CTIS: The COVID-19 Trends and Impact Survey

Tracking a Pandemic in Real Time

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December 7, 2021

Delphi

- Since 2012, Delphi has developed "the theory and practice of epidemic forecasting, and its role in decision making"
- Led by Roni Rosenfeld and Ryan Tibshirani, with several participating faculty and graduate students
- Participated in annual CDC flu forecasting challenges, won several
- Named an Influenza Forecasting Center of Excellence by the CDC in 2019
- Published open code and data, including numerous influenza surveillance streams
- [I joined in April 2020]

https://delphi.cmu.edu/

Delphi's COVID-19 Response

March 2020 saw a rapid expansion in Delphi and a change in goals

Now, with over 70 members, Delphi develops COVIDcast: data sources, maps, surveys, and code to support researchers, plus COVID forecasting

not everyone! →

Today's Focus

This presentation is the reverse of most applied statistics talks.

1. The COVIDcast project
2. The COVID-19 Trends and Impact Survey (CTIS)
3. Statistical challenges and results
4. All the *other* challenges and results
5. How you can get involved

COVIDcast

Motivation

Imagine yourself in March 2020. How do you help public health officials make decisions when little data is available?

A hierarchy of data types:

1. Deaths – publicly available
2. ICU use – not consistently available
3. Hospitalization – harder to get (EMR, insurance claims...)
4. Case ascertainment – publicly available (lab tests)
5. Outpatient visits – harder to get (EMR, insurance claims...)
6. Symptoms – ???
7. Infections – only via seroprevalence surveys
8. General population – mobility data

We want to fill out the hierarchy of public data.

COVIDcast

The COVIDcast project has many parts:

1. Code and infrastructure to obtain "indicators" daily—each indicator measures some signal relevant to COVID-19
2. Unique relationships with healthcare and tech partners granting us access to indicators
3. A historical database of all indicators, including revision tracking, with >2.3b observations
4. An open API for requesting this data, with R and Python packages for easy access
5. An interactive visualization, built on the API, at delphi.cmu.edu/covidcast/
6. Forecasting and modeling work building on the data and API

COVIDcast Indicators

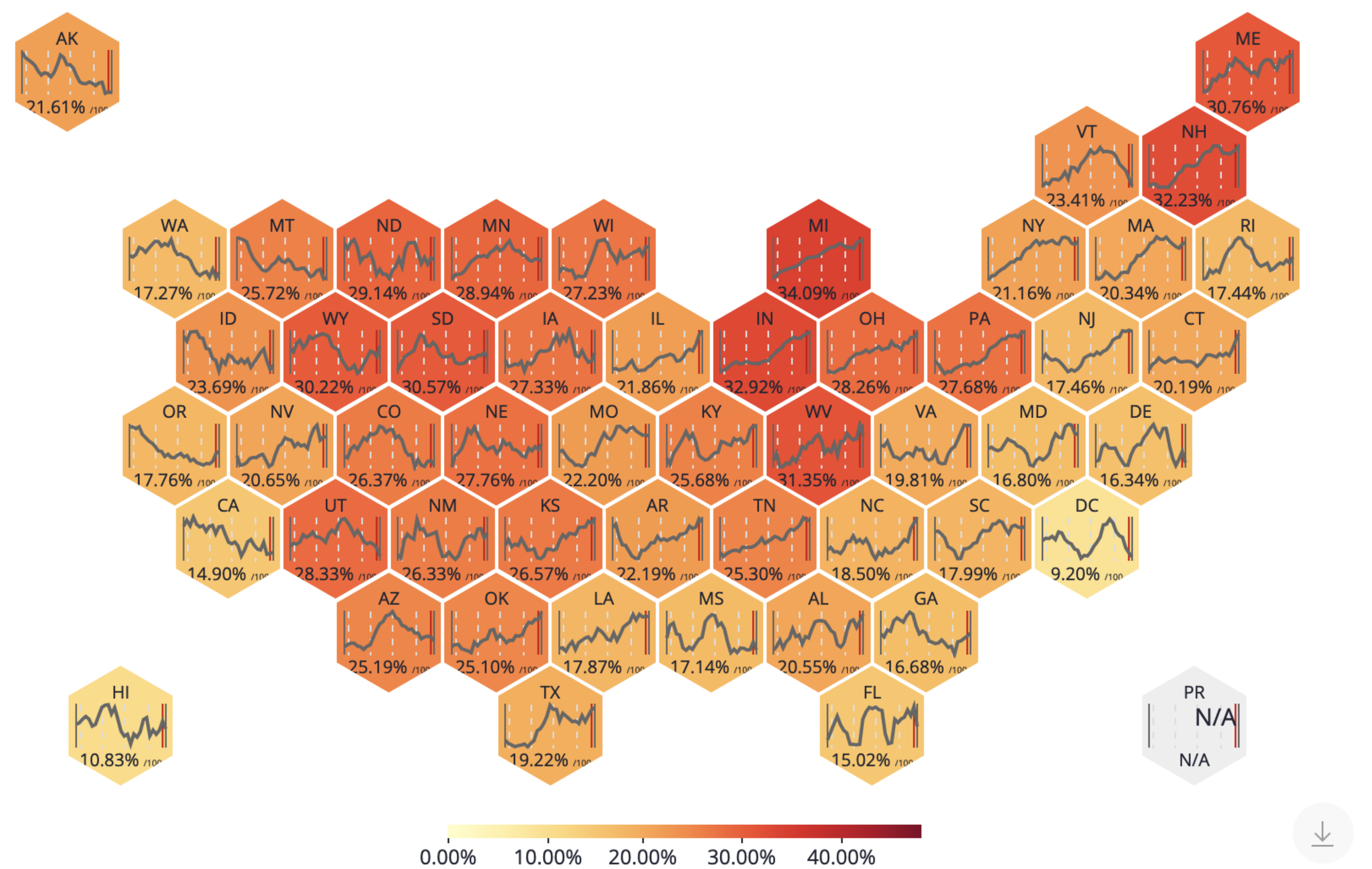
Freely available through the COVIDcast API, updated daily:

1. **Deaths** – from public reports
2. ICU use – not yet
3. **Hospitalization** – from claims data and HHS data
4. **Case ascertainment** – from public reports, Quidel antigen tests, CTIS
5. **Outpatient visits** – from claims data
6. **Symptoms** – from CTIS, Google Search Trends
7. Infections – not yet
8. **General population** – SafeGraph mobility, plus CTIS

Most at the county level!

