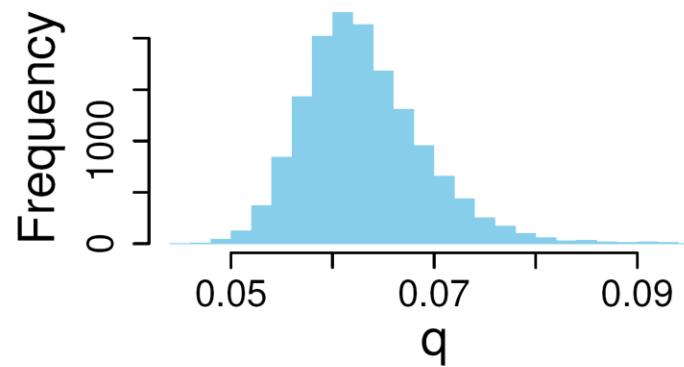
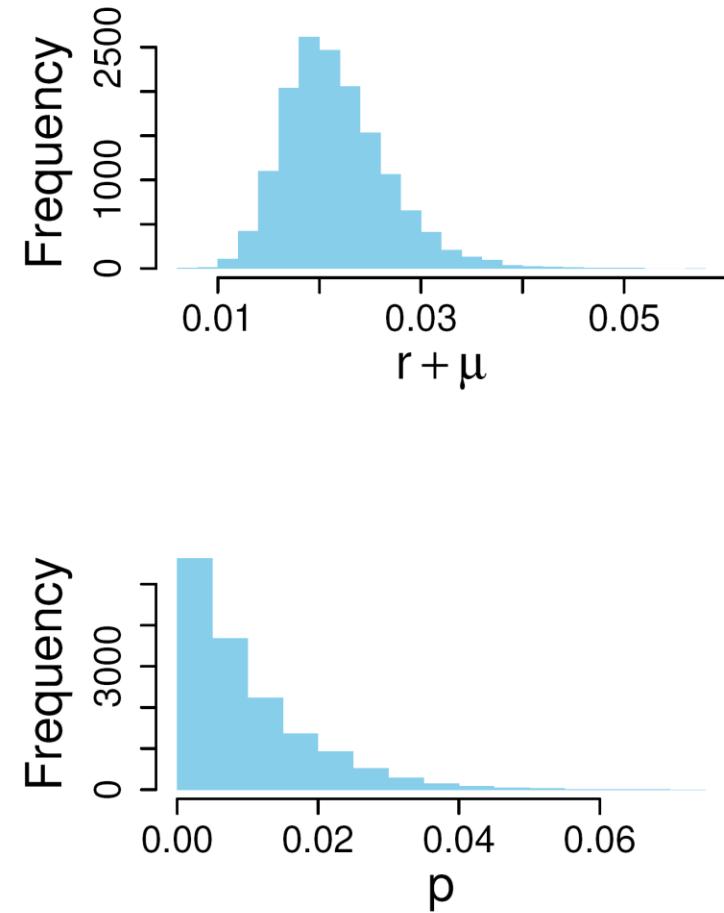
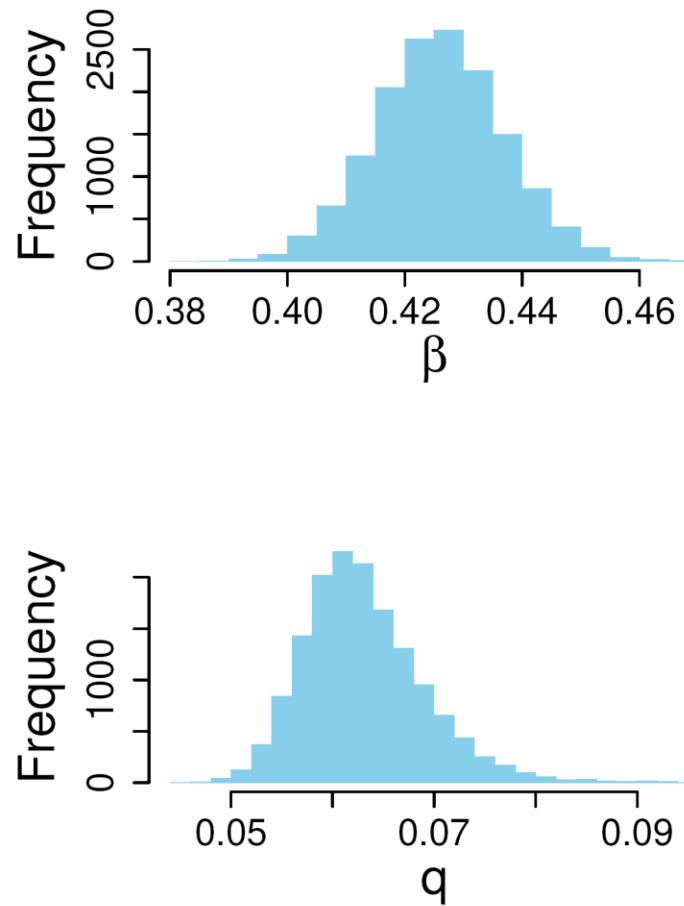
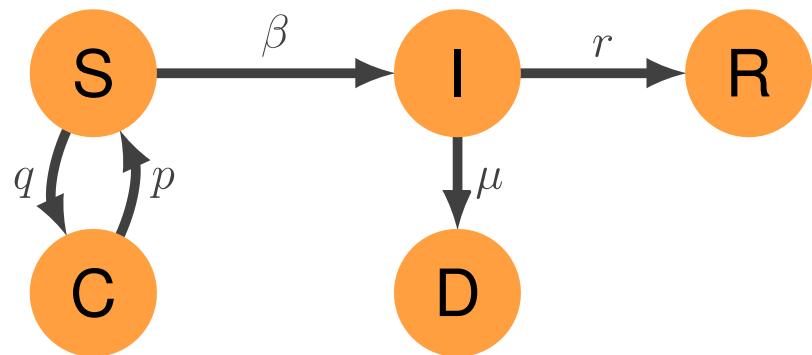
$$1/\sigma_D^2 \sim \Gamma(0.01, 0.01),$$

$$p \sim \mathcal{U}(0, 5),$$

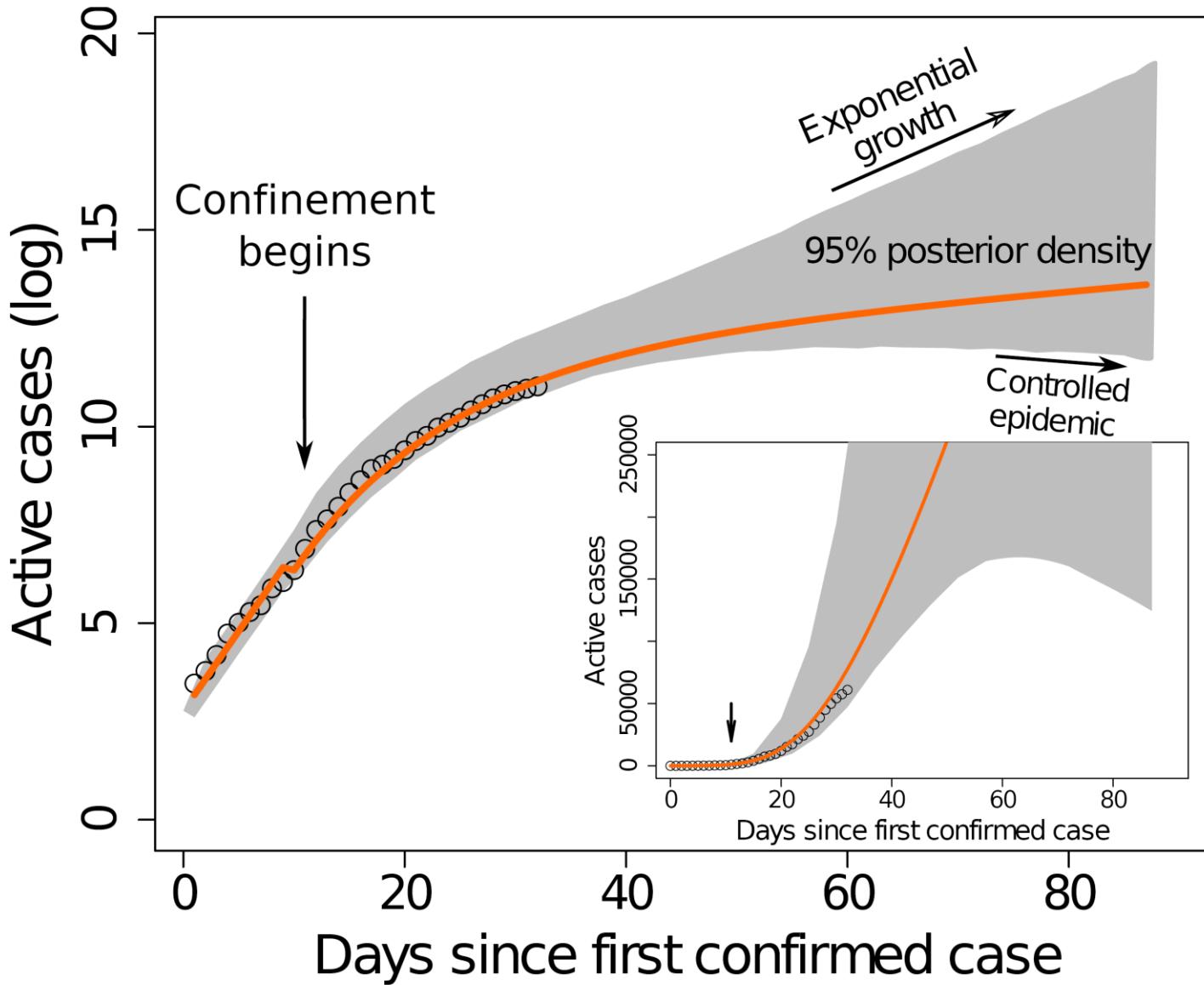
$$1/\sigma_X^2 \sim \Gamma(0.01, 0.01),$$

$$q \sim \mathcal{U}(0, 5),$$

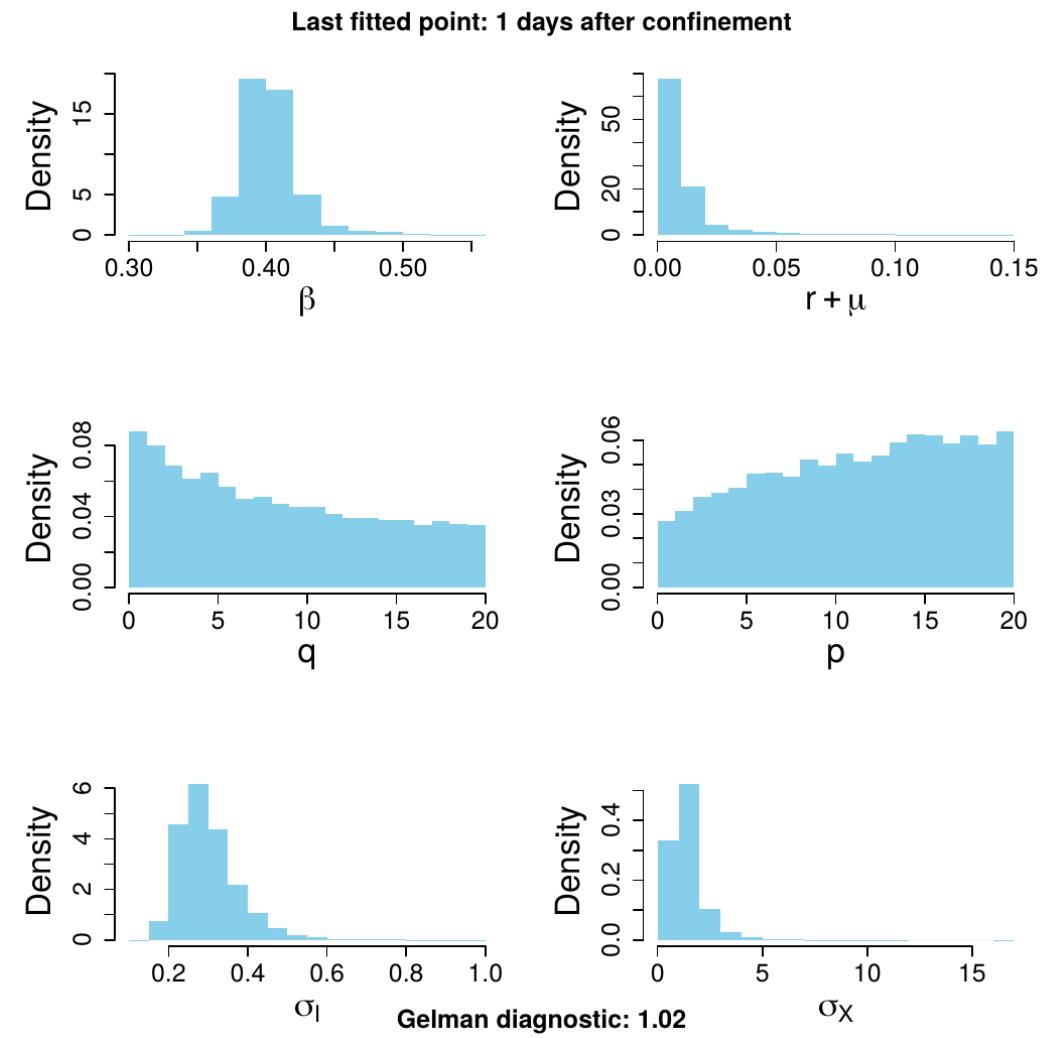
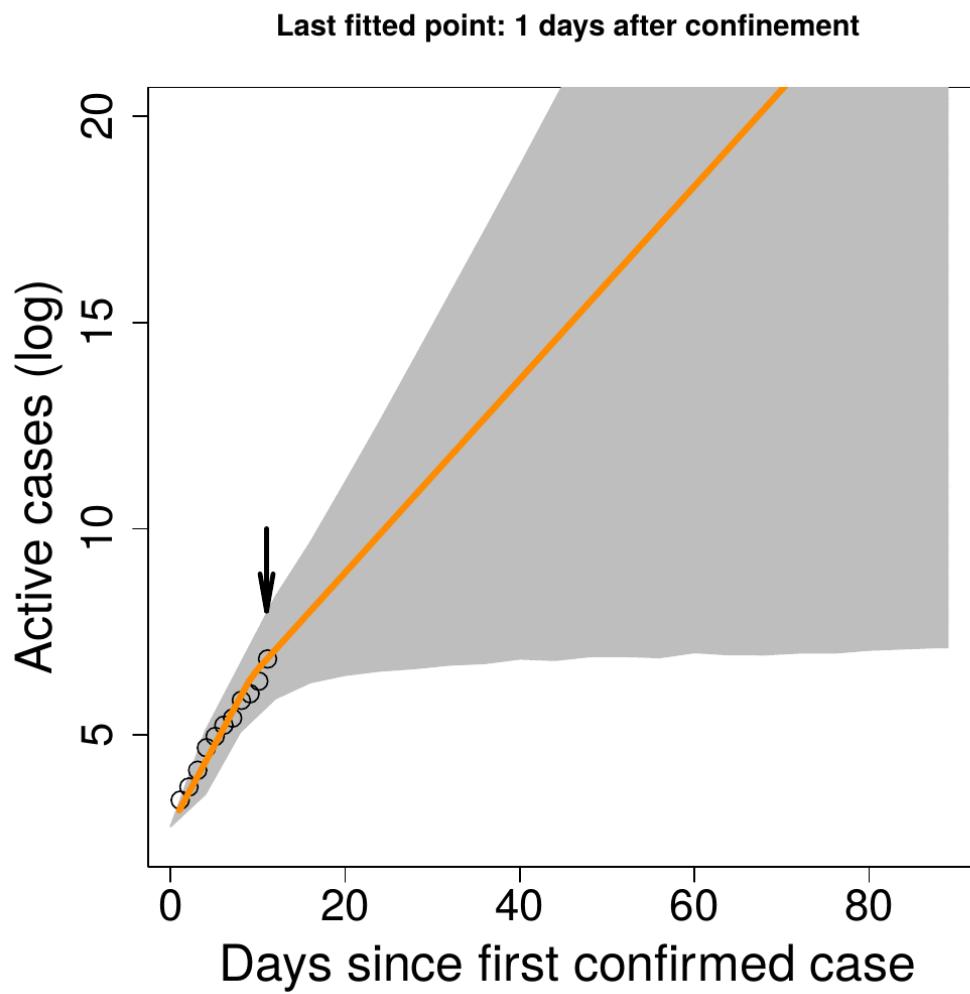
There is a range of parameters compatible with observations

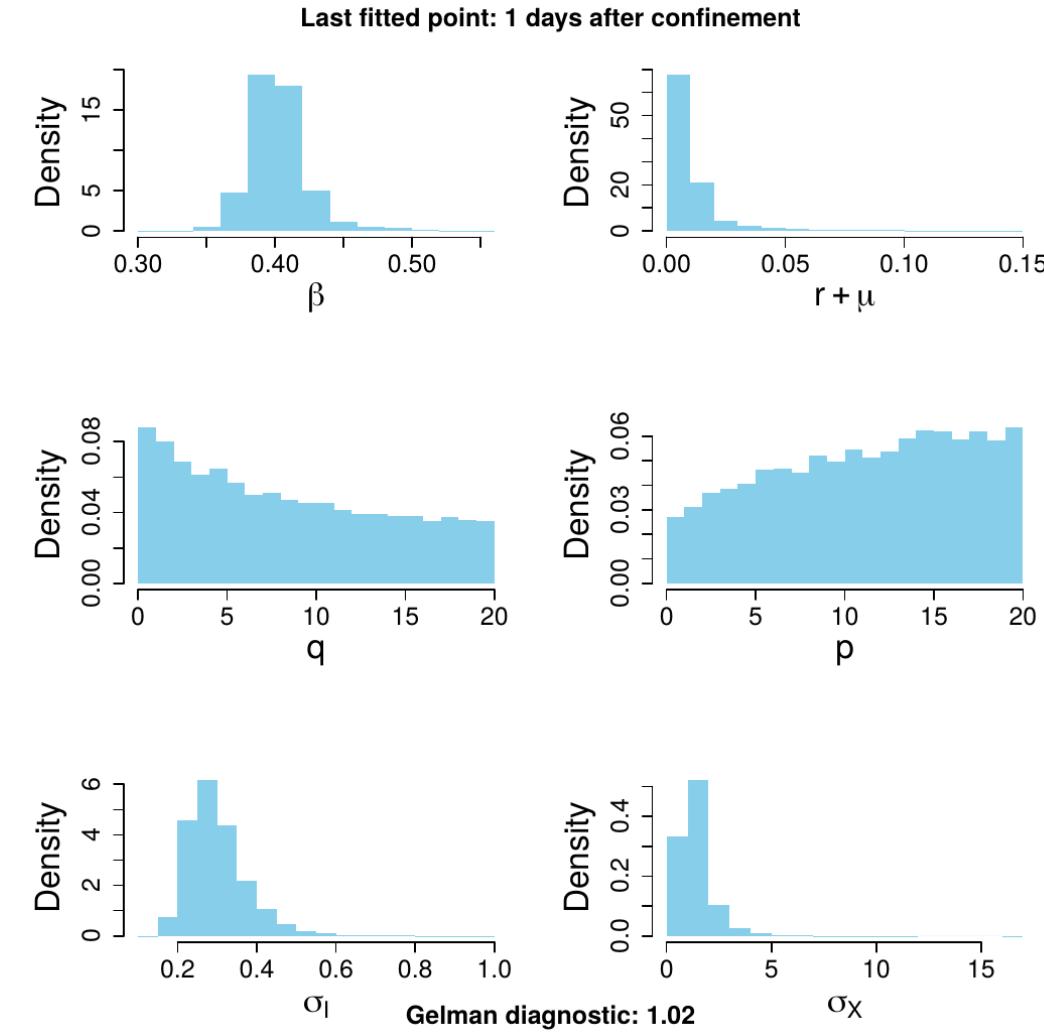
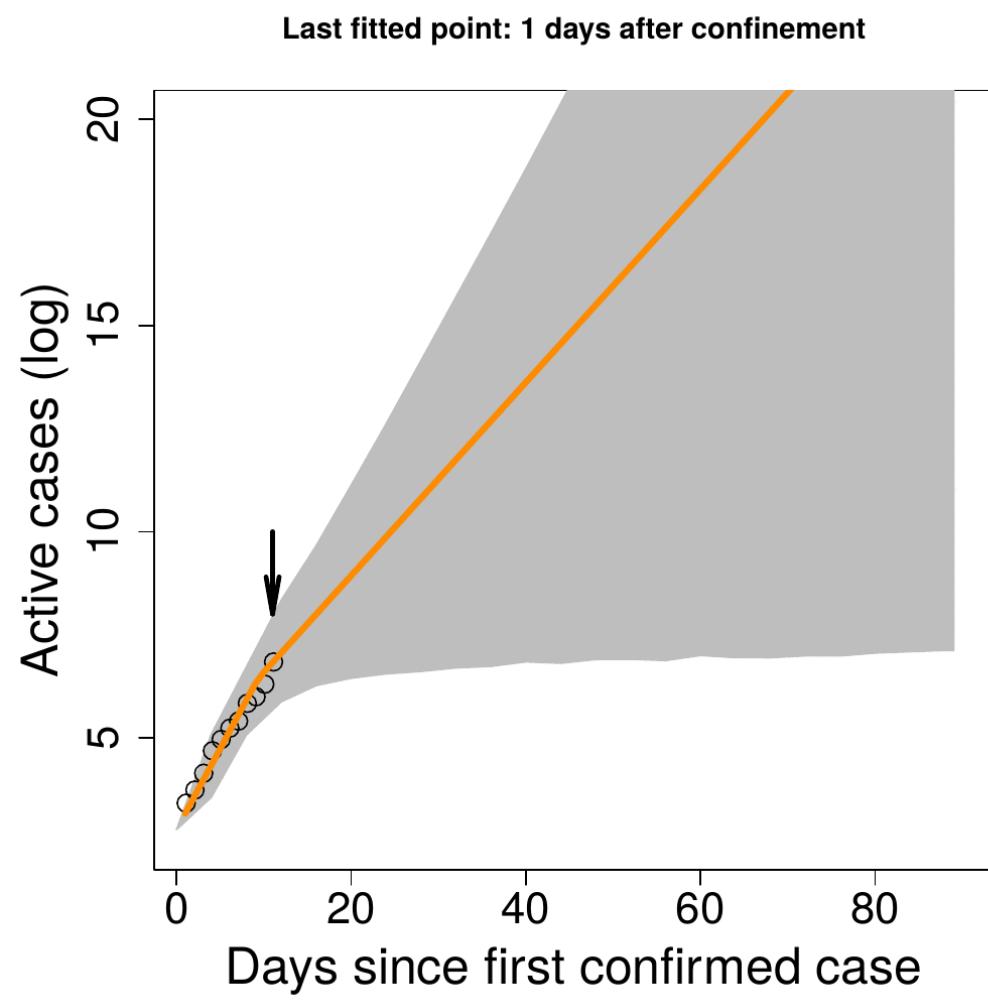


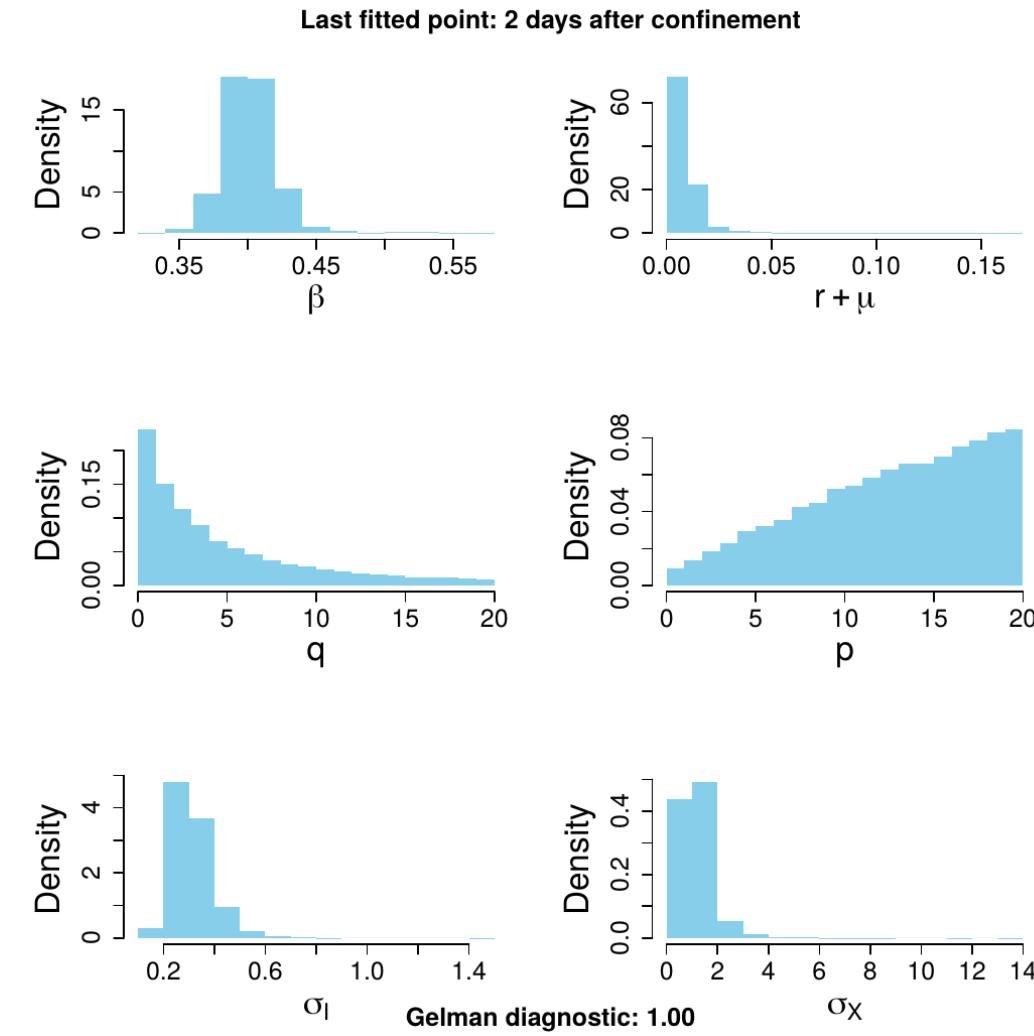
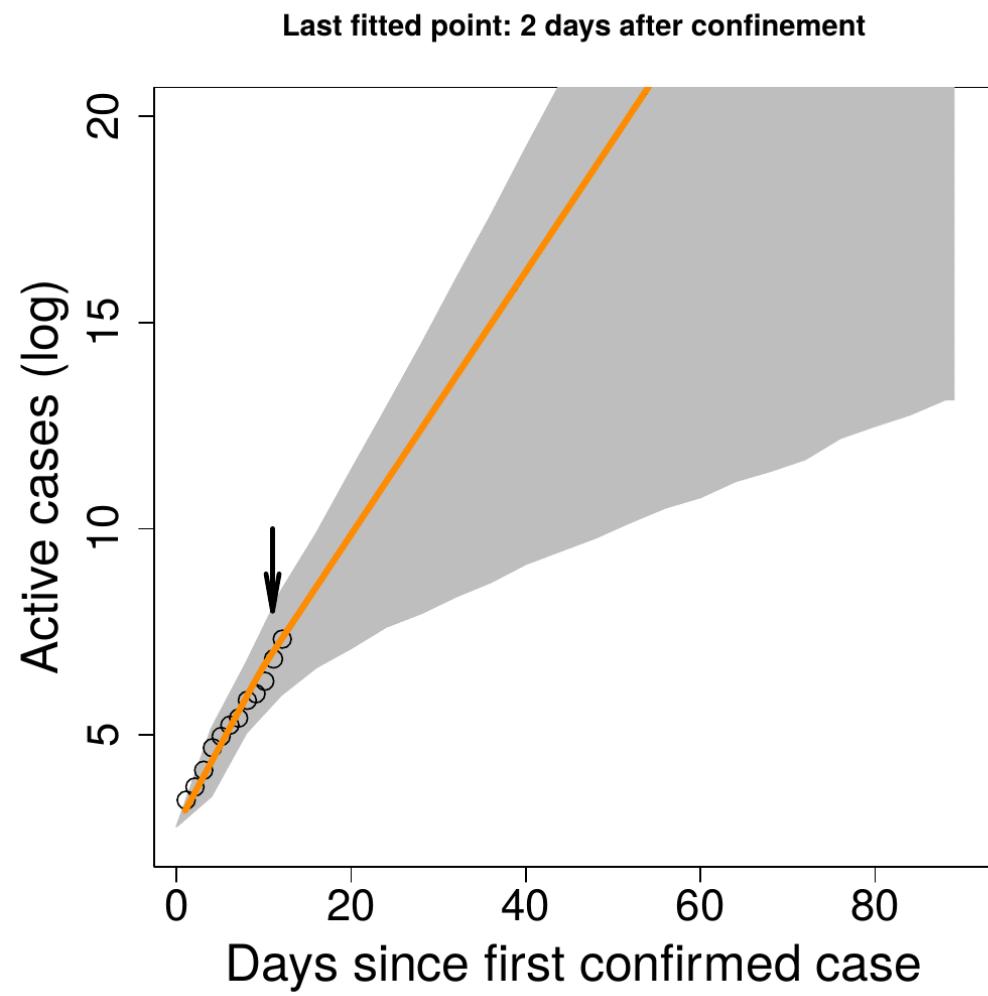
Parameter uncertainty is amplified exponentially fast

