Making Useful Use of Particle Physics Experience in Epidemiology

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PUNCH4NFDI

and what does that have to do with Epidemiology?

Examples for Applying Particle Physics Methods

- Monte Carlo Methods
- Learning from Modelling
- Calibrating in the Most Physical Way
- Using Mathematical Methods from Particle Physics Simulations

How I finally started to be interested in soccer

An Example for a Possible Outlook: Anomaly Detection

PUNCH4NFDI and Epidemiology

PUNCH4NFDI

The National Research Data Infrastructure (in original German: Nationale Forschungs-Daten Infrastruktur NFDI) has the objective to systematically index, edit, interconnect and make available the valuable stock of data from science and research.

PUNCH4NFDI also offers services for the efficient scientific exploitation of research data. In doing so, PUNCH4NFDI collaborates closely with its European and international partners at the forefront of research in scientific data management.

https://punch4nfdi.de

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Most Particle Physicists think in the context of *Events*

- In the area of epidemiology, that would mean that **every** single detected case was a separate **event** and we would know
  - Gender, age, location, occupation, recent travels, movement data, contact history, . . .
  - living conditions, eventual family, . . .
  - Medical history, vaccination history, infection history . . .
  - Testing history, sequencing, viral load tracking, exact history of COVID19 symptoms, medical treatment history, time until recovery or worse, . . .
  - All observables were readily calibrated for known inefficiencies and delays in a central processing and then analysed
  - A lot of detailed control/testbeam experiments/measurements would be performed, all auxiliary/environmental data would be tracked
  - All data would be treated uniformly and shared worldwide, *but (if unlucky) only within 2 competing collaborations*
- For obvious reasons of privacy and data protection, this is neither possible nor attractive

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Let's Measure Currents instead of Particles

- This is more like (the ideal case of) the situation we encounter with epidemiological data:
  - Date, gender, age, location is resolved in pre-defined bins and data is reported in an *aggregated* and *anonymized* way
  - It is often unclear what the reference date means – reported, symptoms onset, sample taken . . .
  - Different reporting delay structures for different data or different countries
  - No official recording of the detailed implementation of political measures
  - Movement, contact, cohort study, medical/hospital data . . . is reported in separate independent studies
  - The binning or the time resolution is not guaranteed to be coordinated between any of the above
  - The most sensitive auxiliary data (contact networks from cell phone GPS data) is not publicly available
- For obvious reasons this is not ideal. While it is paramount that the data is *aggregated* and *anonymized*, I still would think that the data can be provided in much better shape

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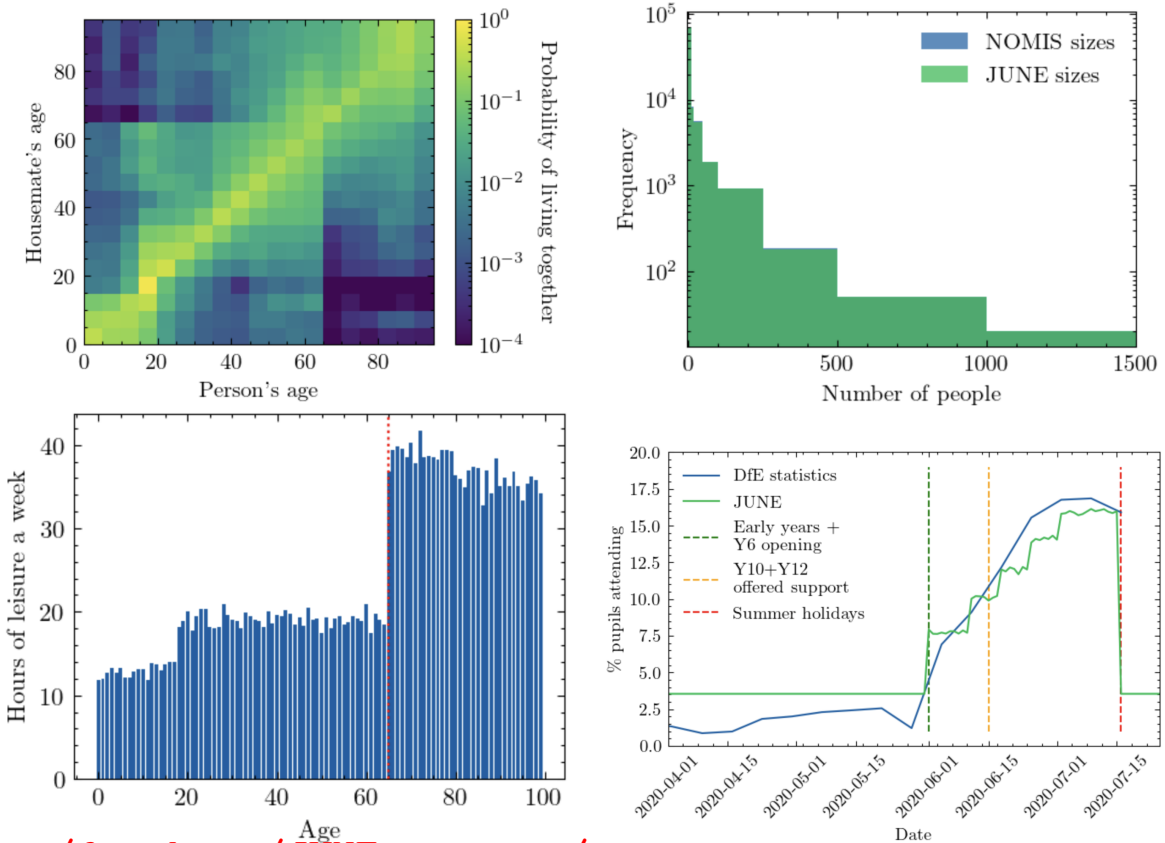
Therefore, let's try to be helpful in a dire situation

- We identified three areas where PUNCH4NFDI could be helpful and in March 2021 contacted the NFDI4Health consortium and Viola Priesemann
- Naive ideas wher ewe could be helpful:
  - Data Management and Distributed Data Analysis
  - Statistical Tools for Inferrence
  - Machine Learning Tools for Anomaly Detection
- Let's see how it turned out

Examples for Applying Particle Physics Methods

Independent from PUNCH4NFDI: From SHERPA to Agent Based Models

- Matthias Schott (Mainz) and Friedemann Neuhaus applied the JUNE framework written by Frank Kraus *et al.* to Germany



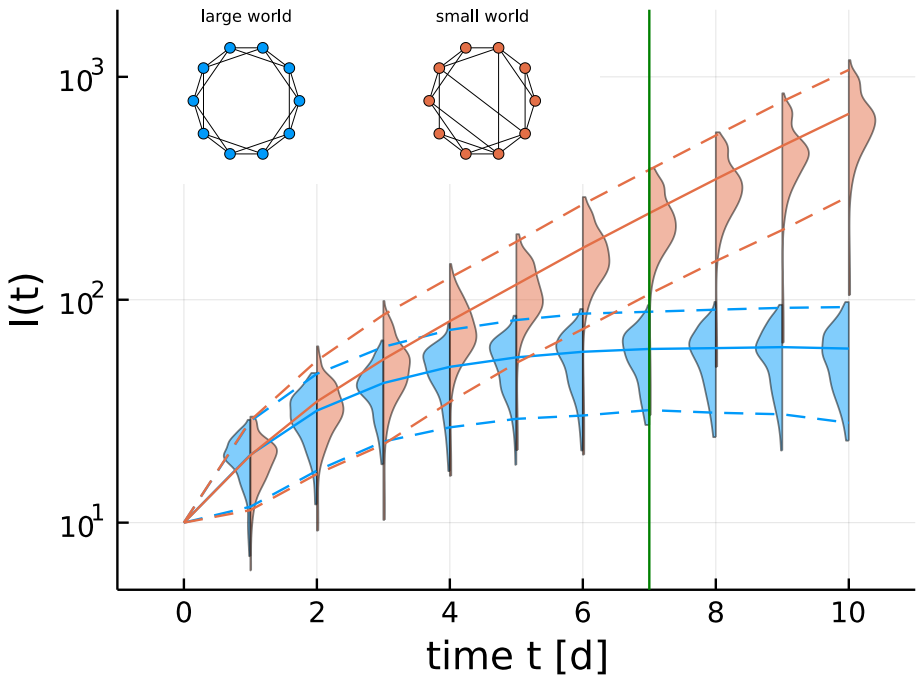
https://github.com/fneuhaus/JUNE_germany/

