Airline network evolution and the acceleration of pandemic spread



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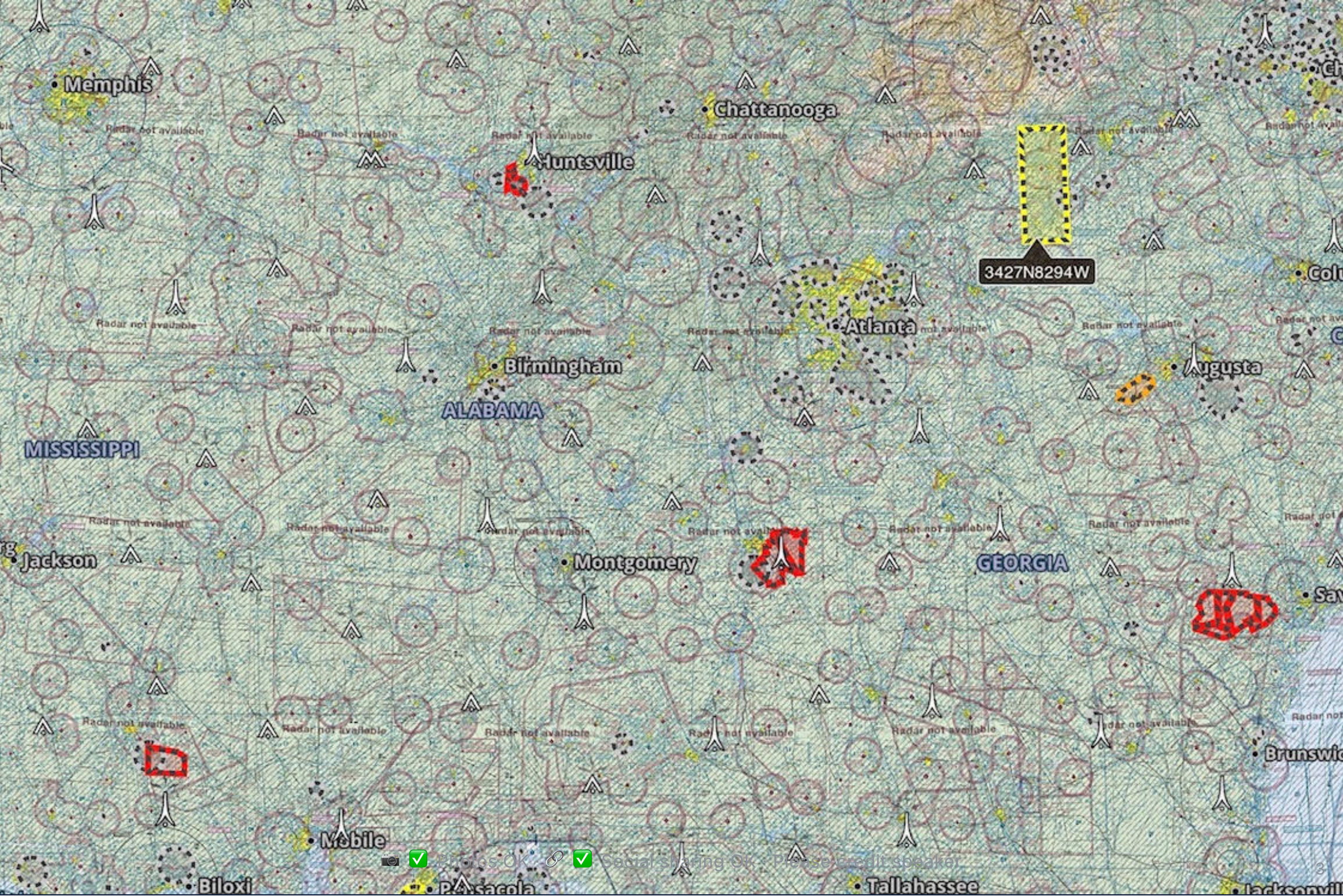
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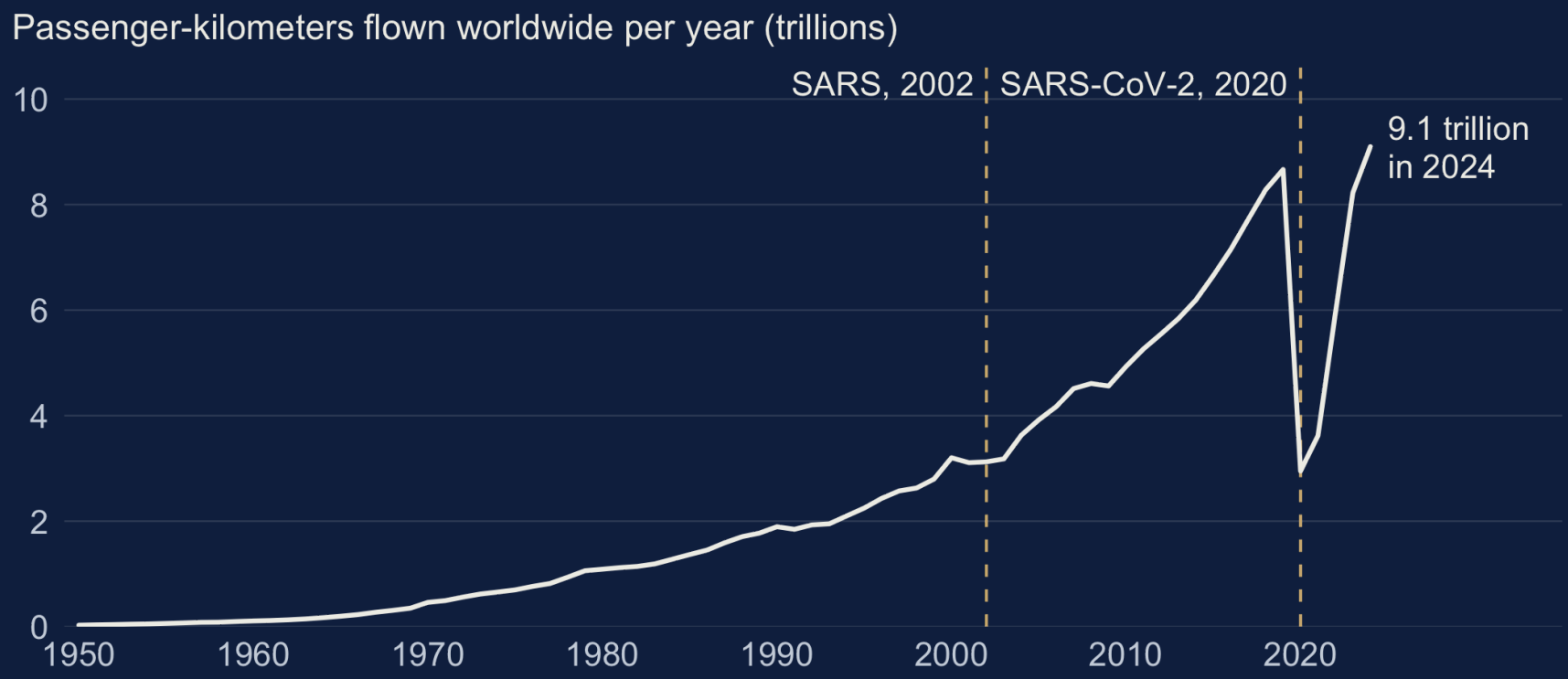