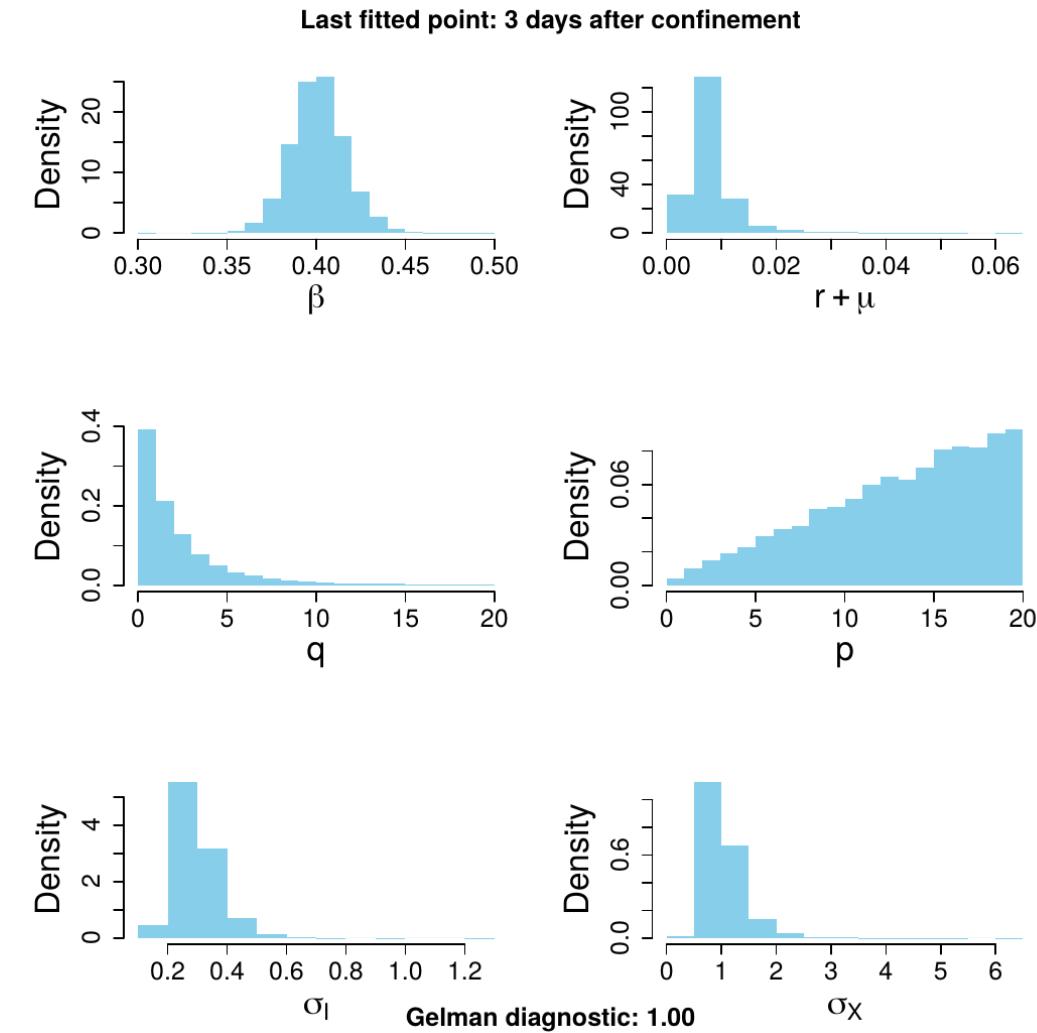
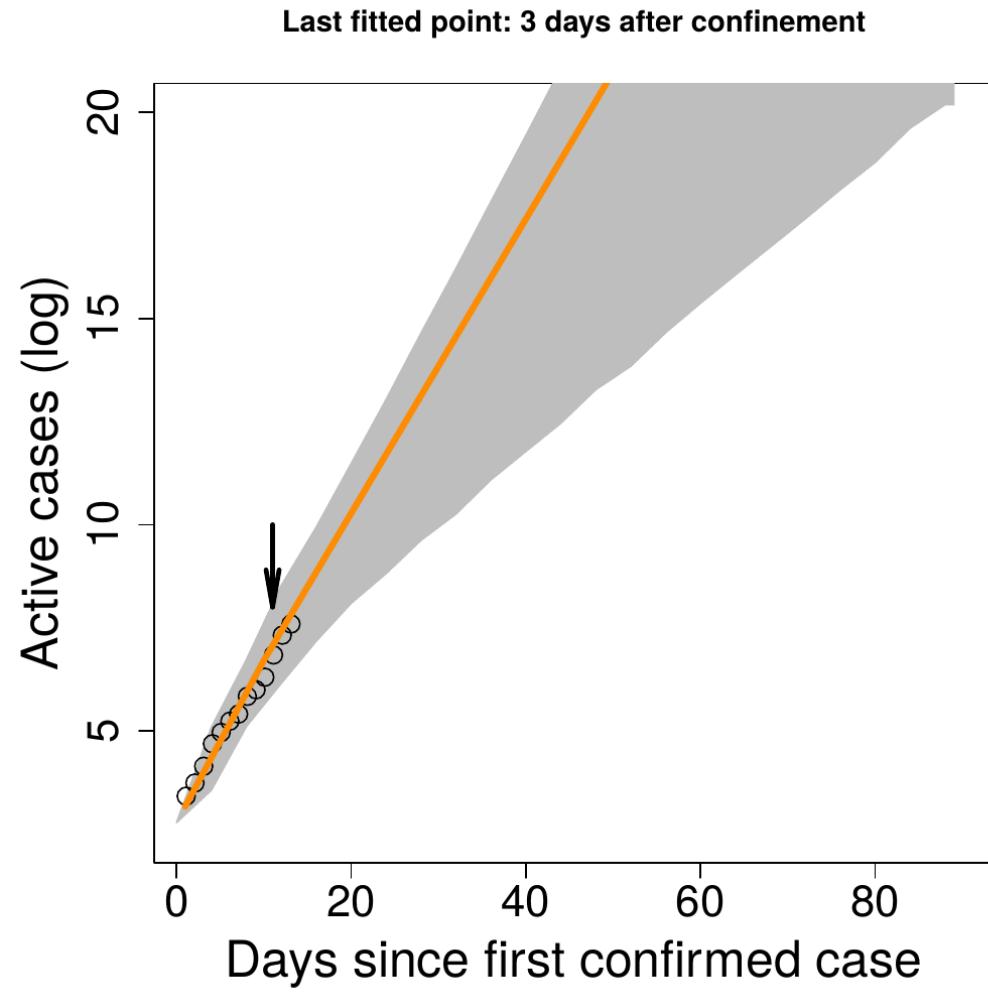


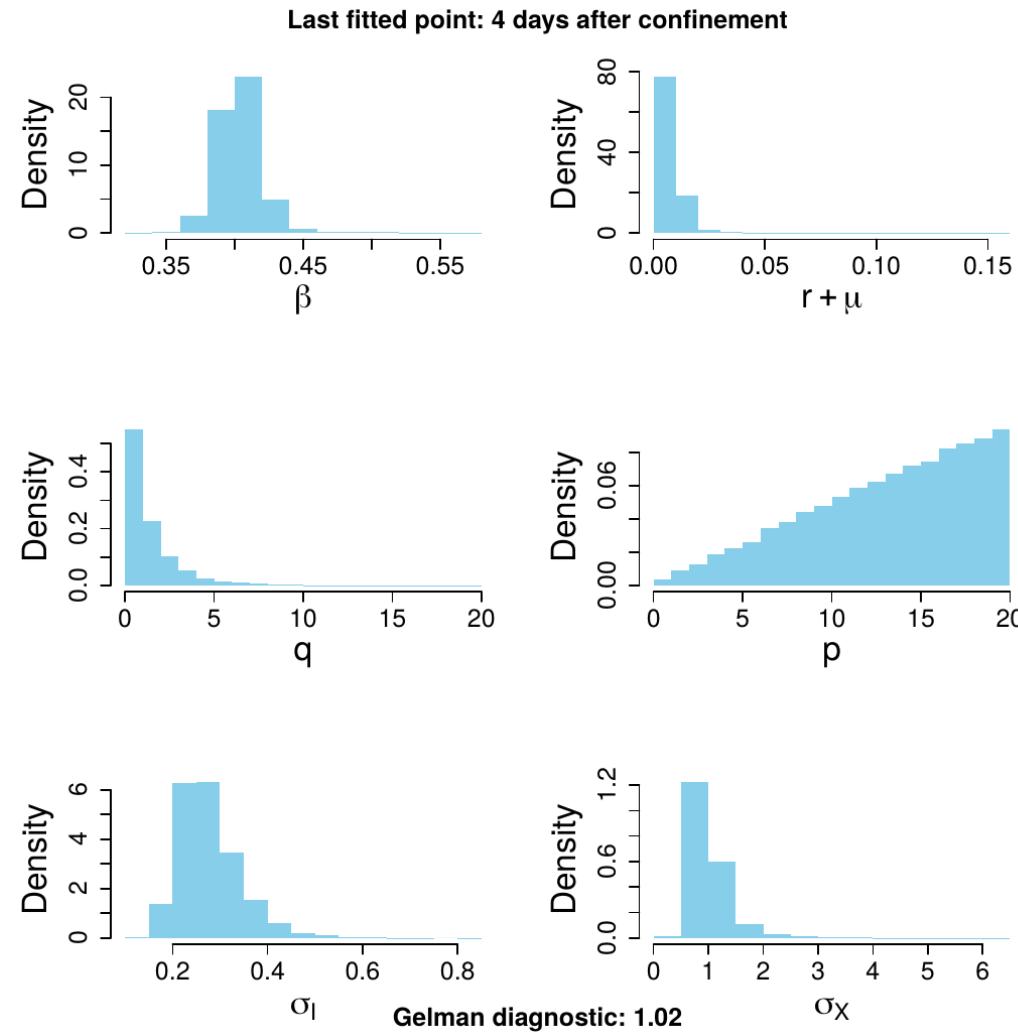
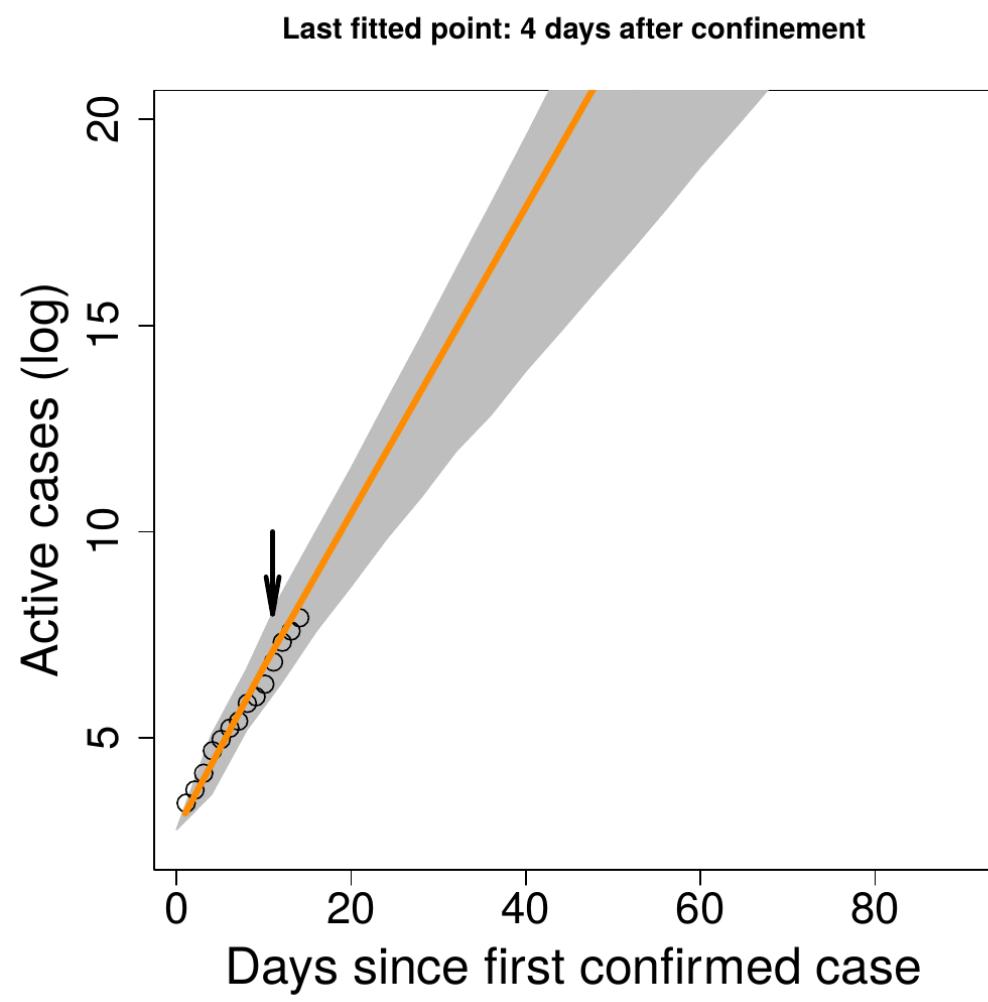
Every new data point modifies the prediction

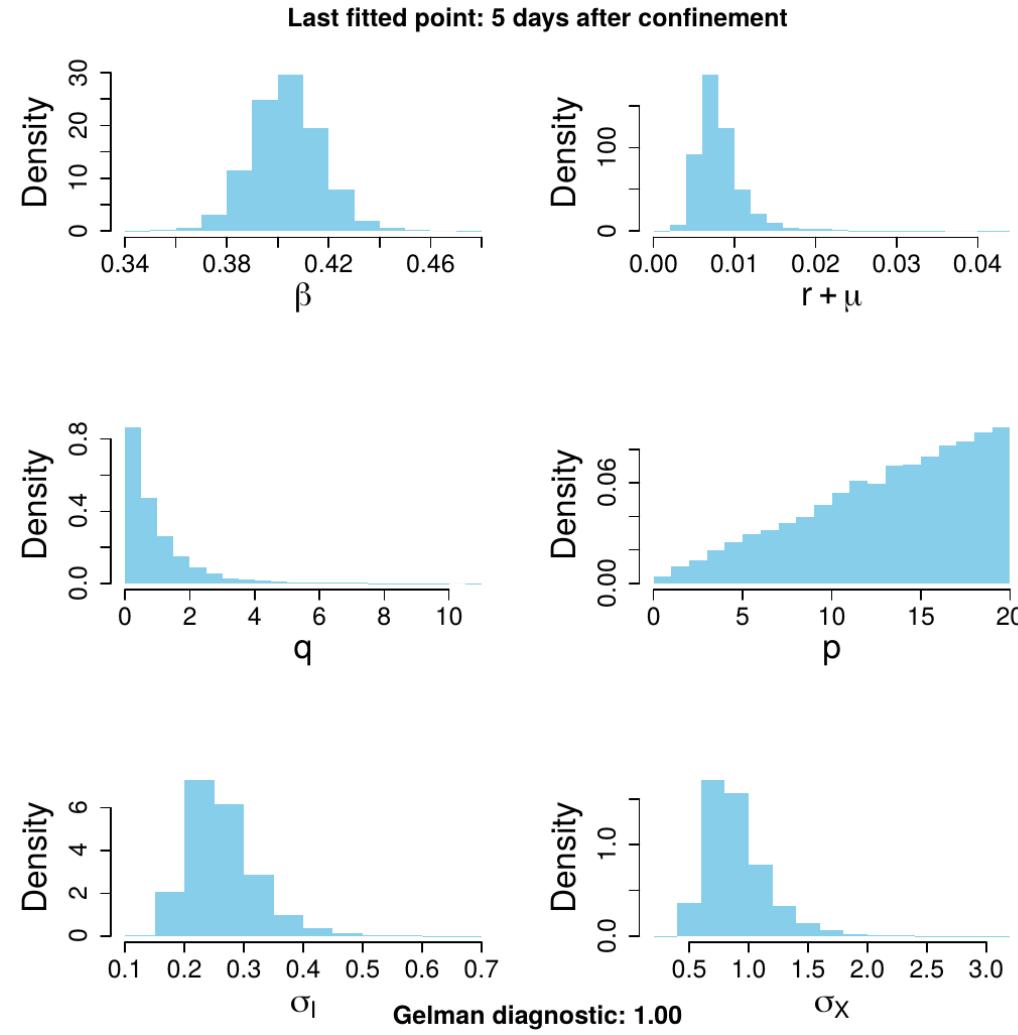
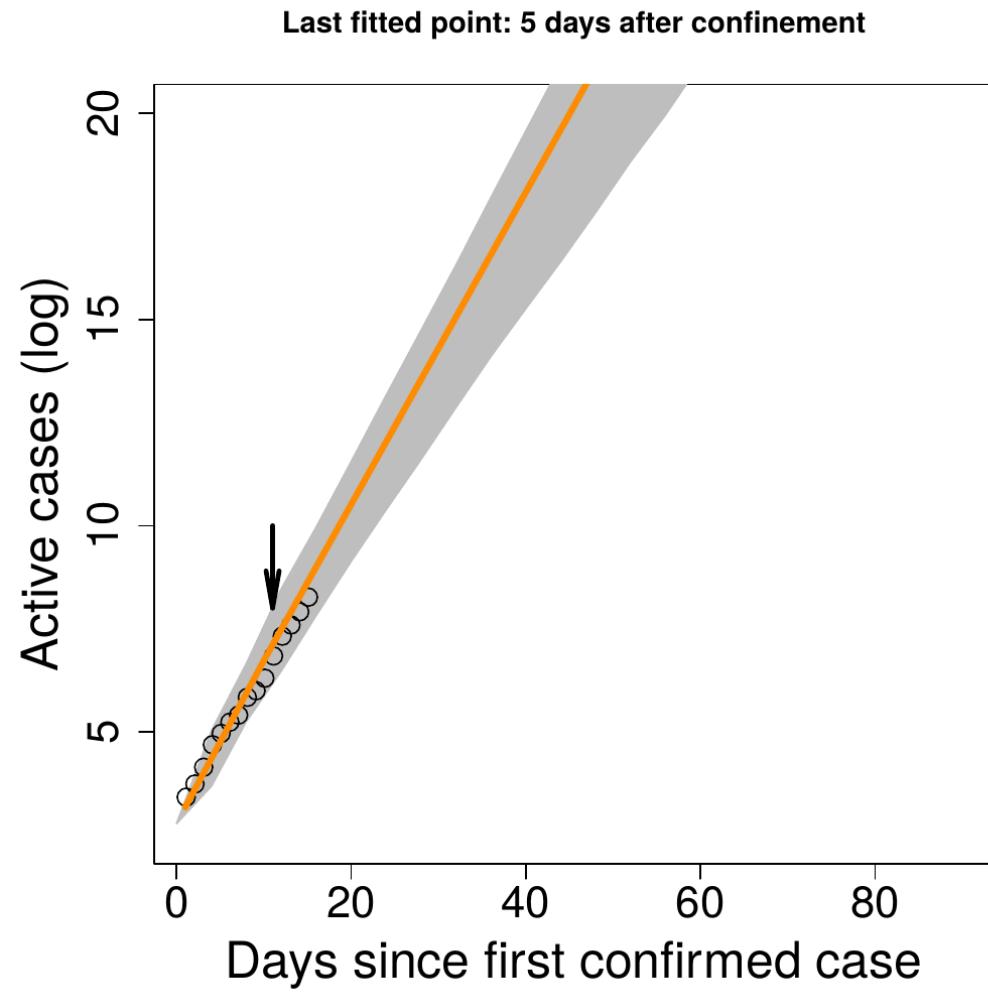


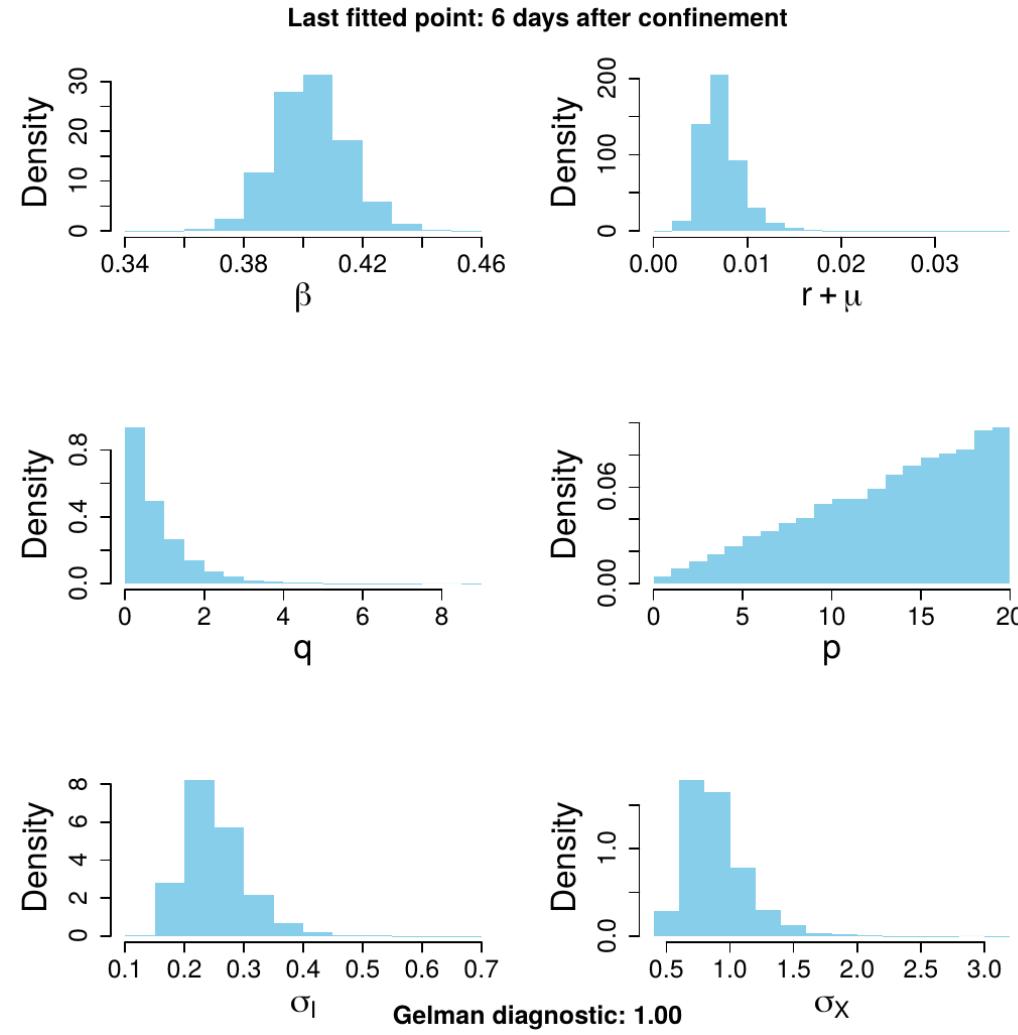
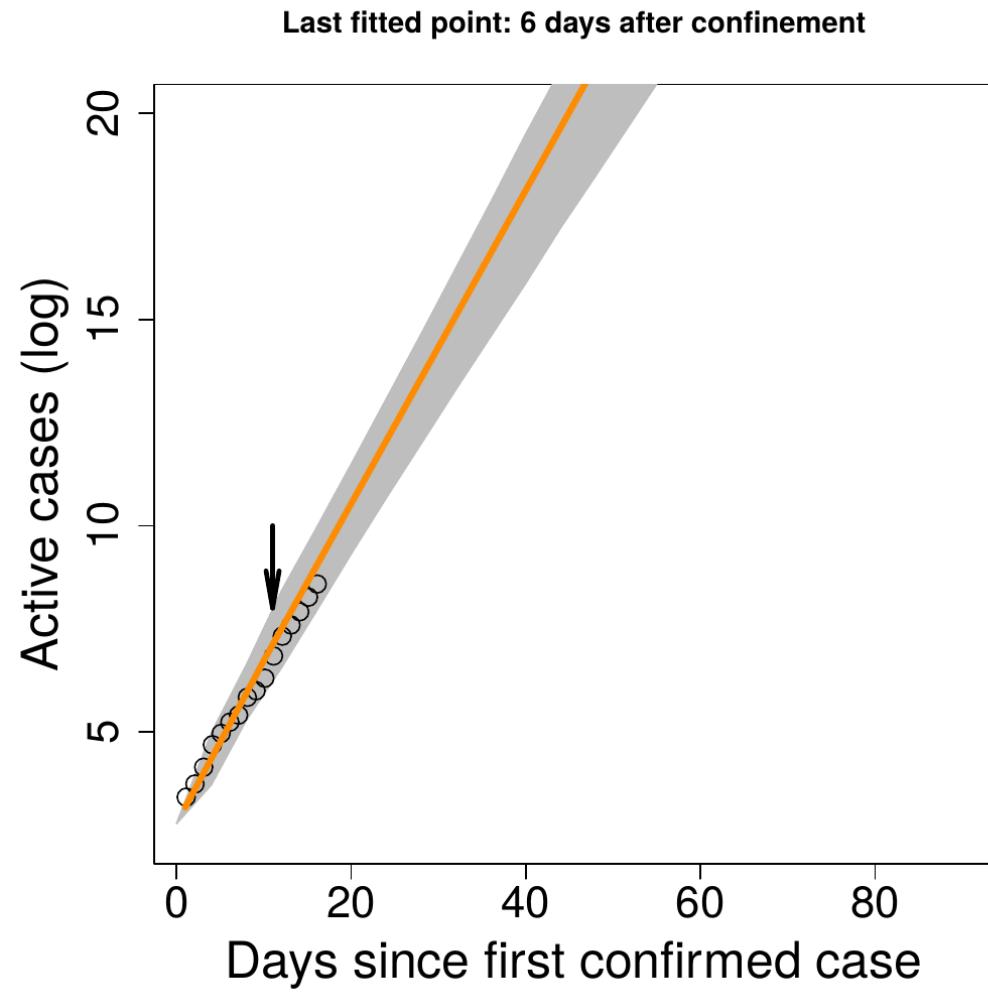


