Non-traditional data-driven approaches to epidemiology

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Engineering and Physical Sciences Research Council

Medical Research Council

i-sense

Research team, collaborations & funding

- UCL Computer Science, UCL AI Centre
- UCL Health Informatics, Epidemiology, Institute for Global Health, Division of Medicine
- Imperial College London, Harvard, Bar-Ilan universities
- Public Health England, World Health Organisation
- Microsoft Research, Google Health
- i-sense (i-sense.org.uk), VirusWatch (ucl-virus-watch.net) projects
- Funding: EPSRC, MRC, Google (> £19 million since 2014)

Engineering and Physical Sciences Research Council

Medical Research Council

Public Health England

Traditional epidemiology

- Traditional ≈ *conventional*, *established*
- Data streams based on interactions with health services
- Methods: statistics, mechanistic models, rarely machine learning
- Challenges
  - Biases in the cohorts (*sampling bias*)
  - Reporting latency
  - Non-established health systems
  - A pandemic!

Alternative data streams for epidemiology

Microsoft Bing

Google

- Web search activity, social media
- Different *data*, different *methods*?
- Complementary to conventional approaches
  - Larger cohorts, broader/different demographic and geographic coverage
  - Reduced latency
  - Lower cost
  - Not particularly affected by closure days and *pandemics*
  - Applicable in locations where health surveillance is less established

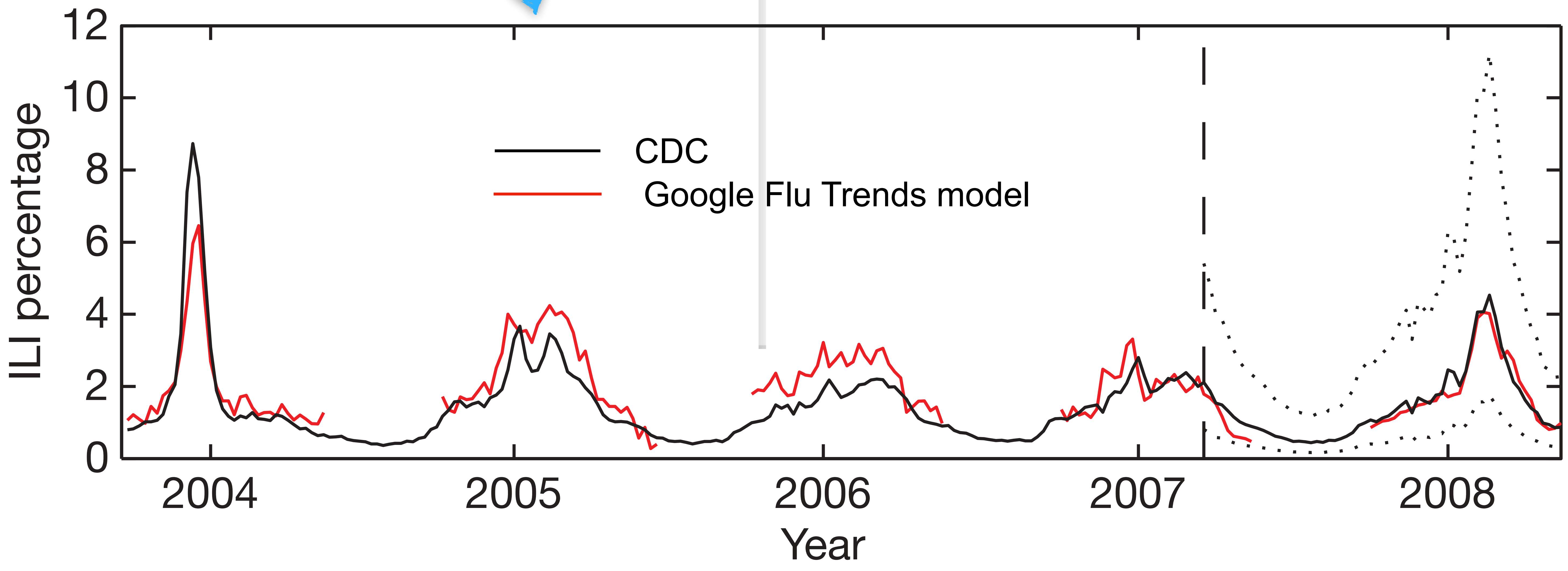
Wagner, Lampos, Cox, Pebody. *Sci. Rep.* (2018), doi:10.1038/s41598-018-32029-6

Mapping web search activity to disease rate estimates

Google

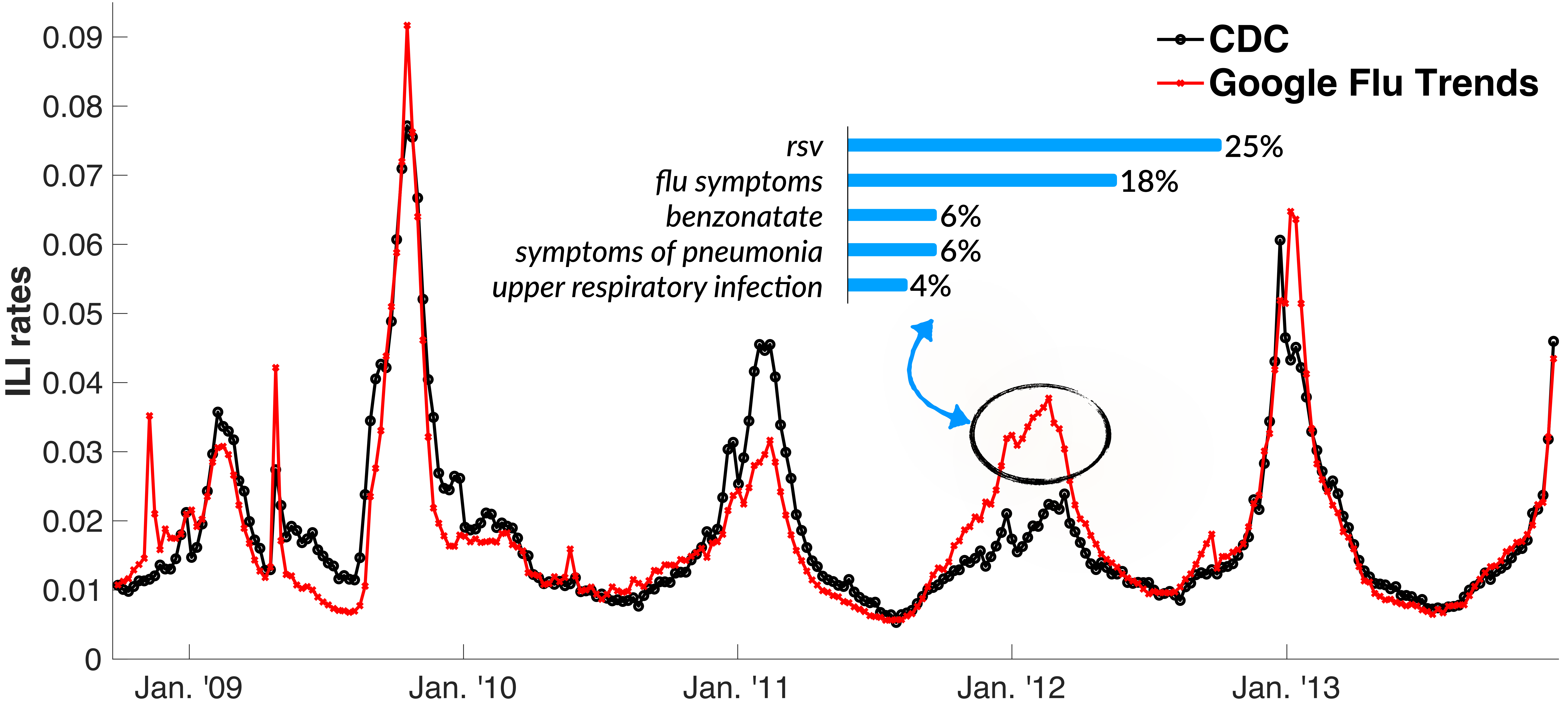
flu treatment

flu treatment
flu treatment **kids**
flu treatment **otc**
flu treatment **natural**
flu treatment **medication**
flu treatment **toddler**



Eysenbach, *AMIA* (2006); Polgreen et al. *Clin. Infect. Dis.* (2008); Ginsberg et al. *Nature* (2009)

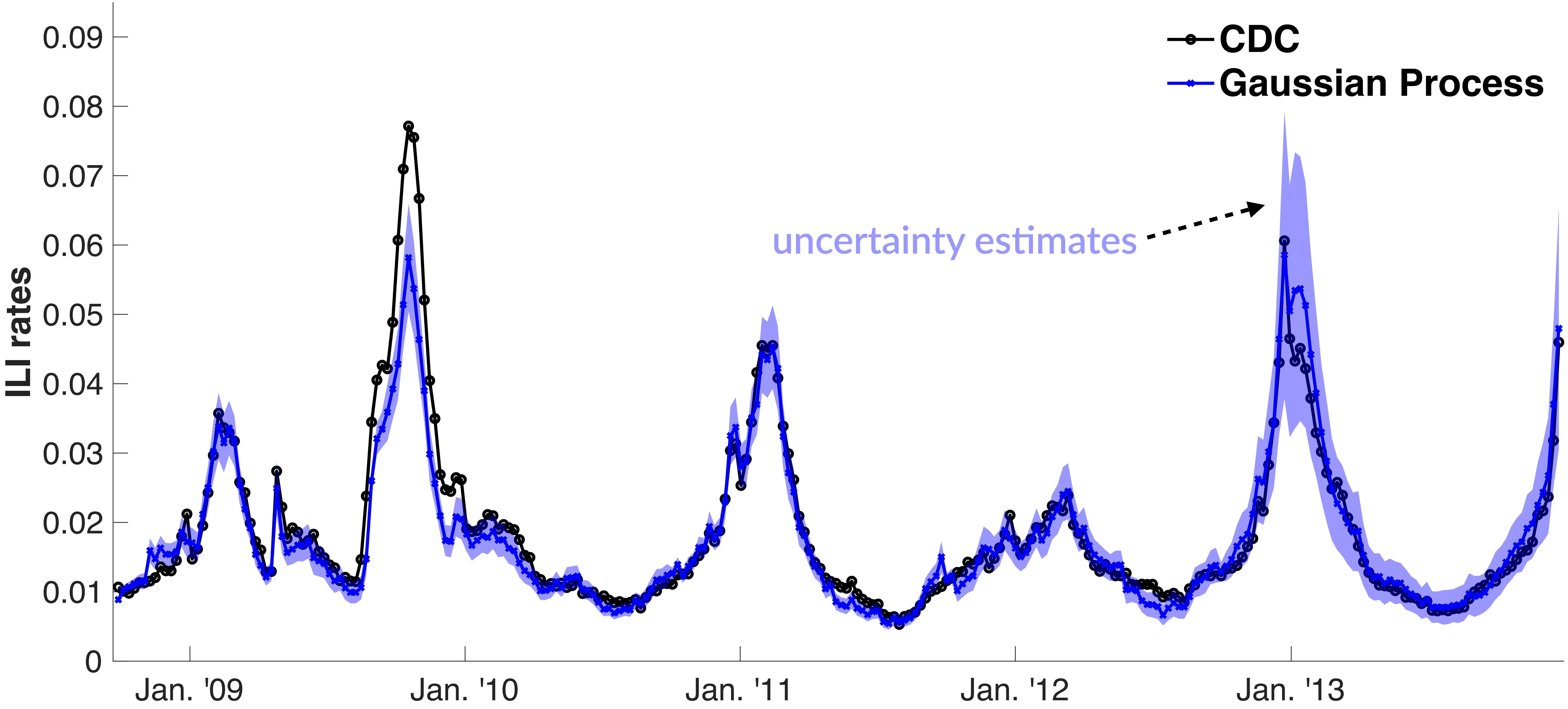
What went wrong with Google Flu Trends?