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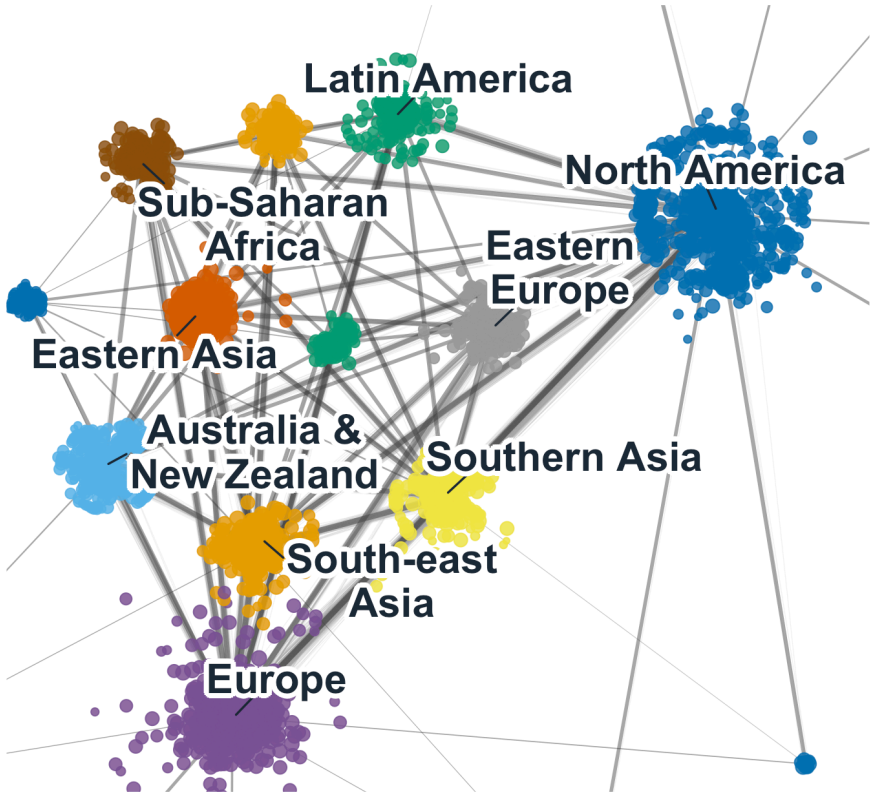
How has this new technology, and the way it has changed the behavior of an already highly mobile, social species, affected the spread of its infectious diseases?