https://github.com/IDAS-Durham/JUNE

https://royalsocietypublishing.org/doi/full/10.1098/rsos.210506

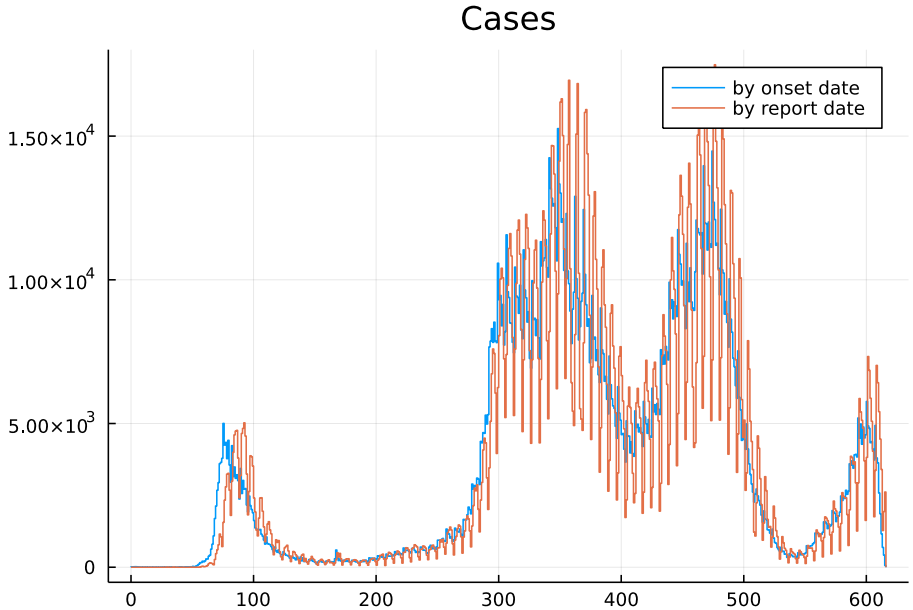
In Collaboration with NET CHECK

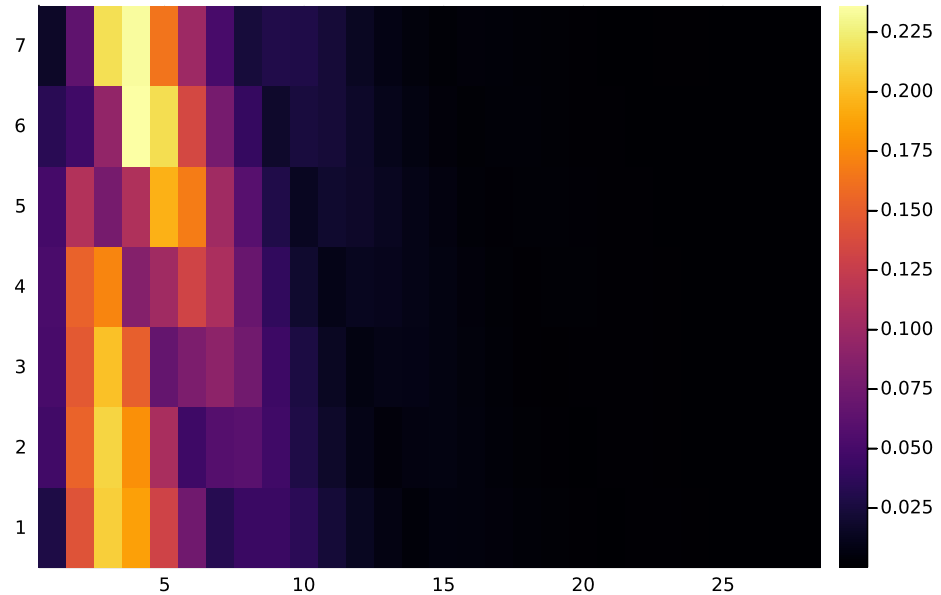
- Together with Sten Rüdiger and Steven Schulz from NET-CHECK
- Contact networks influence how pandemics spread
- **Effective contact network** is different for different transmission paths
- Conventional wisdom: Need to know the transmission path to know the effective contact network
- Try to turn this around: If we knew the physical contact network, observing the pandemic spread would allow to extract the dominant transmission path (works if enough auxiliary parameters are known)

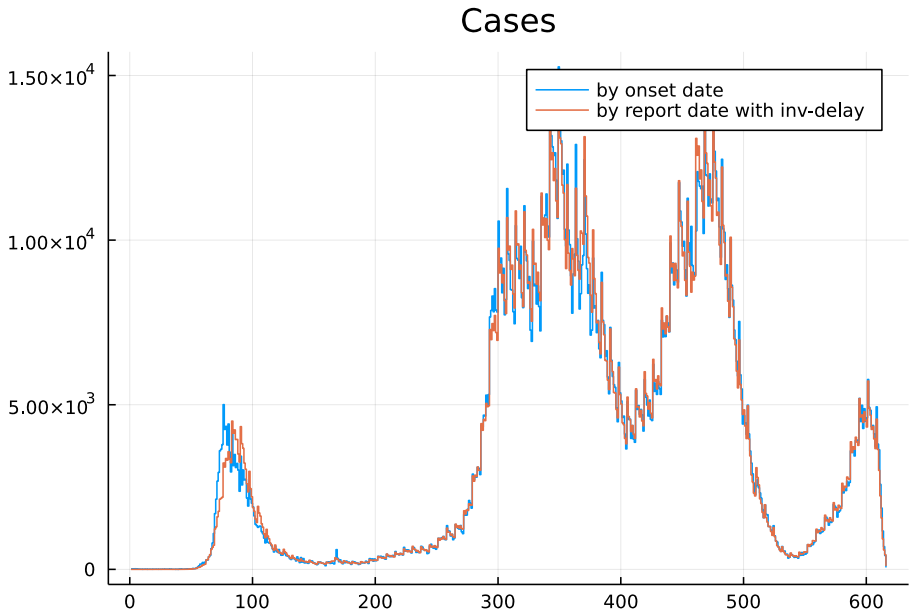


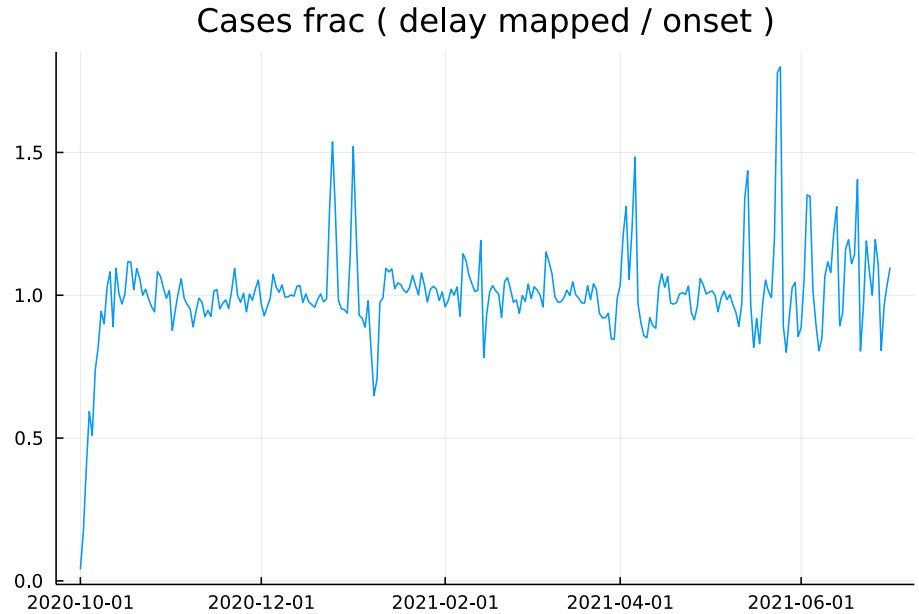
Example: Calibrating in the Most Sensitive Way

- From Oliver Schulz and Arne Gottwald



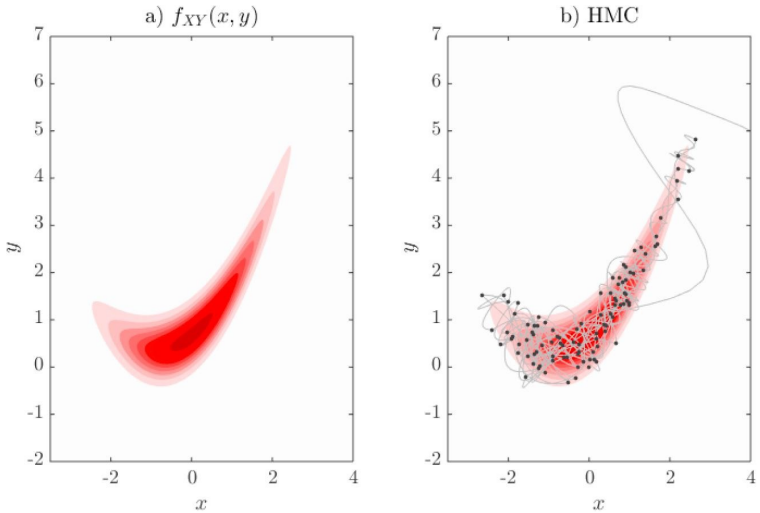






Bayesian Inferrence Using Hamiltonian Monte Carlo

- Hamiltonian Monte Carlo, developed in the context of QCD on the lattice, is widely employed to sample the posterior space of Bayesian Compartmental Models – here using `BAT.jl`



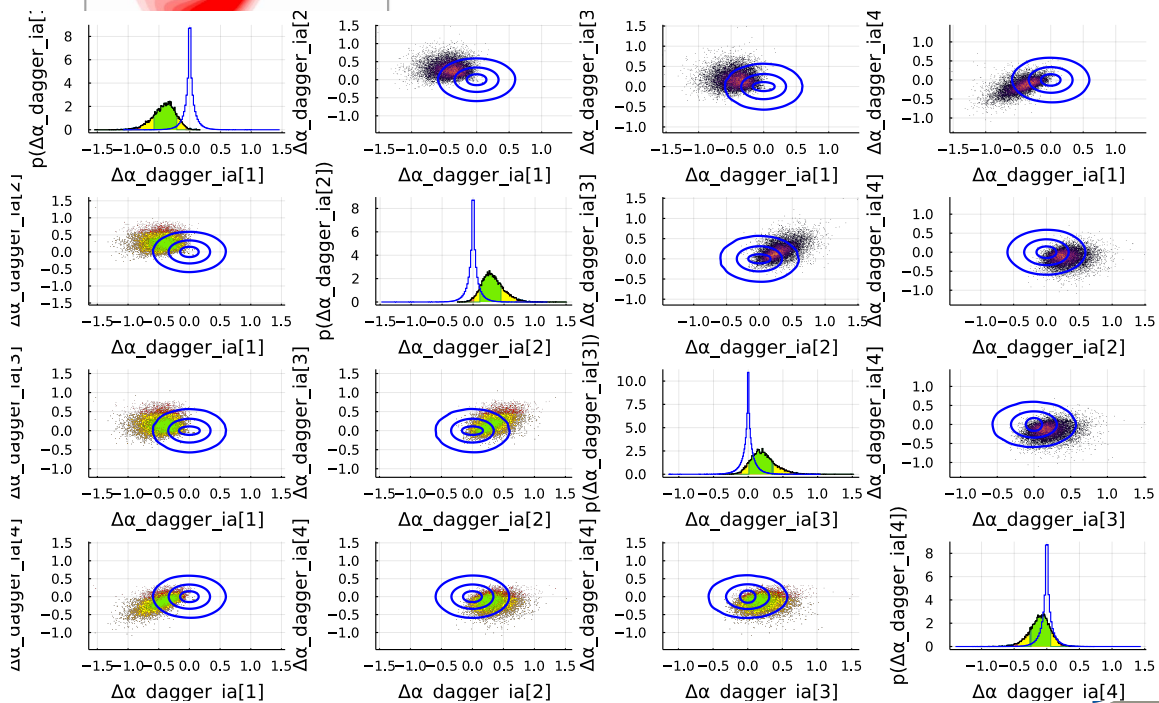


Image on the left from `https://doi.org/10.1016/j.strusafe.2018.05.005`

How I finally started to be interested in soccer

Was the EURO 2020 (in 2021) safe?