Influenza-like illness (**ILI**) rate estimates in the US during the 2011/12 flu season were greatly affected by web searches that were not related to flu.

Lampos, Miller, Crossan, Stefansen. *Sci. Rep.* (2015), doi:10.1038/srep12760

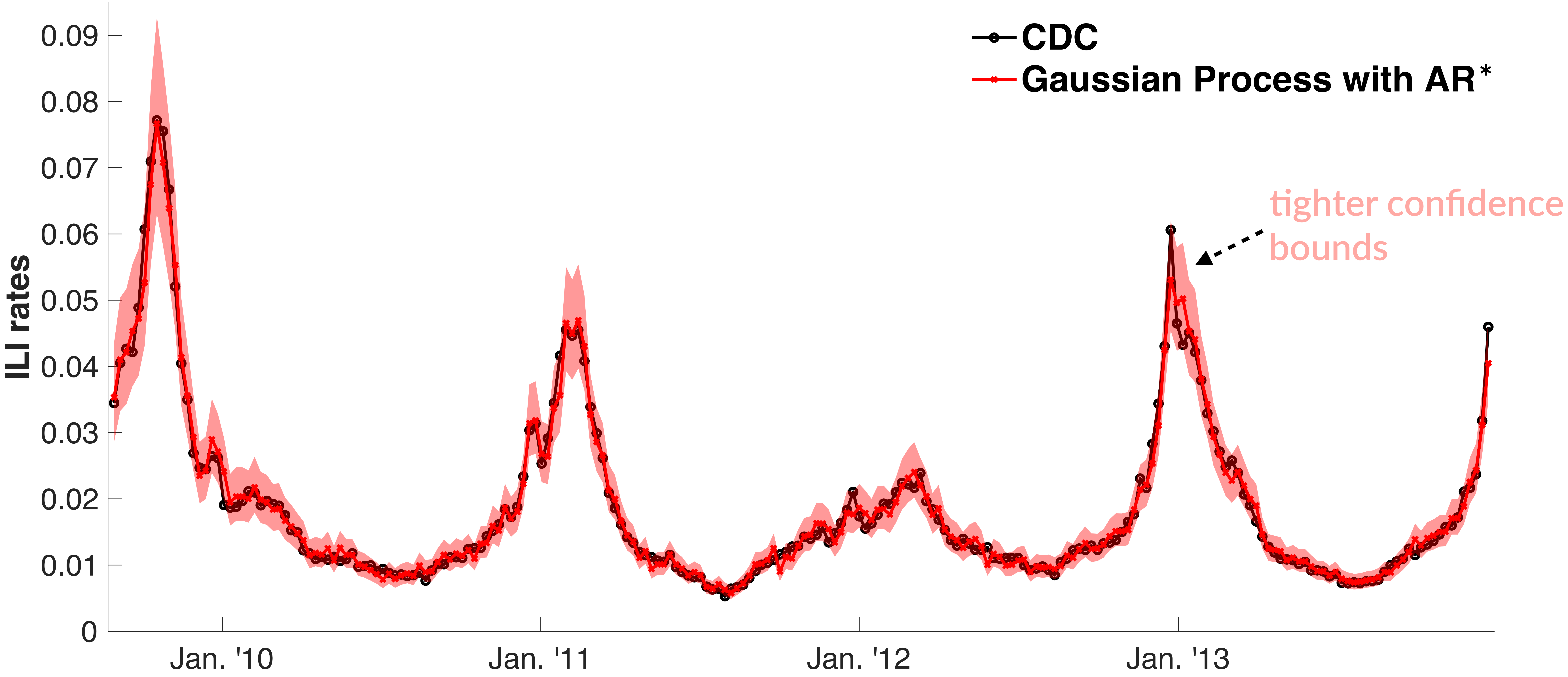
Estimating flu rates using web search activity (*US*)



- **Model:** *Gaussian Process* covariance functions on clusters (*temporal topics*) of search queries
- **42%** mean absolute error reduction compared to Google Flu Trends

Lampos, Miller, Crossan, Stefansen. *Sci. Rep.* (2015), doi:10.1038/srep12760

Estimating flu rates using web search activity (*US*)

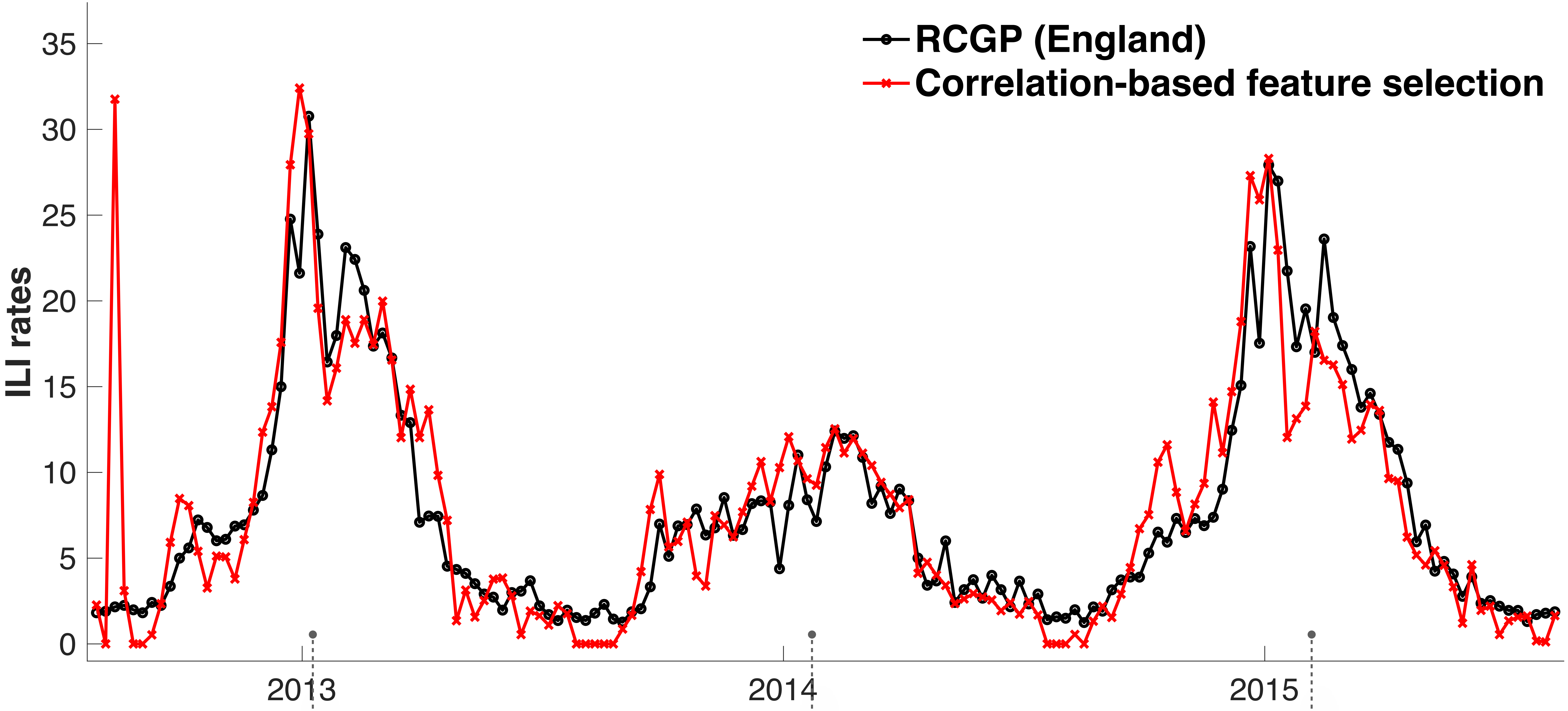


- **Model:** *Gaussian Process* flu rate estimates in ARMAX — 1 week lag for the CDC rates
- 27% mean absolute error reduction compared to using Google Flu Trends estimates in ARMAX