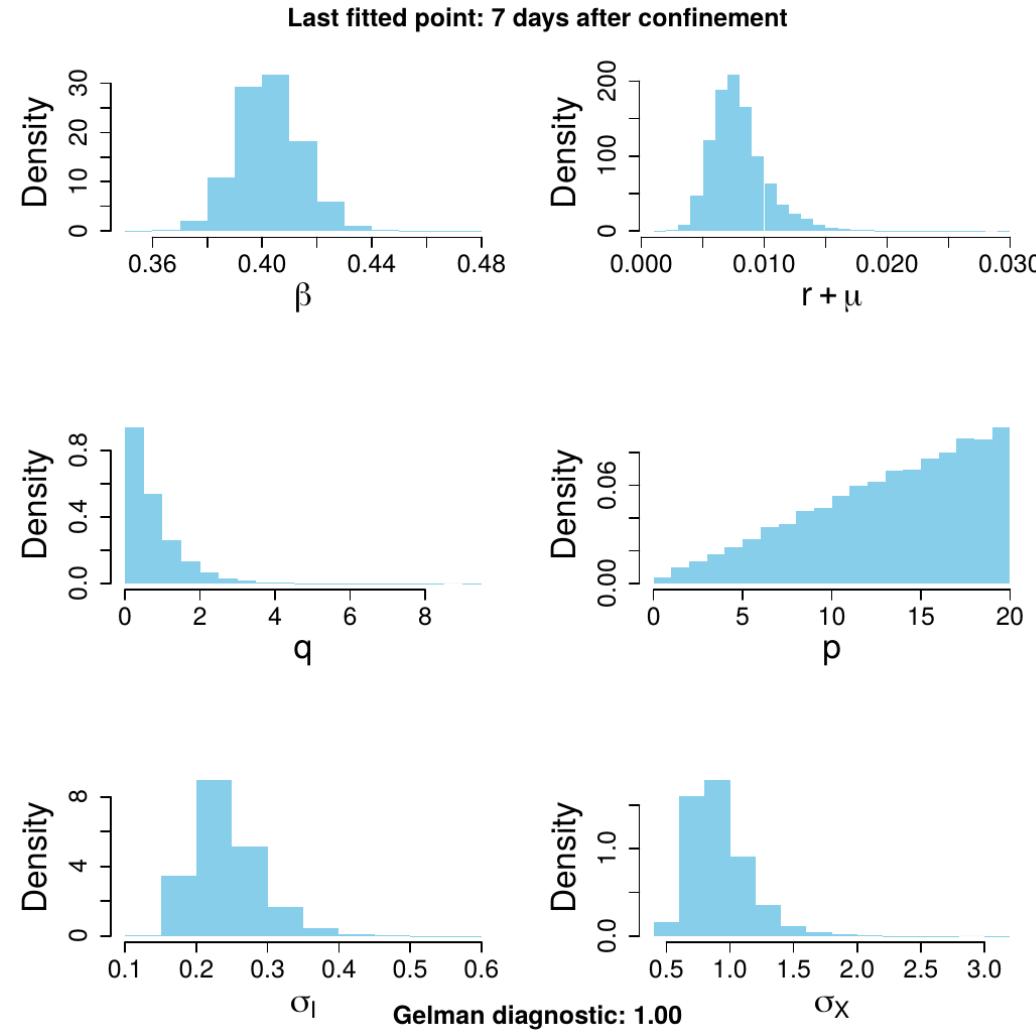
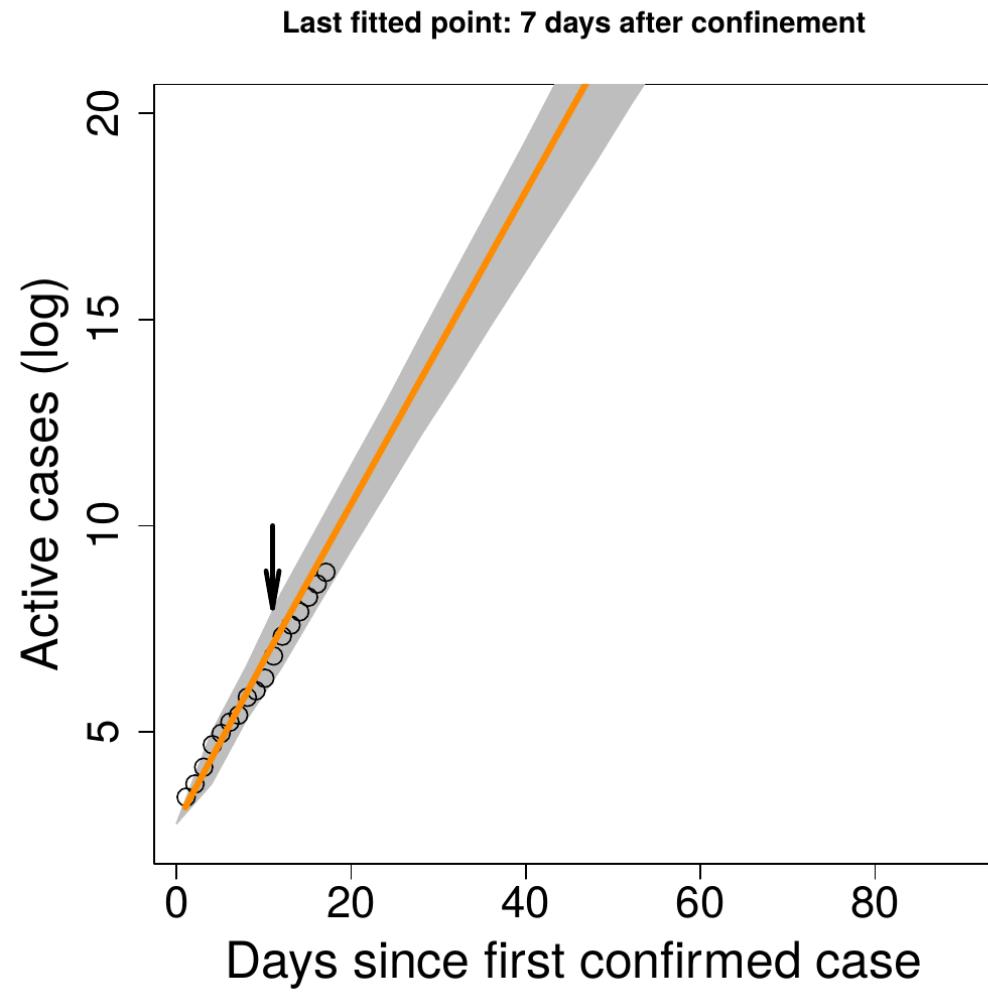


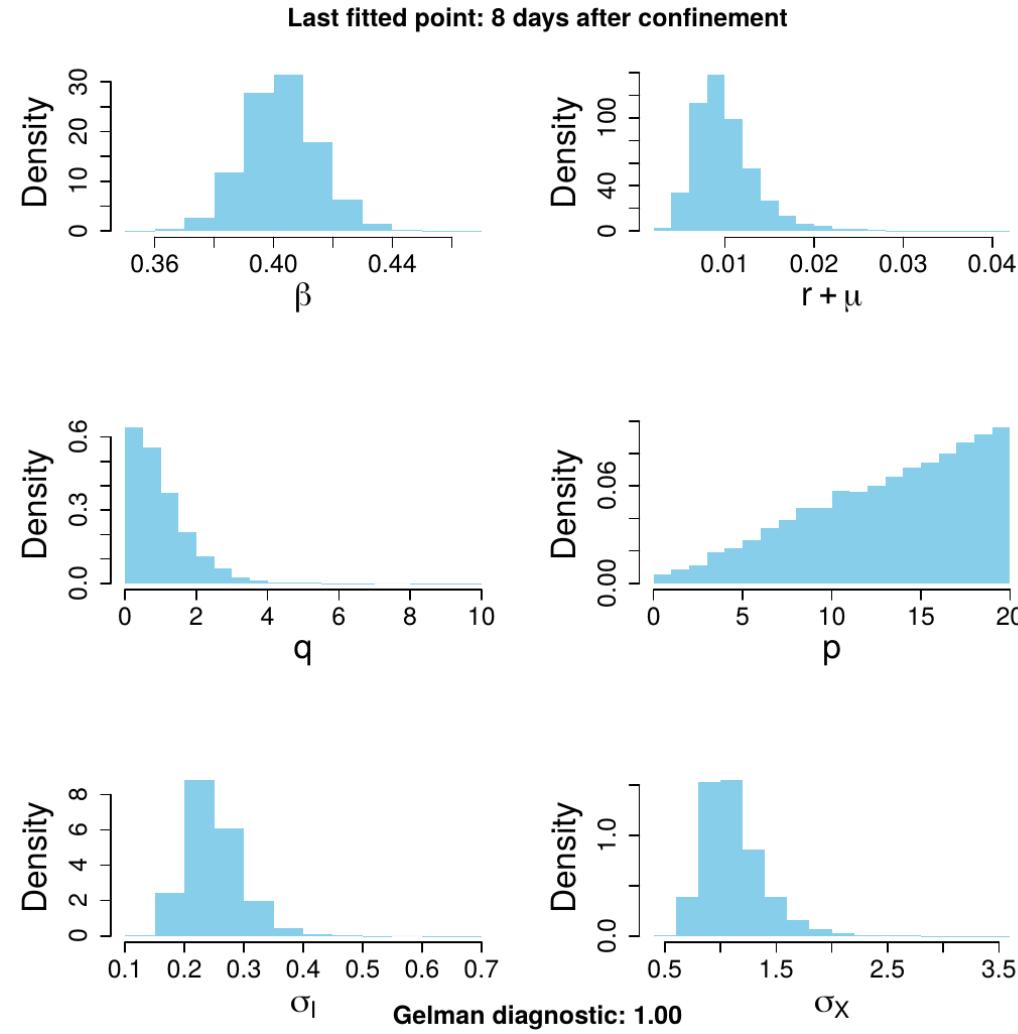
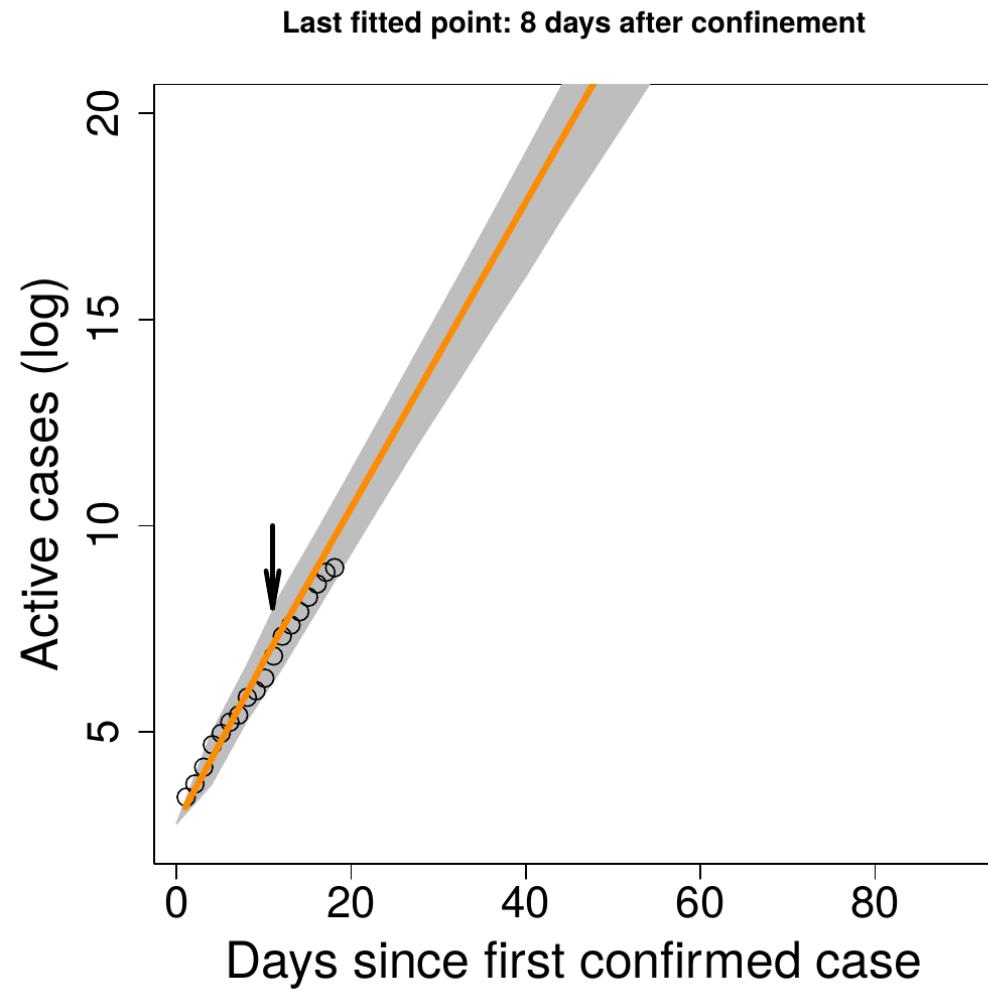


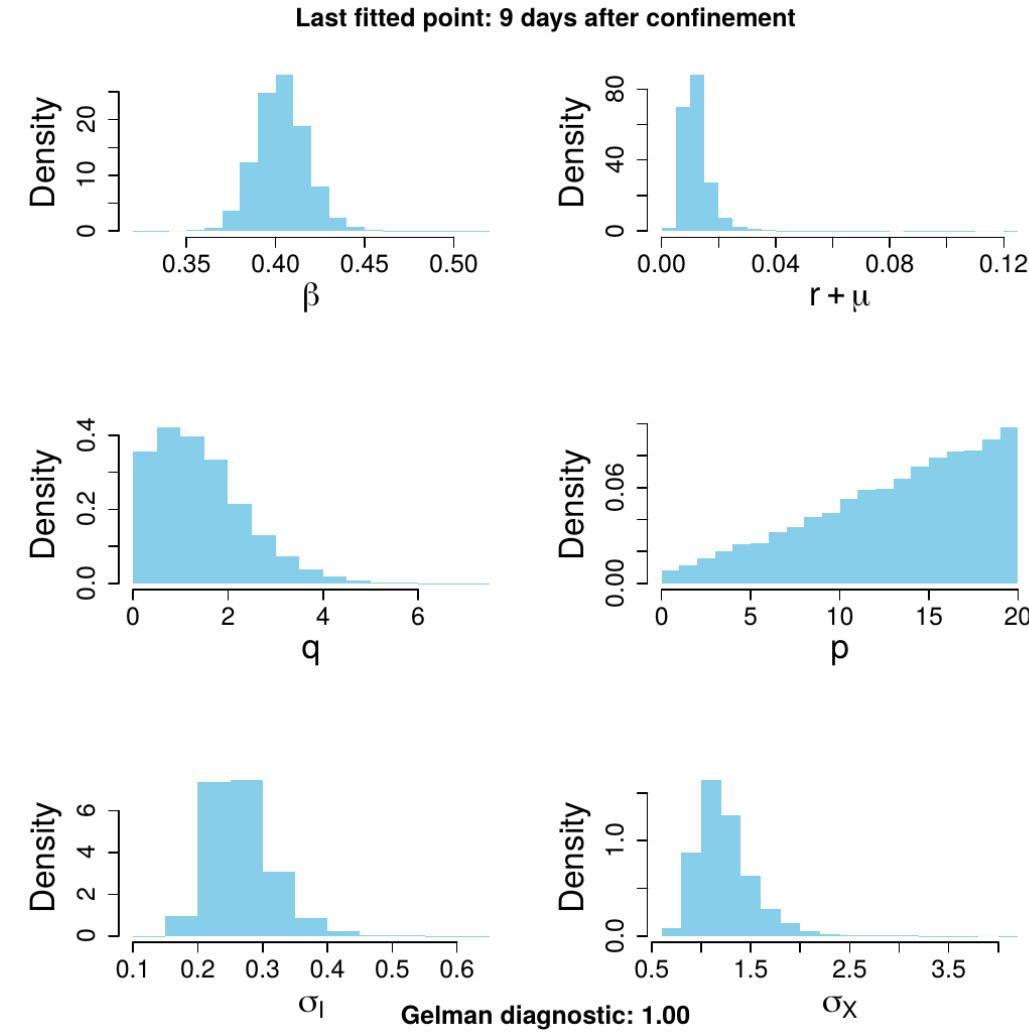
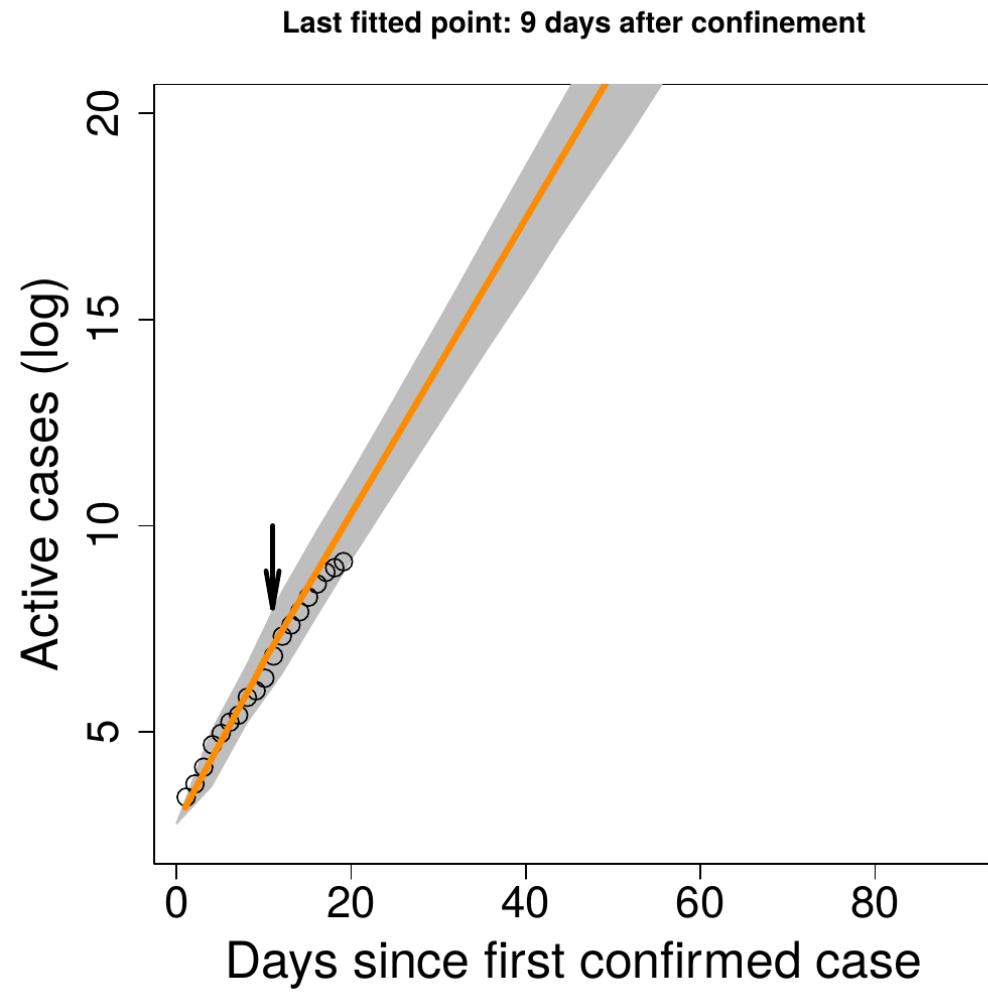


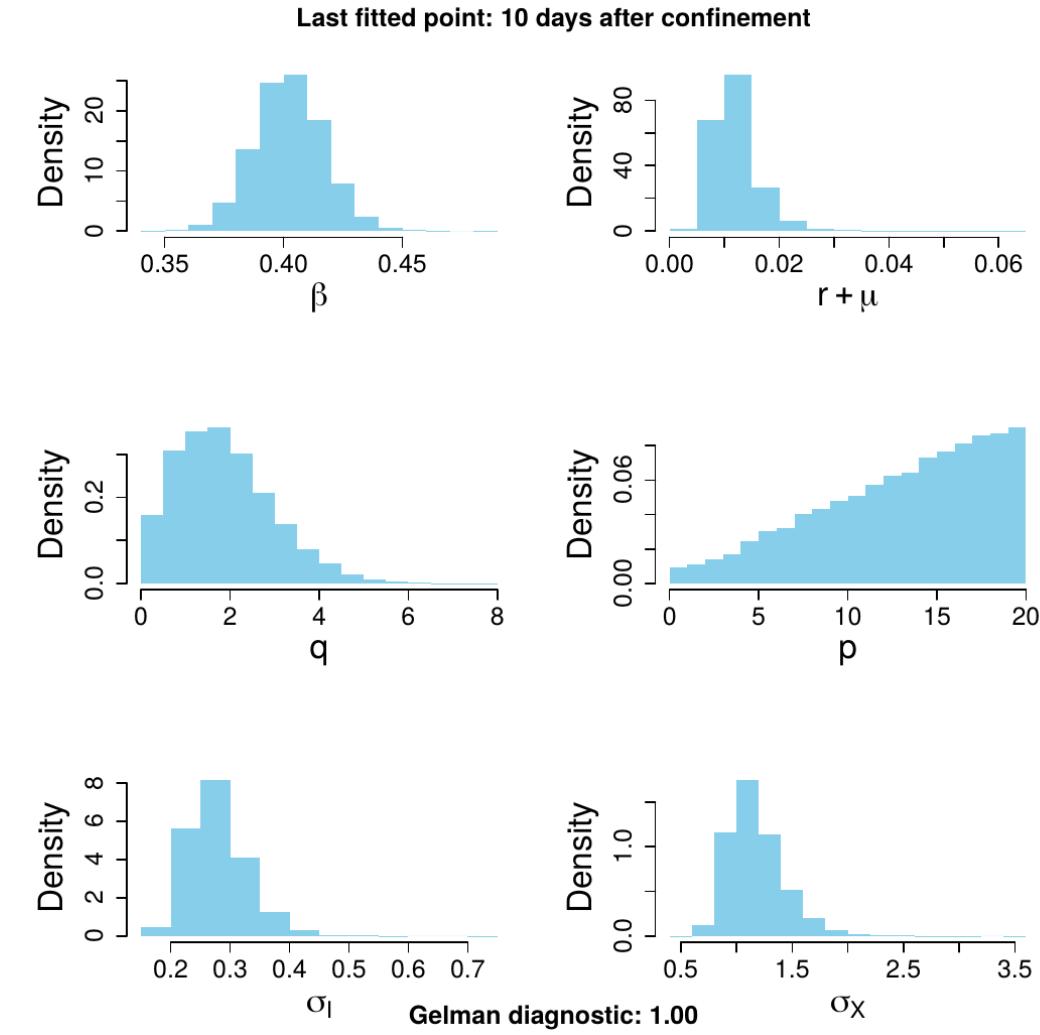
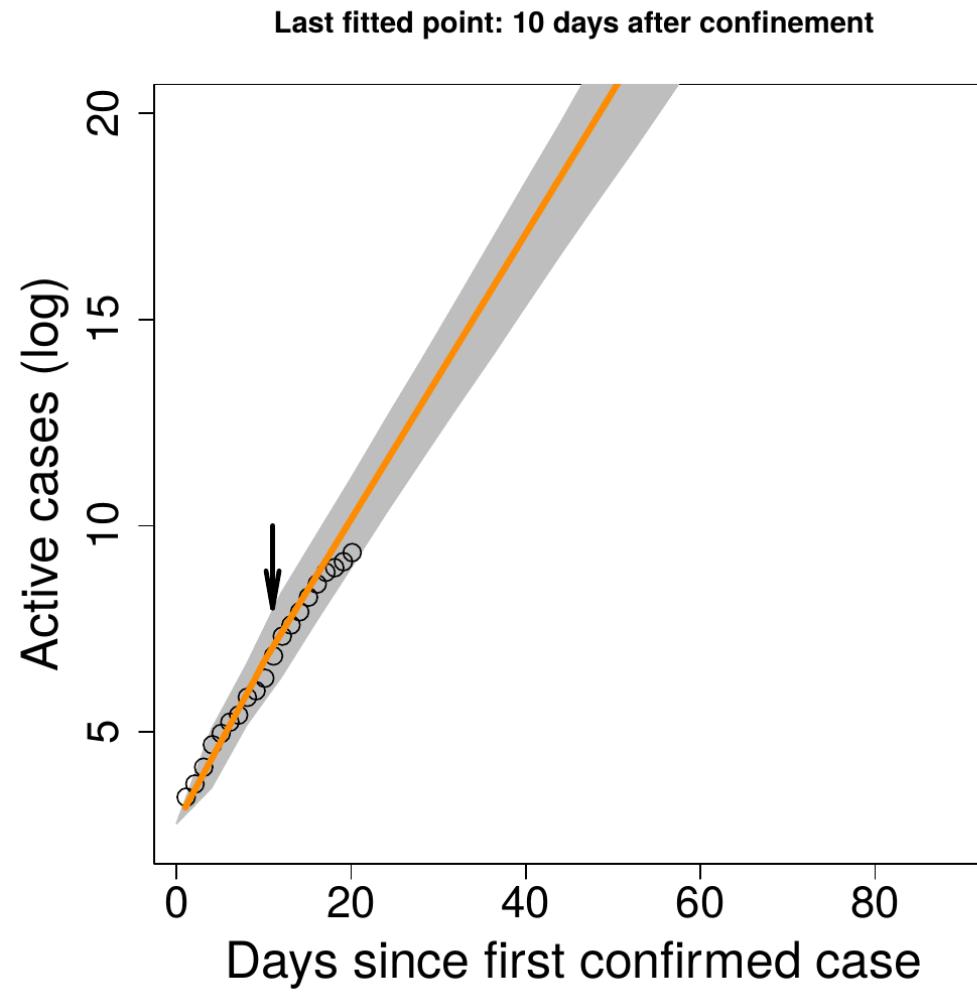