Upcoming paper:

Using gender disparities to measure the EURO 2020 match-induced effect on COVID-19 cases in selected European countries

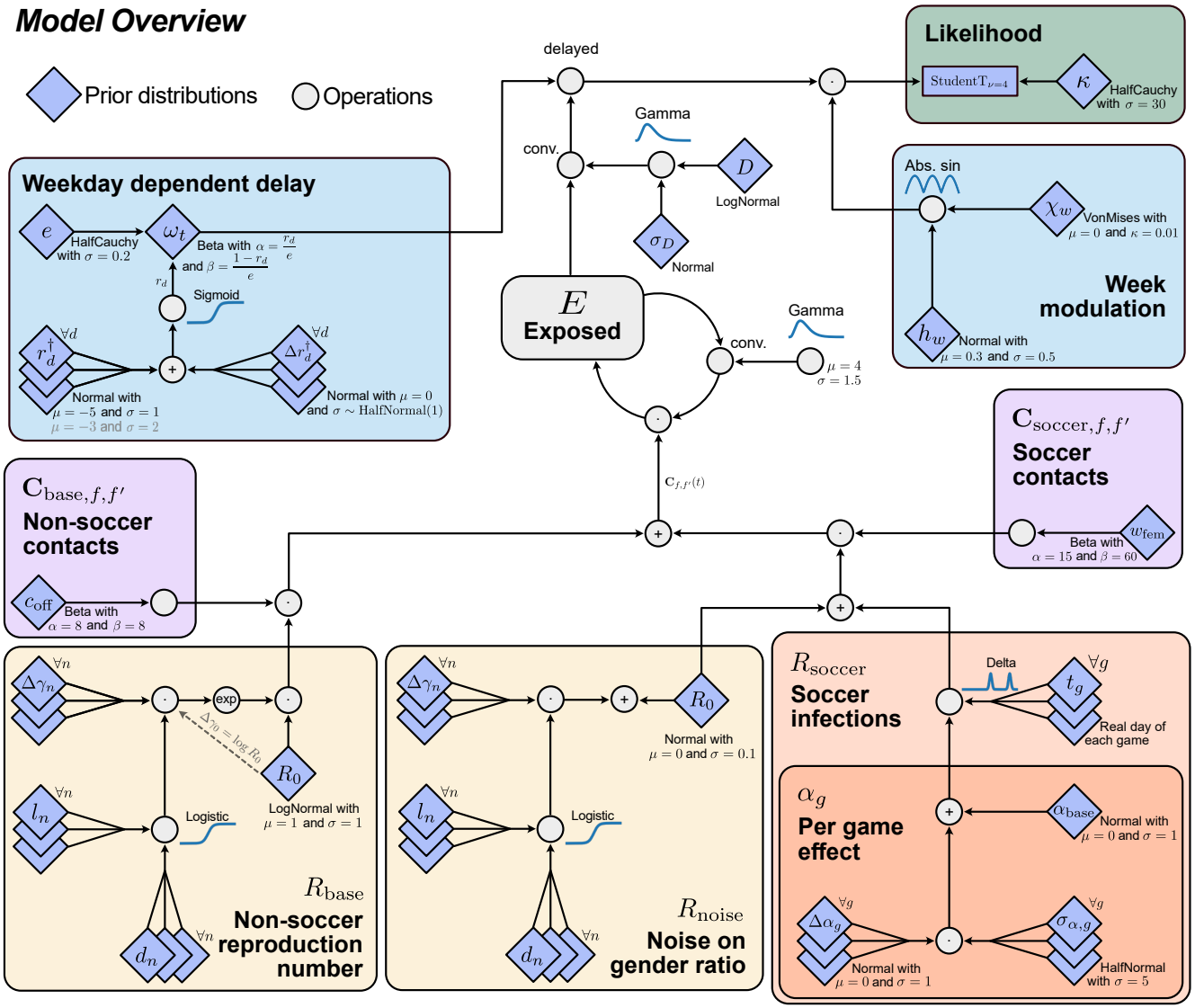
Sebastian B. Mohr[1,¶], Jonas Dehning[1,¶], Philipp Dönges[1], Sebastian Contreras[1], Emil Iftekhar[1], Oliver Schulz[2], Philip Bechtle[3], and Viola Priesemann[1,4*]

[1]Max Planck Institute for Dynamics and Self-Organization, Am Faßberg 17, 37077 Göttingen, Germany.
[2]Max Planck Institute for Physics, Föhringer Ring 6, 80805 München, Germany
[3]Physikalisches Institut, Universität Bonn, Nußallee 12, 53115 Bonn, Germany
[4]Institute for the Dynamics of Complex Systems, University of Göttingen, Friedrich-Hund-Platz 1, 37077 Göttingen, Germany.

Just to introduce the methods: A friendly SIR Pandemic Compartmental Model

$$\frac{\mathrm{d}S}{\mathrm{d}t} = -\lambda \frac{SI}{N_{\mathrm{pop}}}$$
$$\frac{\mathrm{d}I}{\mathrm{d}t} = \lambda \frac{SI}{N_{\mathrm{pop}}} - \mu I$$
$$\frac{\mathrm{d}R}{\mathrm{d}t} = \mu I \,.$$

A model capable of identifying the fraction of EURO 2020 related infections



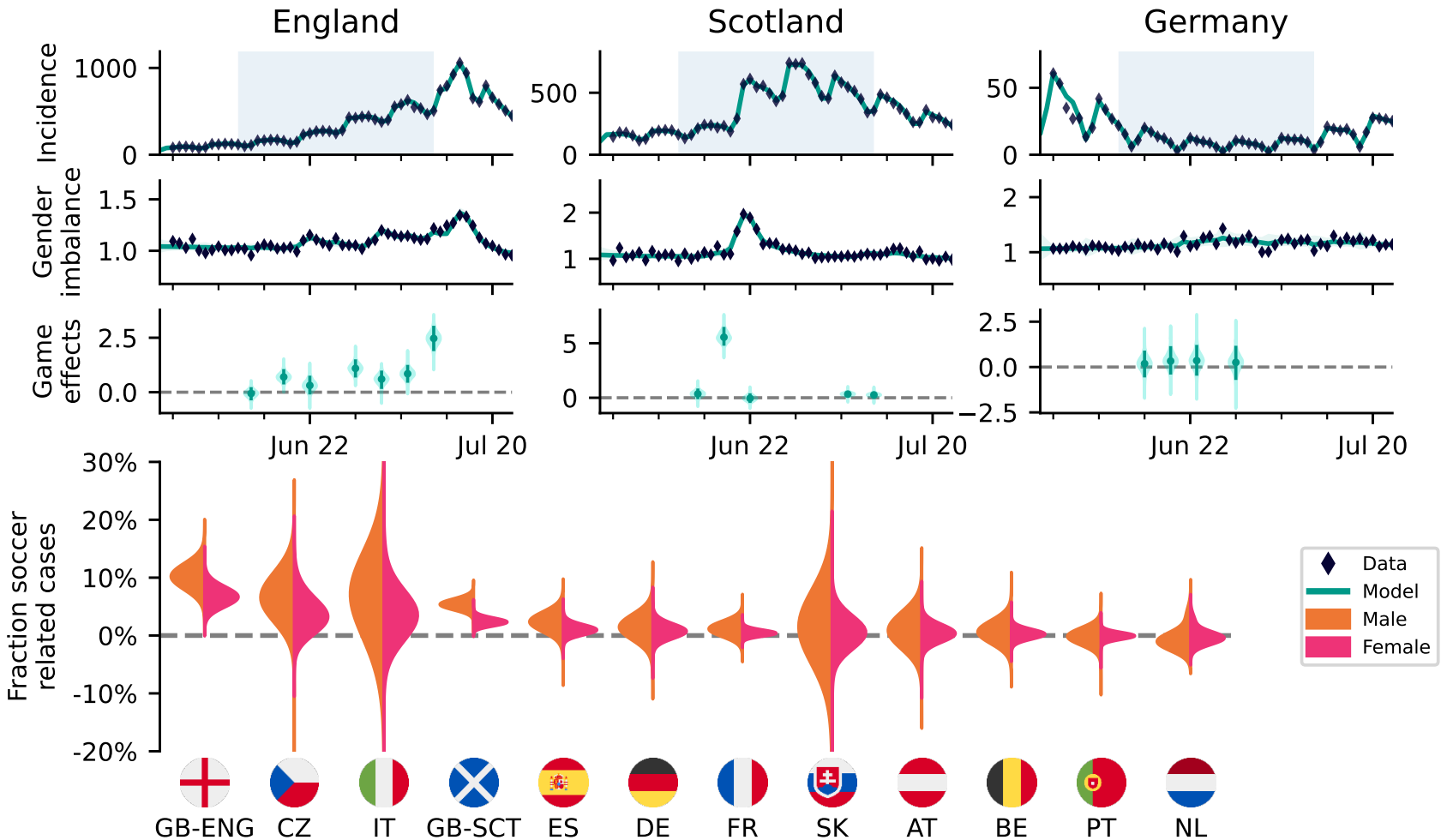
Of course this is futile, because . . .