* *AR reinforces systemic biases (not always desirable)*

Lampos, Miller, Crossan, Stefansen. *Sci. Rep.* (2015), doi:10.1038/srep12760

Feature (*search query terms*) selection

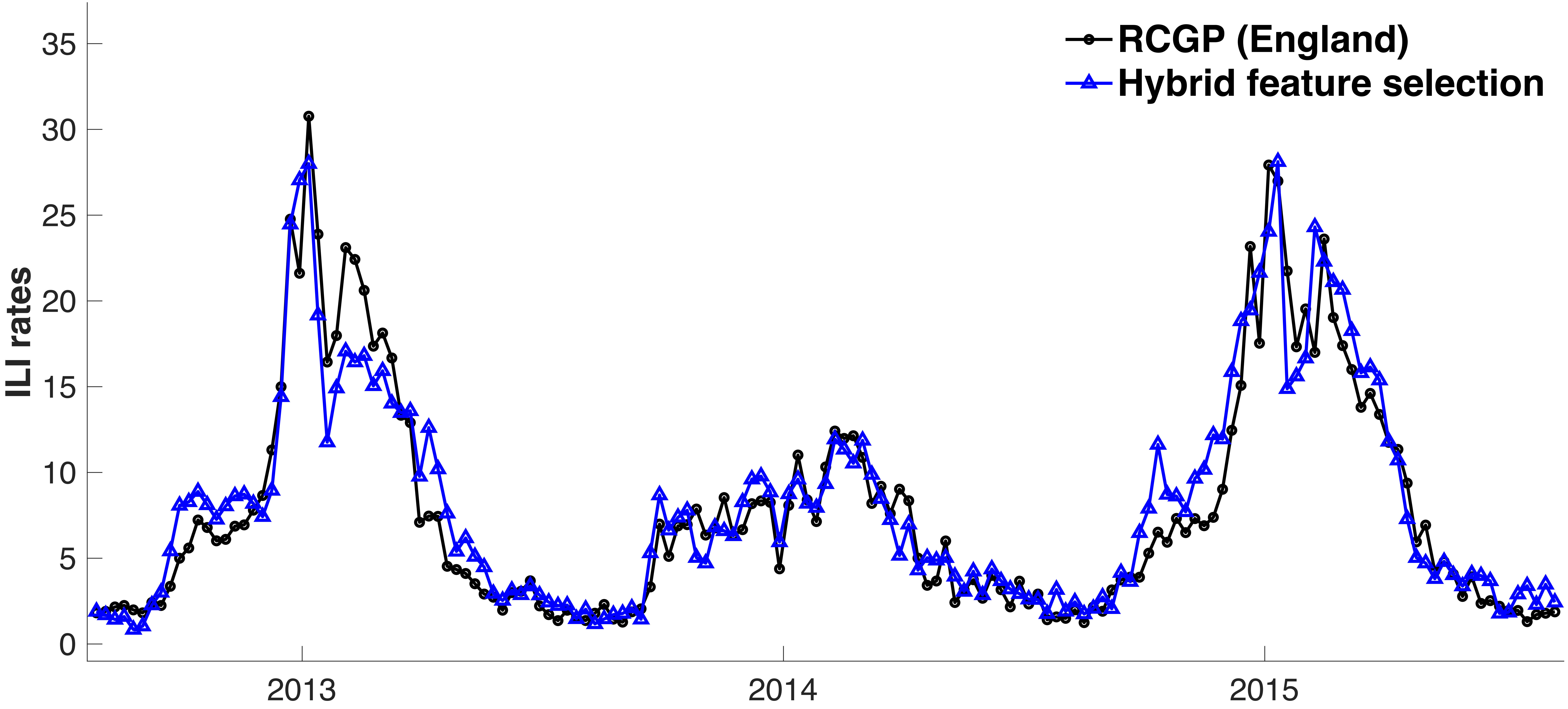


spurious search queries

'Prof. *Surname*', 'heal the world', 'heating oil', 'The White Company'	'Broken Sword', 'Snow Rock', 'gas homecare', 'North Face', 'low cost flights'	'Florence and the Machine Lungs', 'pleurisy symptoms', 'Boots sale', '*Name Surname*'

Lampos, Zou, Cox. *WWW* (2017), doi:10.1145/3038912.3052622

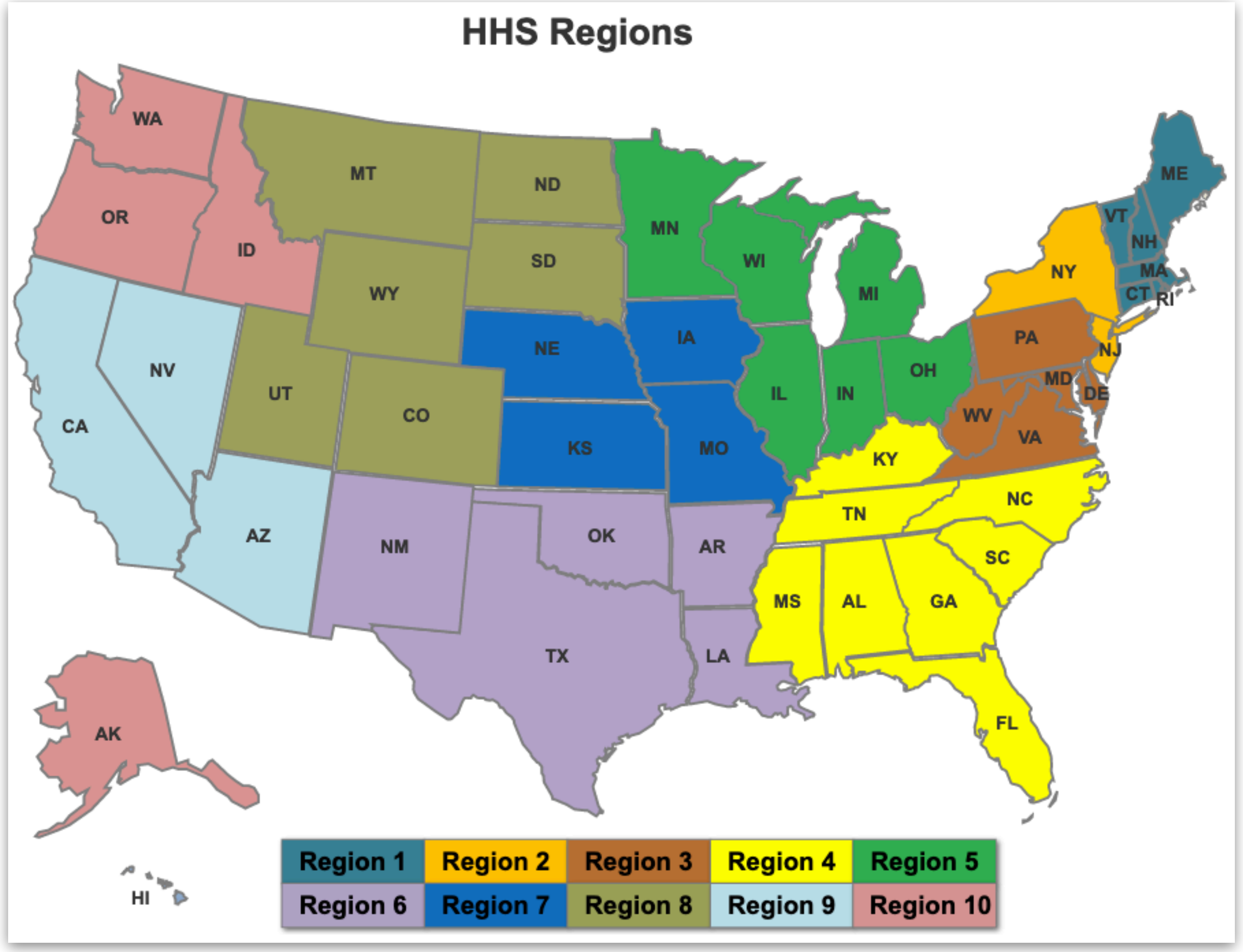
Feature (*search query terms*) selection