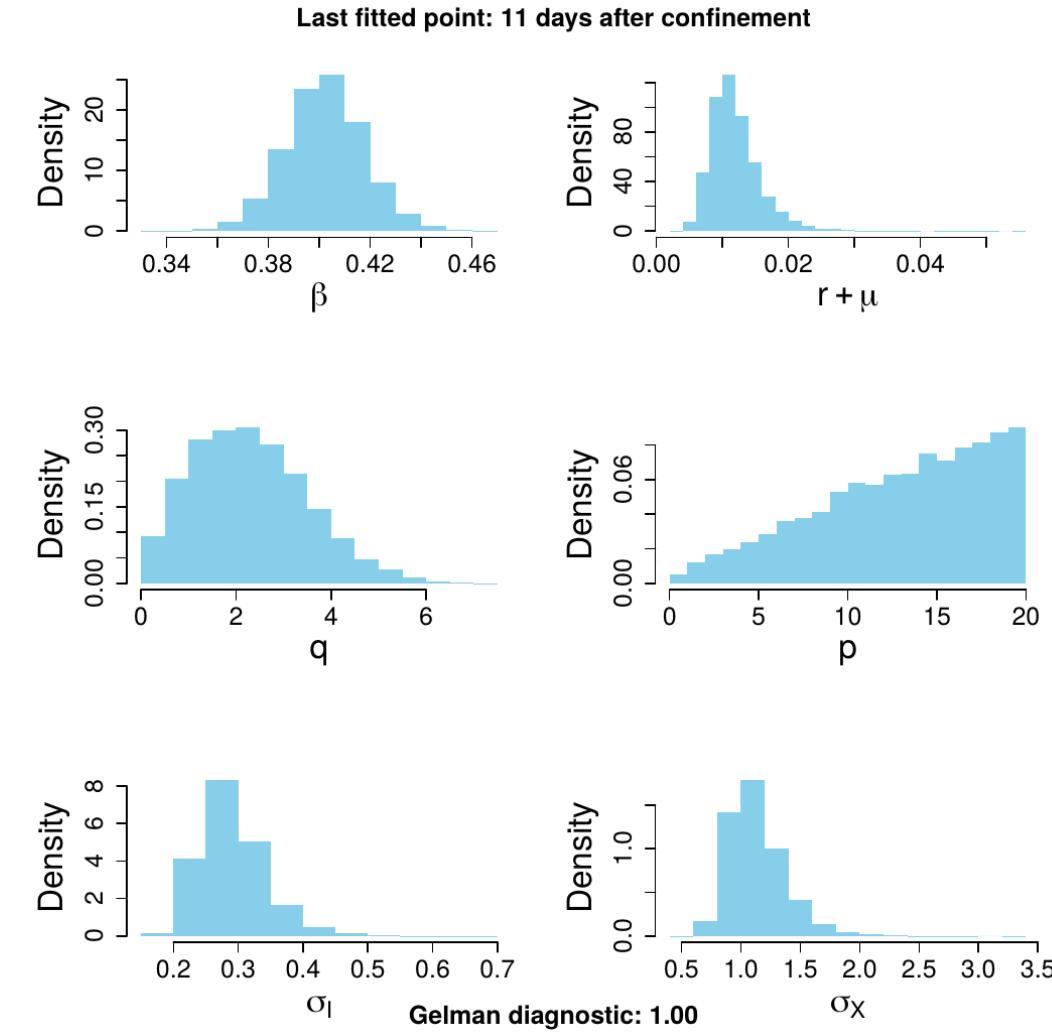
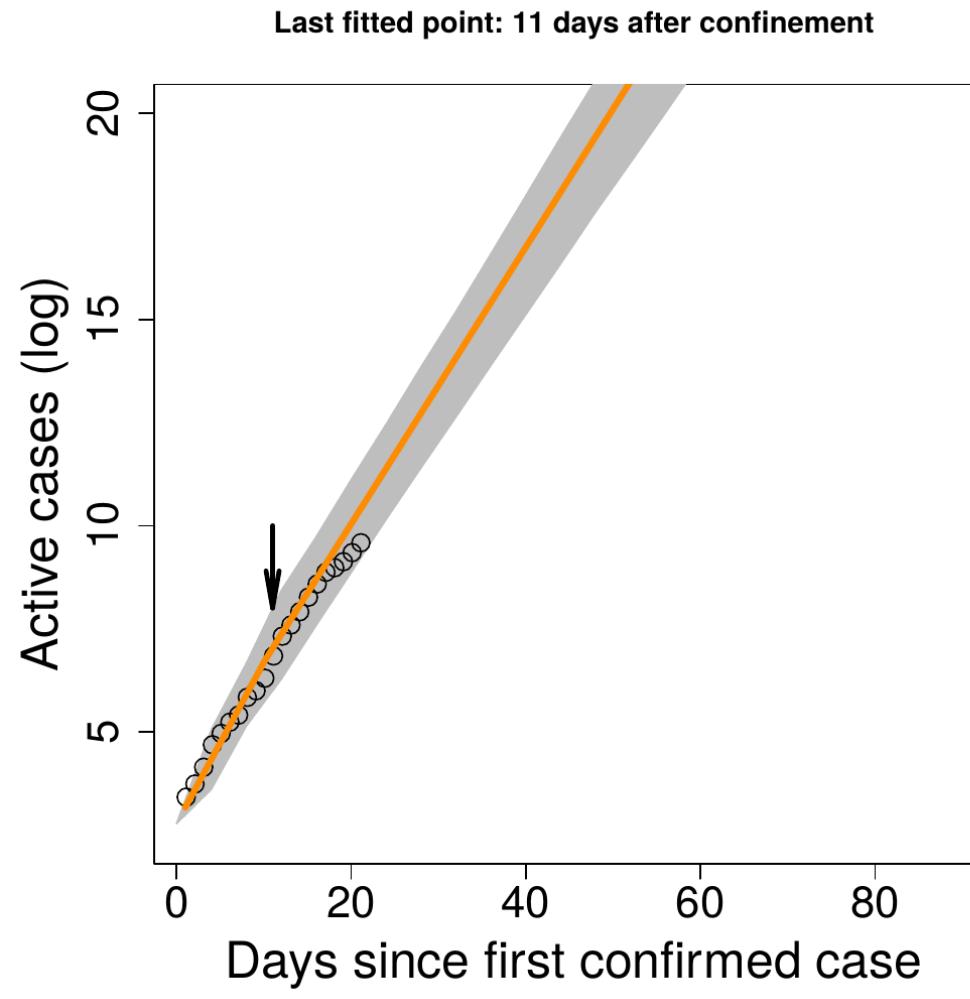


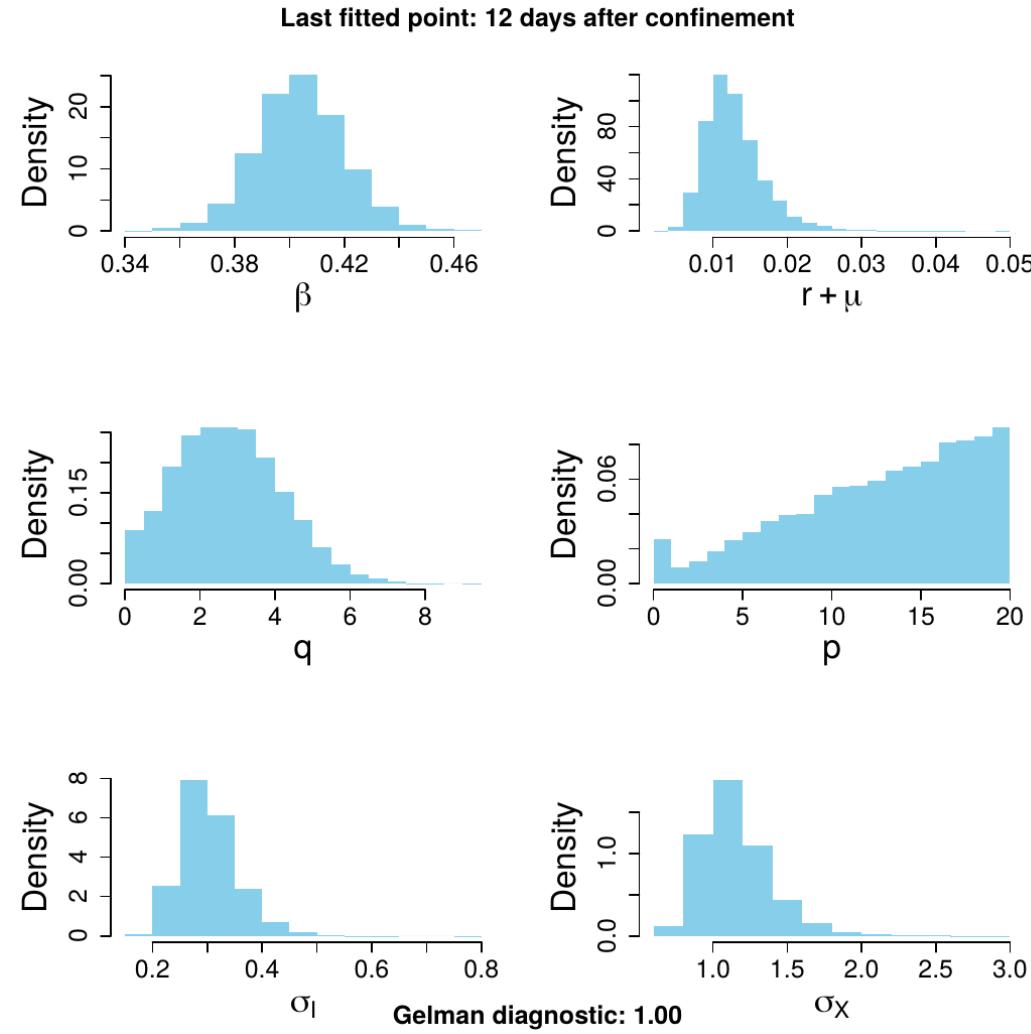
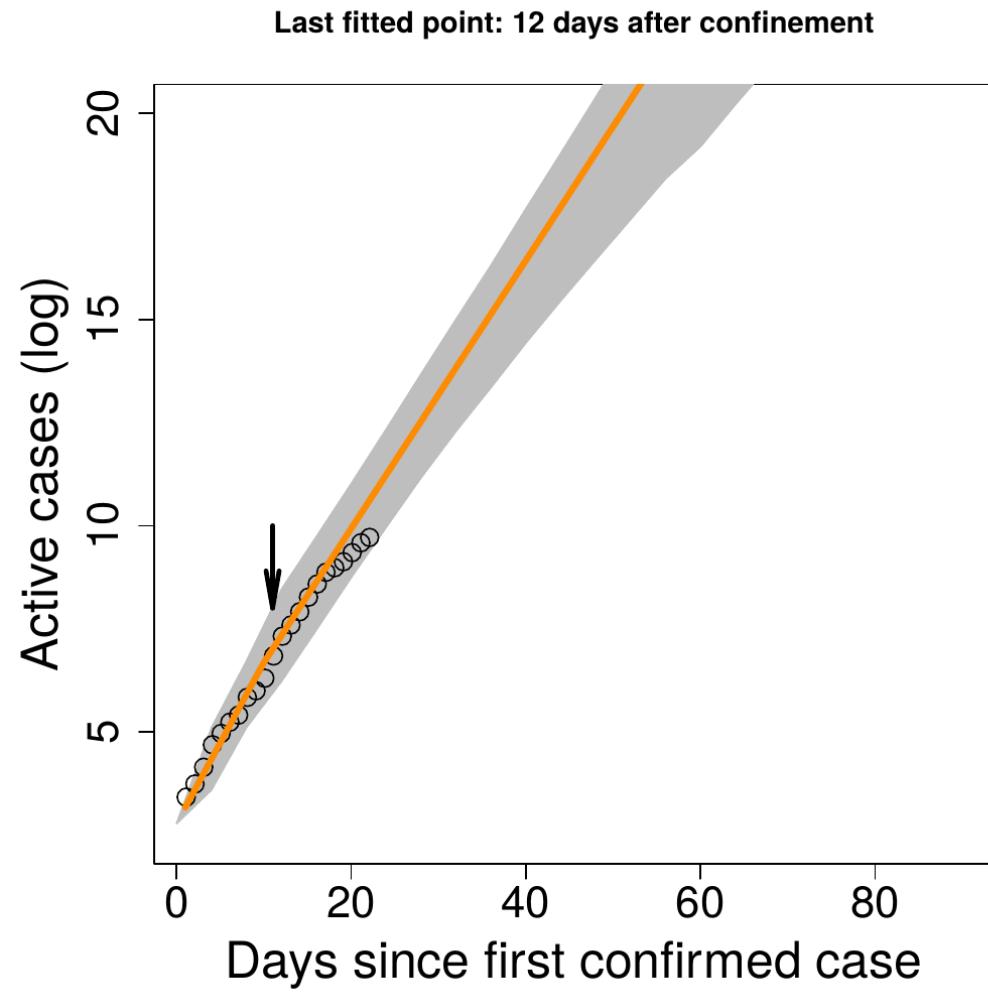


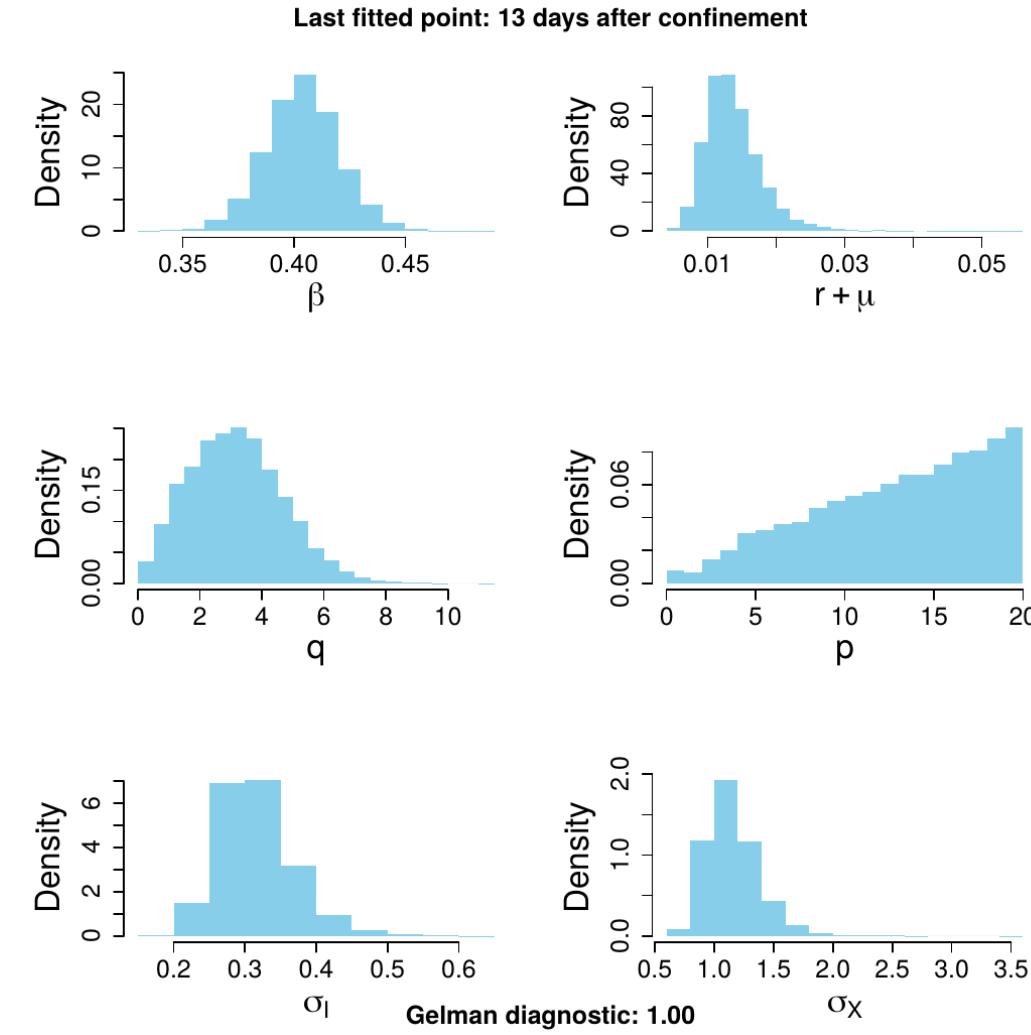
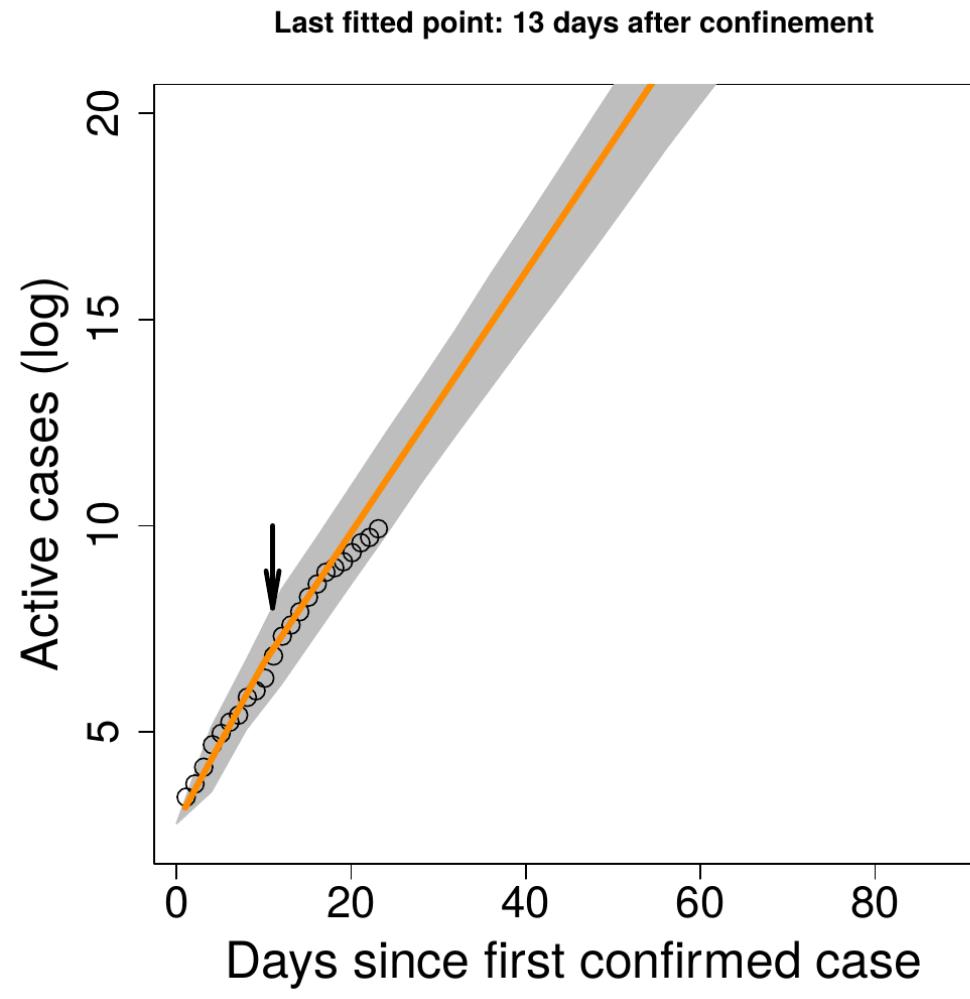


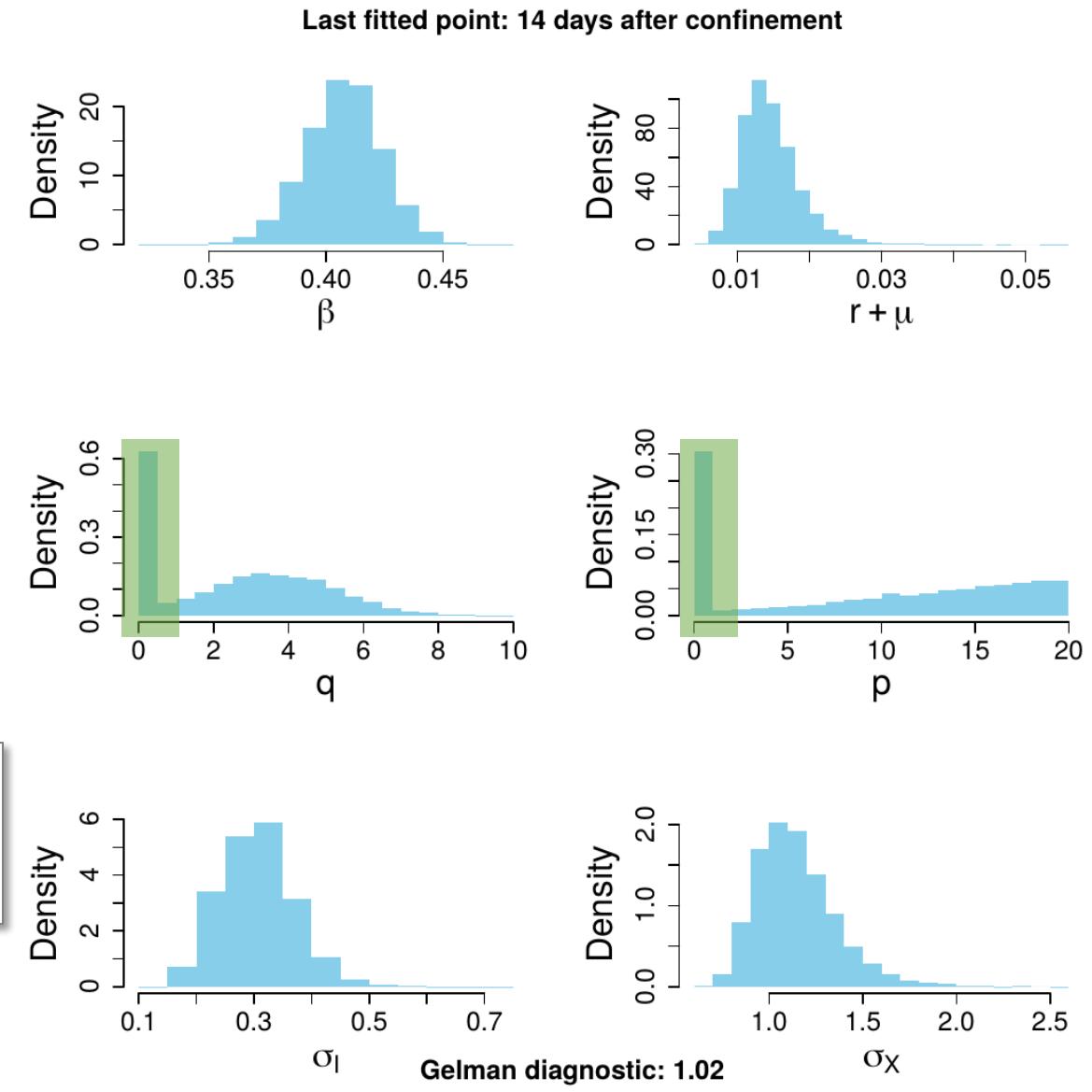
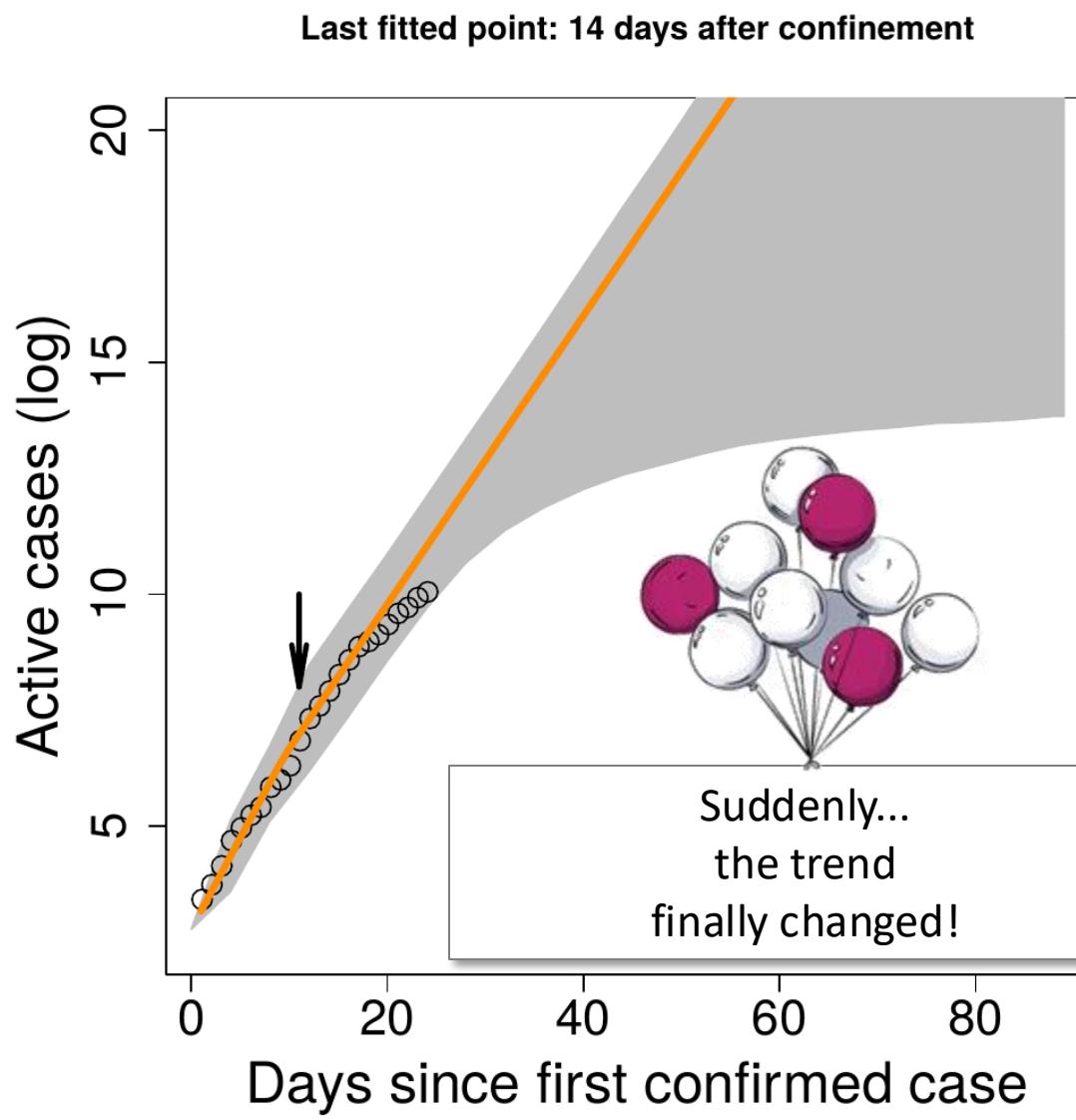