The UEFA of course knew better all the time:

> **At this stage of the tournament, how do you judge the success of the COVID-19 mitigation measures that have been put in place for the EURO?**
>
> **Dr Bahtijarević:** We do not see any big increase in the number of cases across the EURO 2020 host venues, or in most of the countries of the participating nations. This demonstrates that our measures are effective and being implemented correctly.
>
> **Dr Bahtijarević:** UEFA has put in place a number of mitigation measures and, so far, we are satisfied with the overall outcome. We are constantly monitoring how these measures are working, and whenever we see areas to improve, we react together with the competent local authorities to tackle them.

https://www.uefa.com/returntoplay/news/026a-129e7a75d53b-81e501a50eb2-1000--covid-measures-at-uefa-euro-2020/

Infections from fan activity related to the EURO 2020



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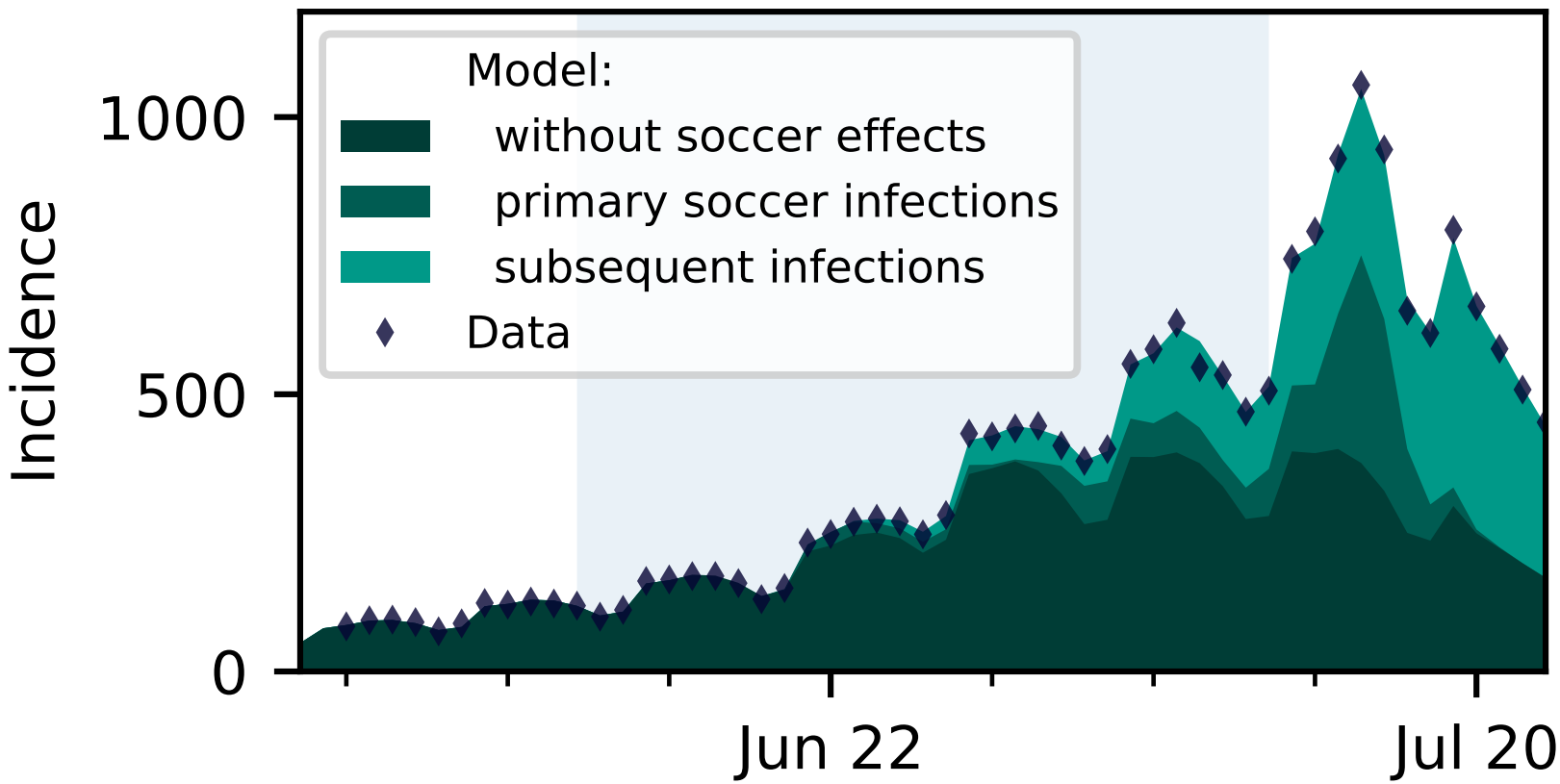

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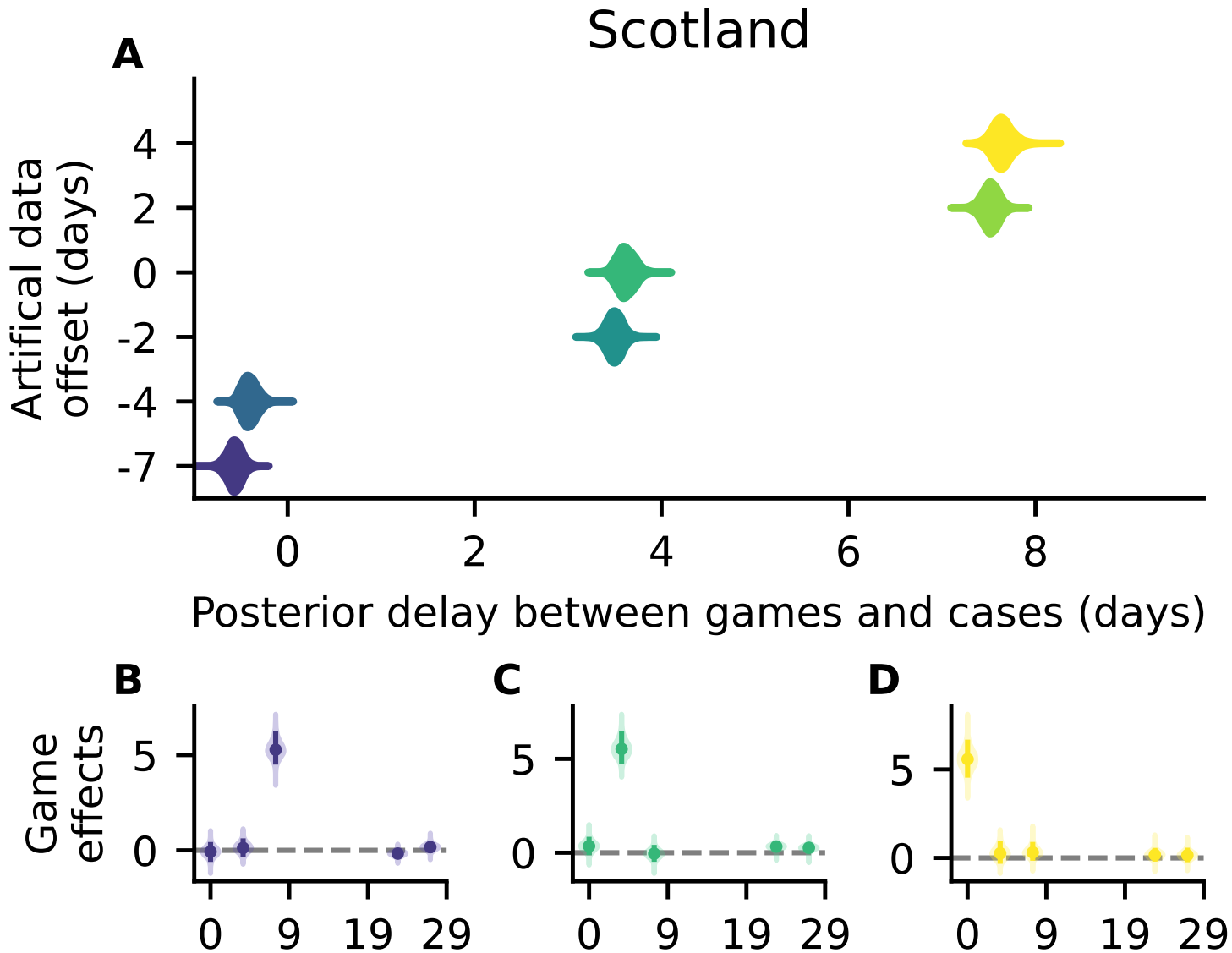