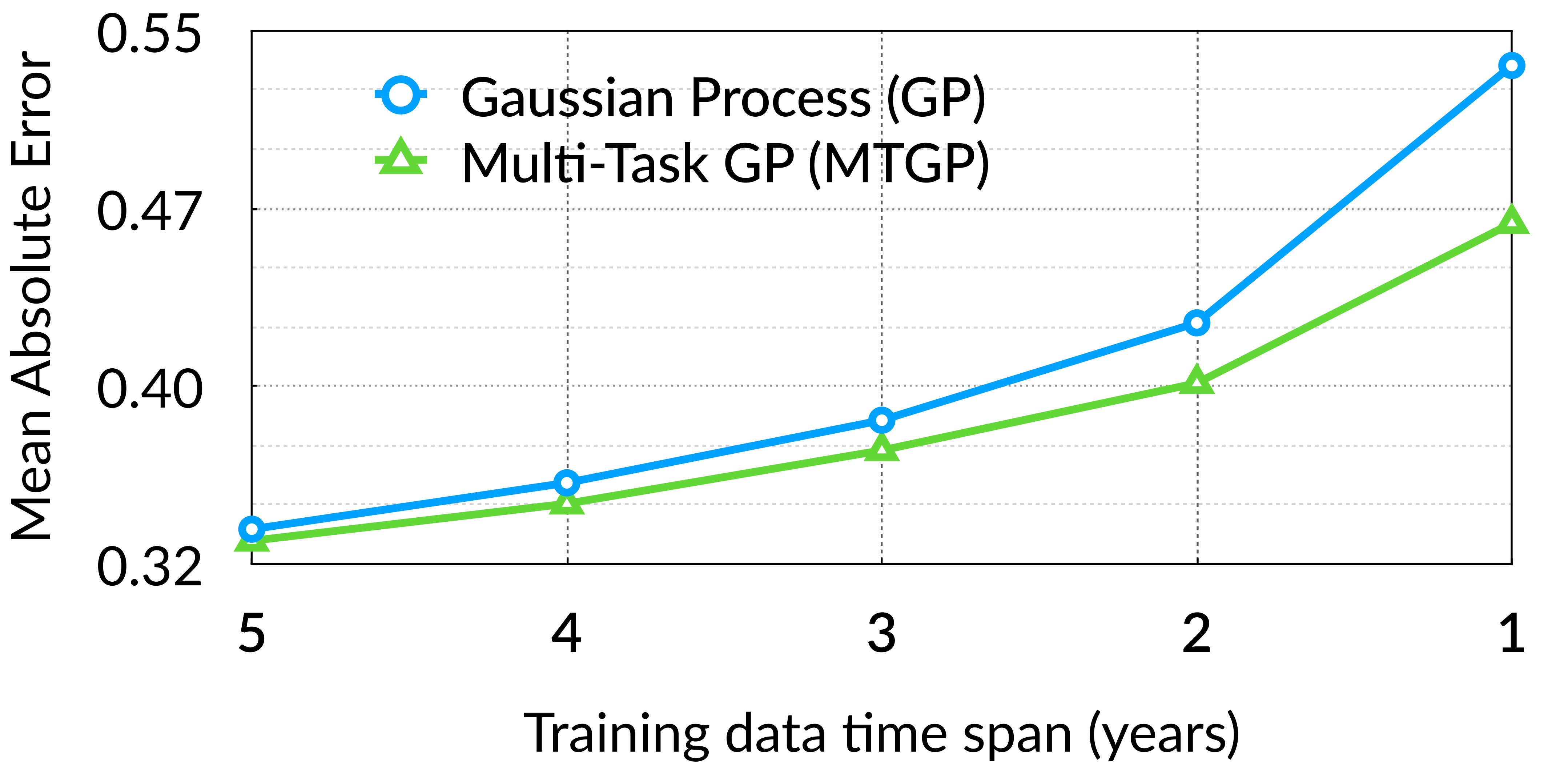


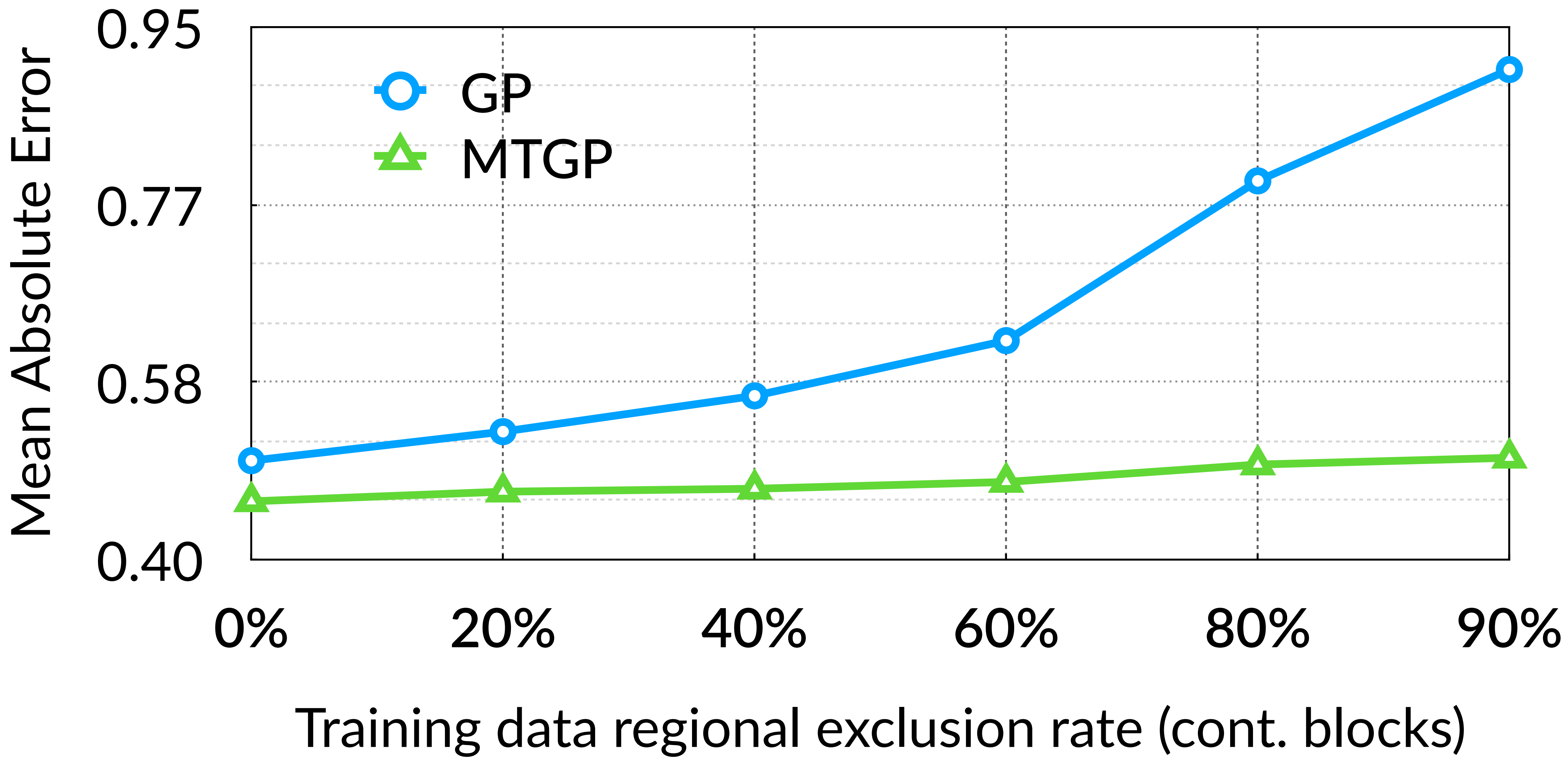
- Accuracy improved by **12.3%** (*mean absolute error*)
- Bivariate correlation of **.91**

Lampos, Zou, Cox. *WWW* (2017), doi:10.1145/3038912.3052622

Multi-task learning for robust *subregional* flu models (*US*)





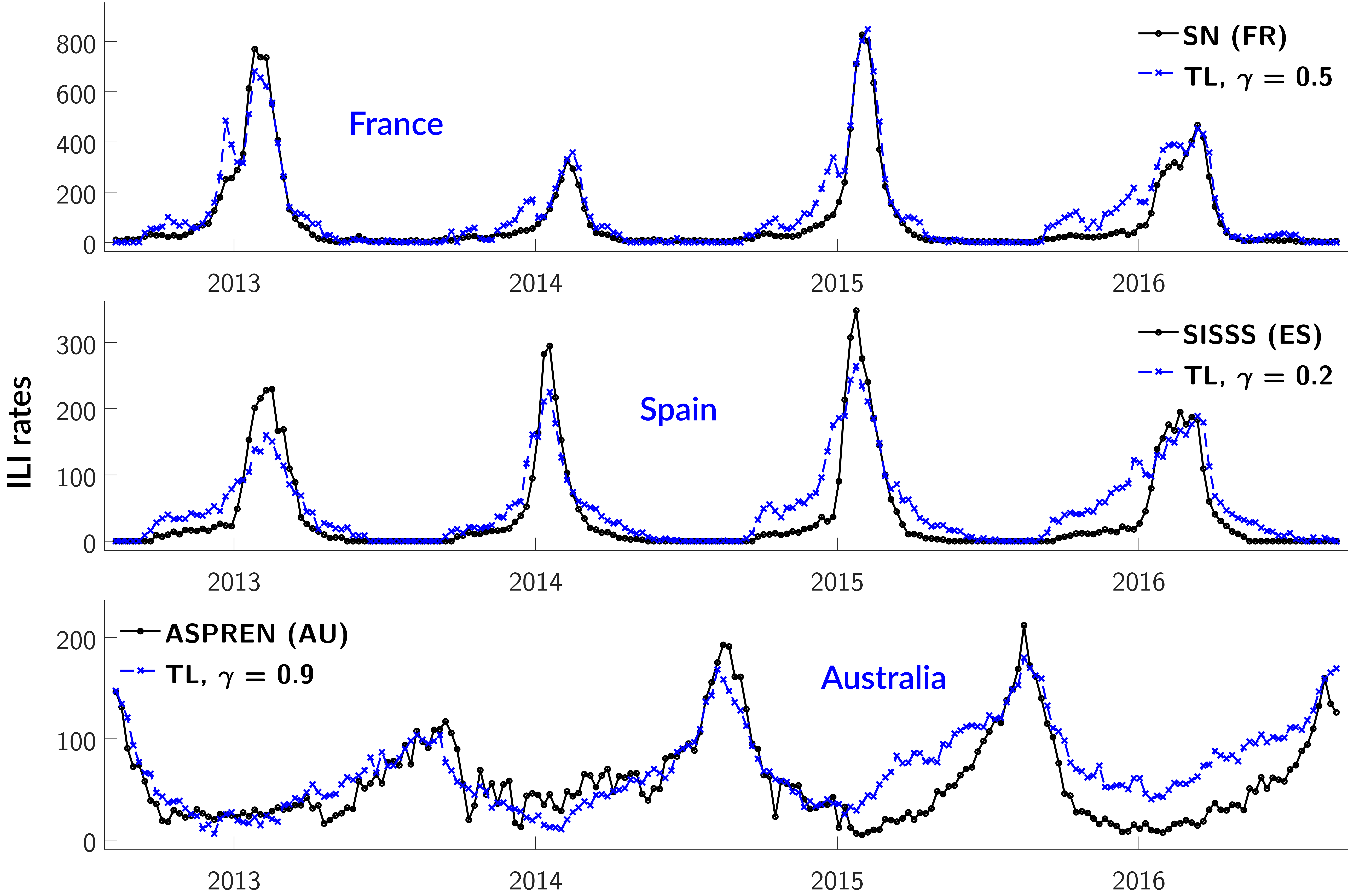


Multi-task learning models estimating flu rates in US regions:

- yield stat. sig. benefits when historical training data is limited (< 3 years)
- are mildly affected by data loss

Zou, Lampos, Cox. *WWW* (2018), doi:10.1145/3178876.3186050

Transferring flu models based on web search activity

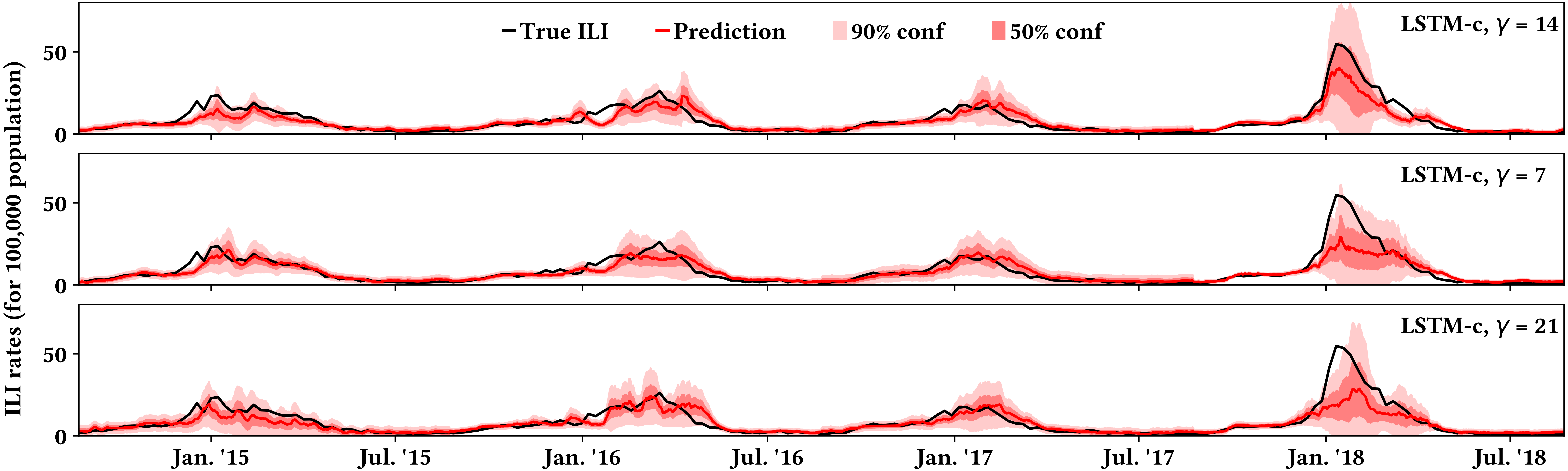


Transfer learning

- supervised flu model using data from the US
- transfer it to target countries (*no historical flu rates*, *no calibration*)
- γ controls the balance between the temporal and semantic similarity of source (US) and target searches