Full list: https://cmu-delphi.github.io/delphi-epidata/api/covidcast_signals.html

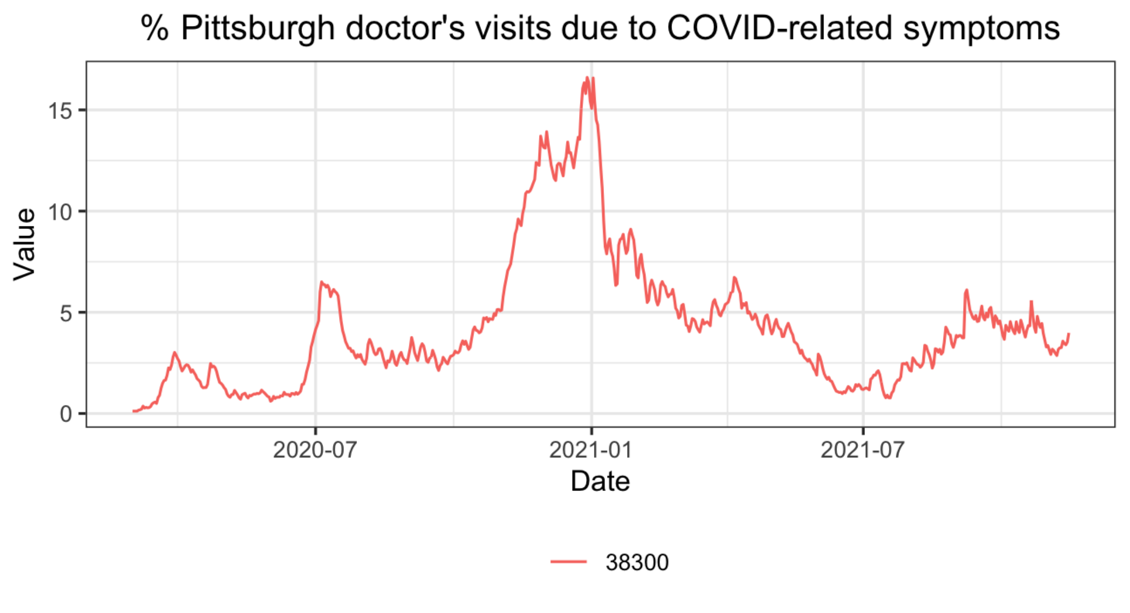
delphi.cmu.edu/covidcast/



COVIDcast API Access

All indicators are freely available through our API:

```r
library(covidcast)
dv_pitt ← covidcast_signal(
  "doctor-visits", "smoothed_adj_cli",
  start_day = "2020-03-01", end_day = "2021-11-15",
  geo_type = "msa", geo_values = name_to_cbsa("Pittsburgh"))
plot(dv_pitt, plot_type = "line") +
  labs(title = "% Pittsburgh doctor's visits due to COVID-related symptoms")
```



Alternate Data Sources

Severity Pyramid

A hierarchy of data types:

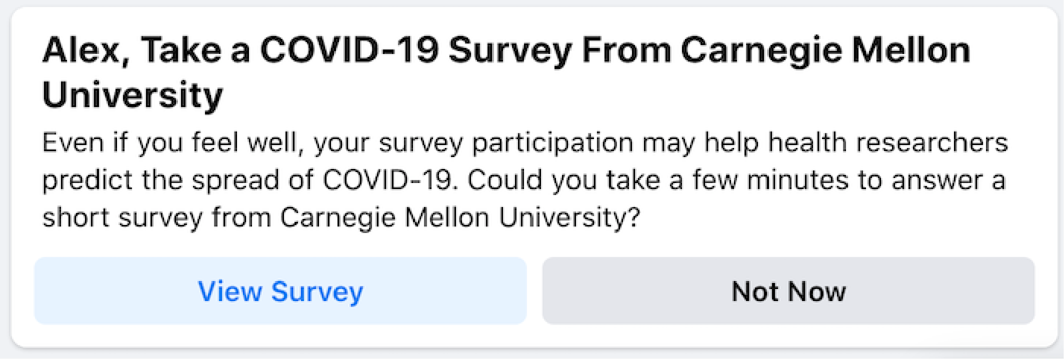
1. Deaths
2. ICU use
3. Hospitalization
4. **Case ascertainment**
5. Outpatient visits
6. **Symptoms**
7. Infections
8. **General population**

CTIS

Through a recruitment partnership with Facebook, Delphi surveys **40,000 people daily** (25 million since April 2020) in the United States about

- symptoms they are currently experiencing
- COVID testing
- COVID vaccination uptake, acceptance, and obstacles
- mask wearing and social distancing
- mental health
- demographics

A parallel effort by the University of Maryland reaches 100+ countries globally.



Alex, Take a COVID-19 Survey From Carnegie Mellon University

Even if you feel well, your survey participation may help health researchers predict the spread of COVID-19. Could you take a few minutes to answer a short survey from Carnegie Mellon University?

CTIS

- Survey implemented on Qualtrics, managed by CMU
- Facebook does **not** receive individual responses
- Designed to take about 10 minutes; about 35 questions
- Questions selected for relevance for forecasting but also for research and public health
- Facebook calculates survey weights designed to demographically match US state age & gender while accounting for non-response bias
- Respondents provide their ZIP code
- Individual response files shared with 60+ research groups

This is the largest non-Census research survey ever conducted (that we know of).

https://delphi.cmu.edu/covid19/ctis/

Details: Salomon, Reinhart, Bilinski, Chua, La Motte-Kerr, Rönn, Reitsma, Morris, LaRocca, Farag, Kreuter, Rosenfeld, and Tibshirani (2021). The U.S. COVID-19 Trends and Impact Survey, 2020-2021: Continuous real-time measurement of COVID-19 symptoms, risks, protective behaviors, testing and vaccination. *Proceedings of the National Academy of Sciences*, in press.

Access to Survey Data

County-level aggregates available in the COVIDcast API:

- COVID vaccine uptake and acceptance; reasons for vaccine hesitancy
- estimated population percentage with COVID-like symptoms
- percentage who know someone who is currently sick
- percentage wearing masks regularly
- working outside home, going to bars and restaurants indoors
- testing rates and test positivity

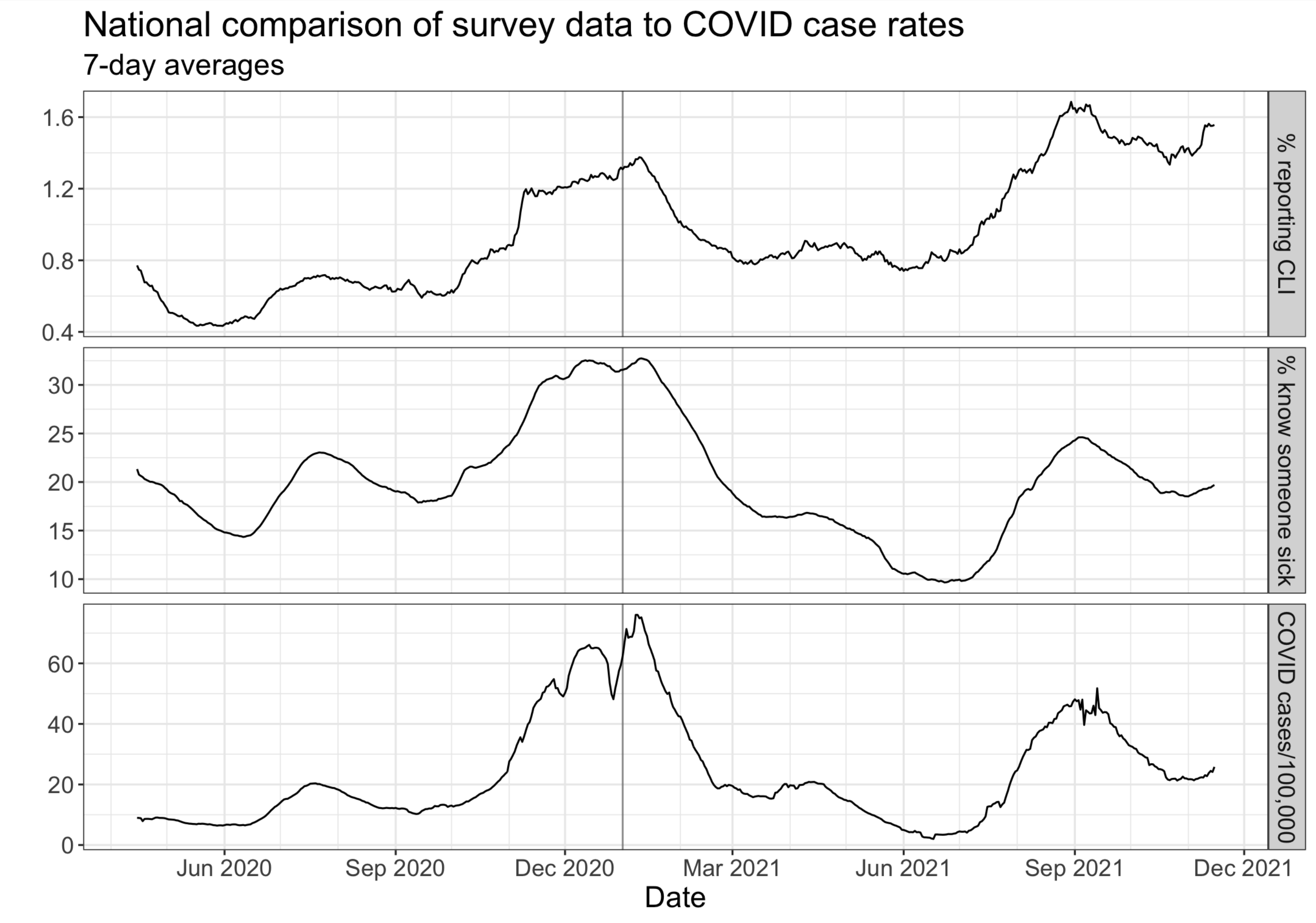
Over 100 signals in total: https://cmu-delphi.github.io/delphi-epidata/api/covidcast-signals/fb-survey.html