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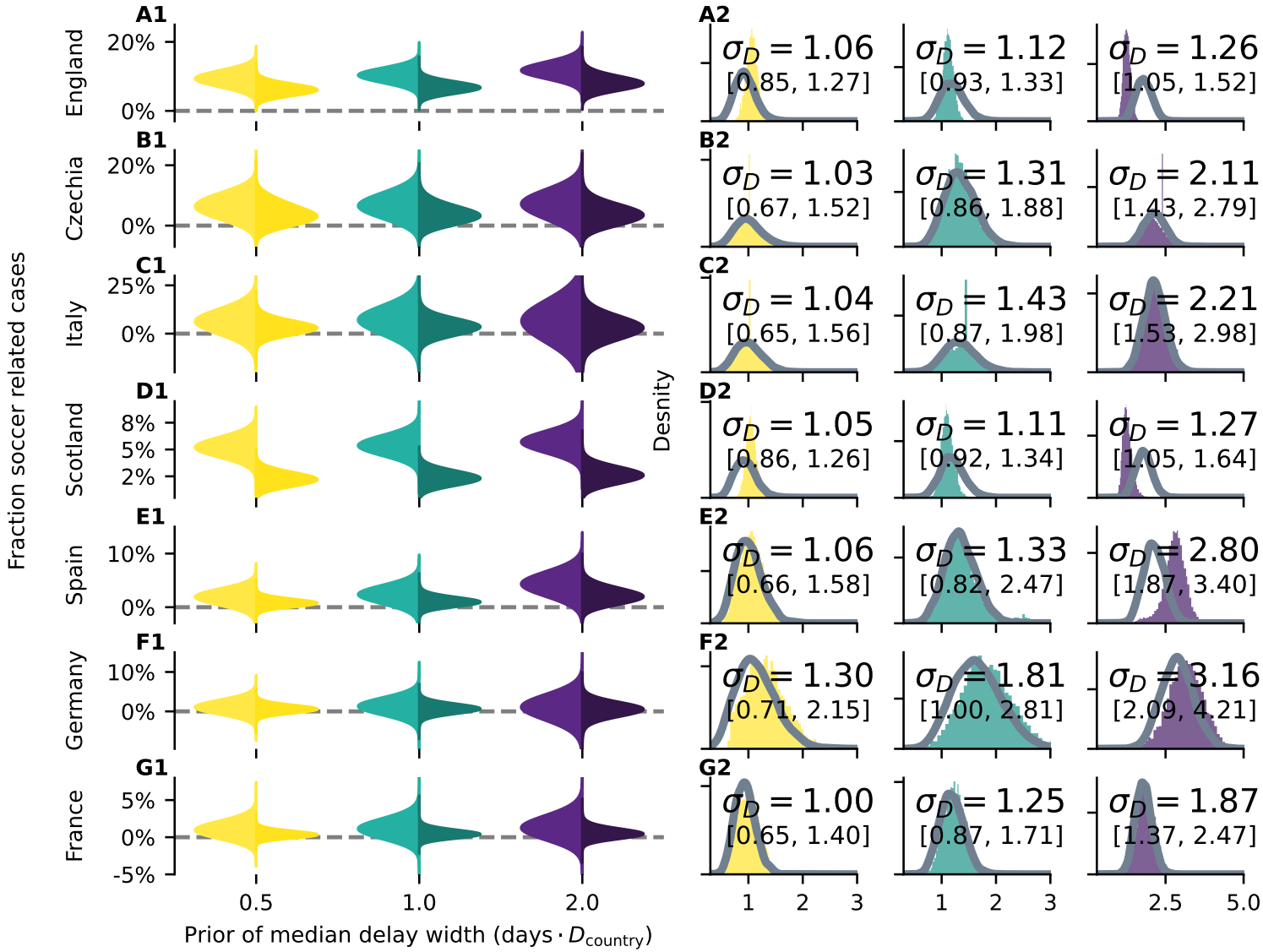

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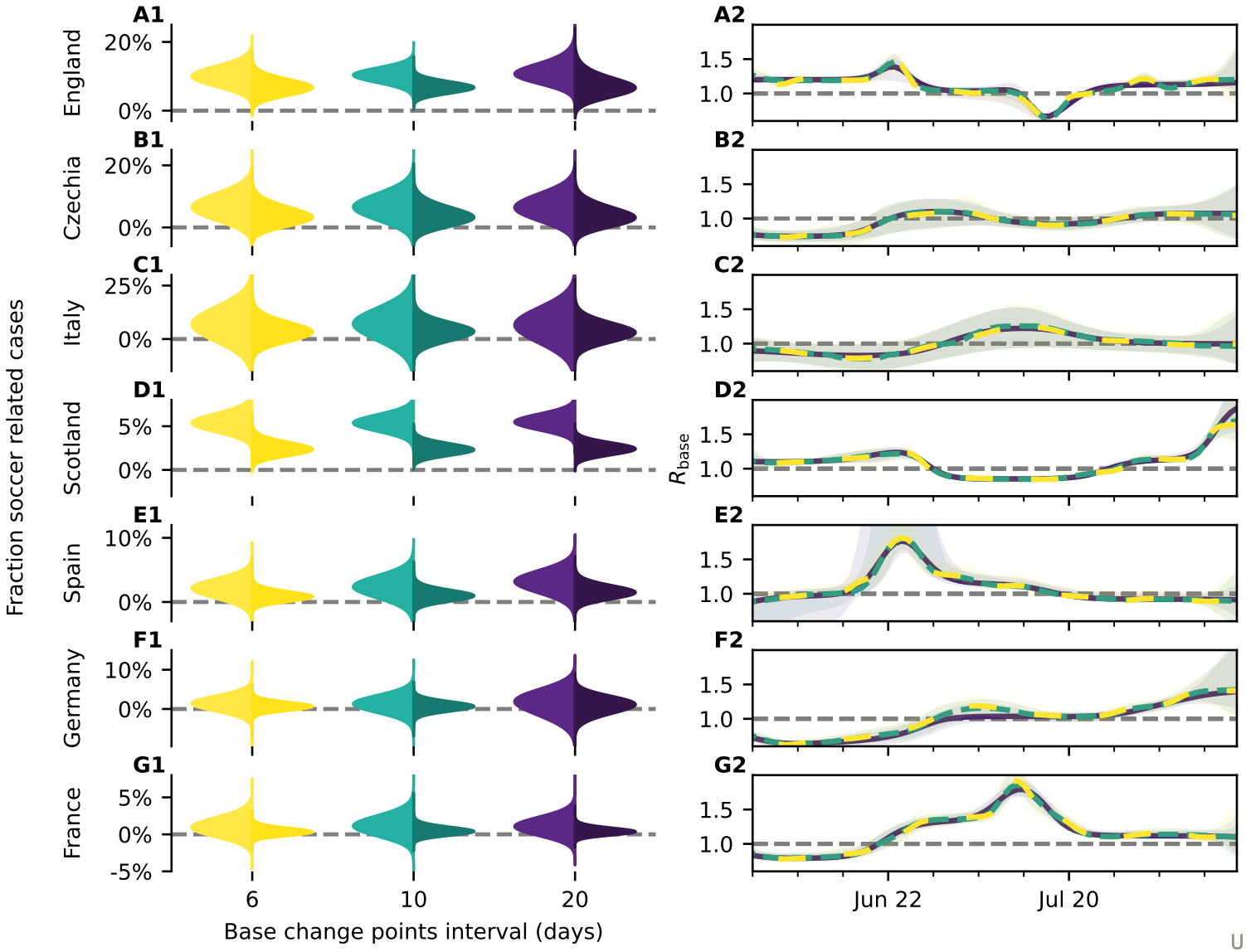

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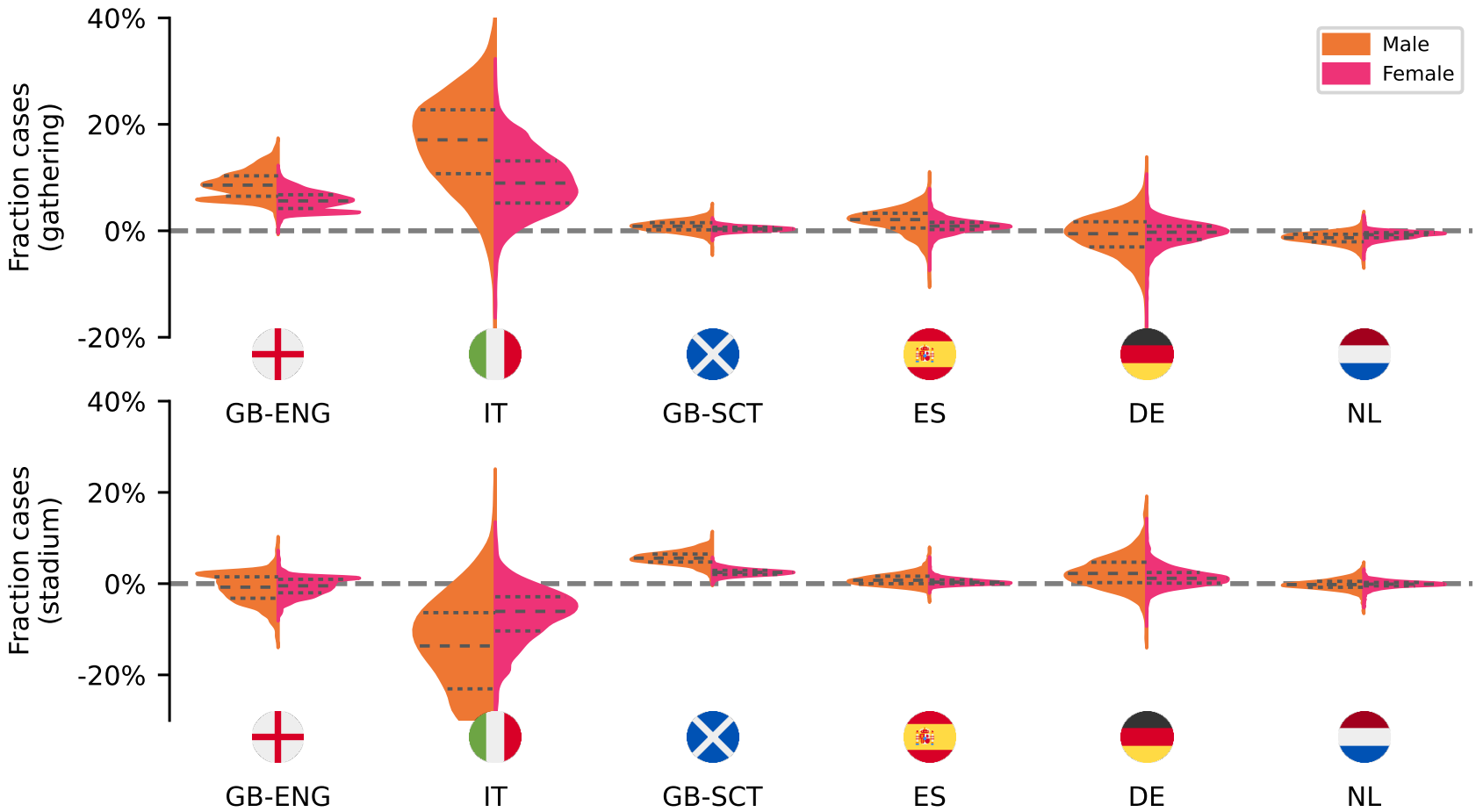

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An Example for a Possible Outlook: Anomaly Detection