Zou, Lampos, Cox. *WWW* (2019), doi:10.1145/3308558.3313477

Forecasting flu rates using web search activity (*England*)

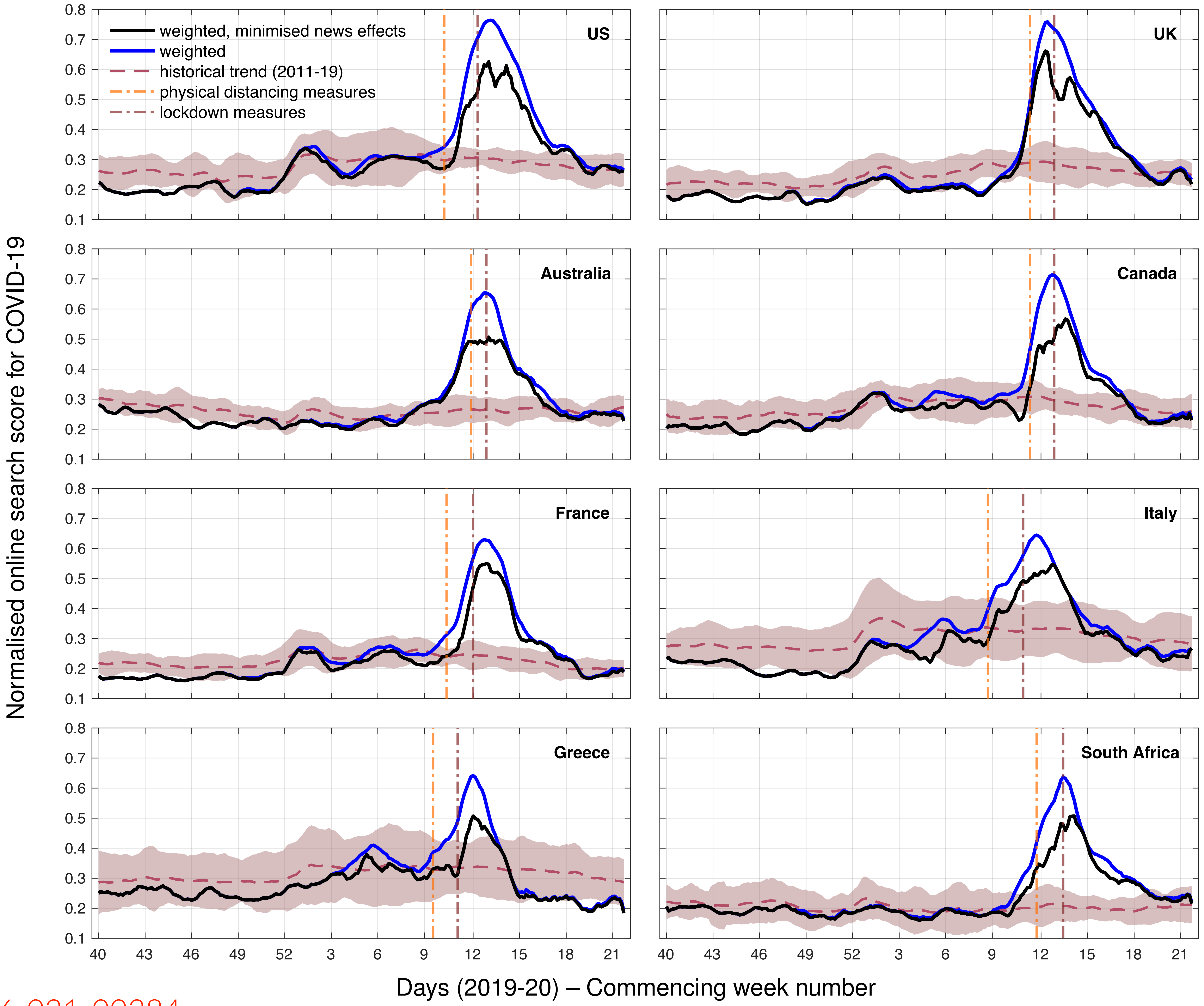


- **Bayesian Neural Networks** can provide forecasts (γ days ahead) with uncertainty without significant accuracy loss
- Combine model (*epistemic*) and data (*aleatoric*) uncertainties
- Web search activity data is key for improving forecasting accuracy

Morris, Hayes, Cox, Lampos. *arXiv preprint* (2021), arXiv:2105.12433

Modelling COVID-19 using web search activity

- Unsupervised learning
- 8 countries — national signals
- Attempt to reduce news media effects
- Scores reduced by 16.4% on average during peak moments



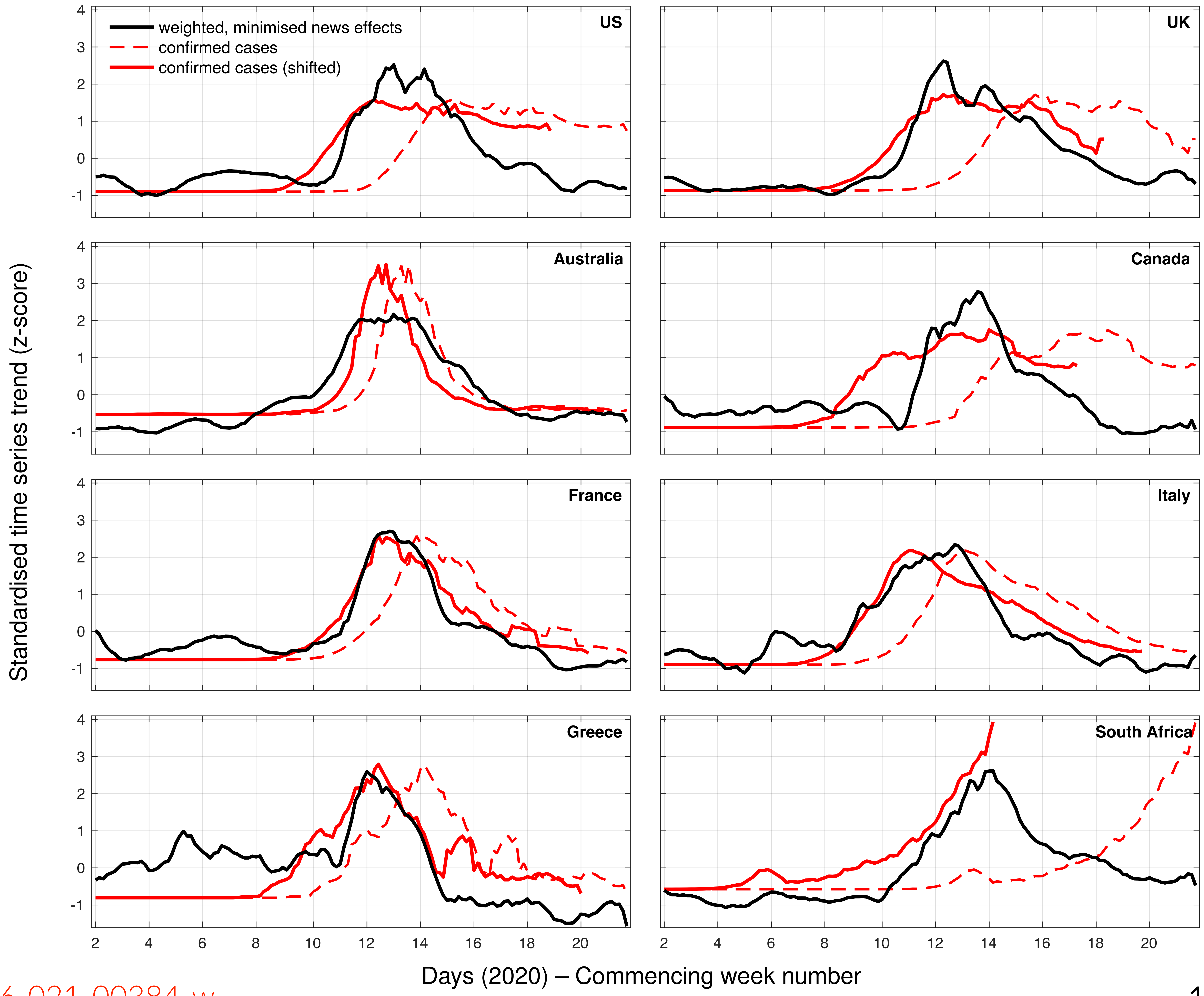
Lampos et al. *npj Digit. Med.* (2021), doi:10.1038/s41746-021-00384-w

Modelling COVID-19 using web search activity

Comparison with confirmed COVID-19 cases

- Average **early-warning**
  16.7 days, CI: 10.2–23.2 days
- Average bivariate correlation
  r = .83, CI: .74–.92