Detailed demographic breakdowns also available: https://cmu-delphi.github.io/delphi-epidata/symptom-survey/contingency-tables.html

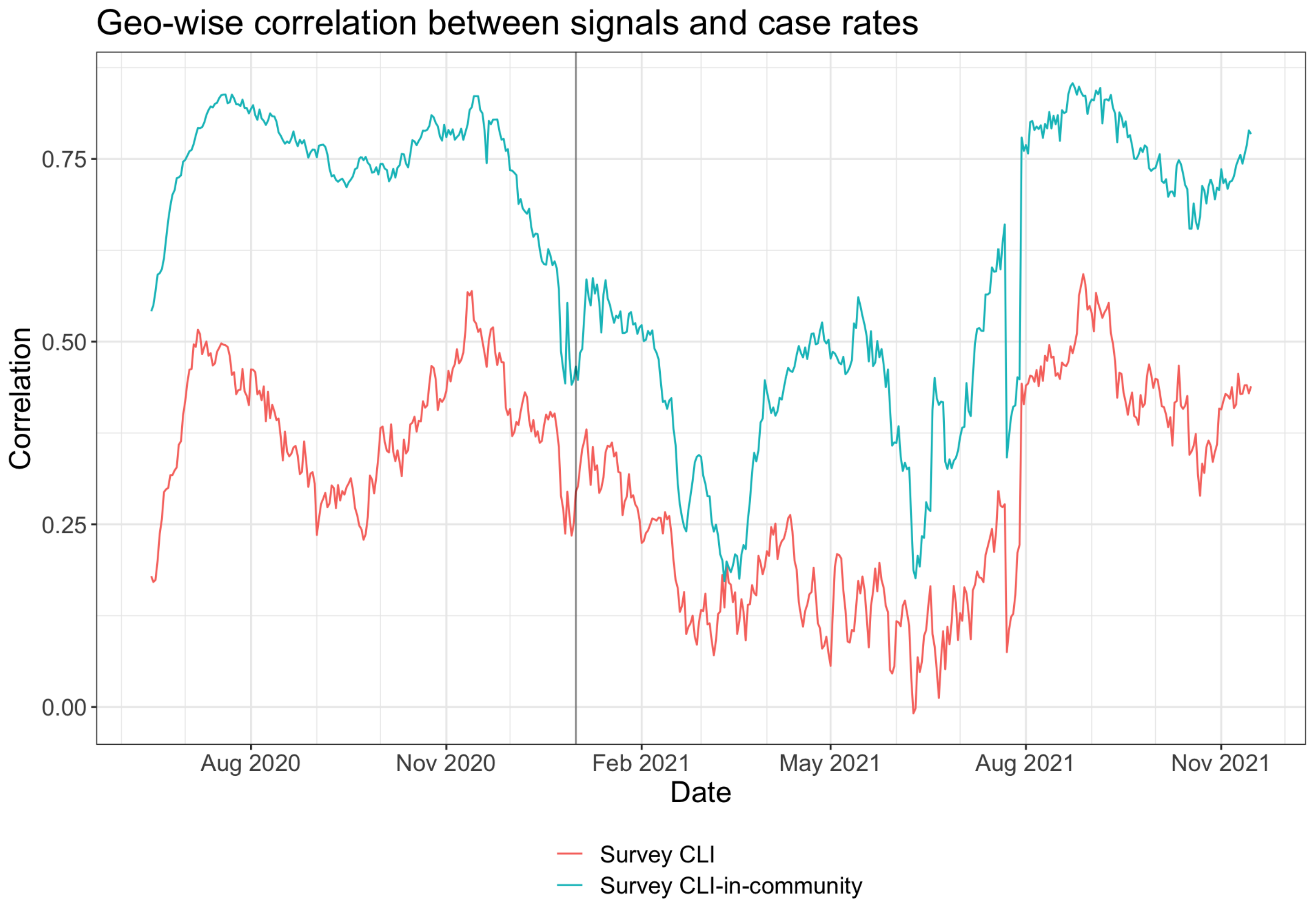
```r
library(covidcast)
d ← covidcast_signal(
  "fb-survey", "smoothed_wwearing_mask_7d",
  "2021-12-01", "2021-12-01",
  geo_values = name_to_cbsa("Philadelphia"),
  geo_type = "msa")
d$value
```

```
## [1] 61.72201
```