Autoencoder example for anomaly detection

- Examples taken from Farina, Nakai, Shih, `https://arxiv.org/pdf/1808.08992.pdf`

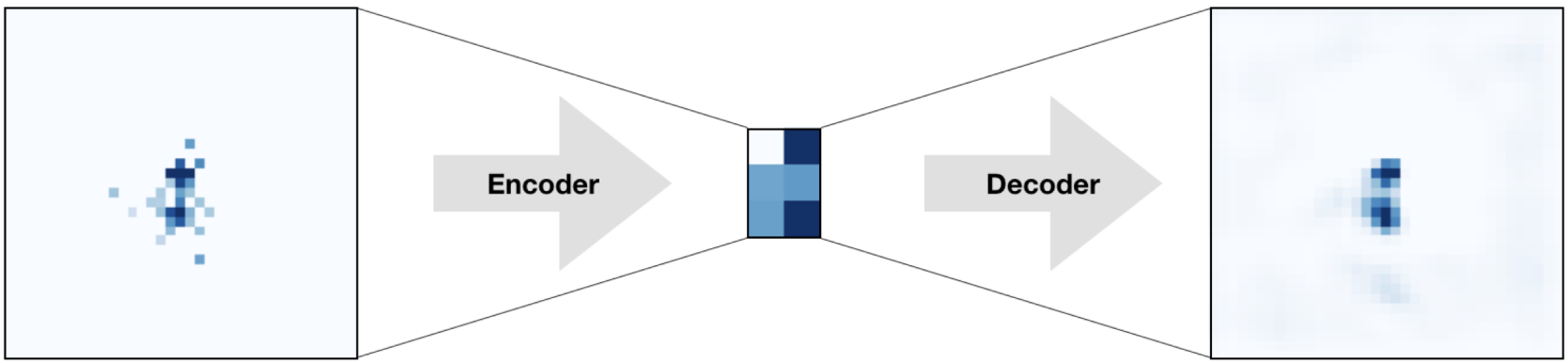
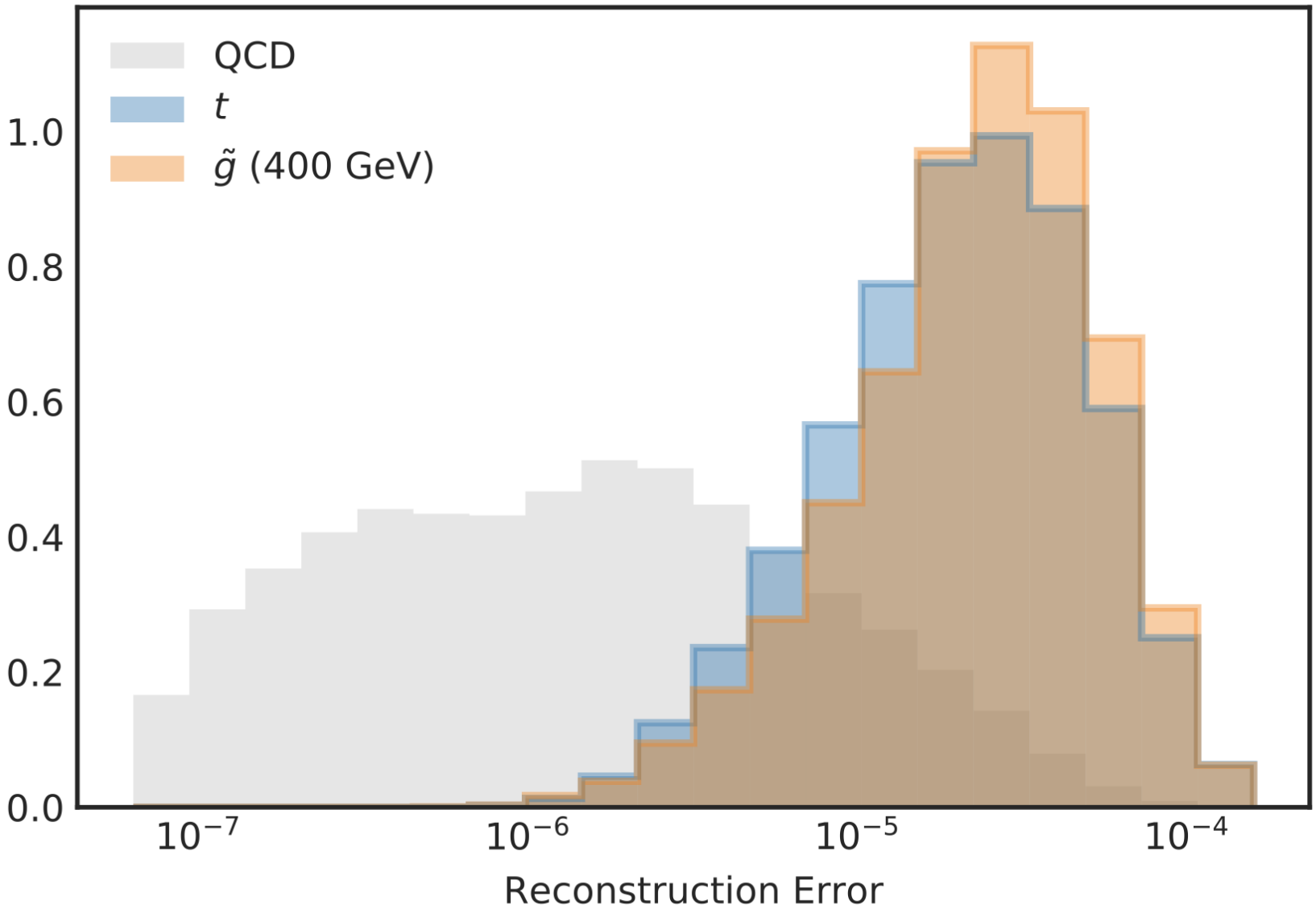
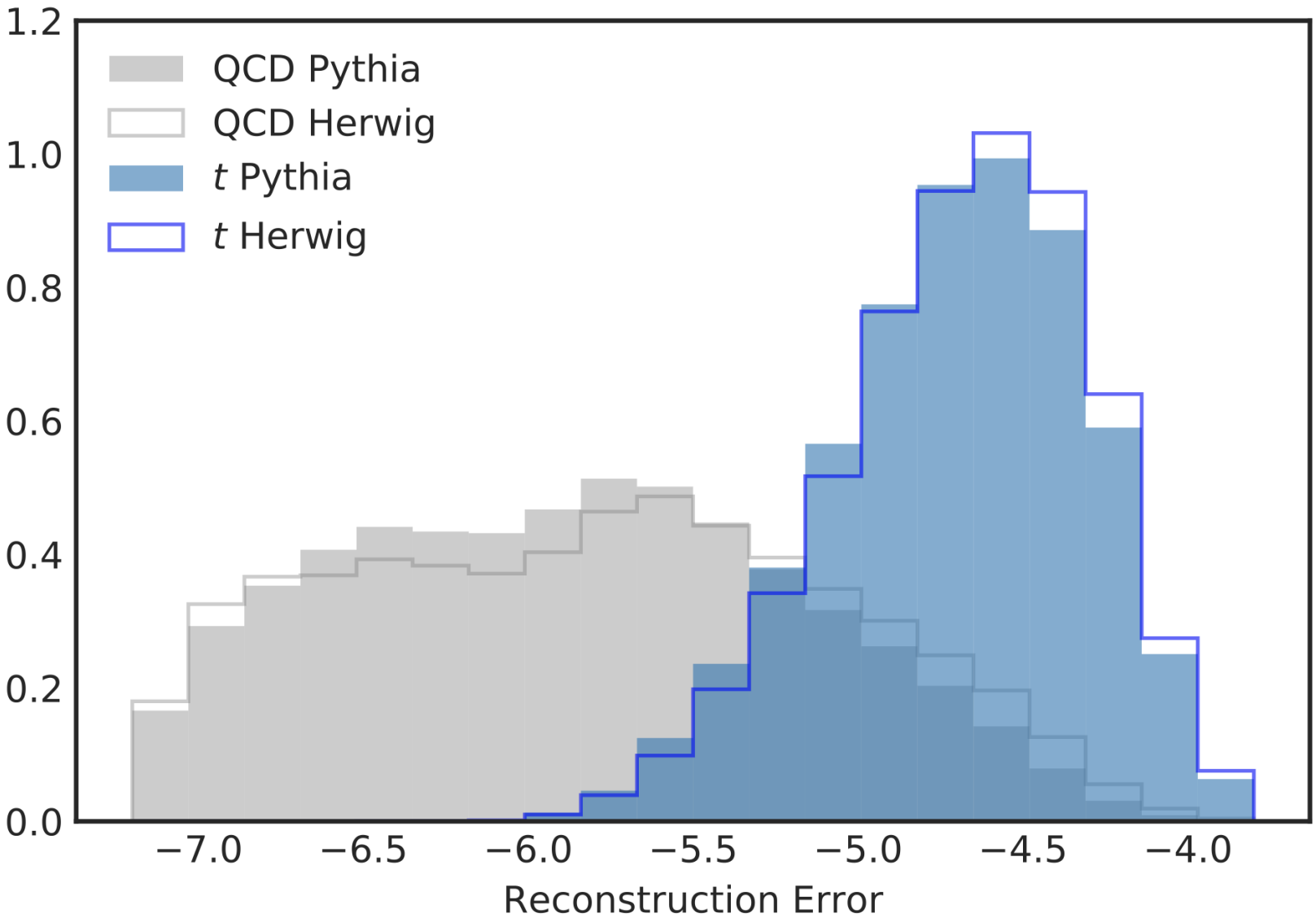


Figure 1: The schematic diagram of an autoencoder. The input is mapped into a low(er) dimensional representation, in this case 6-dim, and then decoded.

- Grey is what mostly happens. The autoencoder was never trained on blue and orange.