<u>Note</u>: *South Africa is excluded from this analysis*



Lampos et al. *npj Digit. Med.* (2021), doi:10.1038/s41746-021-00384-w

Modelling COVID-19 using web search activity

Comparison with deaths of people diagnosed with COVID-19

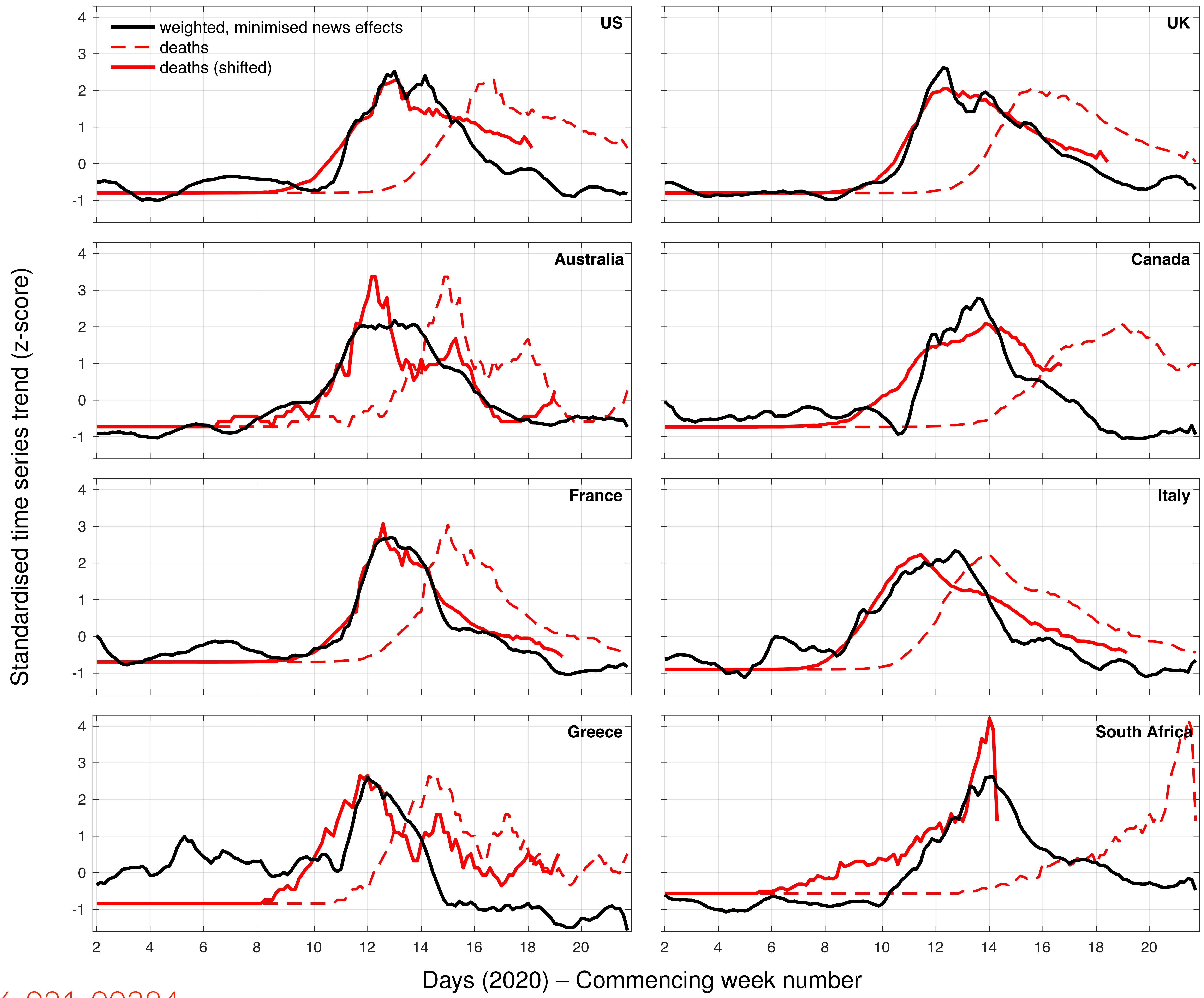
- Average **early-warning**

  22.1 days, CI: 17.4–26.9 days

- Average bivariate correlation

  r = .85, CI: .70–.99

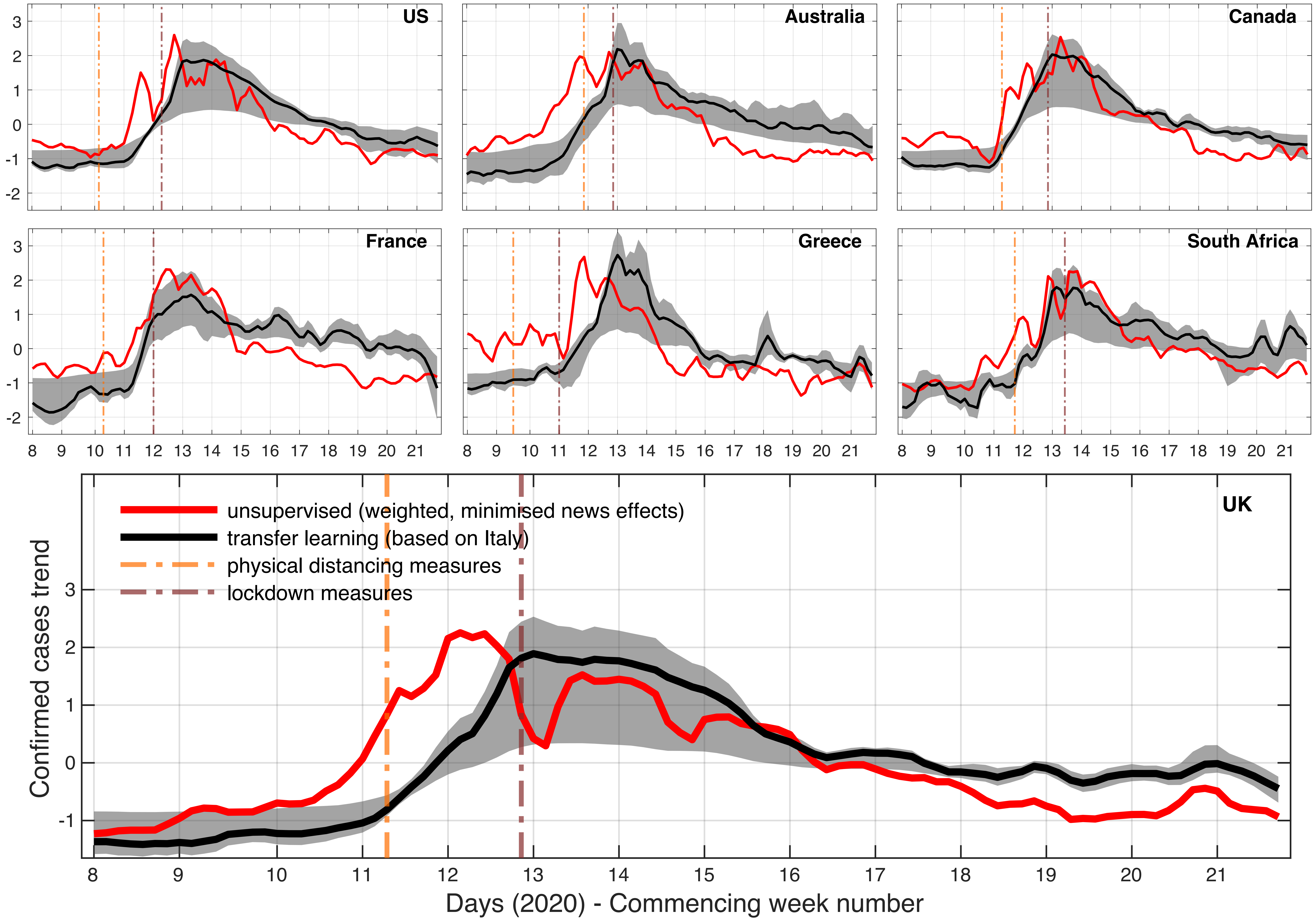
<u>Note</u>: *South Africa is excluded from this analysis*



Lampos et al. *npj Digit. Med.* (2021), doi:10.1038/s41746-021-00384-w

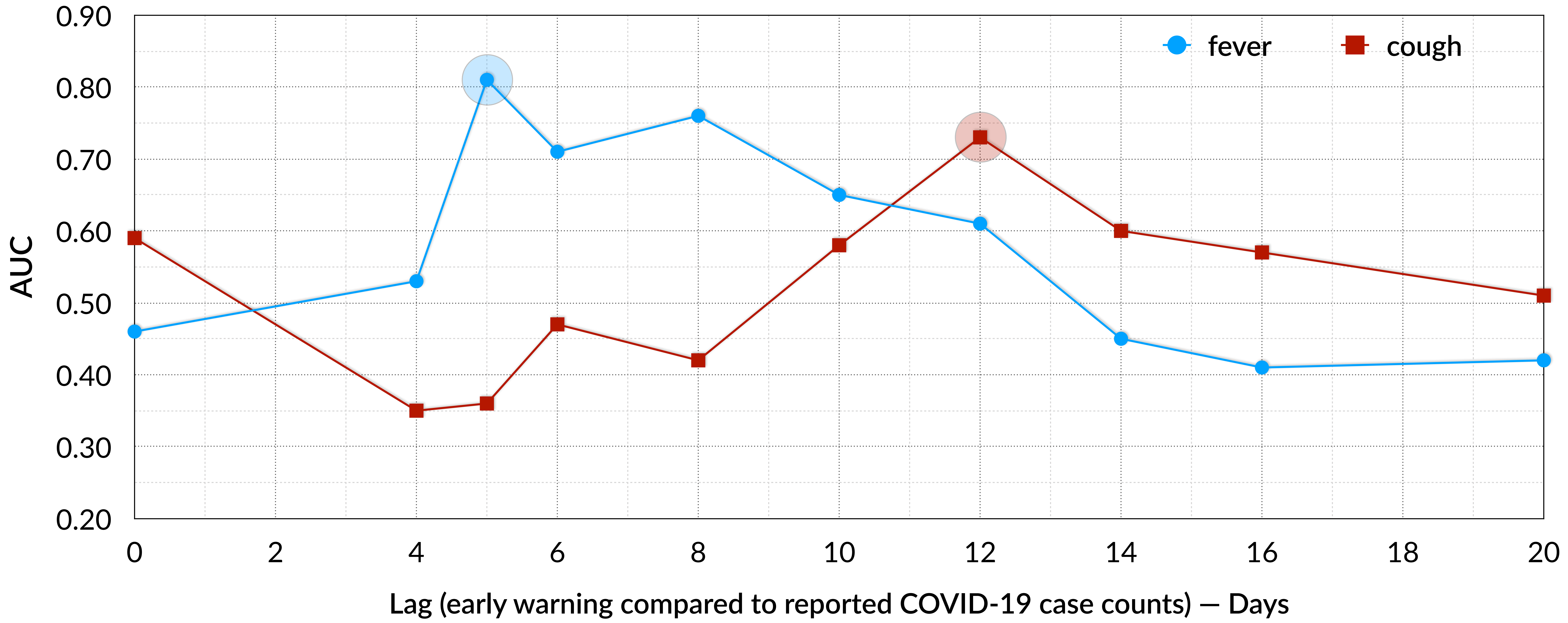
Modelling COVID-19 using web search activity