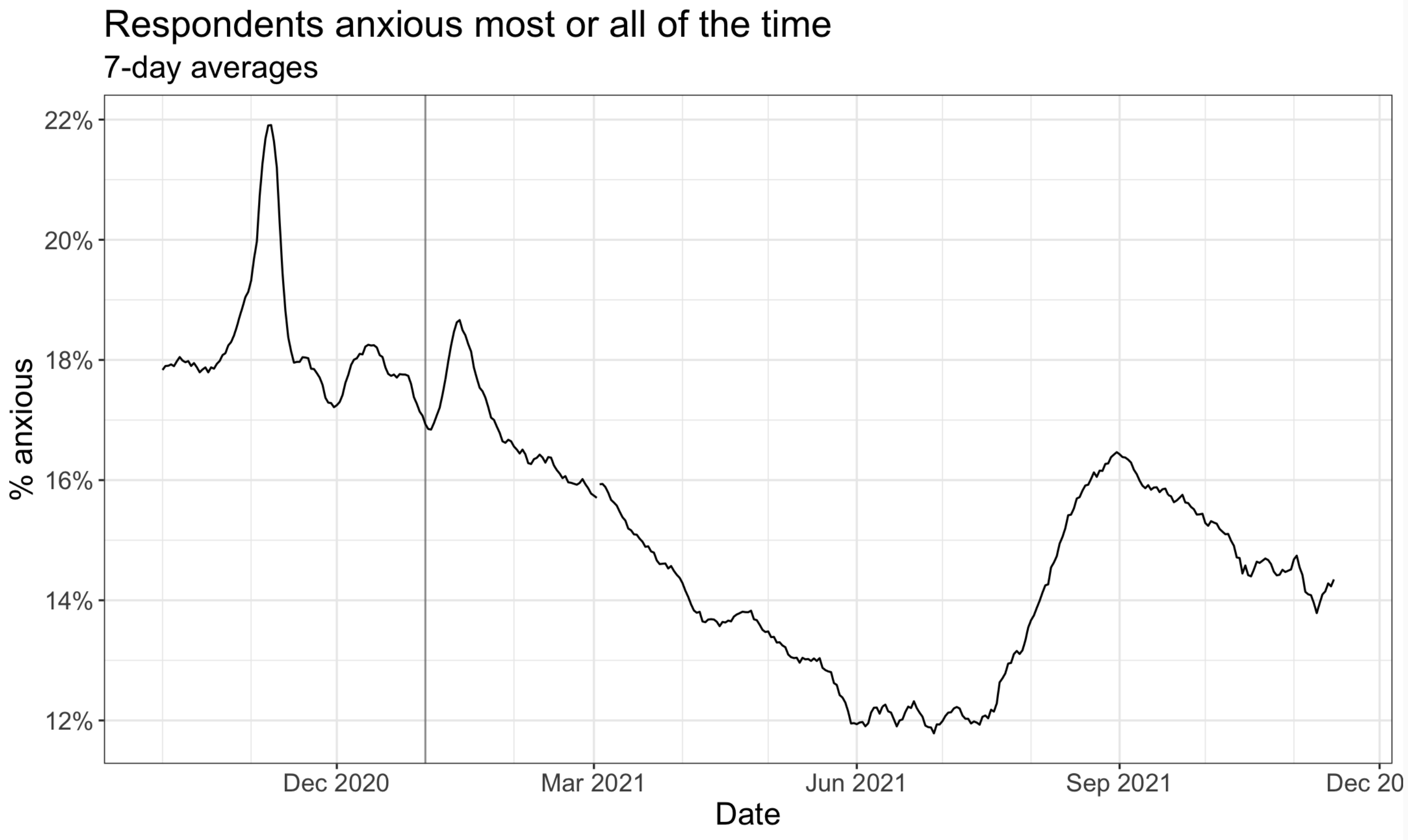
Syndromic Surveillance



Syndromic Surveillance



Not Just Symptoms



Survey Revisions

The survey has gone through 10 versions since April 2020:

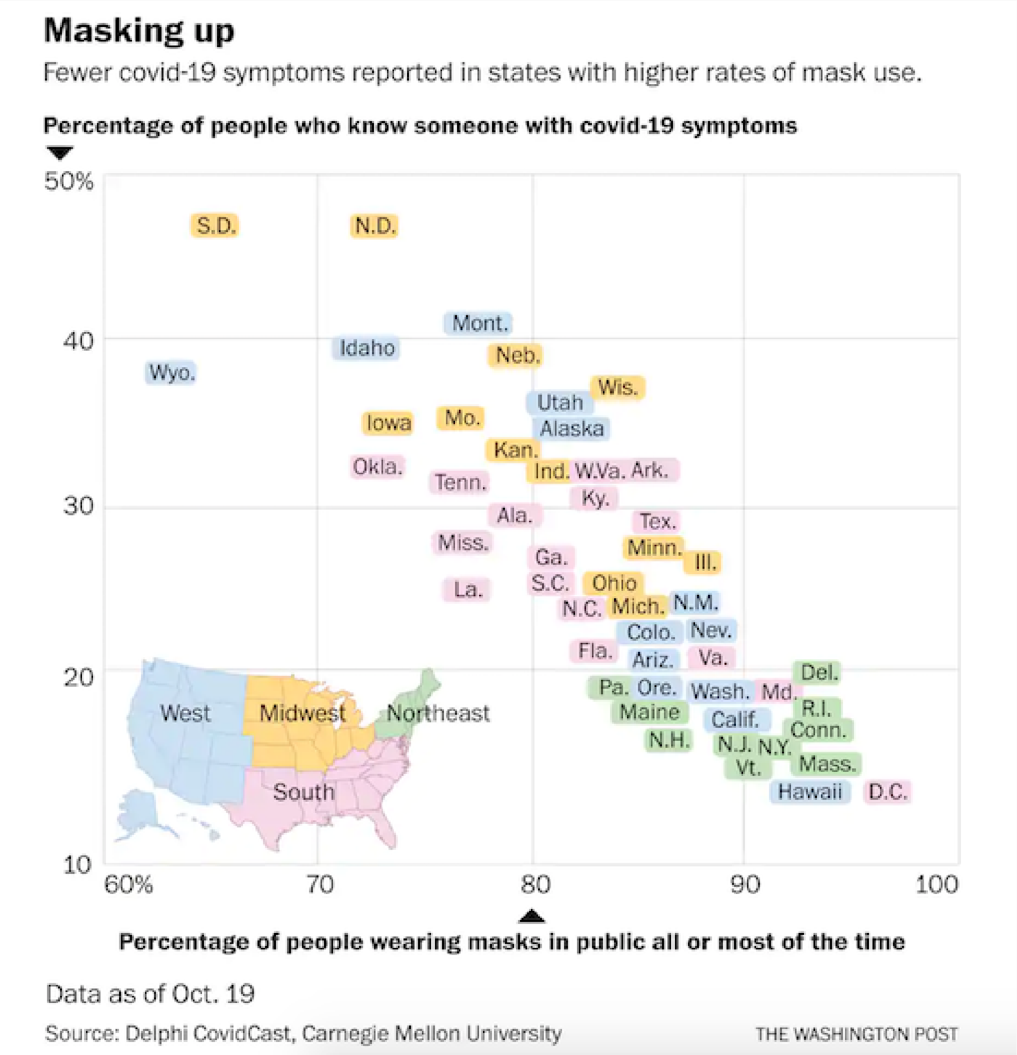
- Added mask-wearing, more social distancing
- New schooling questions
- COVID vaccination questions constantly changing to capture hesitancy and barriers
- New items on knowledge and beliefs about COVID

Revisions require extensive collaboration:

- IHME, White House, CDC, NIOSH, Johns Hopkins, and others have all had input on priorities and item design
- Researchers see this as a free opportunity to get a huge sample size
- ...but even minor changes can cause trend breaks that harm analysis
- Good statistics and survey design sometimes bow to other priorities