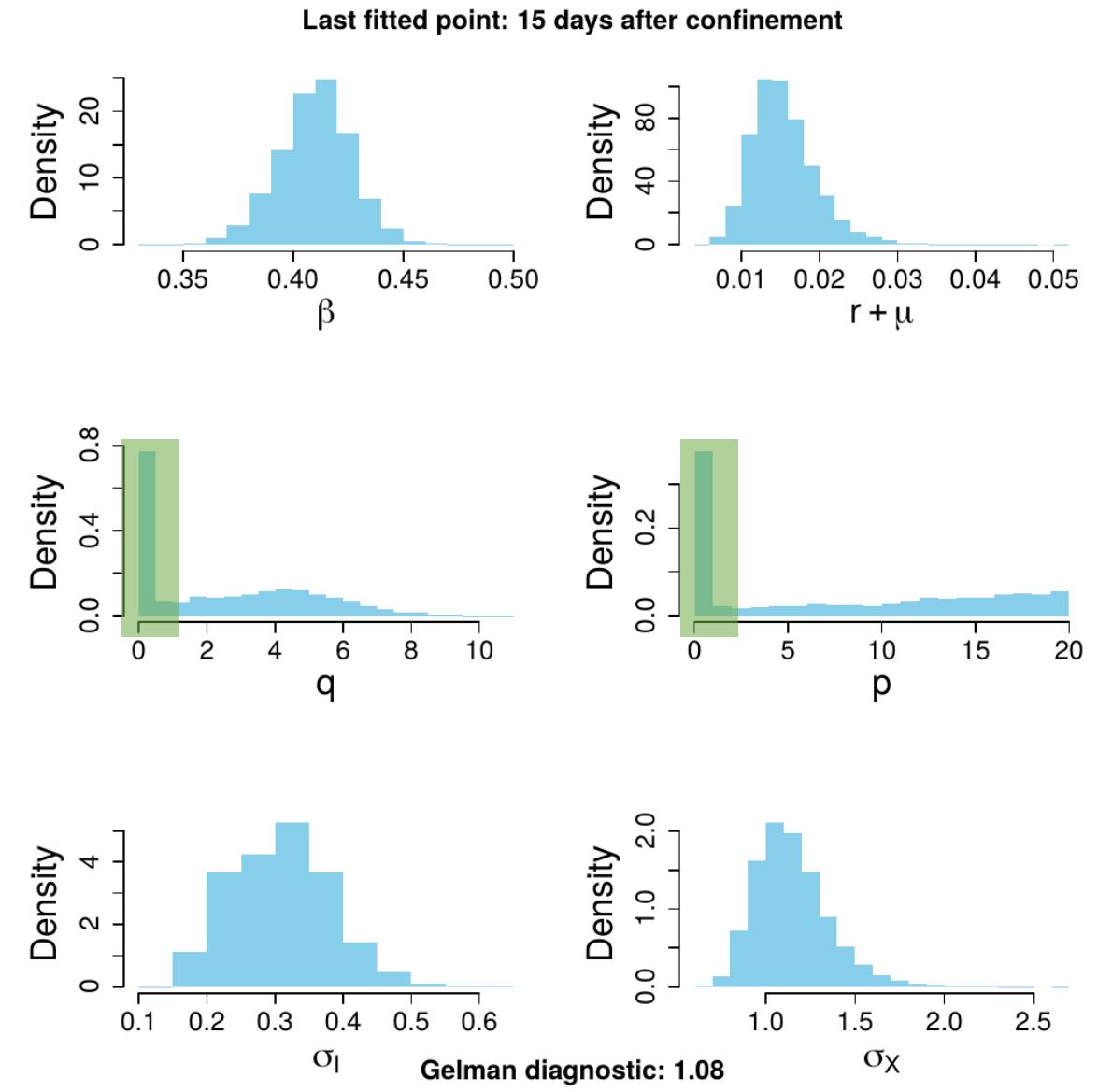
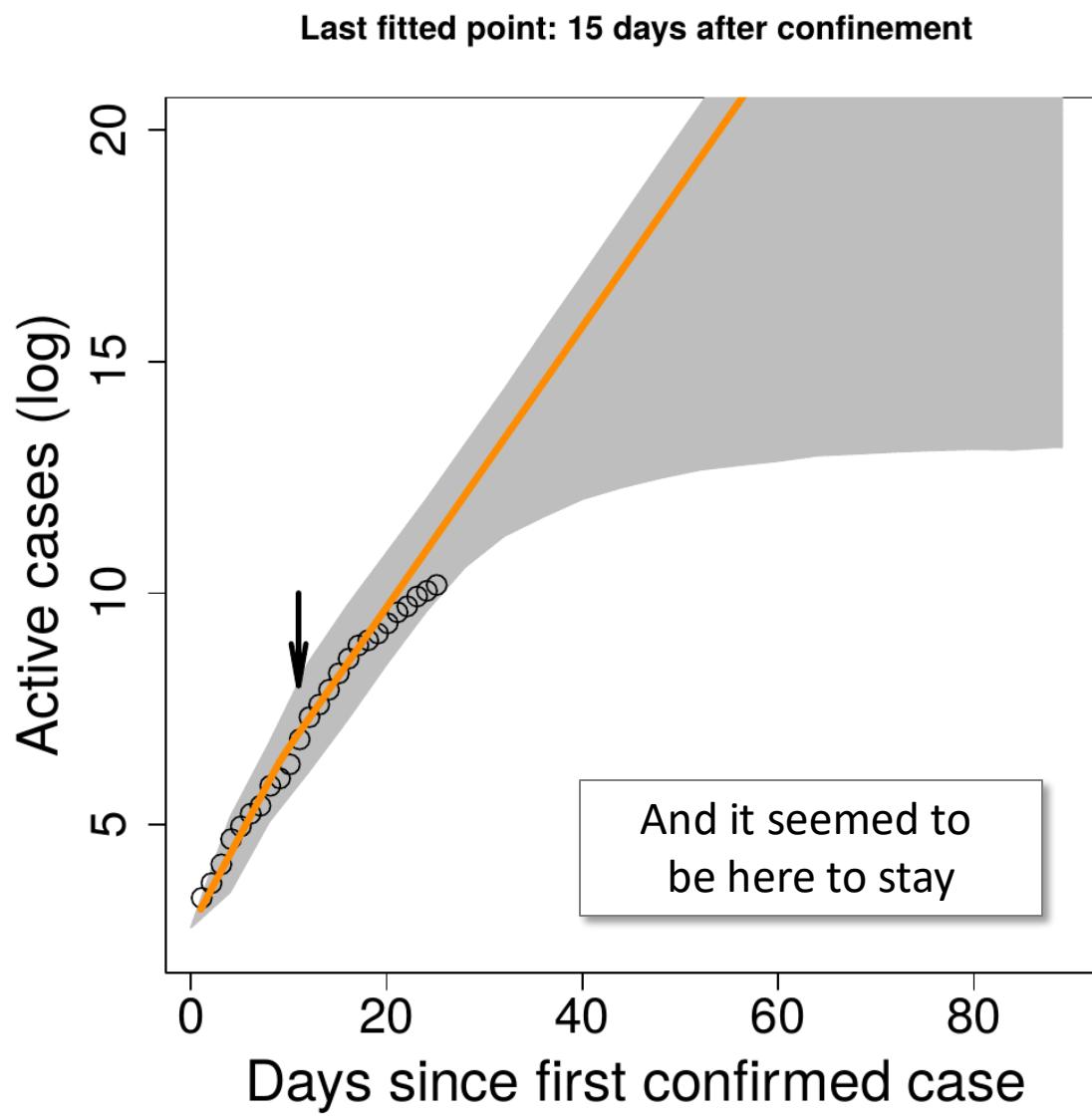


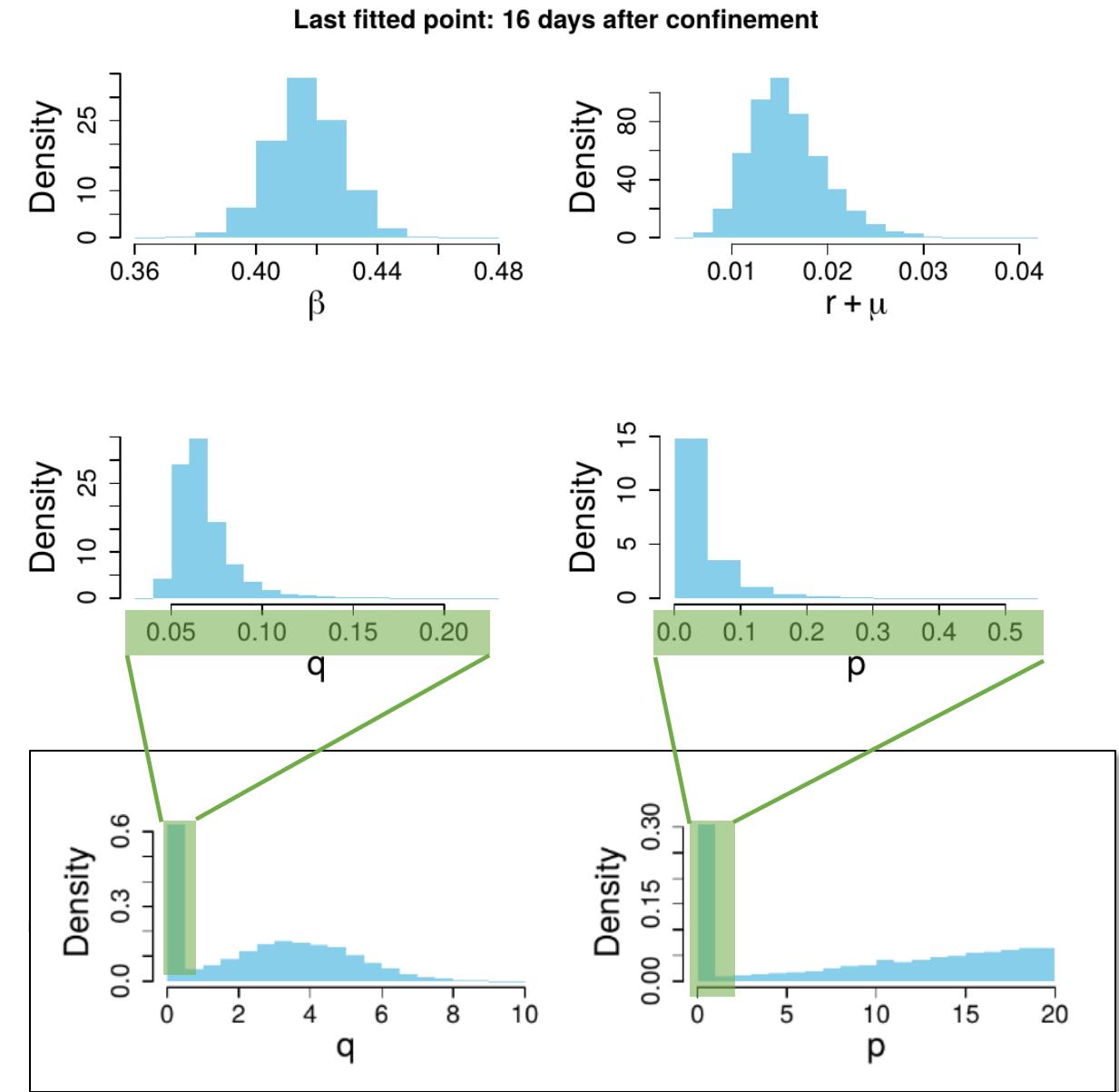
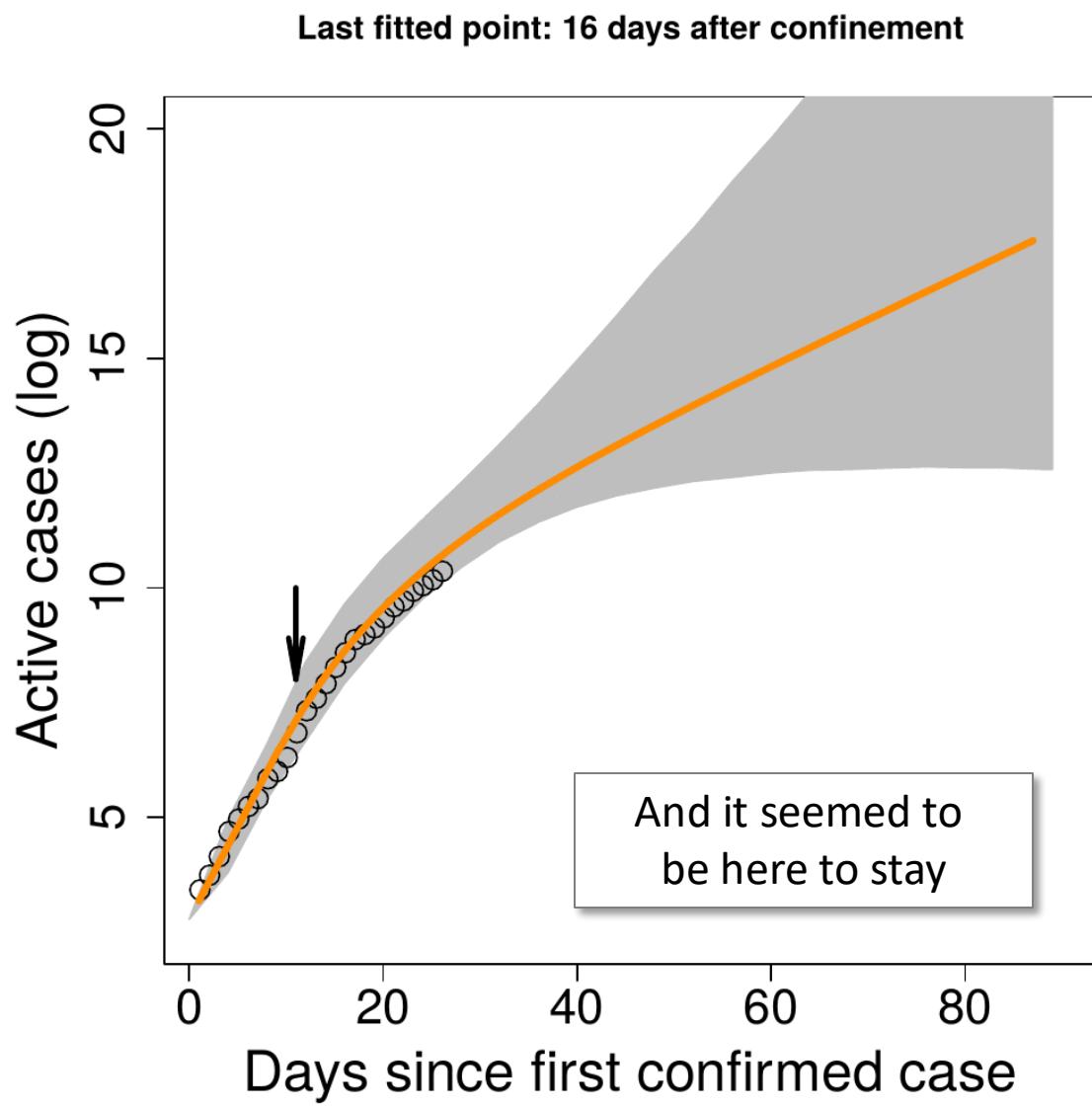


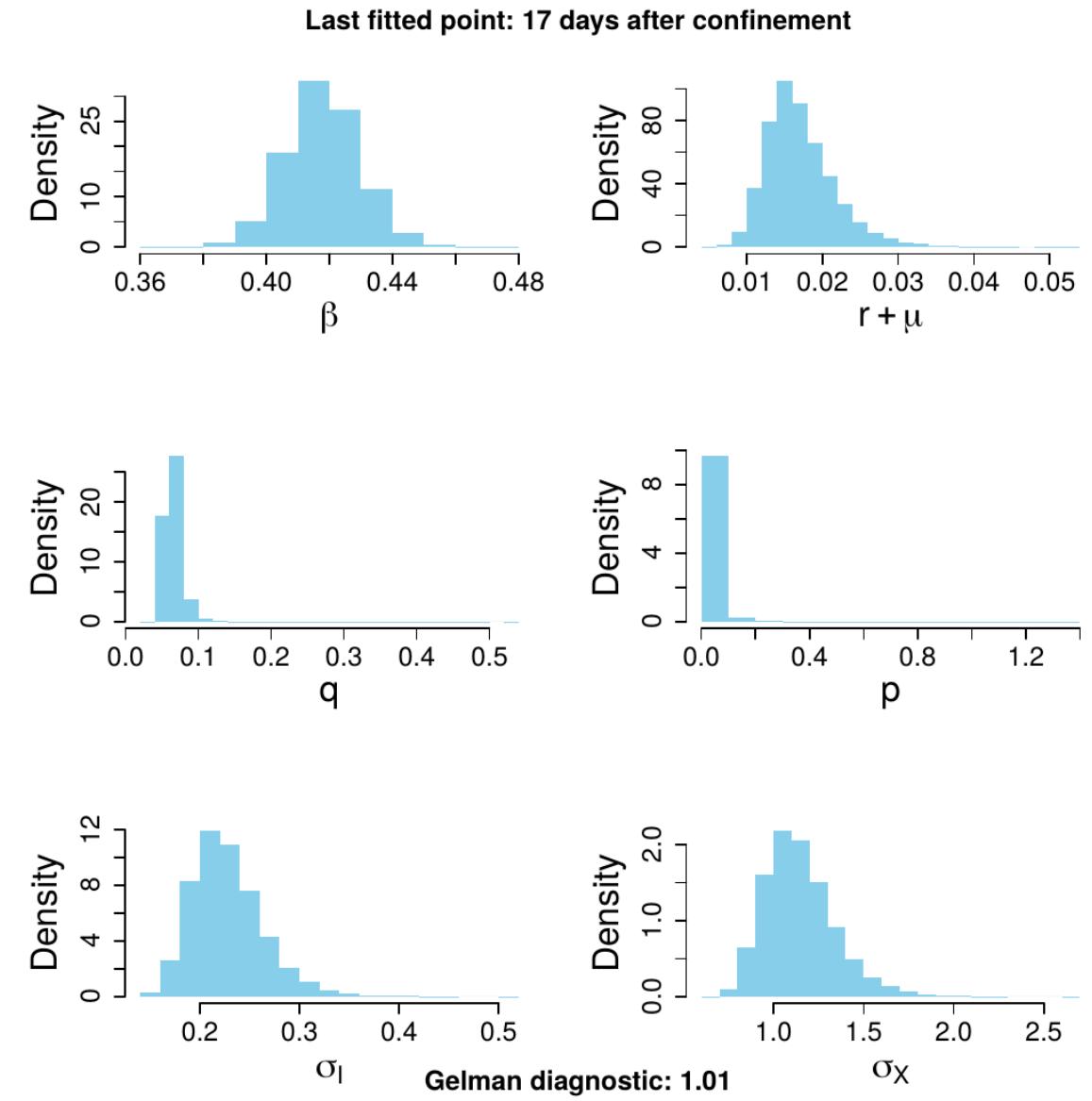
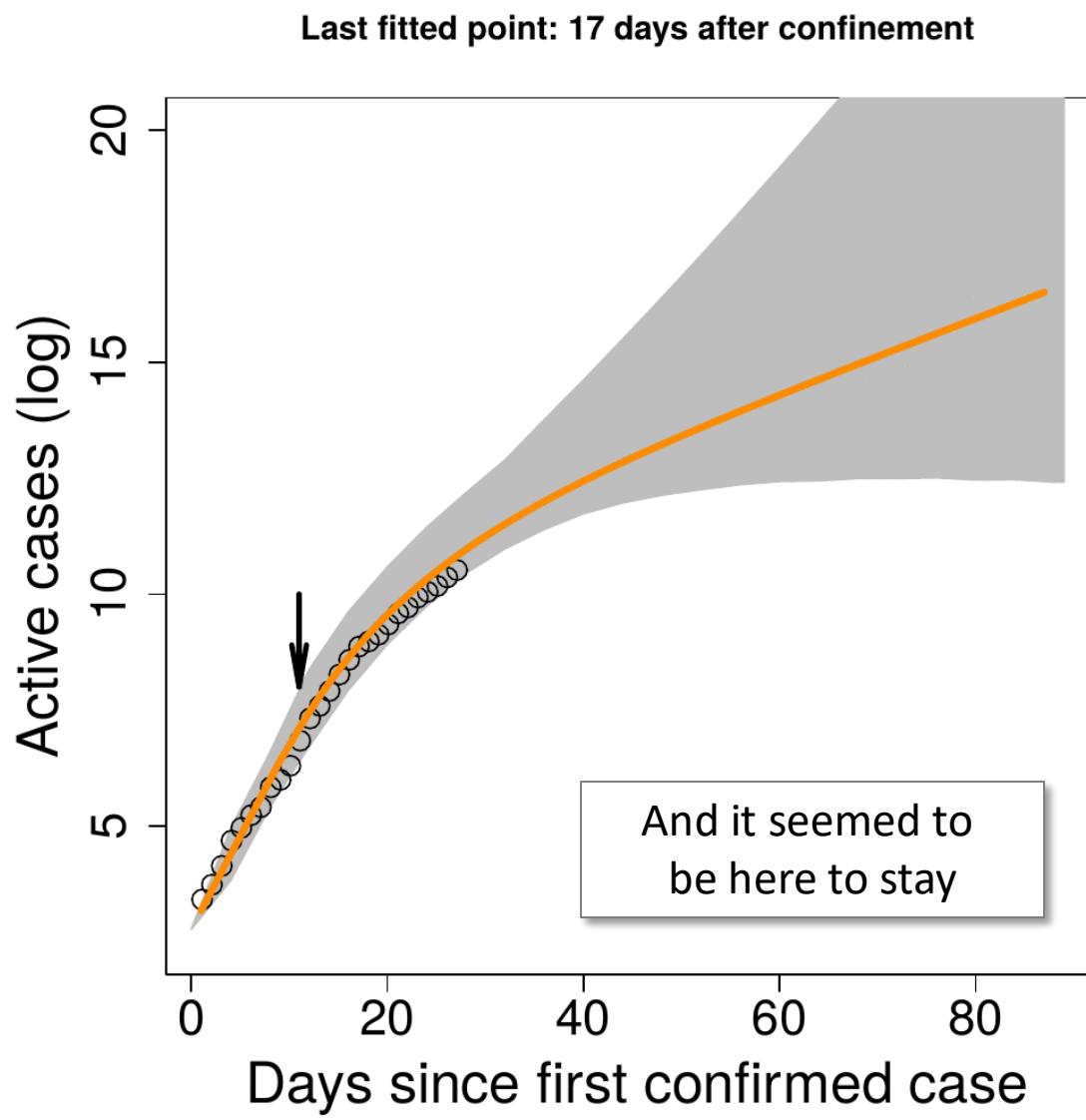


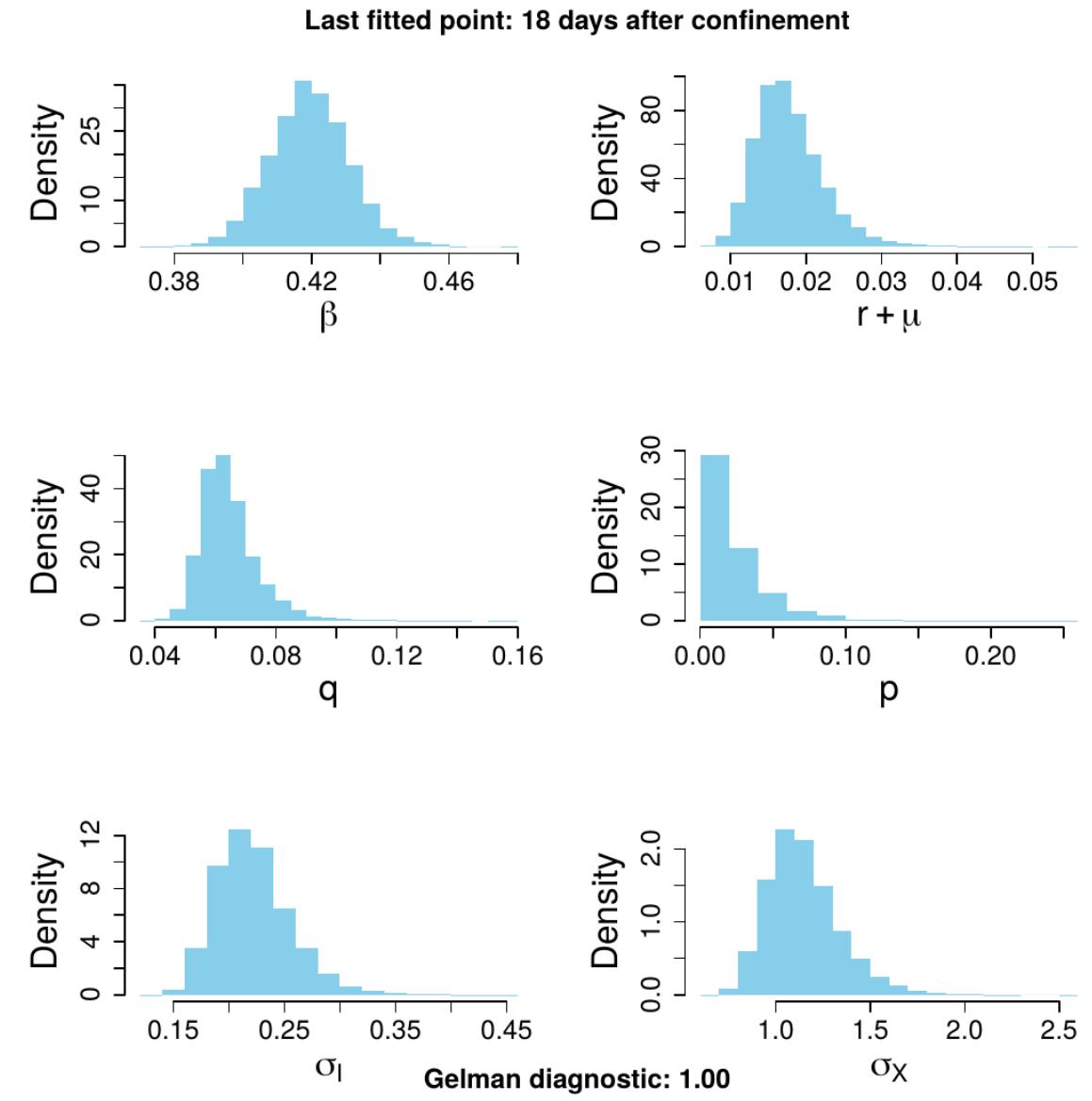
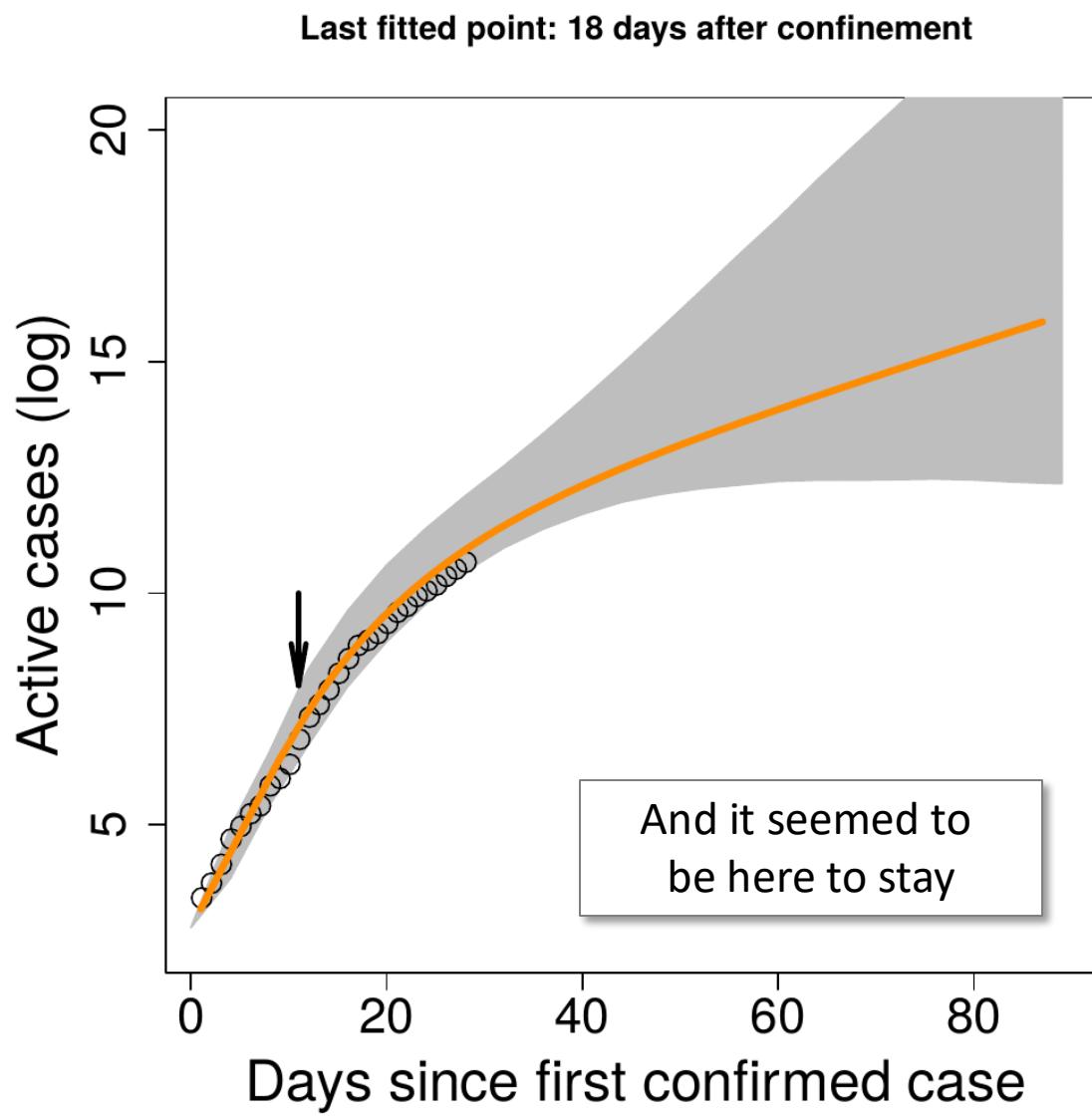