- Transfer a model trained on data from Italy (*confirmed cases, web search activity*)
- Unsupervised learning vs. transfer learning
  - 5 days earlier warning for the unsupervised models
  - curves are similar when aligned temporally



Lampos et al. *npj Digit. Med.* (2021), doi:10.1038/s41746-021-00384-w

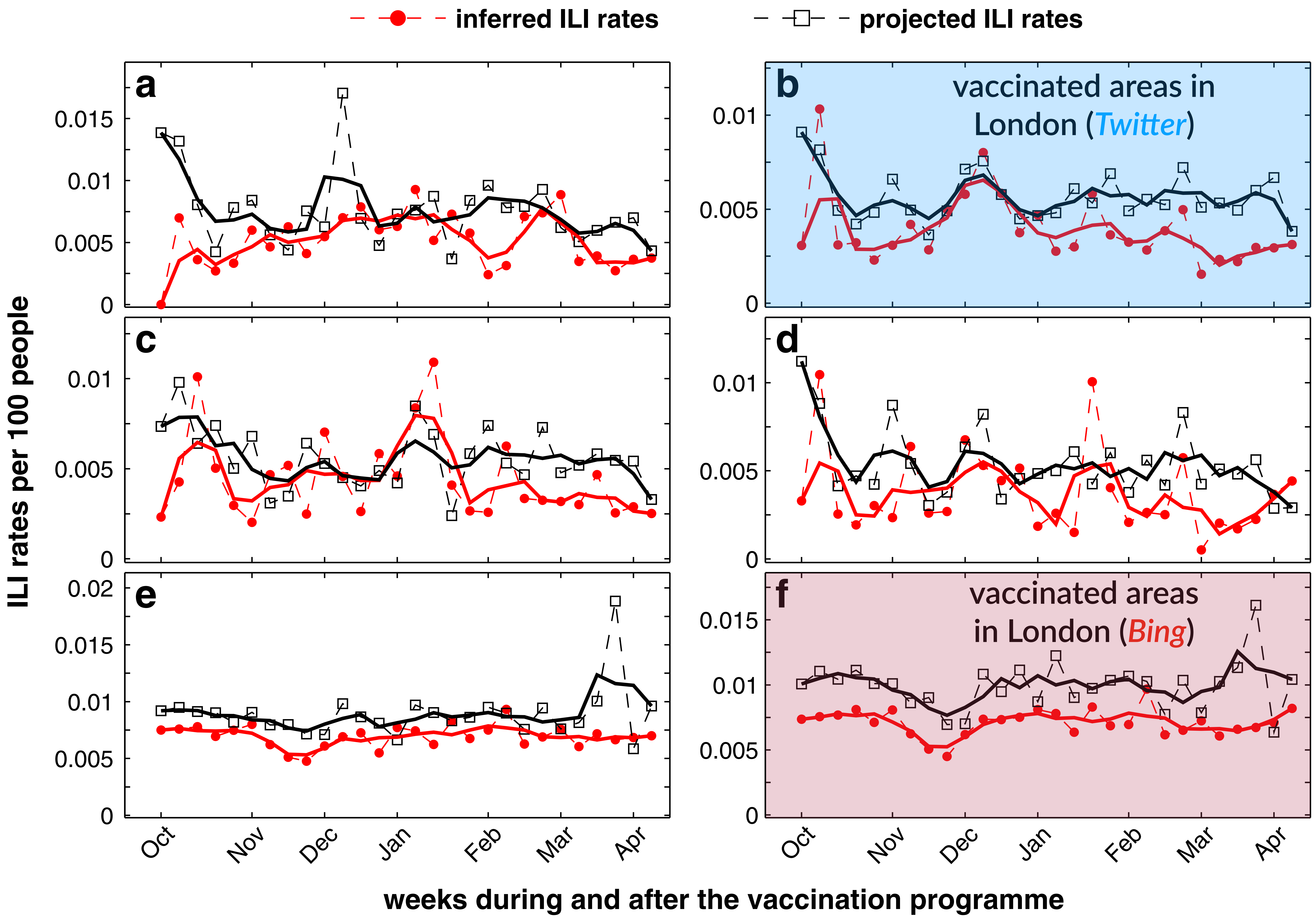
Using web search anomalies to predict COVID-19 outbreaks (*England*)



- Identify anomalies in web searches about COVID-19-related symptoms in local authorities in England (*difference-in-difference* methodology)
- Predict local outbreaks with a substantial early-warning — Caveat: *hard to assess accuracy*!

Yom-Tov, Lampos, Inns, Cox, Edelstein. *arXiv preprint* (2020) — *updated manuscript under review*, arXiv:2007.11821

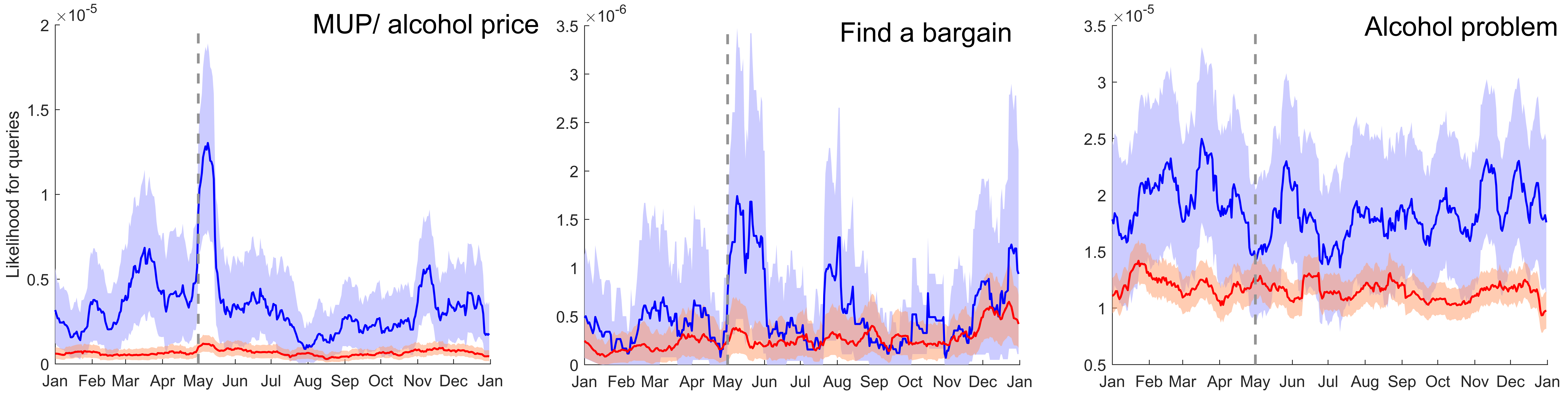
What is the impact of a vaccination campaign?



- Flu vaccination campaign by NHS/PHE (*schools*)
- Launched in a few areas — hard to assess the impact
- What would the flu rates be had the vaccination not taken place?
- **Twitter**: 32.8% reduction
- **Bing**: 21.1% reduction

Lampos, Yom-Tov, Pebody, Cox. *Data Min. Knowl. Disc.* (2015), doi:10.1007/s10618-015-0427-9
Wagner, Lampos, Yom-Tov, Pebody, Cox. *J. Med. Internet Res.* (2017), doi:10.2196/jmir.8184

Minimum Unit Pricing (MUP) of alcohol in Scotland



Search trends (Bing search engine) for alcohol-related topics in England (red) and Scotland (blue) during 2018.

- Alcohol MUP is a public health intervention aimed at reducing alcohol-related ill health in Scotland
- Search trends reflect on the policy introduction (May 1, 2018)
- Attempts to buy cheaper alcohol, circumvent the policy, no observable impact (*at the time of the analysis*)

Leon et al. *Addiction* (2021), doi:10.1111/add.15388

Estimation of secondary attack rates (SAR) from social media activity

Bill Lampos @lampos · Mar 30
My father has had a #COVID19 PCR test a couple days ago and it came back positive. Oh no!

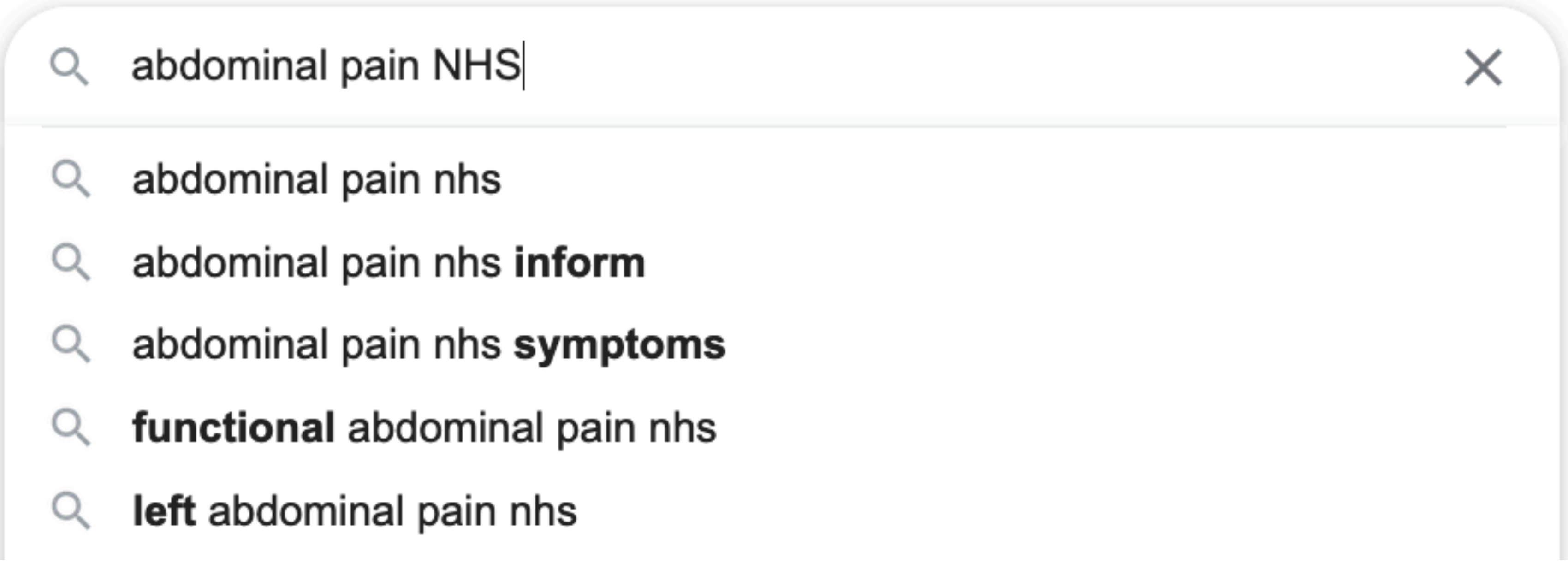
Bill Lampos @lampos · Apr 8
While my father seems to be OK now, I am starting to feel really unwell and my lunch did not taste right. #COVID19