- Check stability against mismodelling by comparing different simulations of the same



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How could that be useful: Infectious desease early warning system

- The idea is probably as clear and simple as it is difficuylt to implement . . .
- Imagine one had all kind of (anonymous) health data (e.g. from routine tests for known antibodies) in point-ofcare centers, hospitals, health insurances, waste water routine analyses, all kind of movement data, all kind of auxiliary data (weather, region, data from social panels, data on potential infectios flies . . .)
- Try to use anomaly detection to find outliers, use onset of COVID19 in different regions in 2019/2020 as benchmark

Conclusions

- We hope we can be helpful
- The situation still doesn't look like politics informed by science has the safe standing we hoped for, but we as scientists can only try to be helpful
- We are coordinators of a consortium with a proposal for a BMBF call (together with V. Priesemann et al., NET-CHECK, others)
- A lot of complex projects are being thought of, and two more rather complex models are being worked on
- Contact us if you are intersted to invest time and to work with us

APPENDIX

A “mechanistic” Compartment Model

$$
\begin{aligned}
\frac{d}{dt} S_{a,r,p\in\{1,2,4\}} &= -\mu_{a,r,p} S_{a,r,p} &&+ \delta^{vacc.}_{a,r,p} \\
\frac{d}{dt} S_{a,r,p=3} &= -\mu_{a,r,p=3} S_{a,r,p=3} &&+ \sum_{g,p\in\{1,2\}} (\chi_{a,p,g} \cdot \tau^{rec.} \cdot R_{a,r,p,g}) \quad + \quad \delta^{vacc.}_{a,r,p=3} \\
\frac{d}{dt} S_{a,r,p=5} &= -\mu_{a,r,p=5} S_{a,r,p=5} &&+ \sum_{g,p\in\{3,4,5\}} (\chi_{a,p,g} \cdot \tau^{rec.} \cdot R_{a,r,p,g}) \quad + \delta^{vacc.}_{a,r,p=5} \\
\frac{d}{dt} E_{a,r,p,g} &= +\mu_{a,r,p,g} S_{a,r,p} &&- \tau^{lat.} E_{a,r,p,g} \\
\frac{d}{dt} I_{a,r,p,g} &= +\tau^{lat.} E_{a,r,p,g} &&- \tau^{inf.} I_{a,r,p,g} \\
\frac{d}{dt} R_{a,r,p,g} &= +\tau^{inf.} I_{a,r,p,g} &&- \tau^{rec.} \cdot R_{a,r,p,g} \\
\frac{d}{dt} D_{a,r,p,g} &= &&+ (1-\chi_{a,p,g}) \cdot \tau^{rec.} \cdot R_{a,r,p,g} \quad .
\end{aligned}
$$

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A “mechanistic” Compartment Model

$$\mu_{a,r,p,g} = \sum_{a_s,r_s,p_s} \left(\mu^M_{r,r_s} \cdot \mu^C_{a,a_s,r} \cdot \mu^R_{a,r} \cdot \frac{I_{a_s,r_s,p_s,g}}{N_{a_s,r_s}} \cdot \mu^T_{g,a,a_s,p,p_s} \right) + \mu^F_g \cdot \mu^{T'}_{g,p} \,.$$

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A “mechanistic” Compartment Model

$$
\begin{aligned}
\mu^{C,home}_{a,a_s} &= r^{home} \cdot t^{home} \cdot C^{home}_{a,a_s} \\
\mu^{C,school}_{a,a_s,r} &= r^{school} \cdot t^{school} \cdot \alpha^{school}_{r} \cdot C^{school}_{a,a_s} \\
\mu^{C,work}_{a,a_s,r} &= r^{work} \cdot t^{work} \cdot \alpha^{work}_{r} \cdot a^{school-work}_{effect} \cdot C^{work}_{a,a_s} \\
\mu^{C,other}_{a,a_s} &= r^{other} \cdot t^{other} \cdot C^{other}_{a,a_s} \,.
\end{aligned}
$$

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A “mechanistic” Compartment Model

$$
\begin{aligned}
\delta^{vacc.}_{a,r,p=1} &= -\delta^{first}_{a,r} \\
\delta^{vacc.}_{a,r,p=2} &= +\delta^{first}_{a,r} - \tau^{partvacc.} \cdot S_{a,r,p=2} \\
\delta^{vacc.}_{a,r,p=3} &= -\delta^{second}_{a,r} + \tau^{partvacc.} \cdot S_{a,r,p=2} \\
\delta^{vacc.}_{a,r,p=4} &= +\delta^{second}_{a,r} - \tau^{fullvacc.} \cdot S_{a,r,p=4} \\
\delta^{vacc.}_{a,r,p=5} &= + \tau^{fullvacc.} \cdot S_{a,r,p=4} \,.
\end{aligned}
$$

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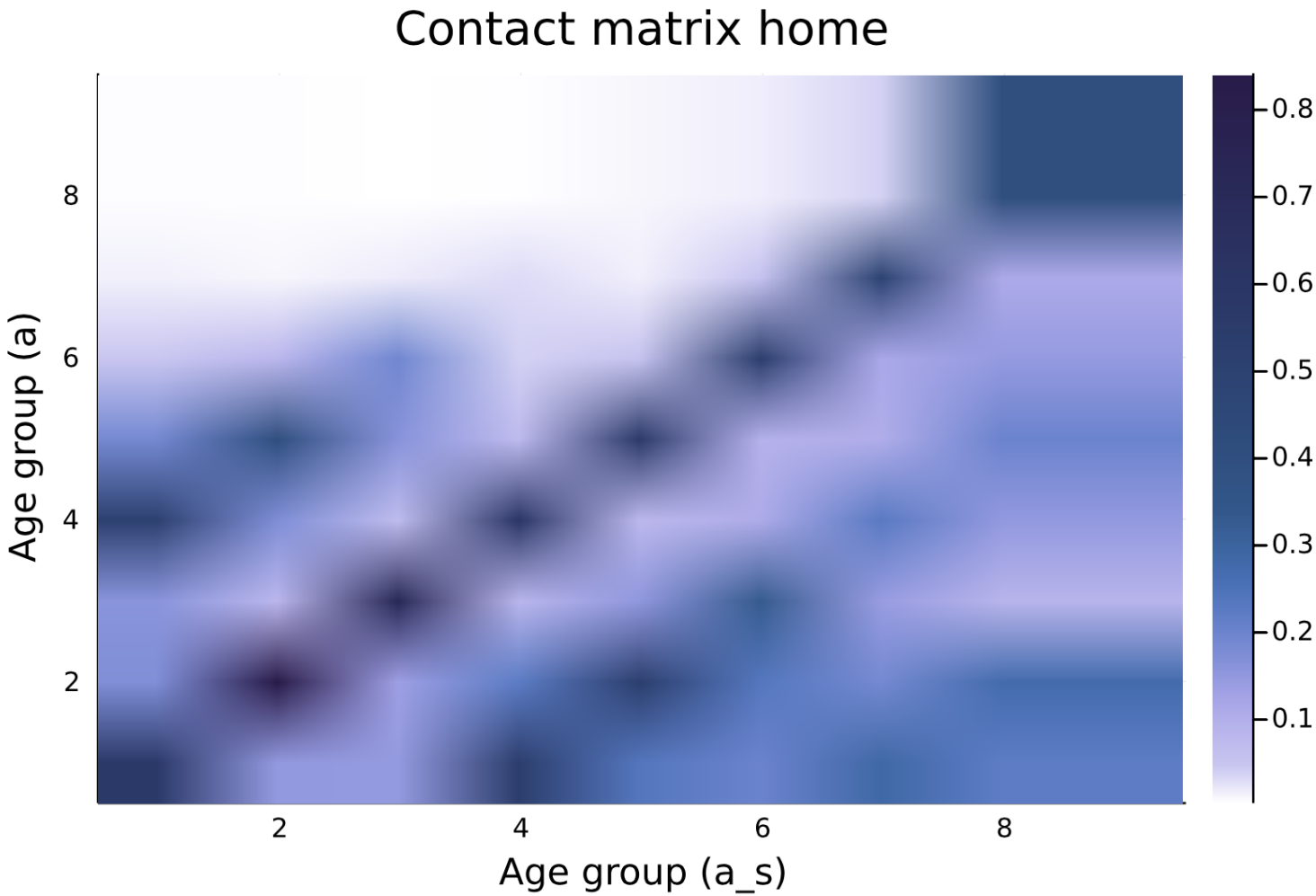
A “mechanistic” Compartment Model