Passenger traffic grew about 325-fold from 1950 to 2024. Data: ICAO via Airlines for America, processed by Our World in Data.

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The airline network is a few dense regional clusters joined by heavy trunk routes

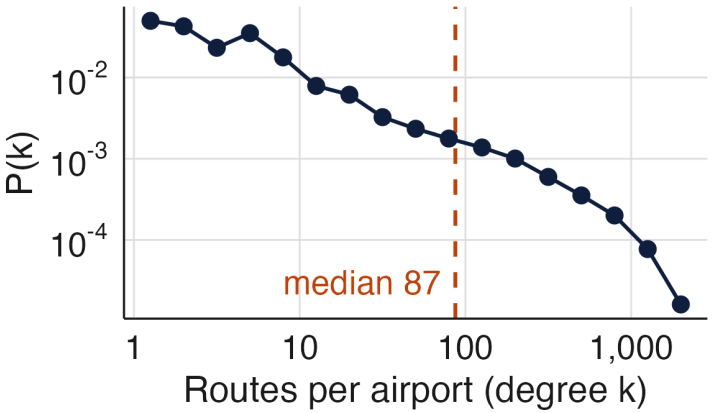


2023 network, February to December: 4,031 airports.

Louvain community detection: 23 communities ($Q = 0.70$), each colored by its dominant region.

Connectance 0.062.