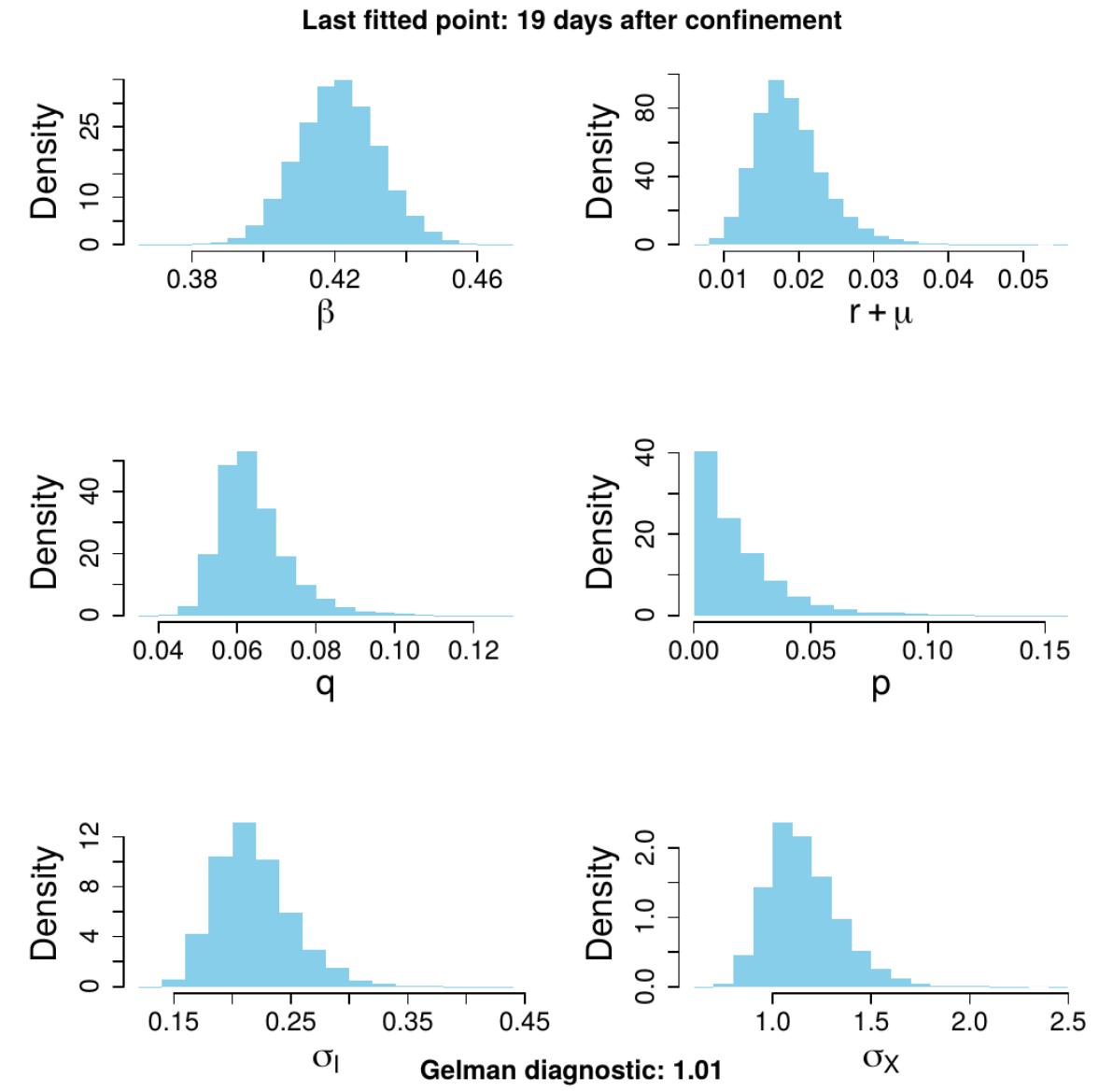
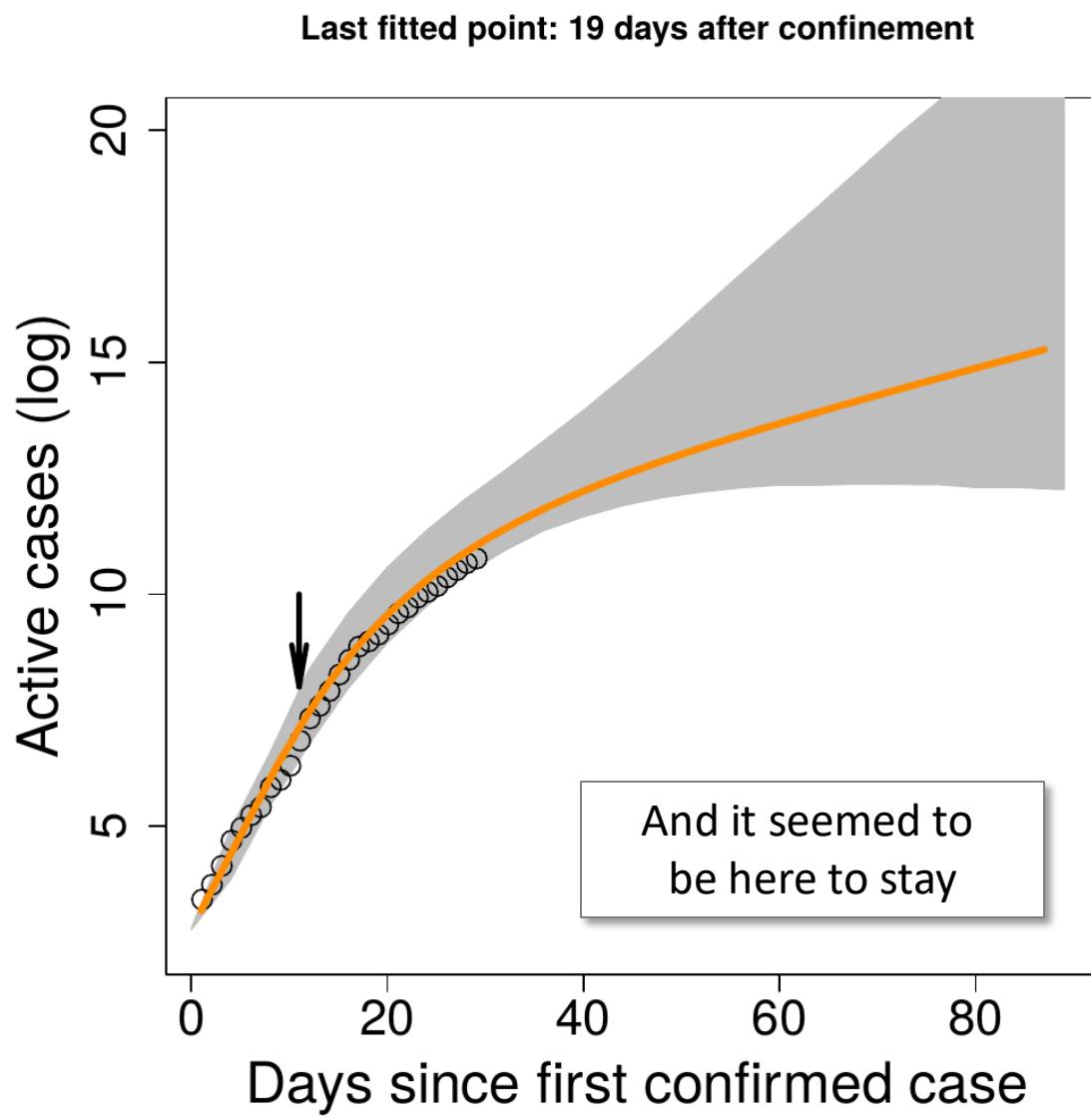


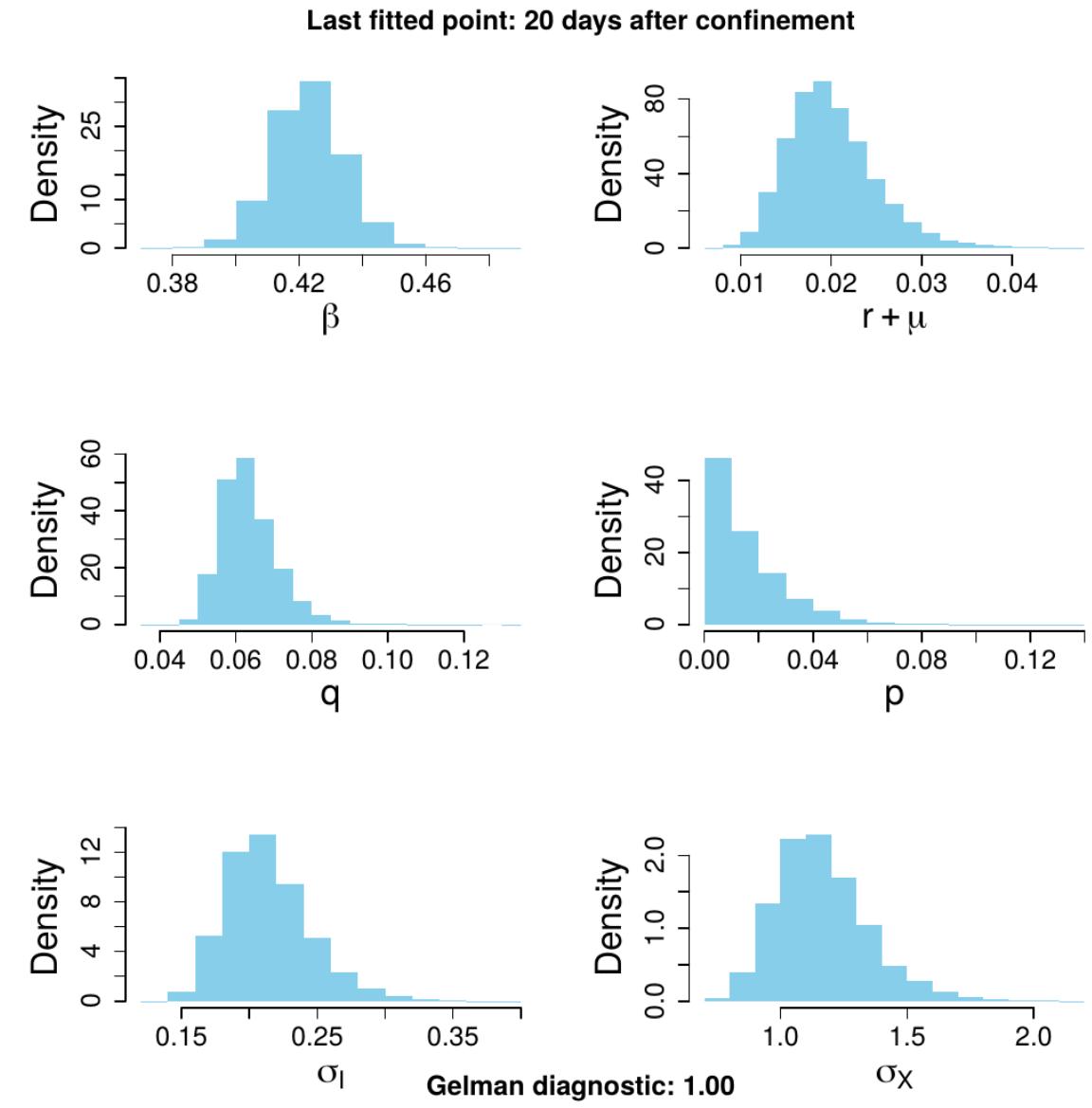
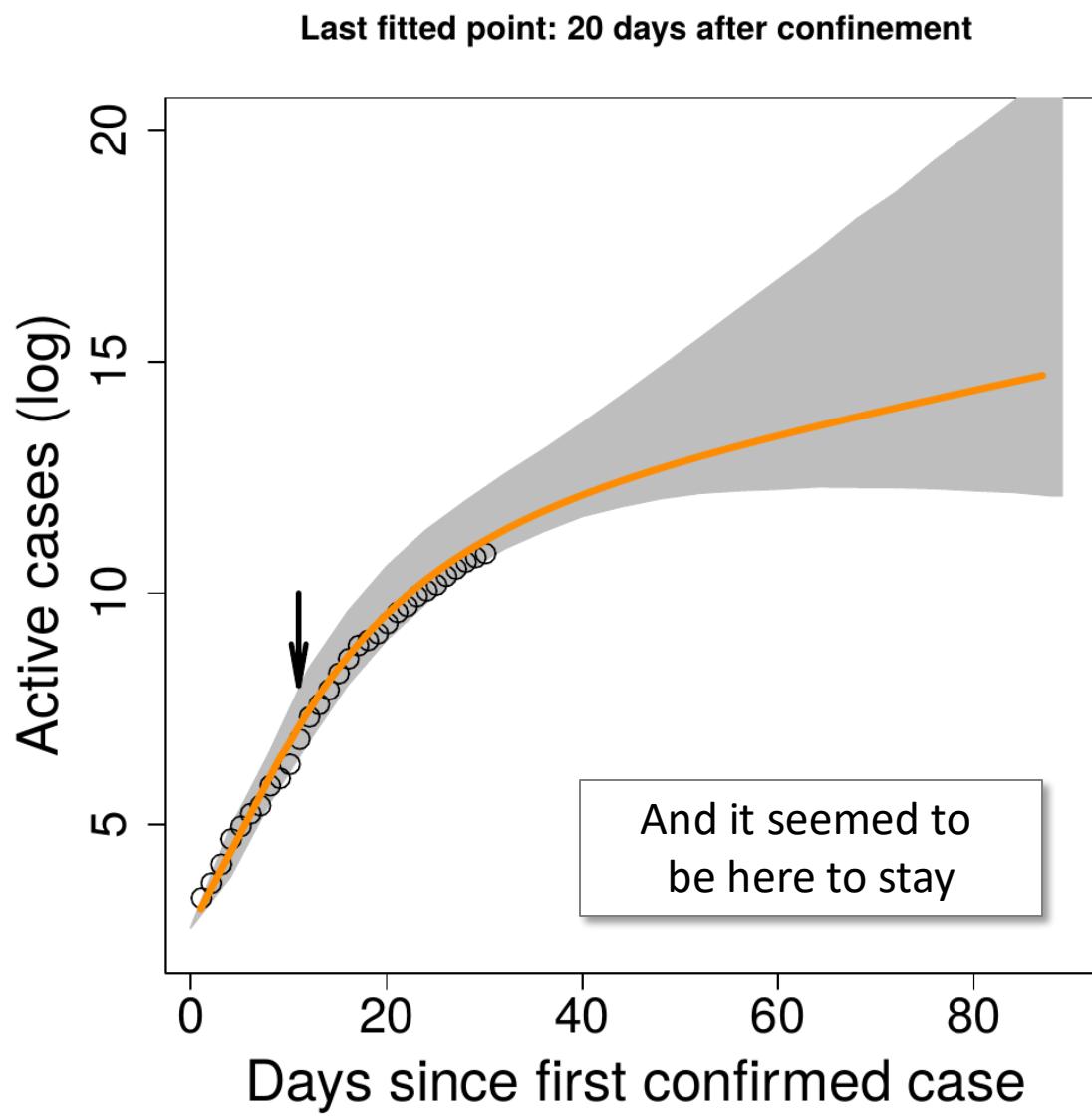


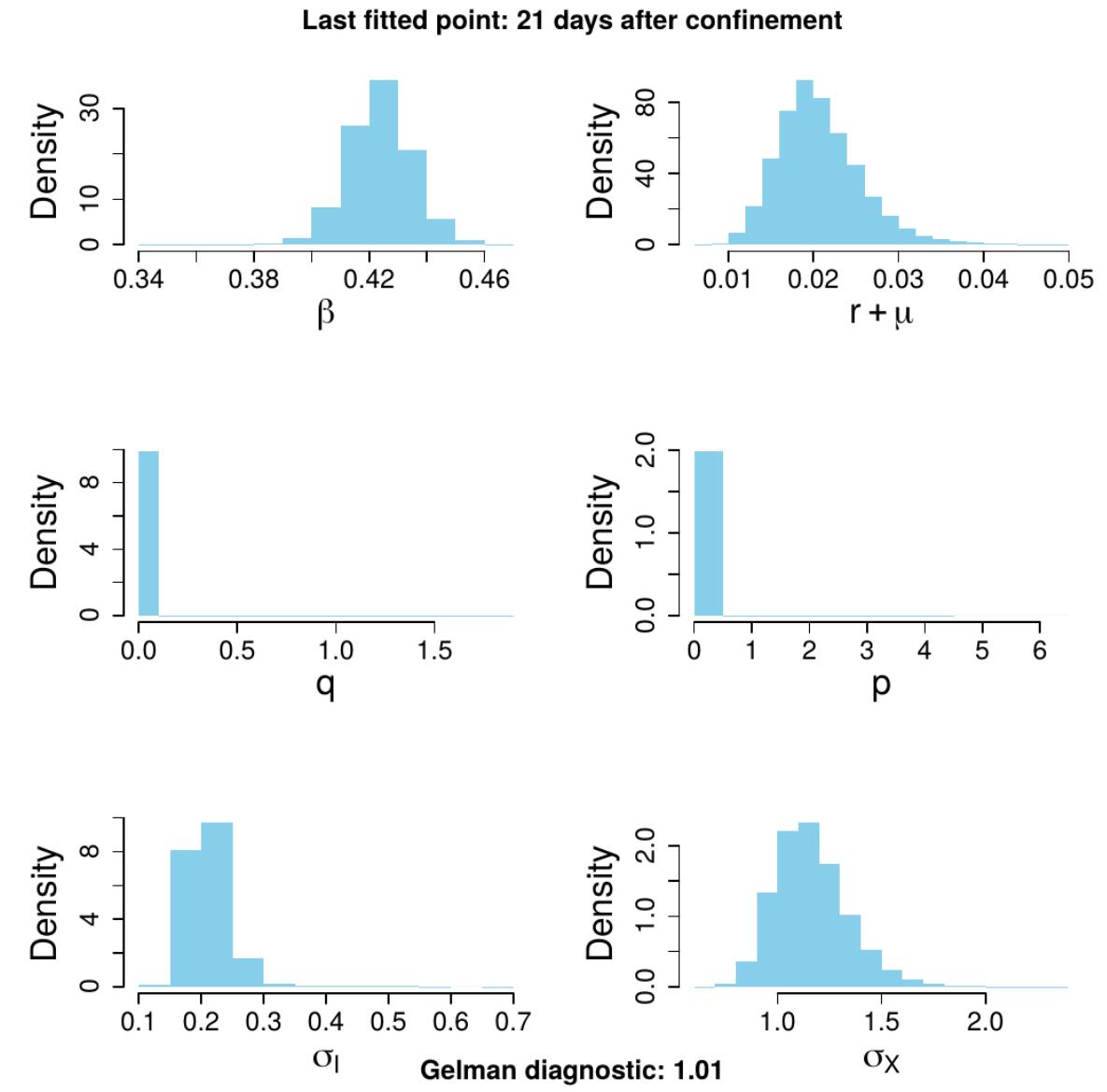
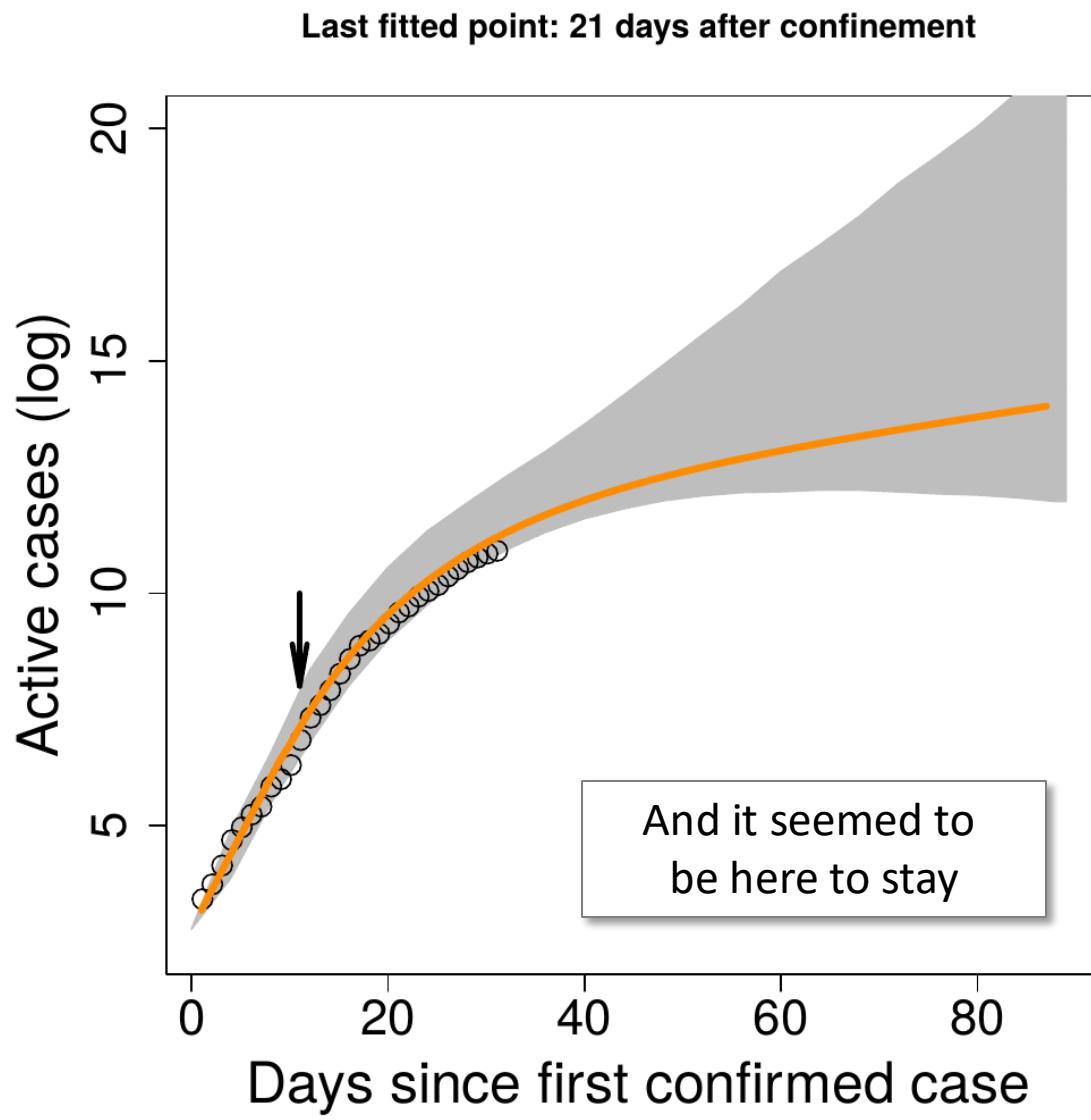