Research and Policy Results

Mask-Wearing



Masking up

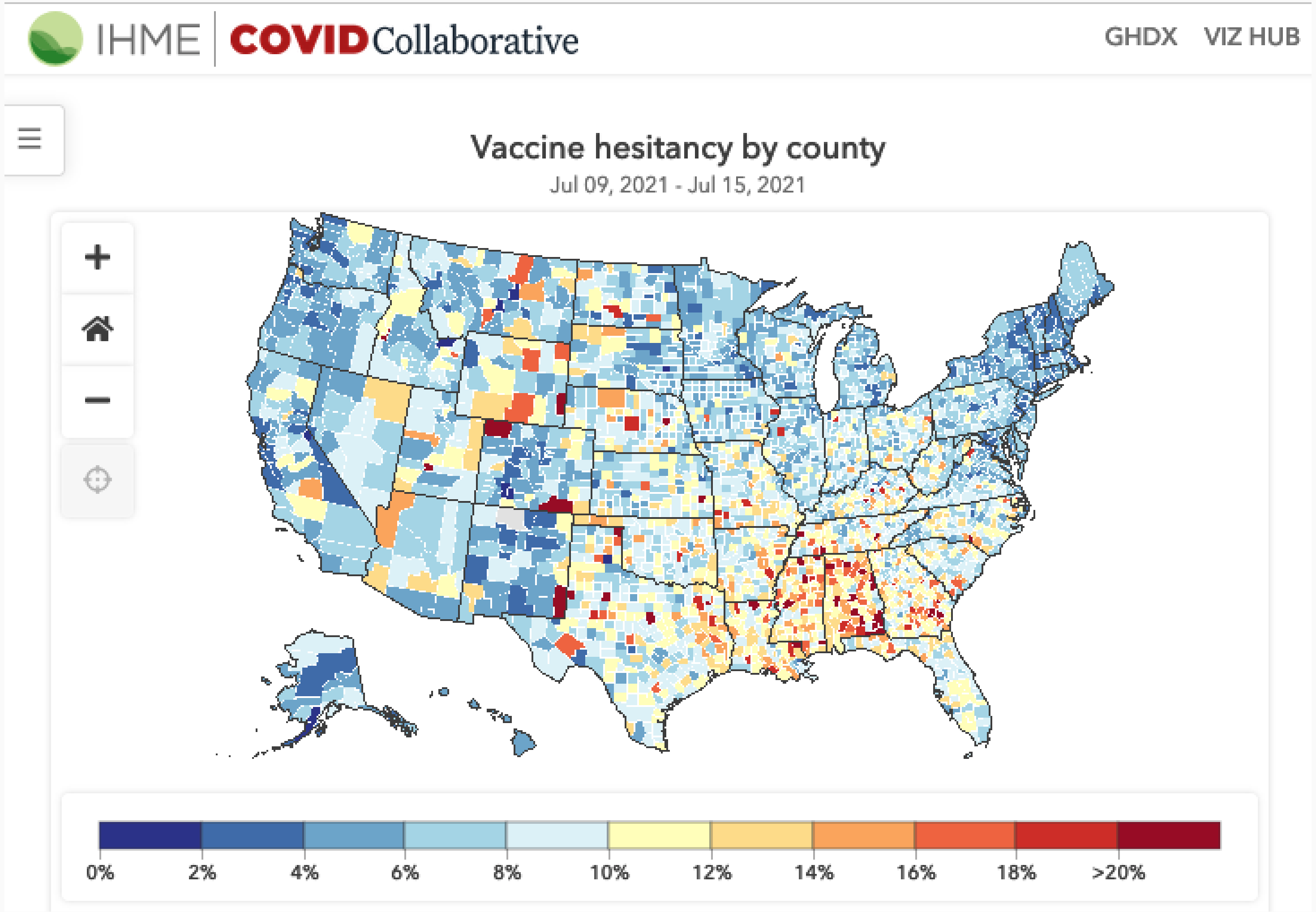
Fewer covid-19 symptoms reported in states with higher rates of mask use.

Data as of Oct. 19

Source: Delphi CovidCast, Carnegie Mellon University

THE WASHINGTON POST

Vaccine Hesitancy



Vaccine hesitancy by county

Jul 09, 2021 - Jul 15, 2021

Research Results

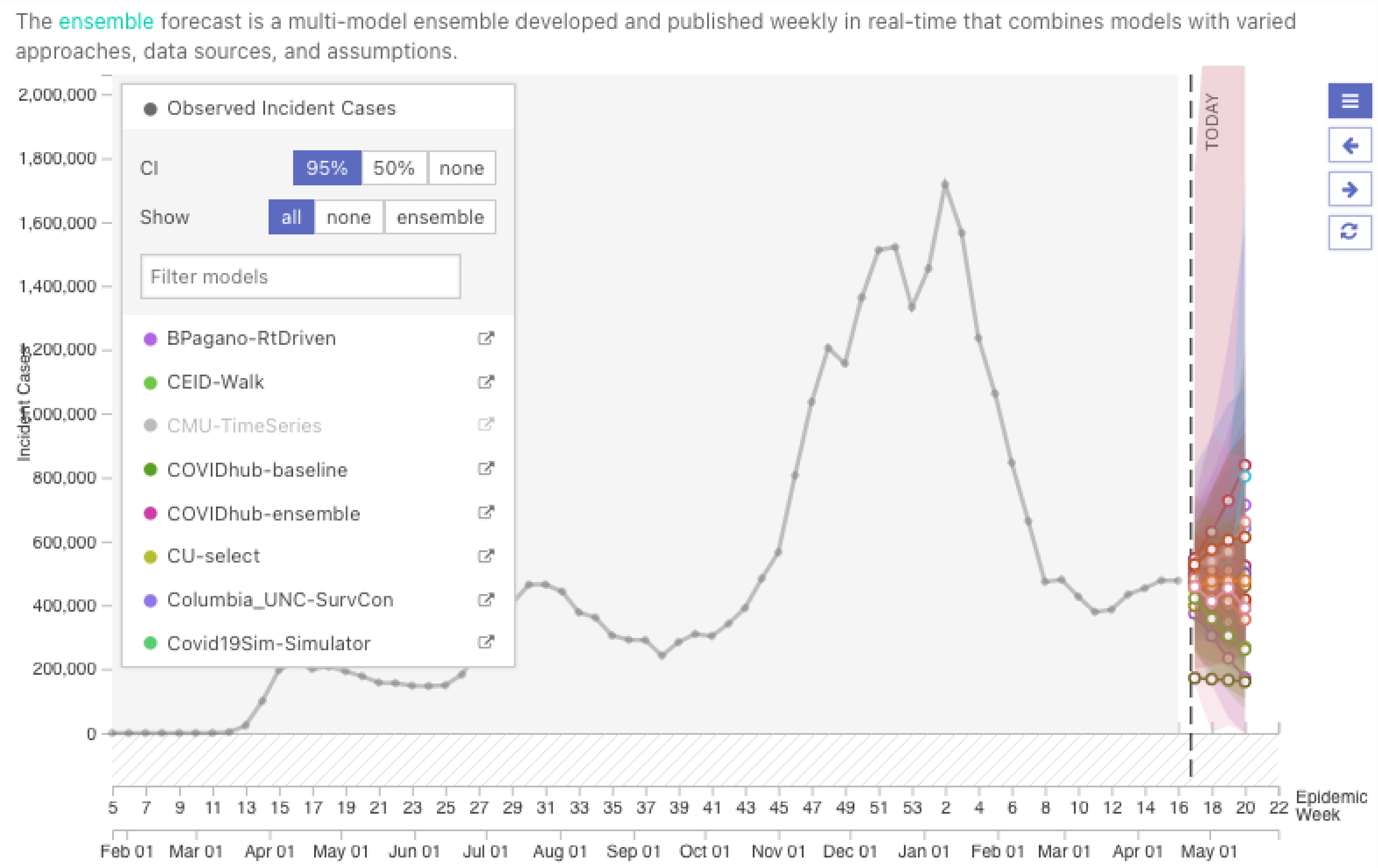
The comprehensive nature of the survey has facilitated many studies outside Delphi:

- Anosmia is the symptom most strongly associated with testing positive for COVID (Sudre et al, 2020)
- People change their behavior in reaction to cases, but possibly too late (Bilinski et al, 2021)
- In-person schooling with sufficient precautions may not be a COVID transmission risk (Lessler et al, 2021)
- Healthcare workers show lower COVID incidence than other occupations (Flaxman et al, 2020)
- Vaccine hesitancy varies widely by occupation (King et al, 2021)

and more.

Forecasting

- The CDC sponsors, though UMass Amherst, the COVID-19 Forecast Hub
- Dozens of teams submit standardized hospitalization, case, and death **distribution** forecasts for counties and states in the US:



The ensemble forecast is a multi-model ensemble developed and published weekly in real-time that combines models with varied approaches, data sources, and assumptions.

CI [✓ 95%] 50% none

Show [✓ all] none ensemble

Forecasting

Prediction is very difficult, ~~especially if it's about the future~~ even if it's about the present.