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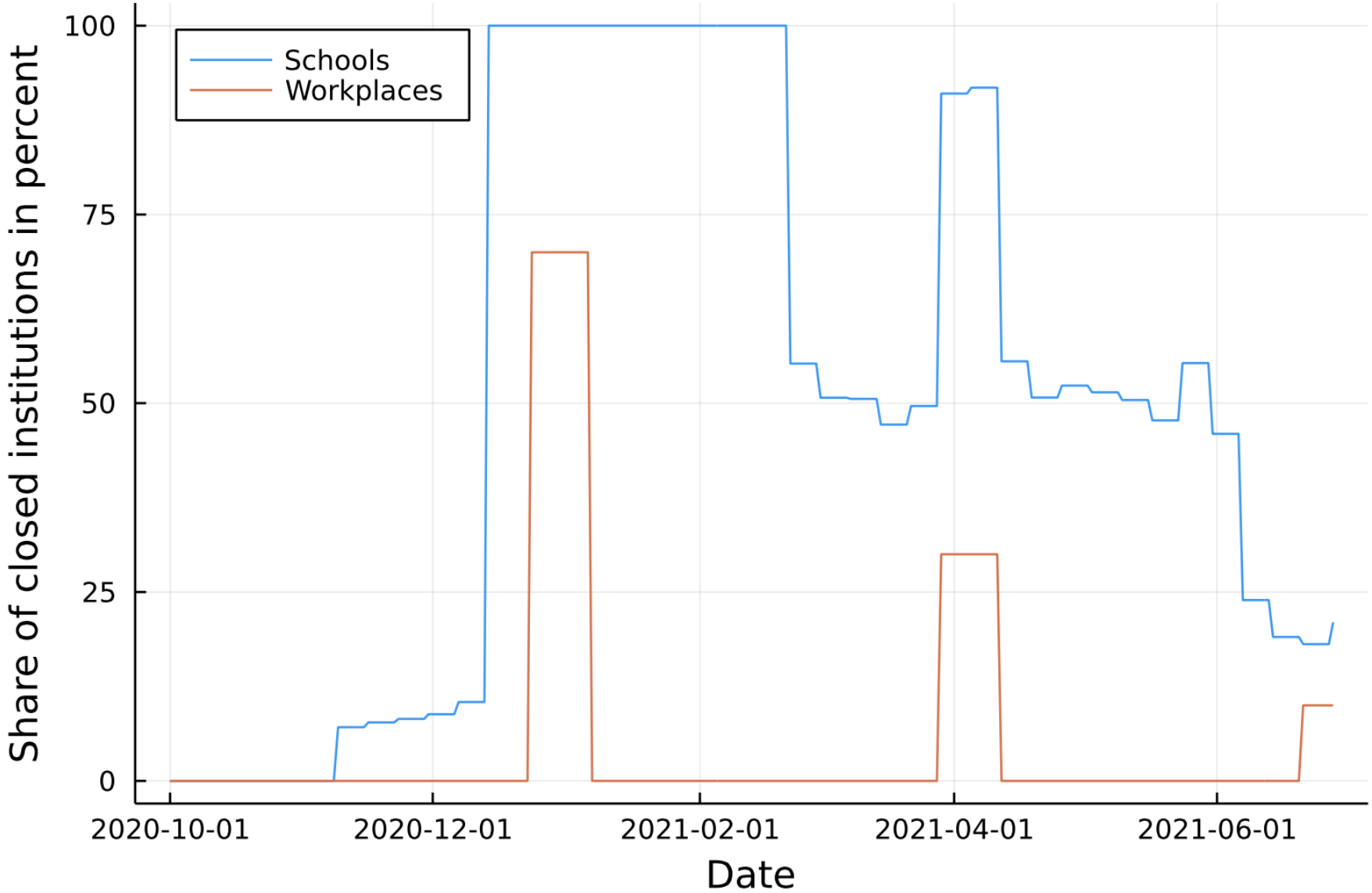

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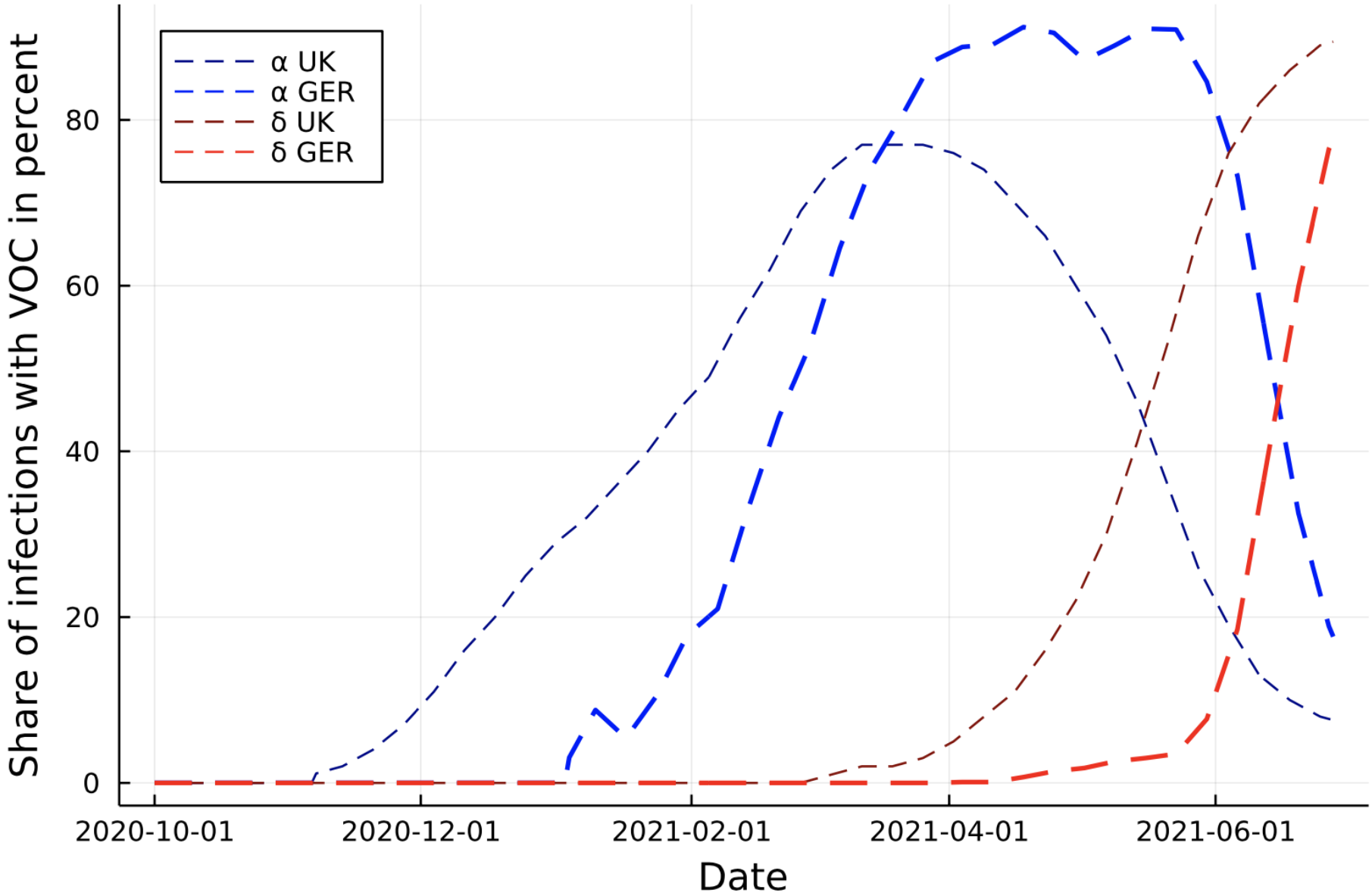

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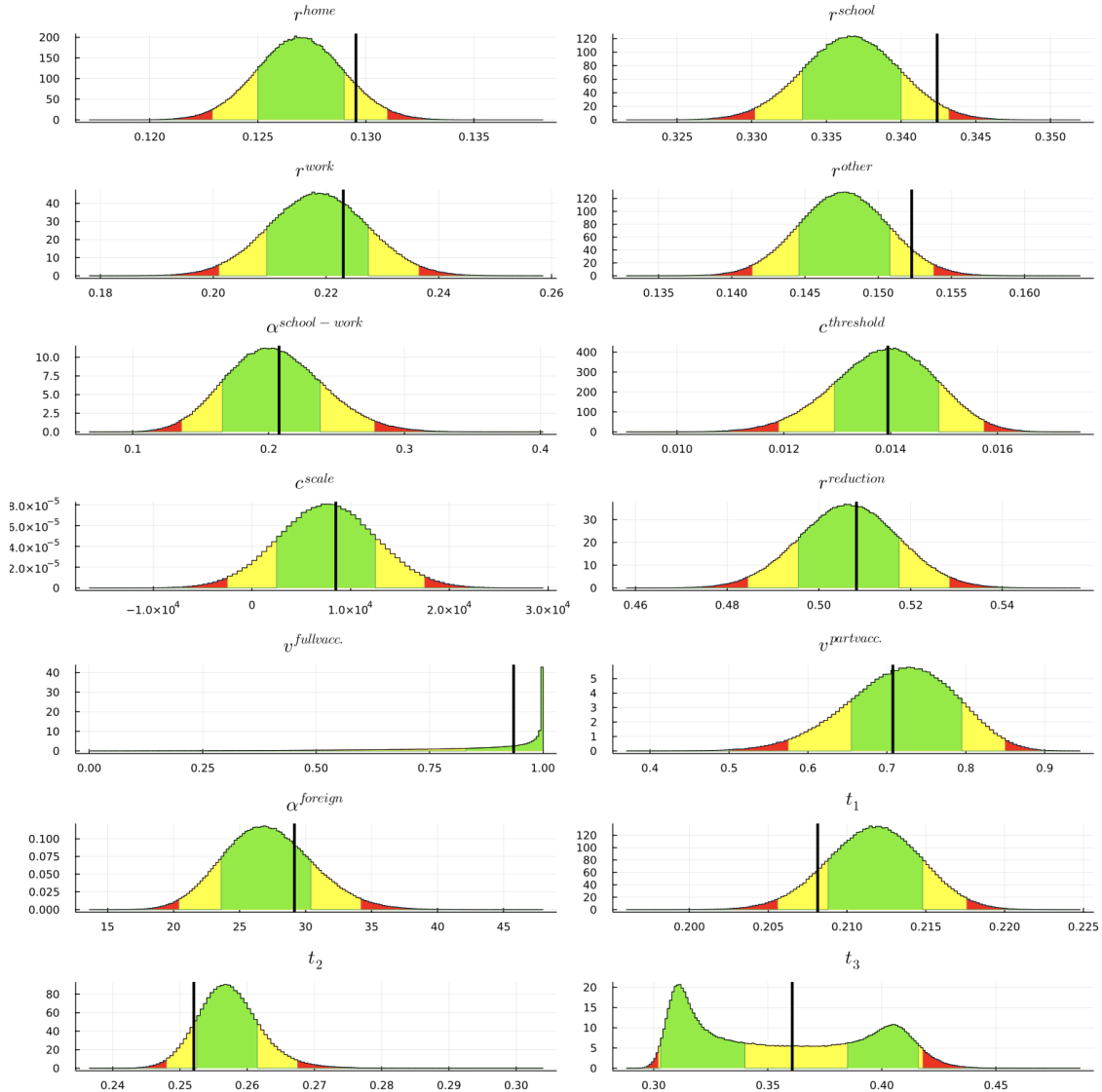

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