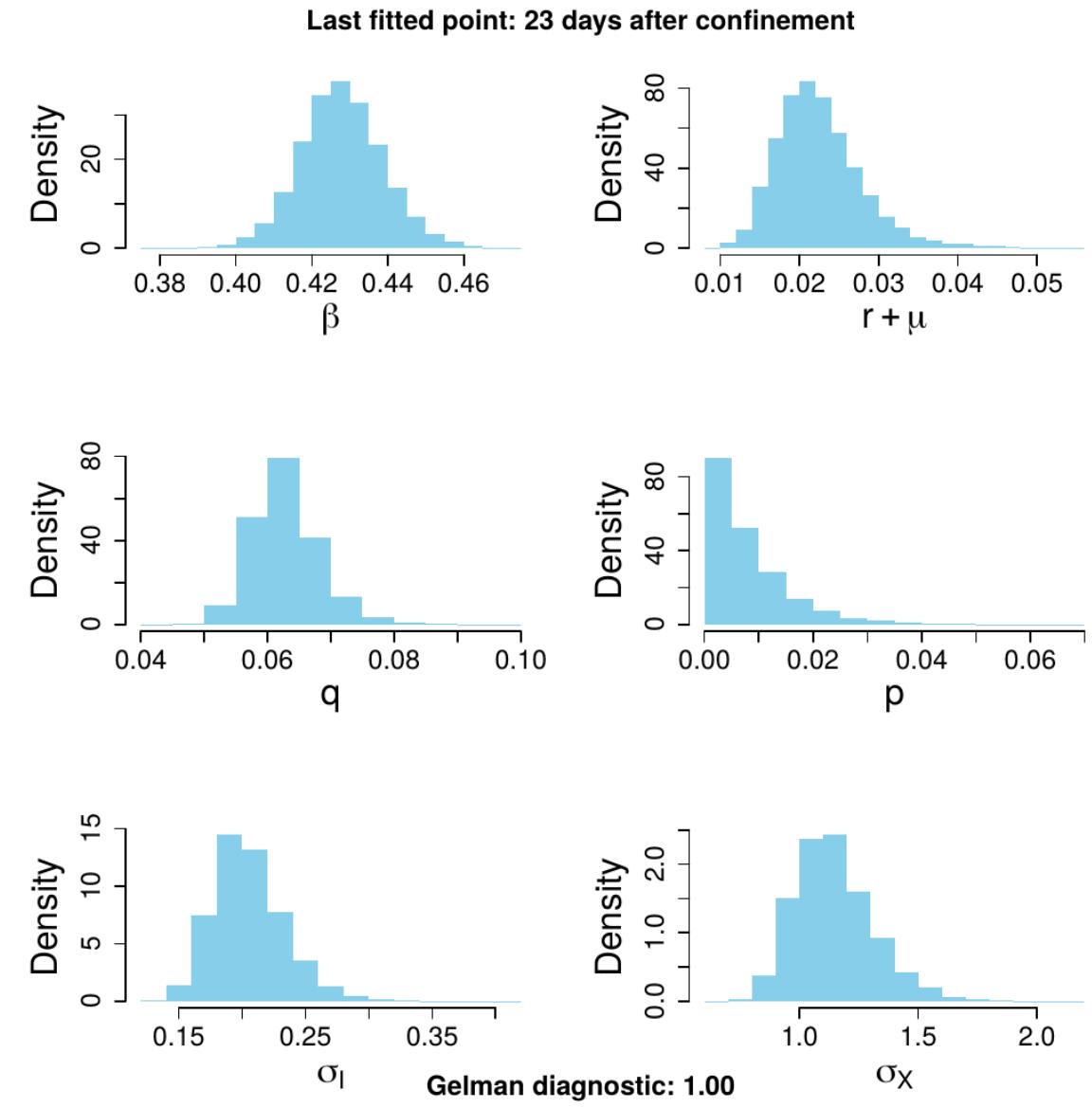
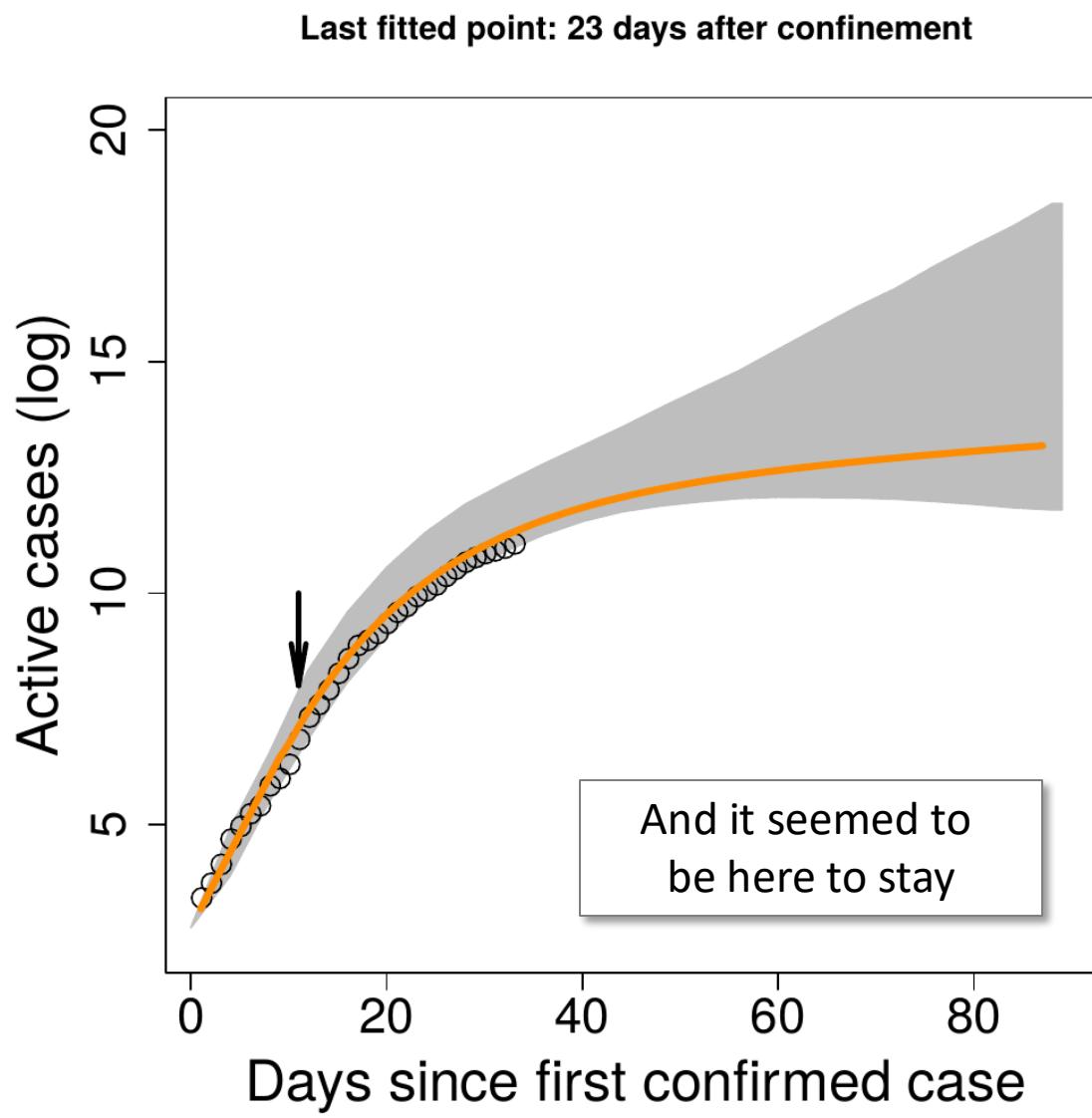




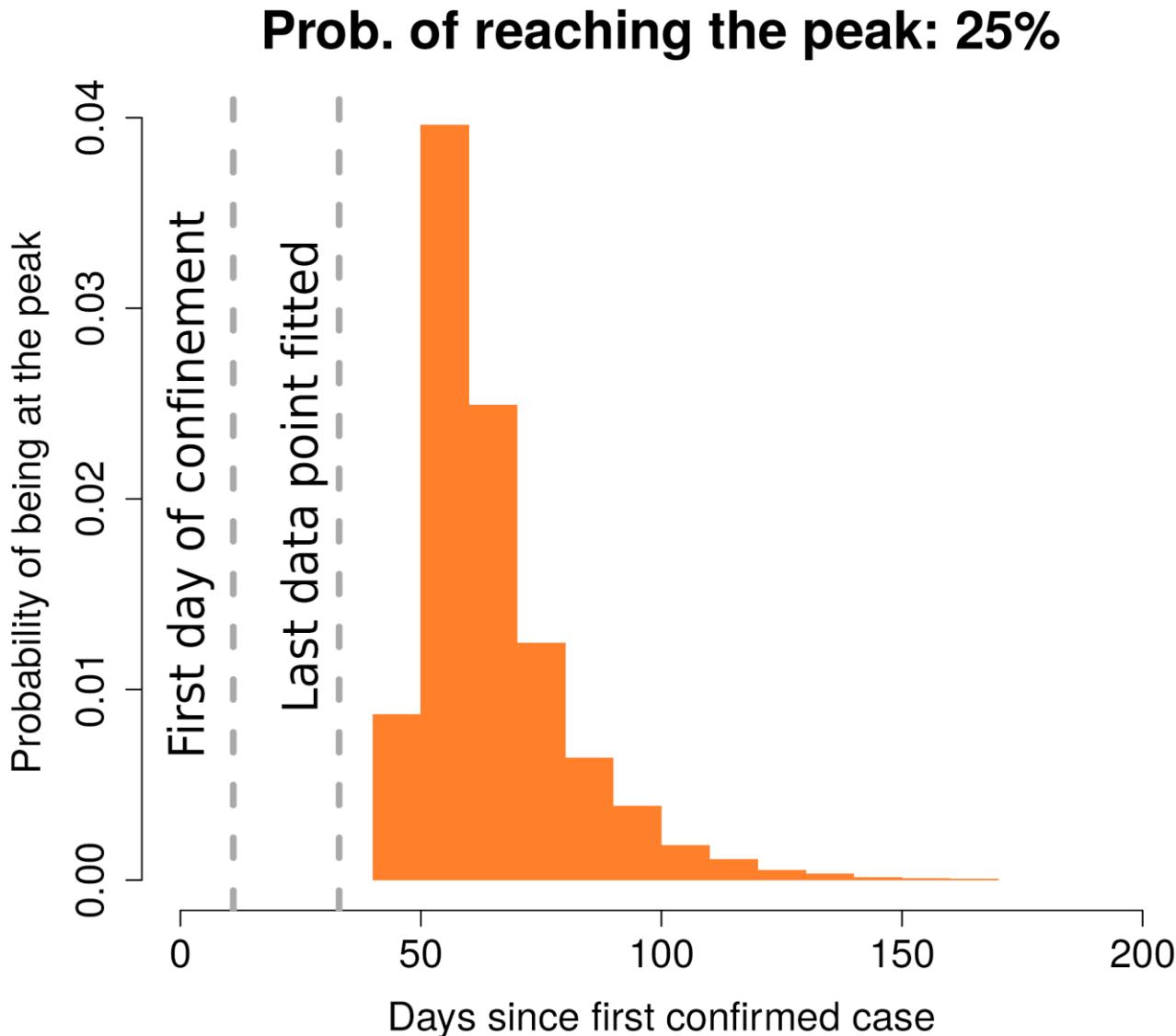








Only probabilistic predictions are meaningful



Before the strict lockdown of March 28, this simple SCIR model predicted that **propagation would be inhibited only with a 25% probability**.

Conditional on reaching the peak, the time at which it would be attained has a long-tailed distribution.

Data is full of errors, incomplete, adds from different locations...

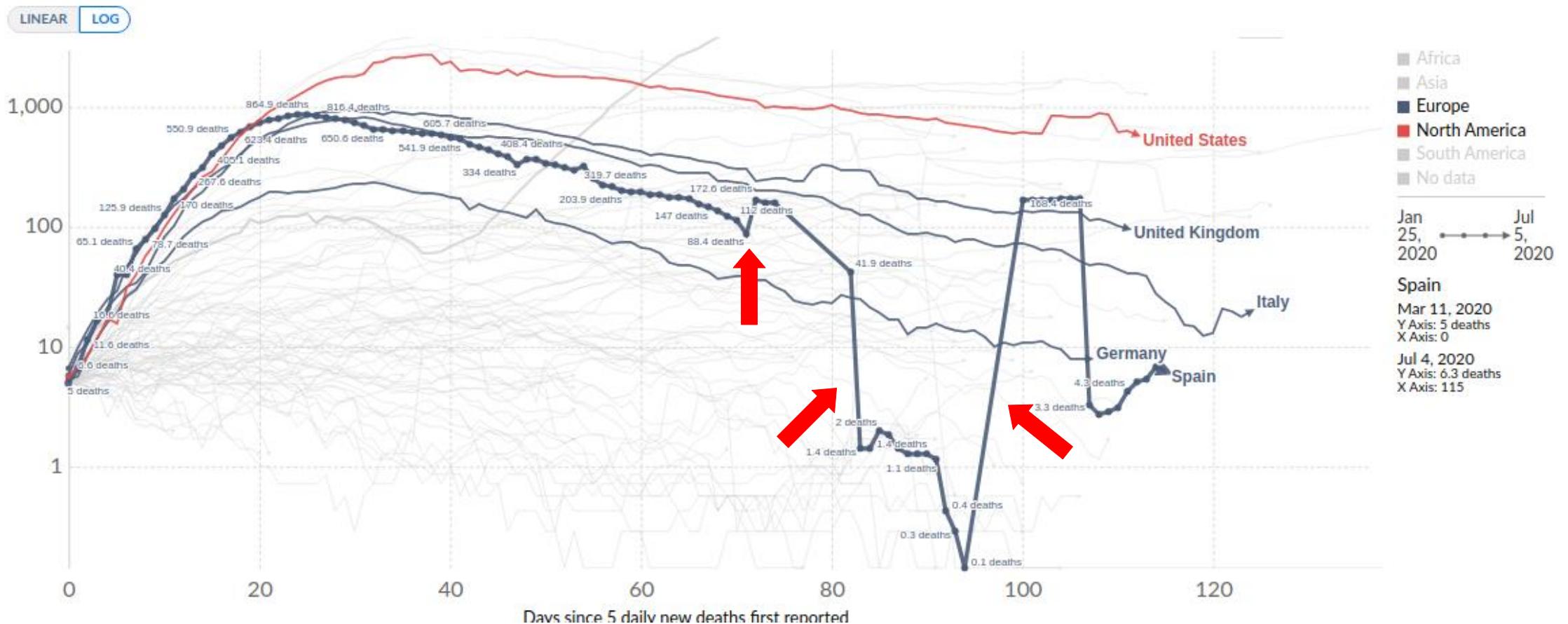
No one believes your model can do the job, it does not represent the real process

are lousy data to blame for the uncertainty?

Daily new confirmed COVID-19 deaths

Our World
in Data

Shown is the rolling 7-day average. Limited testing and challenges in the attribution of the cause of death means that the number of confirmed deaths may not be an accurate count of the true number of deaths from COVID-19.



Neither exact data nor a perfect model lead to precise forecast

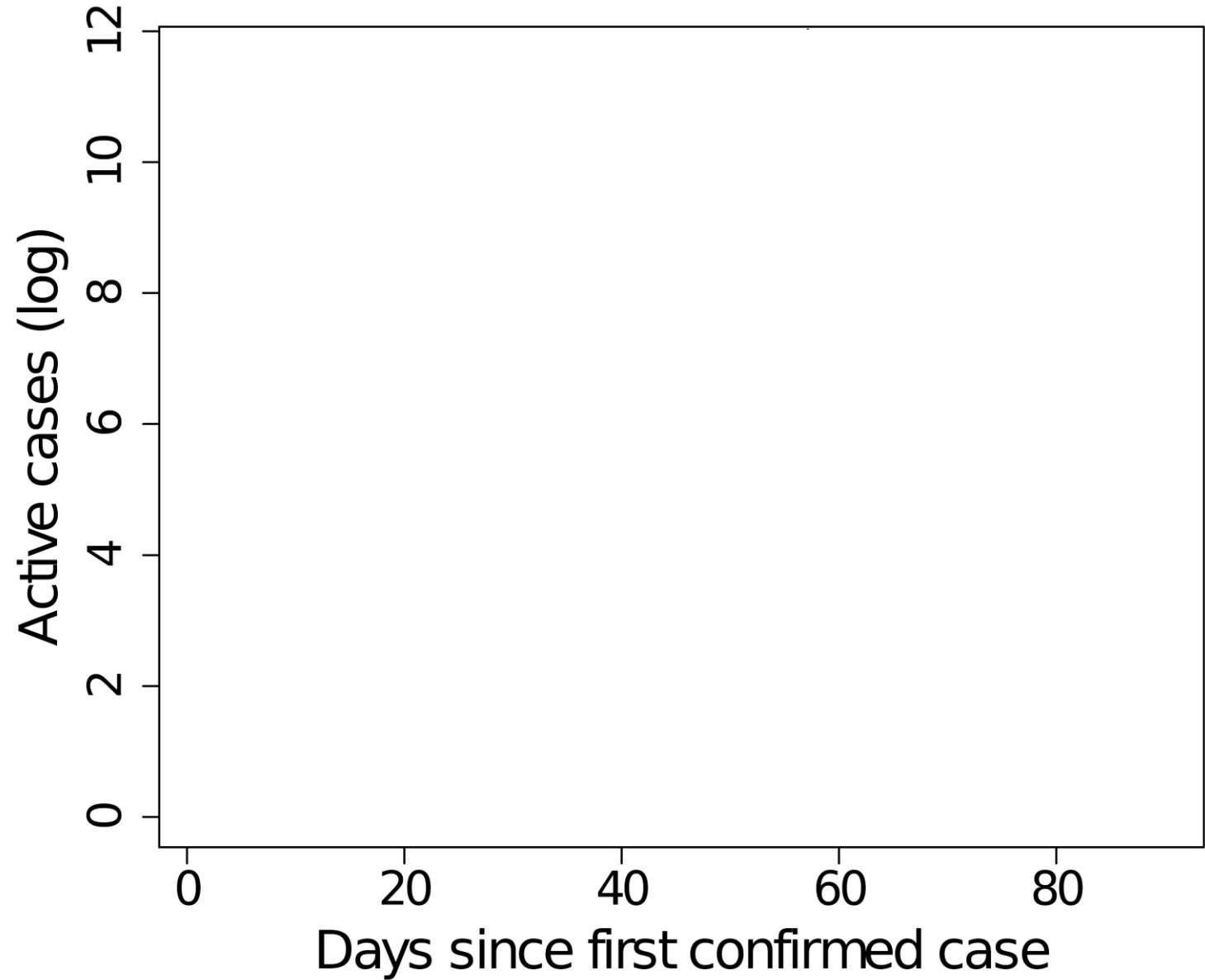
$$\begin{aligned}\dot{S} &= -(q + p)S + pN, \\ \dot{I} &= \frac{\beta}{N}IS - (r + \mu)I.\end{aligned}$$



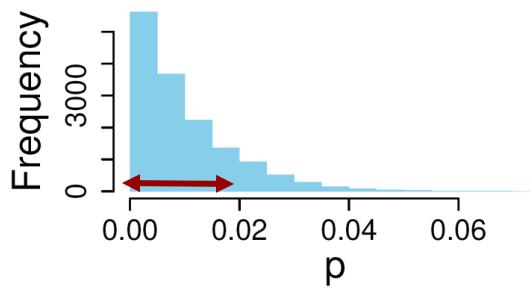
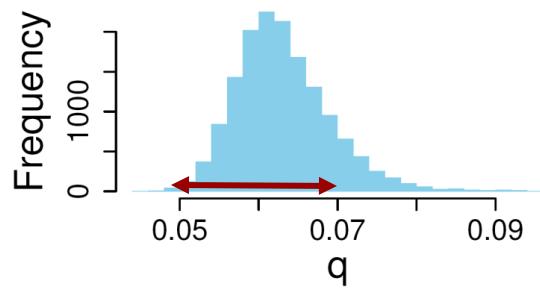
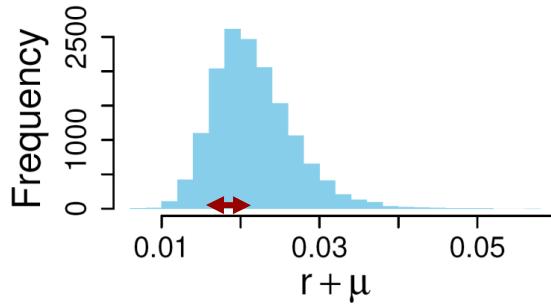
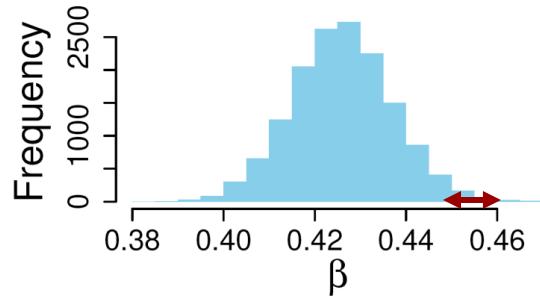
Generate data



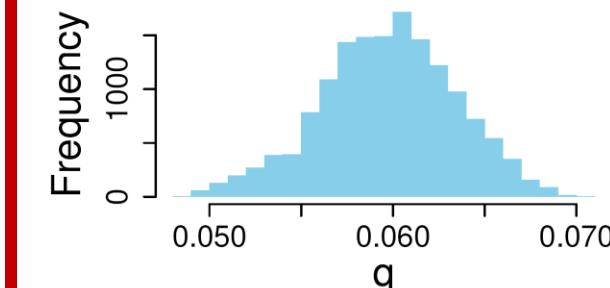
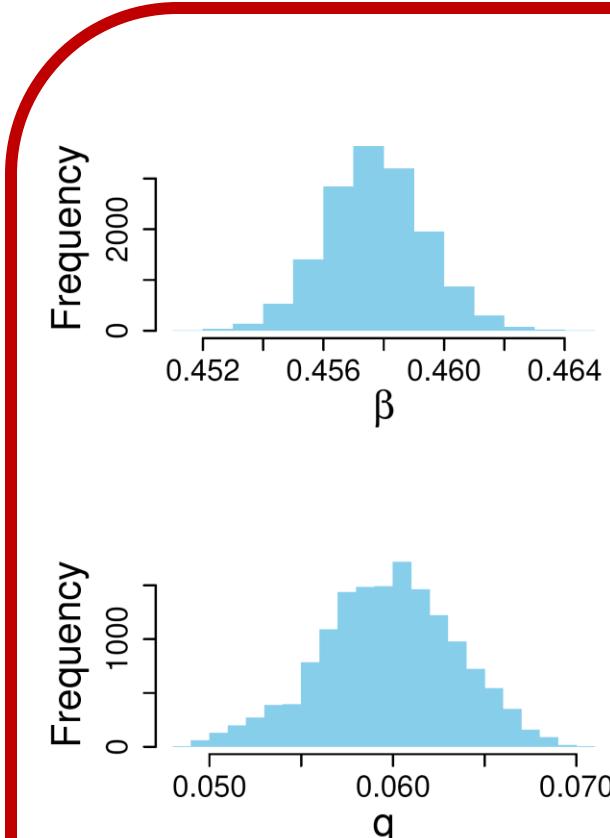
Use Bayesian model
to fit data



Better data narrow the posterior distributions

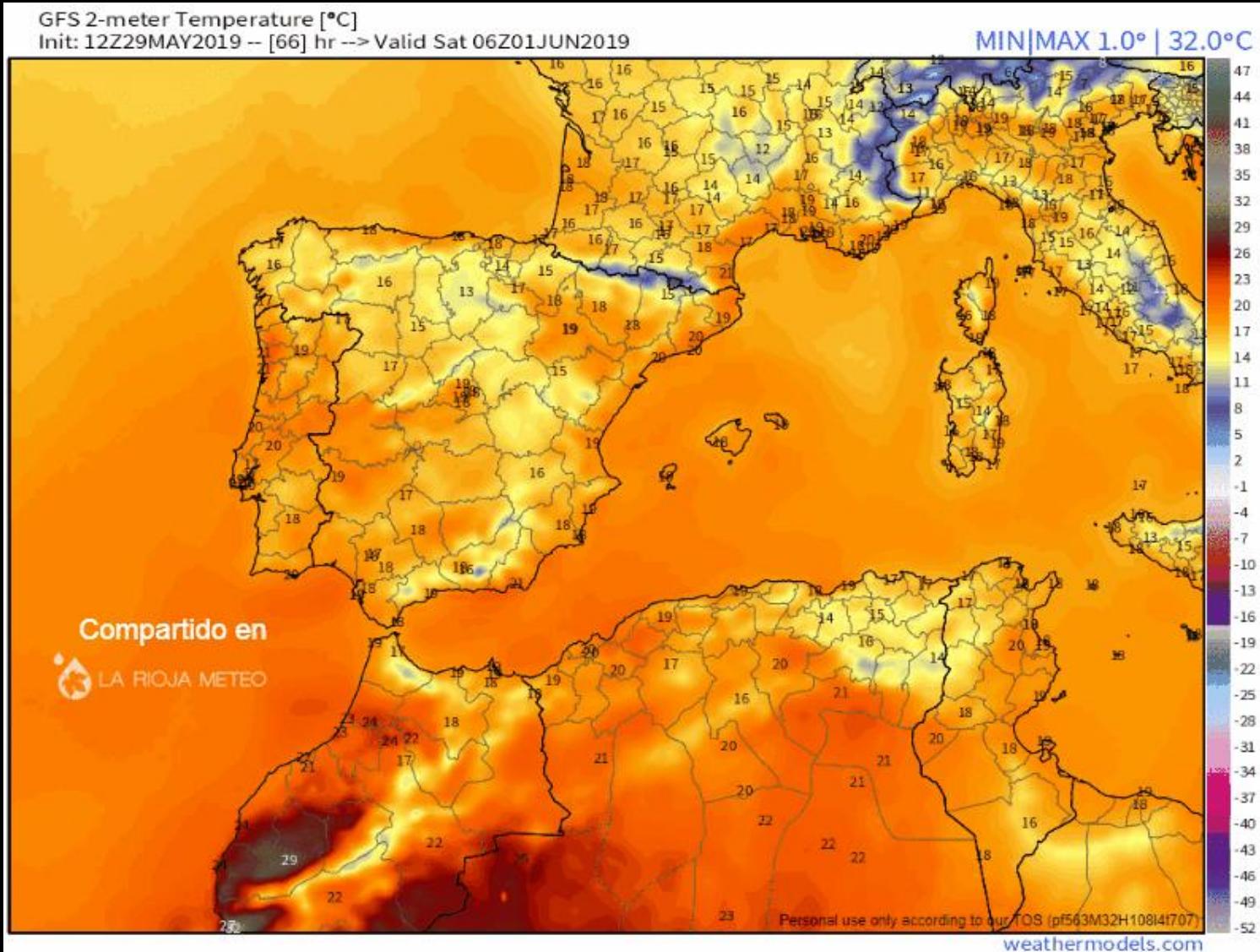
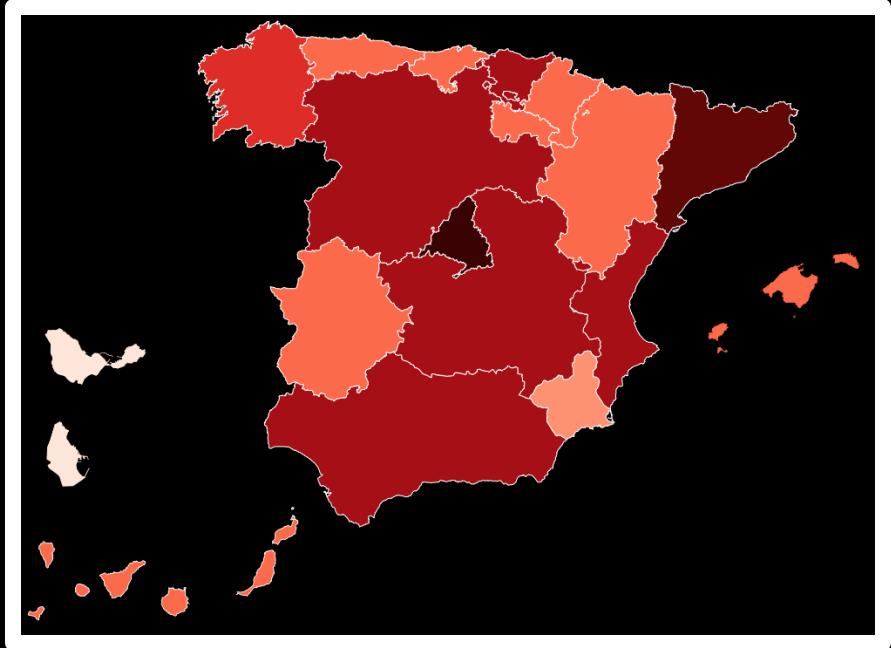


Empirical data



Synthetic data

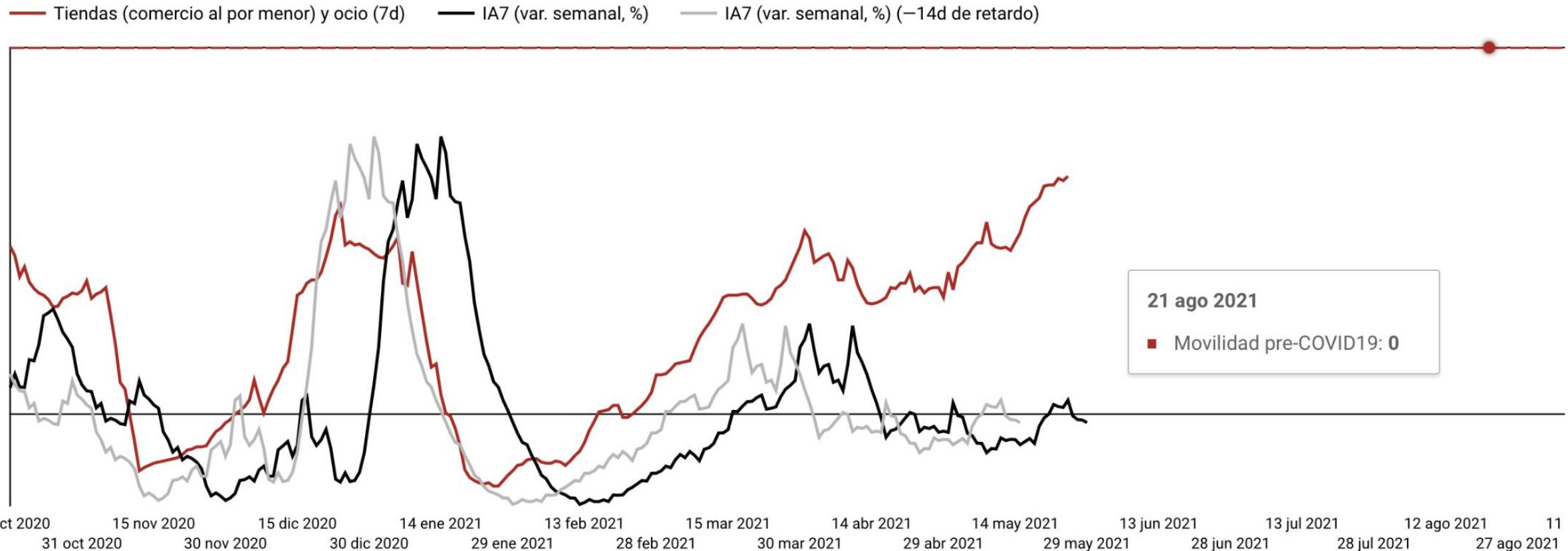
Epidemiology vs meteorology



More data?