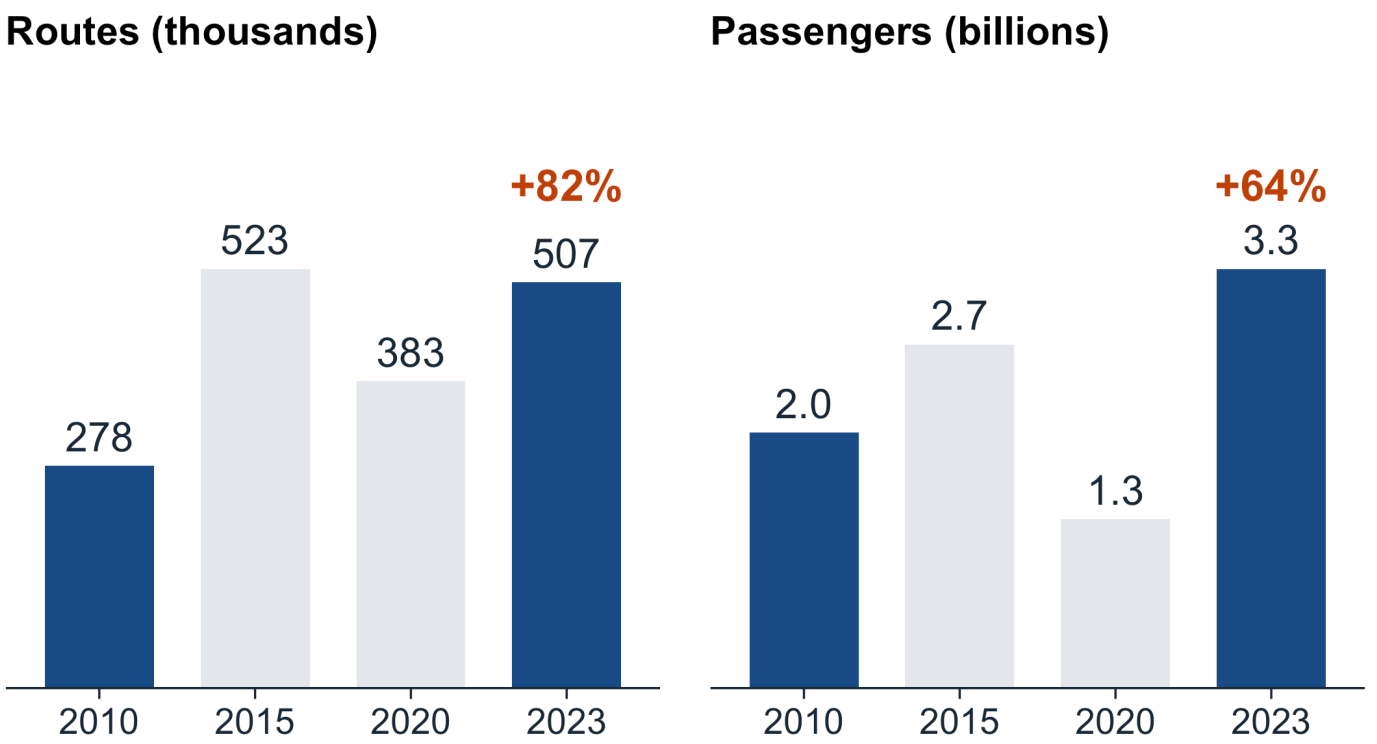
Mean path length 2.35 hops.



Airports sit close together when much traffic flows between them, so position shows connection, not geography.
Data: Official Airline Guide (OAG).

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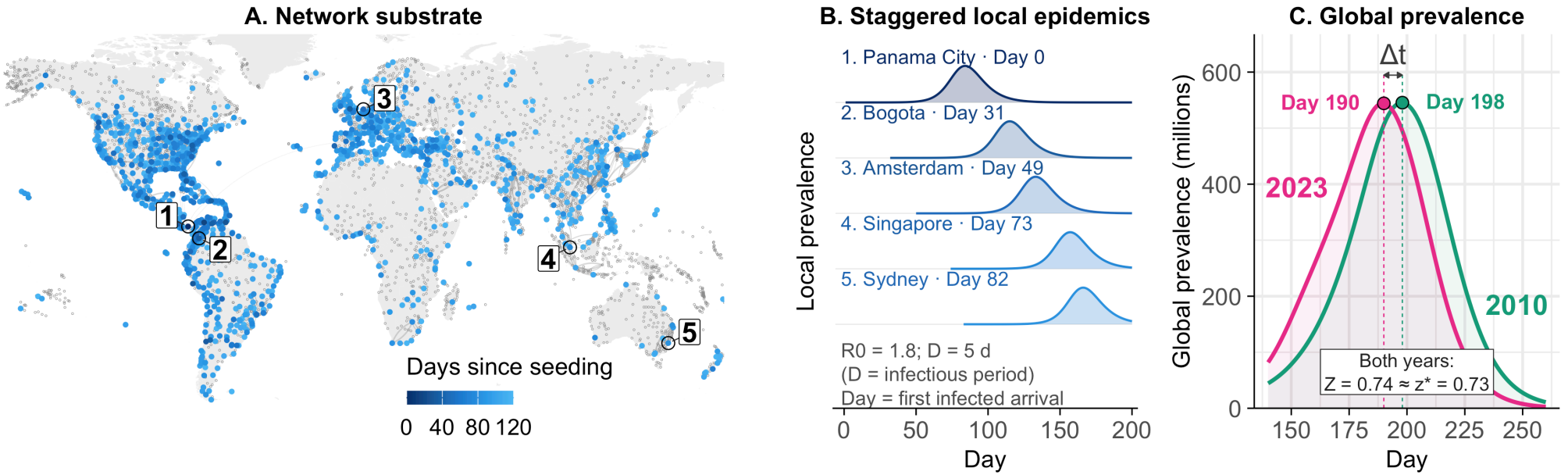
Between 2010 and 2023 the network added 82% more routes and 64% more passengers