- Case and death data is reported with variable lag and varied definitions
- States routinely correct data or post batches of backdated cases
- Case ascertainment varies in space and time

Survey data is (mostly) not subject to these problems, and can be a useful covariate.

- Delphi's Forecast Hub submissions incorporate COVID-like illness estimates from the survey
- Georgia Tech's DeepCOVID does as well
- IHME incorporates survey data in their COVID scenario modeling & policy briefings
- Survey symptom data appears to allow forecasting several days farther in advance

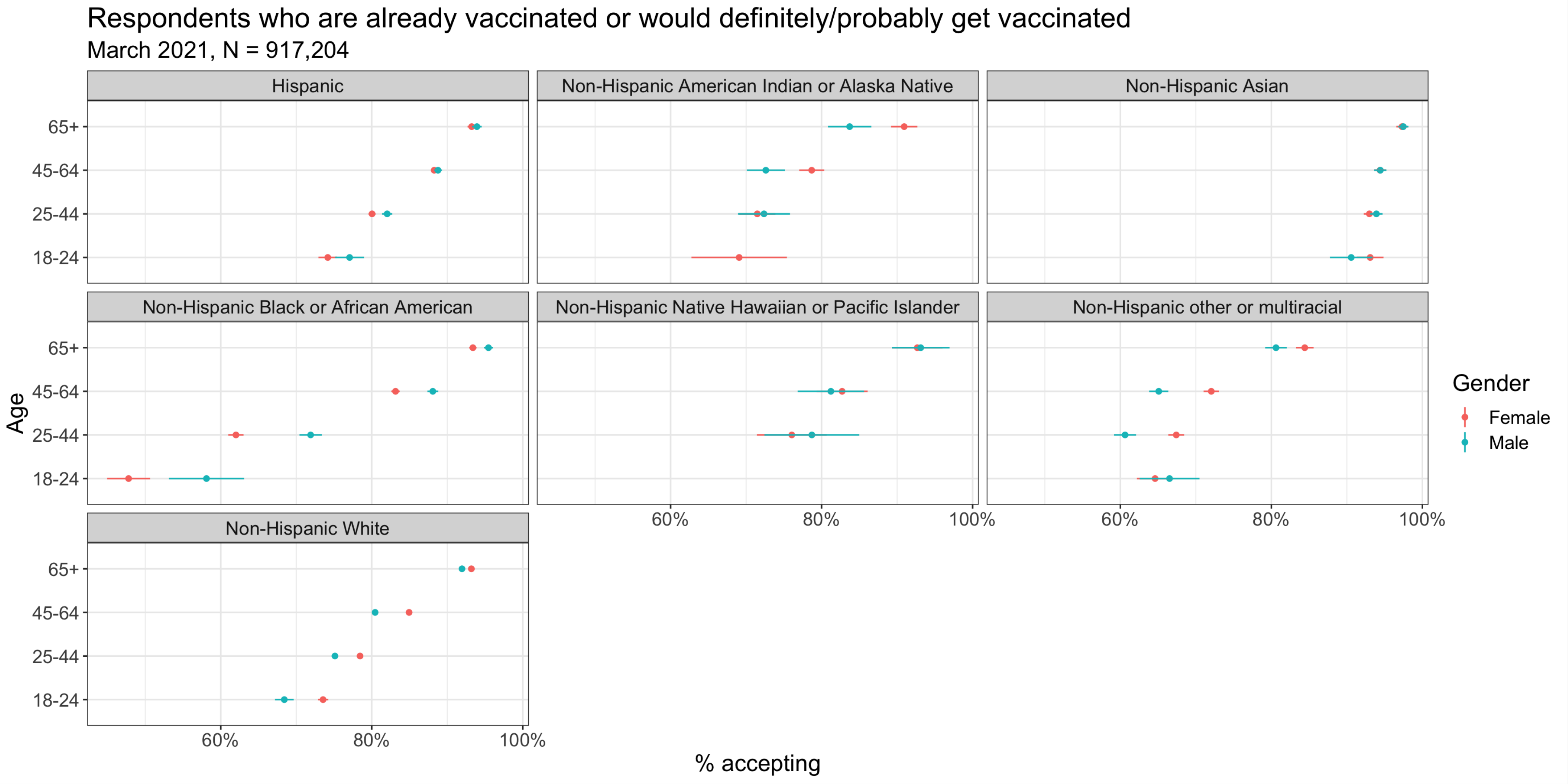
"However, forecasts of cases and hospitalizations showed repeated, sustained lapses in accuracy for longer-term forecasts, especially at key points during some the larger pandemic waves." (Reich et al, 2021)

Statistics and Public Health

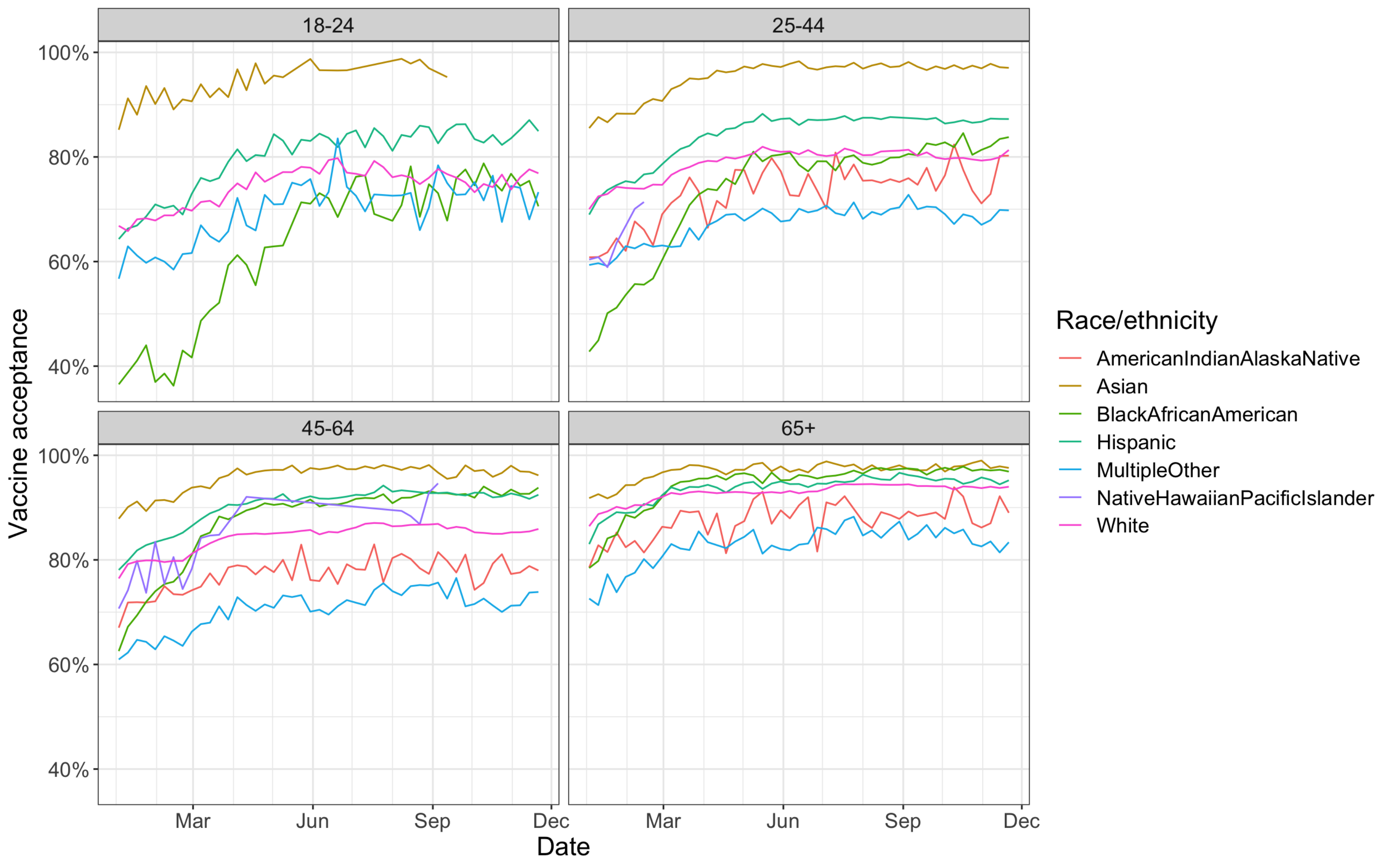
What do Policymakers Need?