- SAR: *probability of infection following contact with an infectious person*
- Original model applied to estimate familial (household) SAR (fSAR) for influenza in the UK
- Ongoing work to estimate fSAR for COVID-19

Yom-Tov, Cox, Lampos, Hayward. *Influenza Other Respir. Viruses* (2015), doi:10.1111/irv.12321
and an ongoing project led by Tomasz Czernuszenko

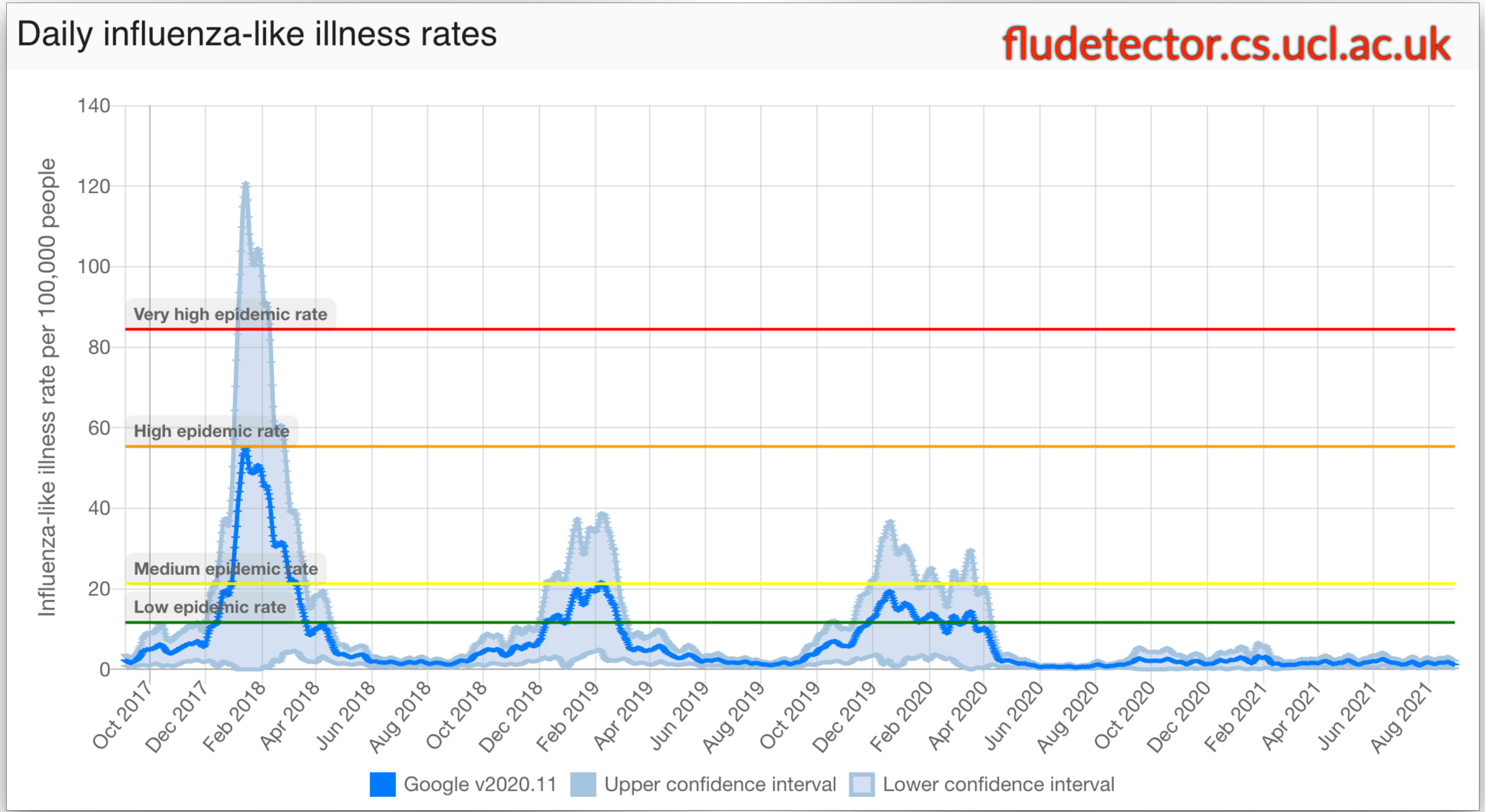
Gynaecological cancer risk prediction through web search activity

- Late diagnosis attributed to vague clinical presentation
- 10-year survival rate for ovarian cancer
  Stage I: 75%, Stage III: 21%, Stage IV: 5%
- Web search activity
  - early-warning to visit a specialist
  - investigate symptom patterns in larger cohorts
- Collaboration with Imperial College London NHS Trust
- Ethics approval, recruiting patients since late 2020
- Data: medical history, web search history



This is an ongoing project that currently involves S. Saso, J. Barcroft, D. Guzman, E. Yom-Tov, I. J. Cox, *and* myself

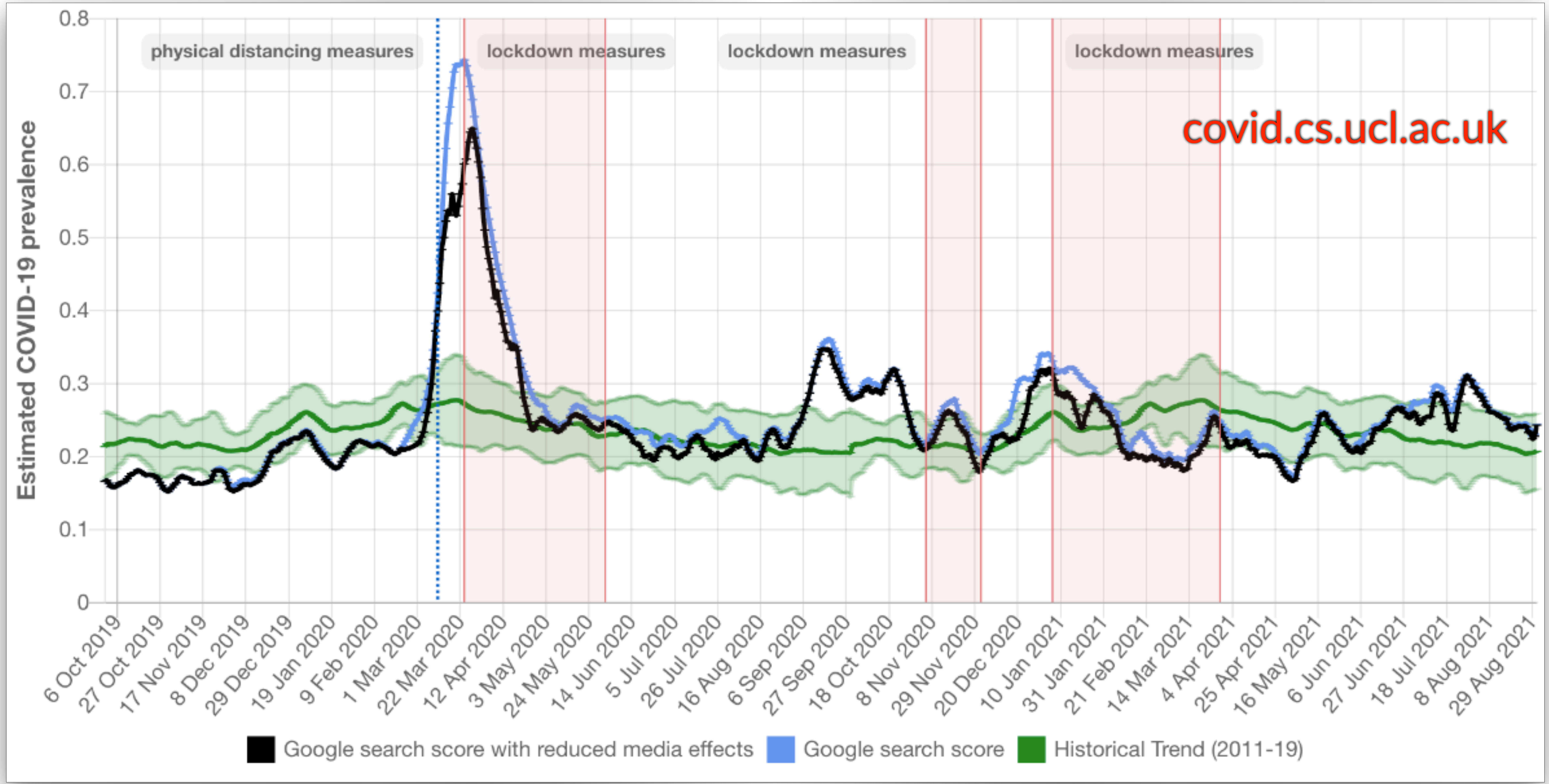
Real-world impact — Flu rate estimates (*England*)



Public Health England

gov.uk/government/statistics/national-flu-and-covid-19-surveillance-reports

Real-world impact — COVID-19 prevalence estimates (*England*)



Public Health England

gov.uk/government/statistics/national-flu-and-covid-19-surveillance-reports-2021-to-2022-season

The future

- ✓ Integrate
- ✓ Evolve
- ✓ Expand
- ✓ Educate
- ✓ Regulate

Acknowledgements

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— Ingemar J. Cox (*UCL*)
— Elad Yom-Tov (*Microsoft Research*)
— Richard Pebody (*WHO*, previously *PHE*)

Collaborators (*in aforementioned research*)
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Data providers
Google, Microsoft, Twitter, Royal College of General Practitioners, Public Health England, Centers for Disease Control and Prevention, NHS patients

Projects / Funding
i-sense (EPSRC), Virus Watch (MRC), Google

?

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