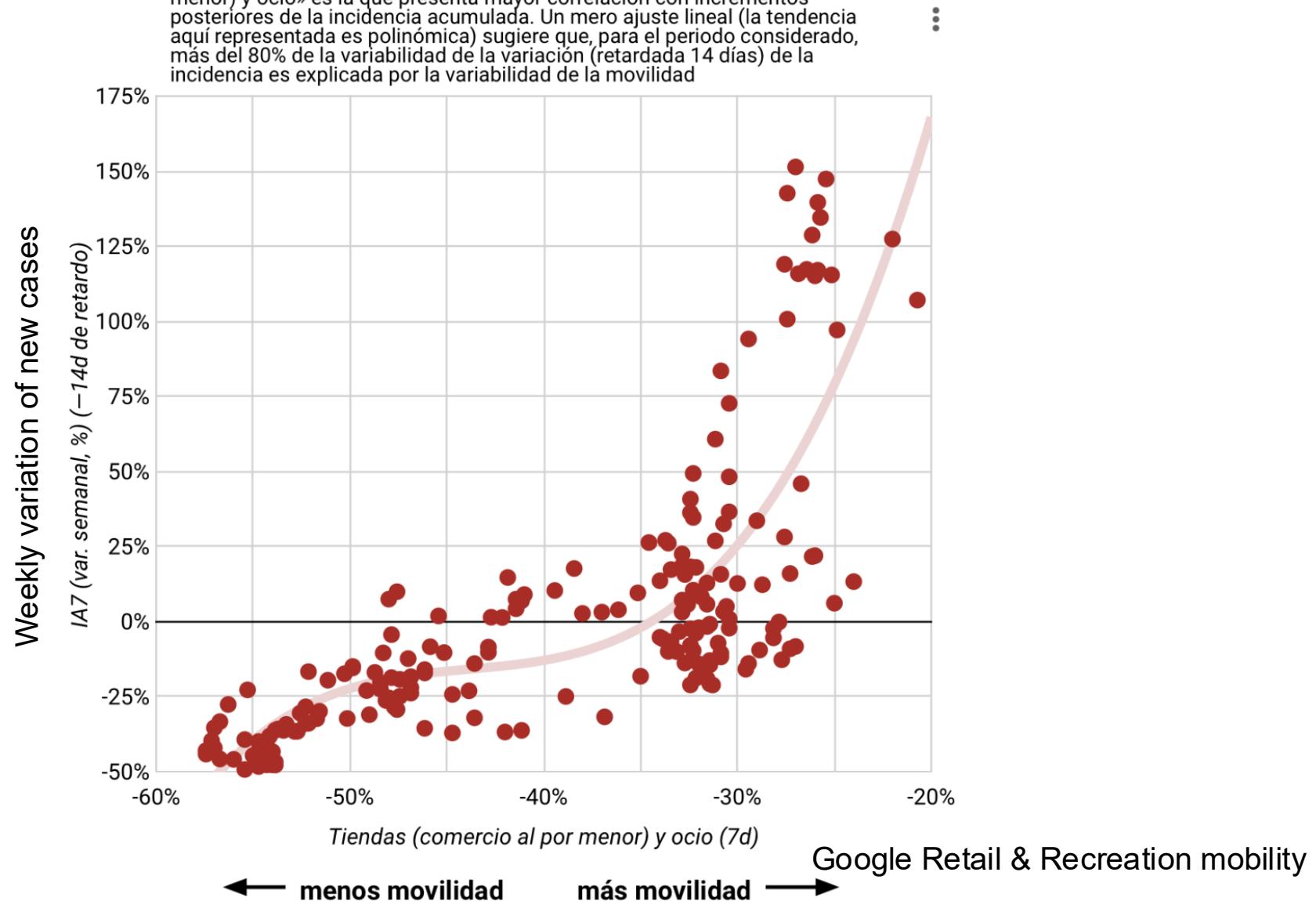
Google Retail & Recreation mobility

Weekly variation of new cases



More data?

De todos los tipos de movilidad, la que se refiere a «Tiendas (comercio al por menor) y ocio» es la que presenta mayor correlación con incrementos posteriores de la incidencia acumulada. Un mero ajuste lineal (la tendencia aquí representada es polinómica) sugiere que, para el periodo considerado, más del 80% de la variabilidad de la variación (retardada 14 días) de la incidencia es explicada por la variabilidad de la movilidad





Unpredictability

=

Uncertainty

+

Exponential growth

Three problems with “predictability”

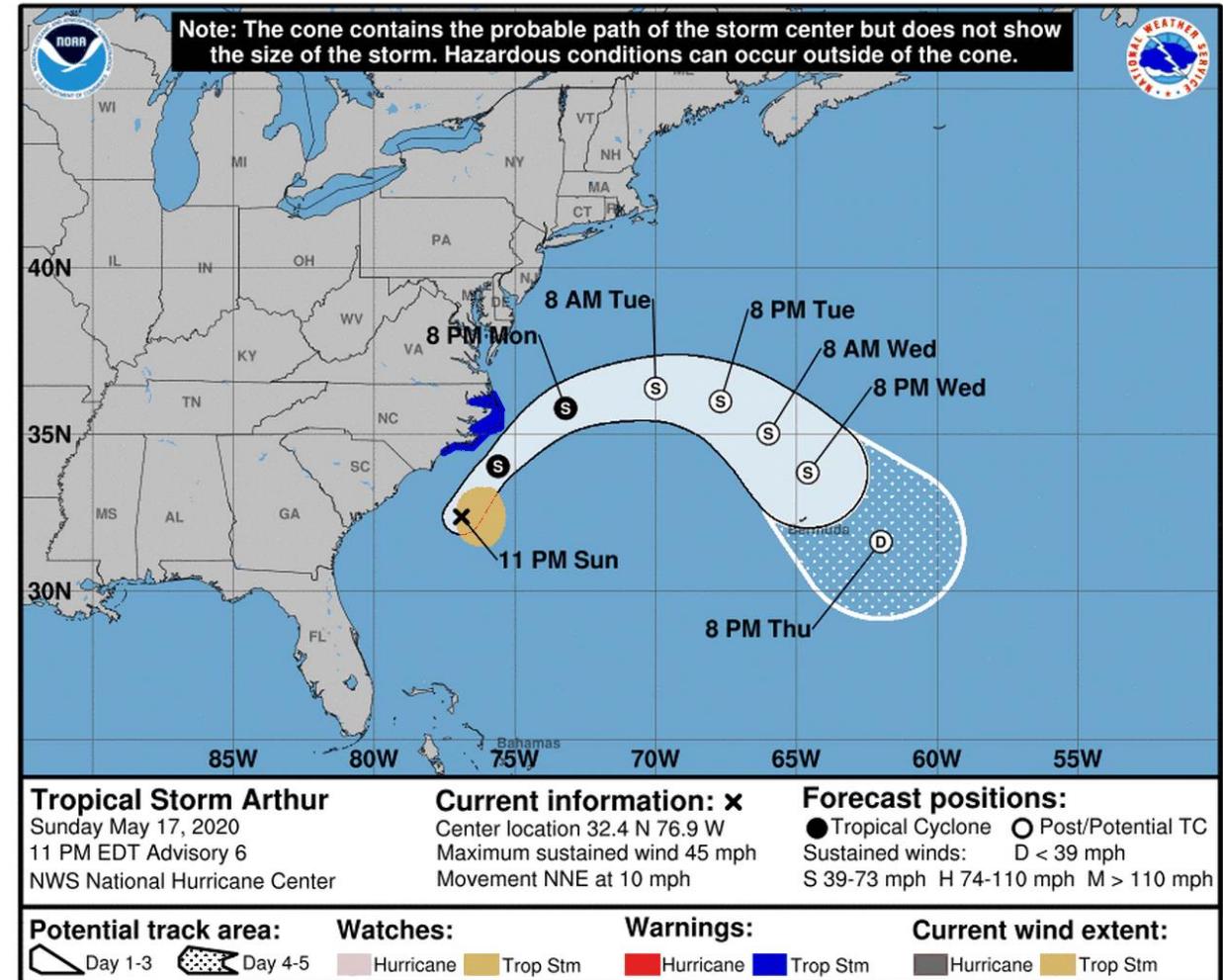
1) Quality of the data (information)

2) Quality of the **models**

(not yours, my friends, but policy makers)

3) Intrinsic uncertainty (exponentially amplified)

PREDICTABILITY: CAN THE TURNING POINT AND END OF AN EXPANDING EPIDEMIC BE PRECISELY FORECAST? (WHILE THE EPIDEMIC IS STILL SPREADING)



What can we do?

	EPIDEMIOLOGY	WEATHER
ORIGIN OF UNPREDICTABILITY	Exponential process	Chaos

Summary

Confinement explains the sub-exponential growth of the number of cases

Reversible confinement yields a threshold for inhibition of propagation

Exponential processes are intrinsically unpredictable; only probabilistic prediction is meaningful

Improving data and model quality is mandatory, but intrinsic unpredictability remains

Models can be useful to illustrate the effect of different non-pharmaceutical actions (confinement, quarantine, testing, changes in mobility...)

The progression of the epidemic depends on social, collective behavior

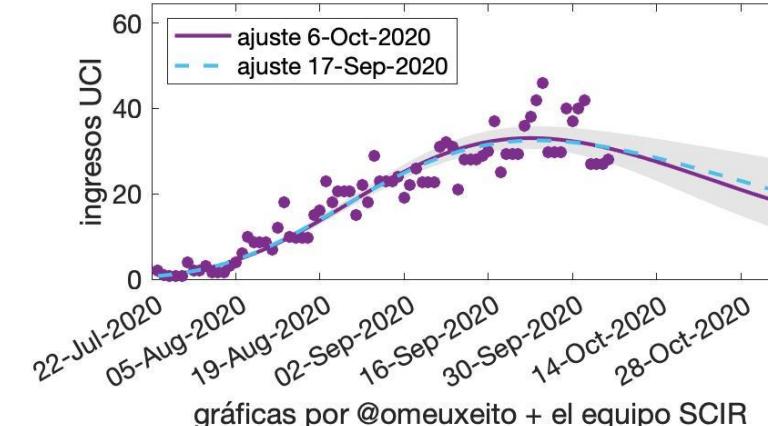
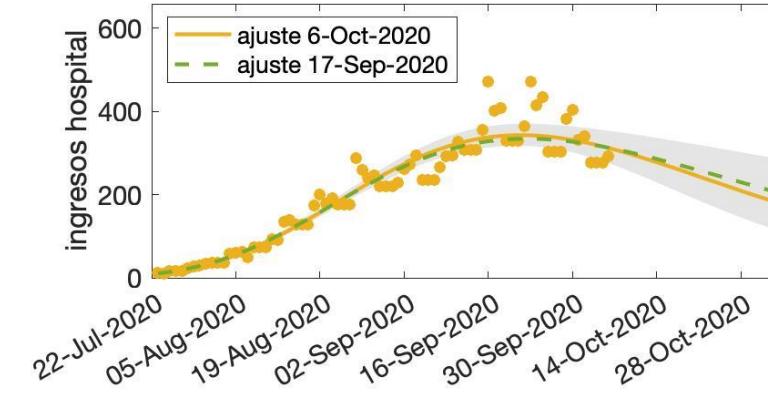
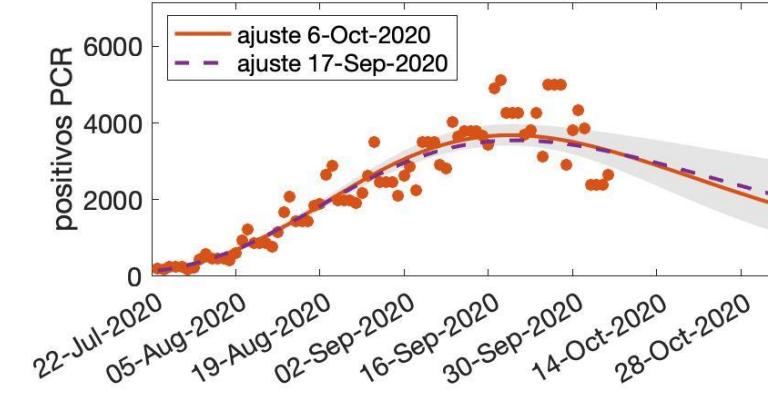
- Blog *Nada es Gratis*, por Anxo Sánchez: “*Ni el pico ni el final de una epidemia se pueden predecir con precisión*” (24/03/2020). <https://nadaesgratis.es/anxo-sanchez/ni-el-pico-ni-el-final-de-una-epidemia-se-pueden-predecir-con-precision>
- *El País* (MATERIA), tribuna por S. Ares, M. Castro, J. A. Cuesta y S. Manrubia : “*De matemáticos y charlatanes: por qué es imposible predecir qué va a pasar dentro de unos días con la COVID-19*” (23/05/2020). <https://elpais.com/ciencia/2020-05-28/de-matematicos-y-charlatanes-por-que-es-imposible-predecir-que-va-a-pasar-dentro-de-unos-dias-con-la-covid-19.html>
- *The Conversation*, por M. Castro, S. Ares, J. A. Cuesta y S. Manrubia: “*¿Se puede predecir la evolución de una pandemia?*” (19/10/2020). <https://theconversation.com/se-puede-predecir-la-evolucion-de-una-pandemia-147782>
- Blog *CNB Divulga*, por S. Manrubia, S. Ares, M. Castro y J. A. Cuesta: “*El incierto futuro de la propagación epidémica*” (11/11/2020).
<http://divulga.cnb.csic.es/index.php/es/item/1469-el-incierto-futuro-de-la-propagacion-epidemica>
- M. Castro, S. Ares, J. A. Cuesta, S. Manrubia (2020) The turning point and end of an expanding epidemic cannot be precisely forecast. *Proceedings of the National Academy of Sciences USA* **117** (42) 26190-26196, <https://www.pnas.org/content/117/42/26190>



Fueron efectivos los cierres perimetrales a partir del 20 de septiembre de 2020 en la Comunidad de Madrid?

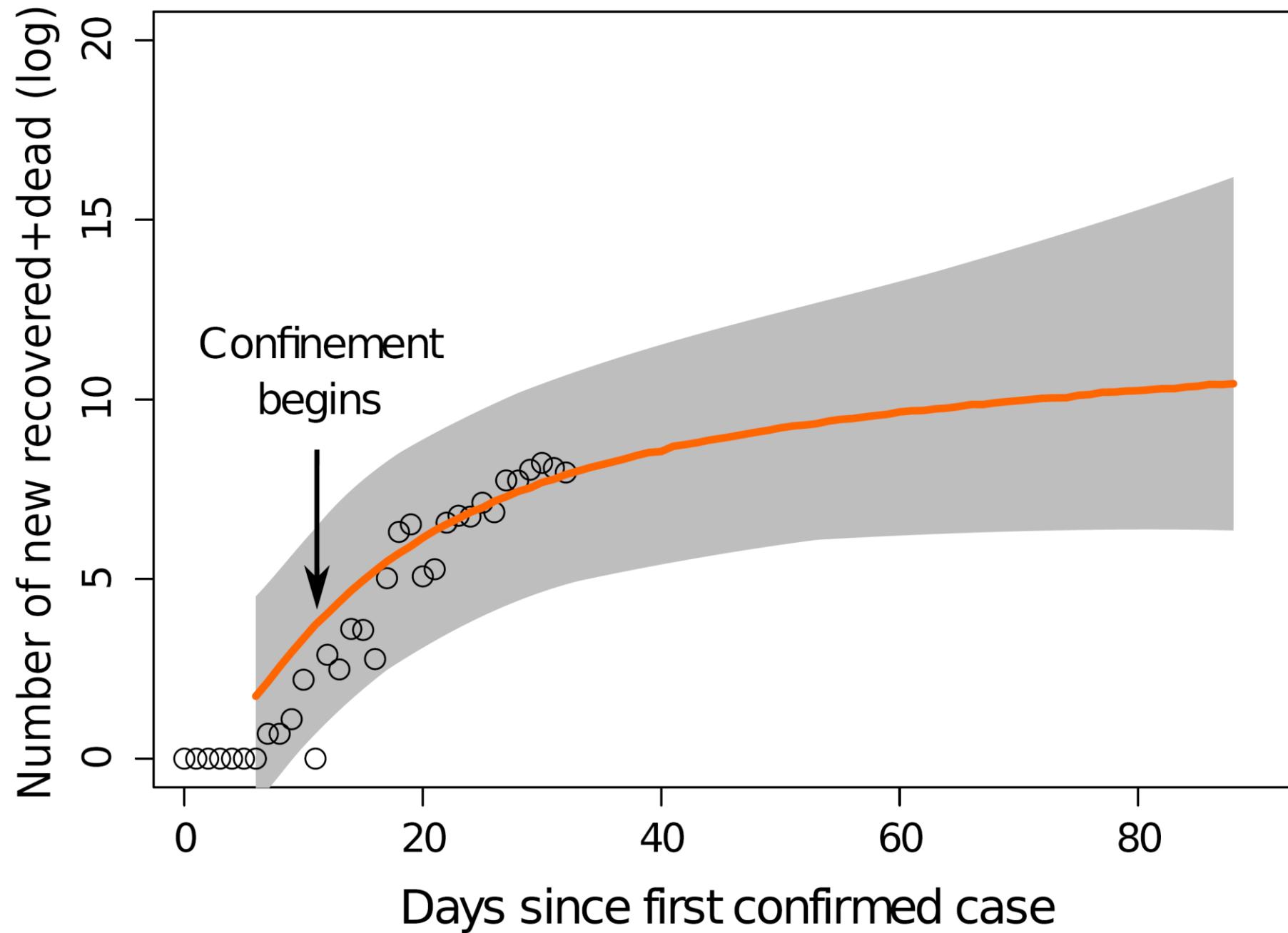
<https://twitter.com/i/status/1316128091585028097>

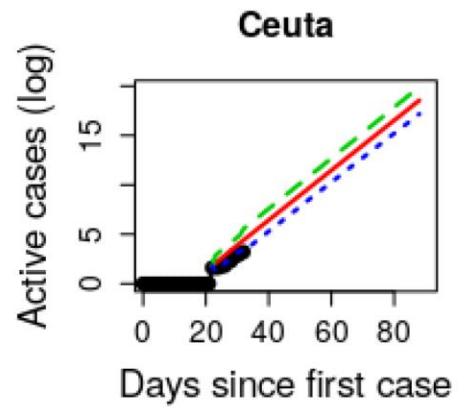
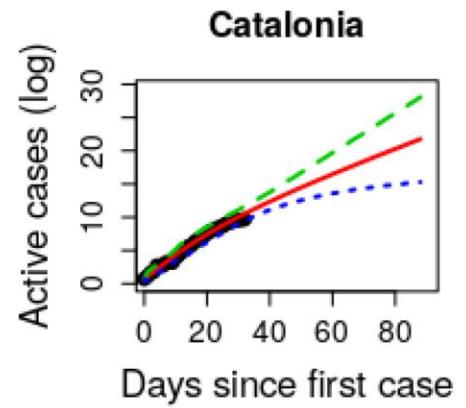
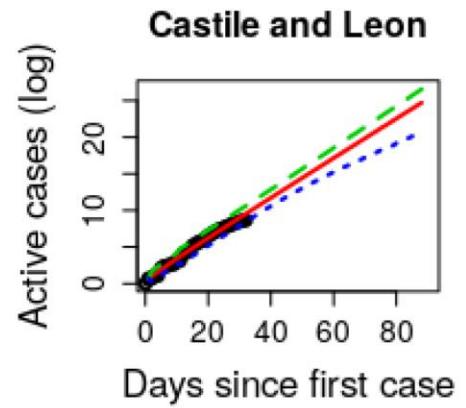
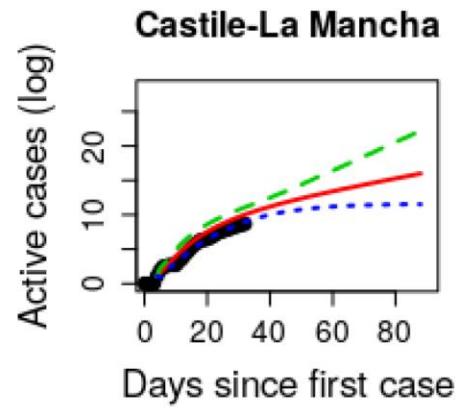
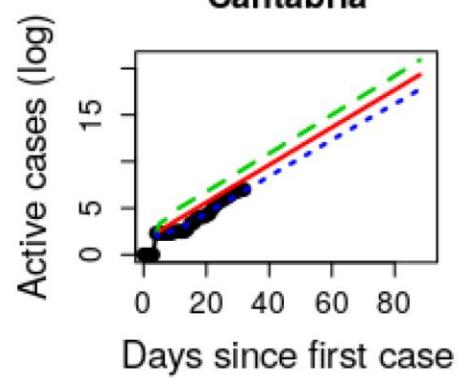
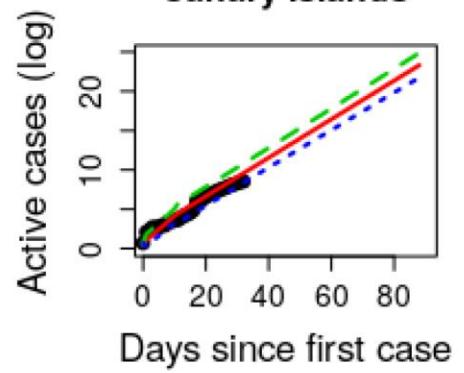
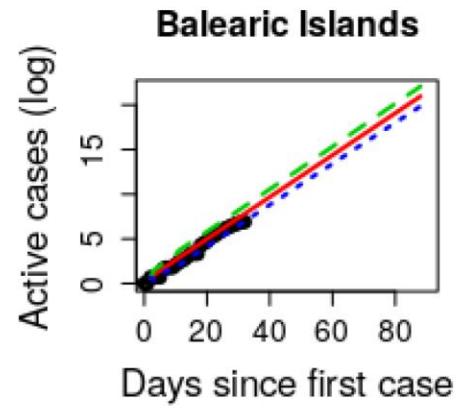
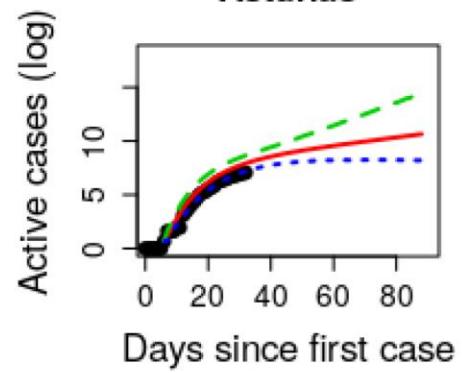
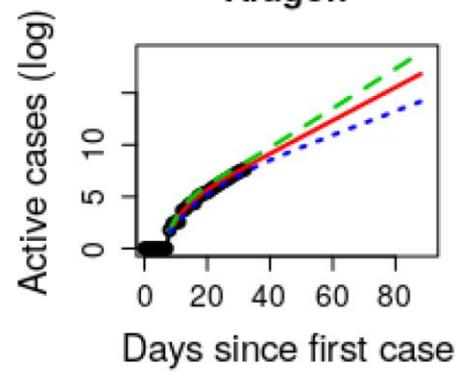
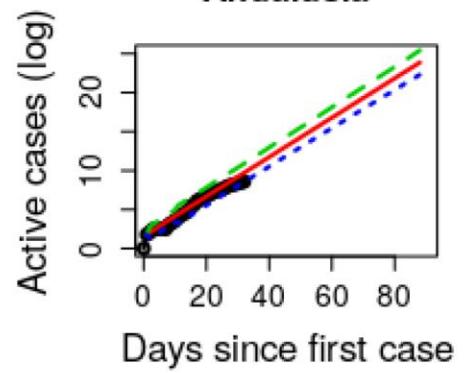
PCR añadidos e ingresos hospital y UCI
fuente: Comunidad de Madrid (vía @alfonsotwr)

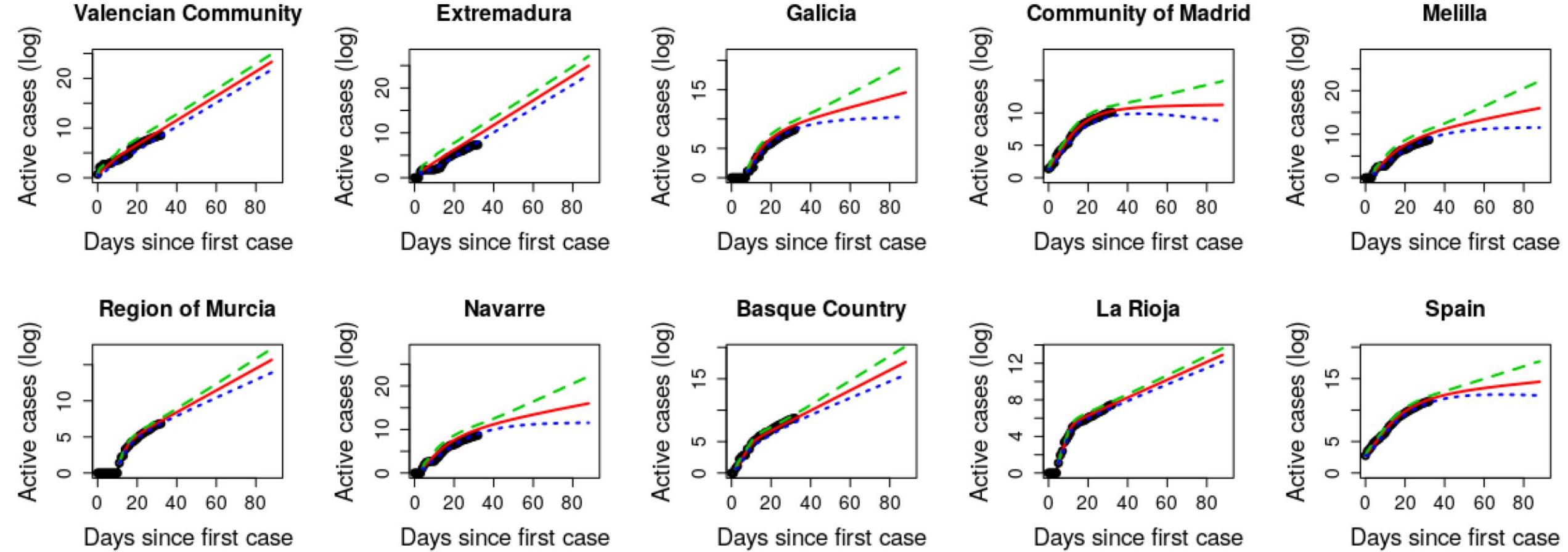


Vaccination strategies in structured populations

<https://mybinder.org/v2/gh/IkerAtienza/SIYRD/main?urlpath=%2Fvoila%2Frender%2FSimulator.ipynb>







Predictability: Can we precisely forecast the turning point and end of an epidemic by fitting past data?

Mario Castro, Saúl Ares, José A. Cuesta, Susanna Manrubia

Abstract

No.