- There are numerous interesting statistical problems to solve using this data
  - What symptoms best predict cases? Can we build a symptom-based risk score?
  - Can symptoms and testing data tell us where cases are underreported?
  - Are there combinations of metrics that can predict sudden case increases ("hotspots") a week in advance?
  - Can survey estimates of social behavior and mask use inform epidemic models?
- Public health officials are a little busy.
- They don't need numbers, models, or dashboards; they need *conclusions*
- Common questions:
  - Where should we direct our messaging about the vaccines? What should it say?
  - Are people wearing masks? Should we continue our campaign?
  - How many hospital beds will we need next week?

Tracking Vaccine Acceptance



Vaccine Acceptance Over Time



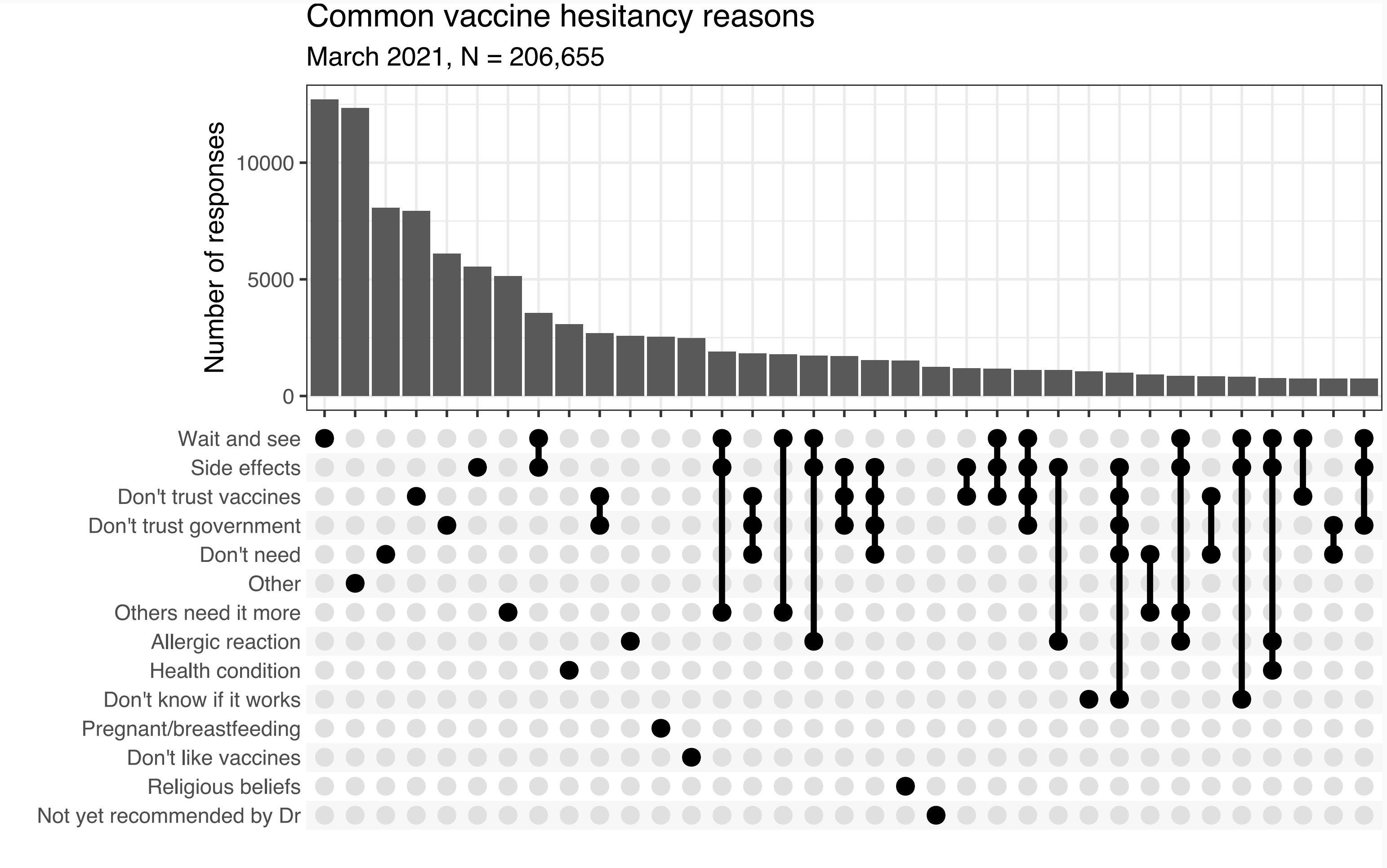
Vaccine Acceptance by Occupation

In November 2021:

Occupation	% accepting	N
Education	92.4	29669
Arts	91.1	10794
SocialService	90.5	13923
HealthcareSupport	89.3	17475
HealthcarePractitioner	89.2	26303
Office	88.9	37820
PersonalCare	82.5	6545
Other	82.3	76254

Occupation	% accepting	N
FoodService	82.1	16410
Sales	80.1	25580
BuildingMaintenance	77.5	6144
Production	74.0	7597
ProtectiveService	73.1	3973
Transportation	71.2	12515
Maintenance	63.9	8651
Construction	58.1	5712

Hesitancy Reasons



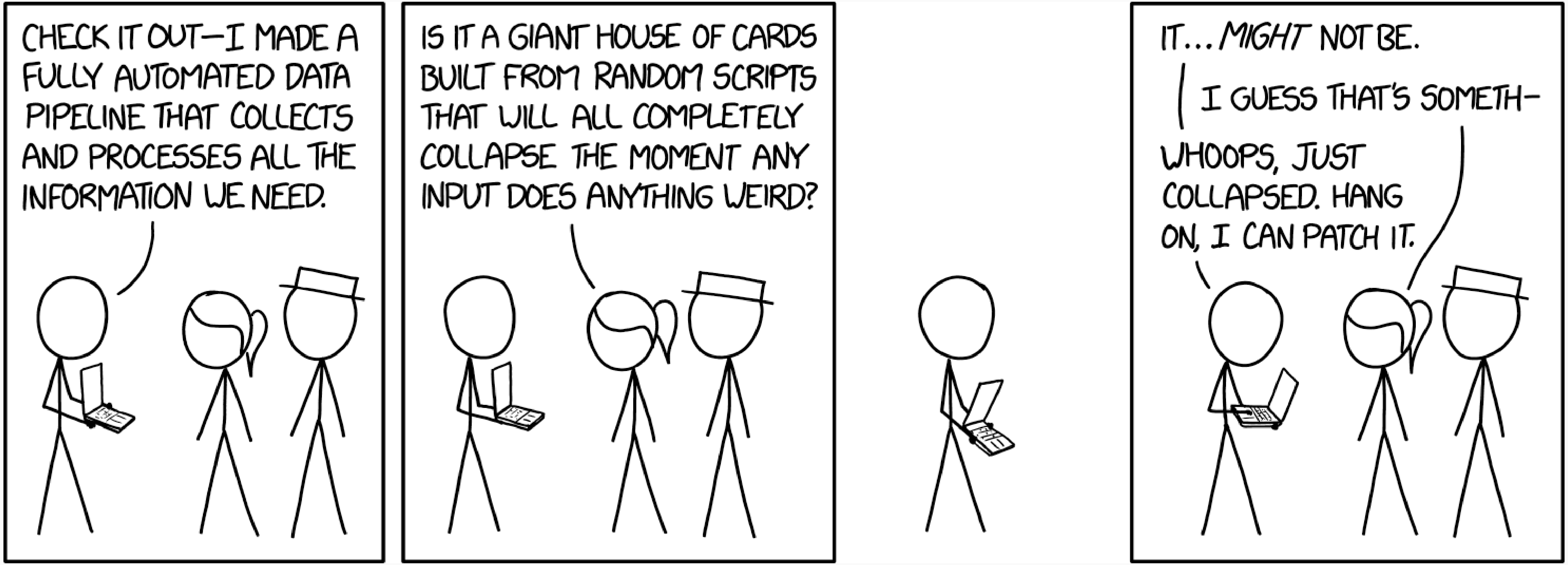
Delivering Results

- Academic publication does not meet the needs of policymakers—at least not for the kinds of localized and specific questions that our data can answer
- But direct engagement with individual agencies requires huge staffing
- ...and many policy questions have *no definite answers*
- Several approaches:
  - Facebook's policy team connects directly with the CDC, which already engages with numerous individual agencies
  - Publishing data directly, with documentation, allows other companies/academics to work with their local agencies
  - Additional staff/consulting helps us deliver data and insight more rapidly

Practicing Statistics in a Pandemic

Software Engineering

- "Statistical computing" usually means "learning R" or "learning MCMC and optimization"
- It almost **never** means "building automated systems with backups, logging, and alerting" or "deploying code automatically on merge" or...

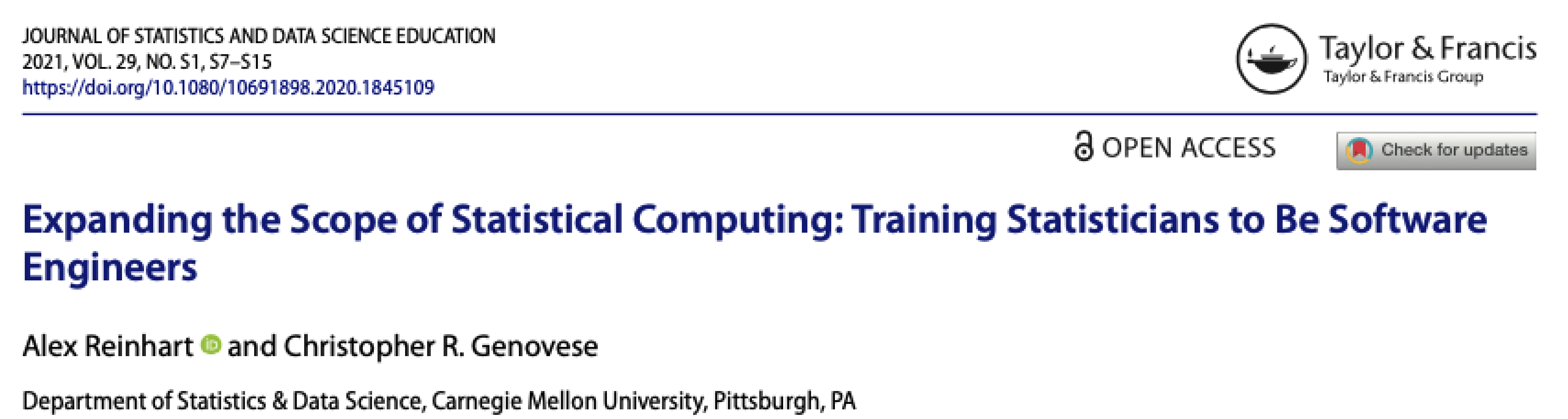

CHECK IT OUT—I MADE A FULLY AUTOMATED DATA PIPELINE THAT COLLECTS AND PROCESSES ALL THE INFORMATION WE NEED.
IS IT A GIANT HOUSE OF CARDS BUILT FROM RANDOM SCRIPTS THAT WILL ALL COMPLETELY COLLAPSE THE MOMENT ANY INPUT DOES ANYTHING WEIRD?
IT... *MIGHT* NOT BE.
I GUESS THAT'S SOMETH–
WHOOPS, JUST COLLAPSED. HANG ON, I CAN PATCH IT.

xkcd #2054

Software Engineering

- Delphi was fortunate to poach skilled technical staff to help manage these processes
- …and to borrow 13 engineers, designers, and managers from Google.org
- Nonetheless, the survey pipeline was a challenge:
    - Just enough statistical detail to require careful review (weights, importance sampling)
    - Data volume meant that naive approaches could take more than 24 hours to calculate each day's aggregates
    - Survey is an airplane built in flight—so maintainability is key
    - Over 6,000 lines of code to build our data products
    - The naive way (giant R script full of dplyr operations) is a route to madness

Software Engineering



JOURNAL OF STATISTICS AND DATA SCIENCE EDUCATION
2021, VOL. 29, NO. S1, S7–S15
https://doi.org/10.1080/10691898.2020.1845109

Expanding the Scope of Statistical Computing: Training Statisticians to Be Software Engineers

Alex Reinhart and Christopher R. Genovese

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- Statisticians & data scientists are now often asked to make *products*, not analyses
- Working as a "data engineer" is much different than working on a data analysis report
- What we're doing isn't too different from what data scientists do in industry all day
- But software engineers are trained to do it and we aren't. Courses need:
    - Realistic long-term projects
    - Topics like unit testing, version control, and software design
    - Basics of algorithms and data structures

Wrapping Up

What a Weird Year

- Surveys on social media can be a surprisingly good tool to track a pandemic
- But delivering them presents numerous challenges:
    - How do you design a practical survey for such a wide audience?
    - How do you rapidly process the data?
    - How do you deliver useful insights fast enough for them to get used?
- Not every interesting statistical question is a *useful* statistical question
- We weren't trained for any of this, so everything had to happen on the fly

(I had never designed or run a survey before July 2020!)

Access to Survey Microdata

Want to study a problem that can be answered with 25 million US survey responses since April 2020? Possible topics:

- Reasons for vaccine hesitancy among specific demographic groups
- Symptoms reported by people testing positive, stratified by chronic conditions, age, etc.
- Test rates and availability by employment and occupation
- Mental health impacts of interventions
- Disparate impacts on minorities and disadvantaged groups
- …anything you can think of

Raw response data is freely available to researchers who can sign DUAs to protect confidentiality of responses.

We're building a network of academic and non-profit researchers to learn from the survey.

https://cmu-delphi.github.io/delphi-epidata/symptom-survey/

Thank you

Thank you all for attending, and many thanks to

- the entire Delphi team
- CMU Legal, Sponsored Programs, Communications, IT, and numerous staff
- Facebook, Google, and Amazon Web Services
- Quidel
- Change Healthcare
- Qualtrics
- Centers for Disease Control and Prevention

Contact: https://delphi.cmu.edu, areinhar@stat.cmu.edu