Routes and passengers both rose between 2010 and 2023, with the 2020 collapse between the 2015 high and the recovery.
Data: Official Airline Guide (OAG).

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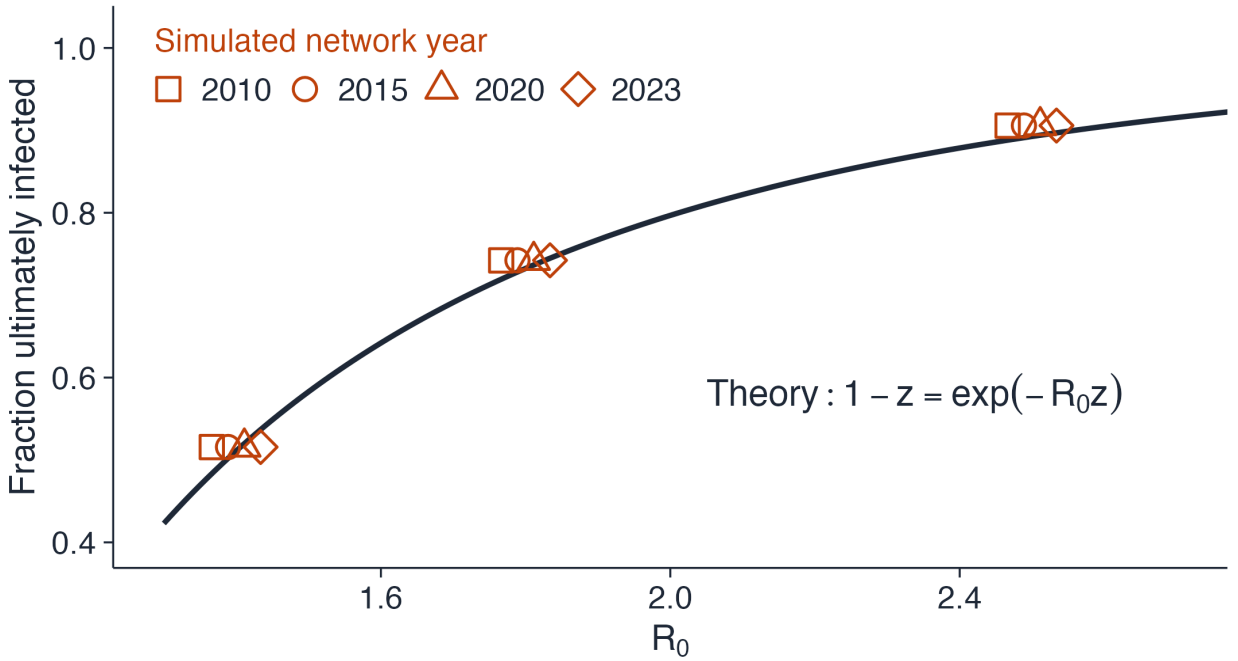
We model a pandemic as stochastically, weakly coupled local epidemics



Stochastic seeding. Each airport runs its own deterministic epidemic. Daily infectious traveler movement proportional to prevalence and edge weight.

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Effects of R_0 and network year on final pandemic size



$$Z = \frac{\sum_{i \in \text{infected}} N_i z_i}{\sum_i N_i} \approx z^*$$

The upper sum runs only over the locations infected. The lower sum runs over all locations.

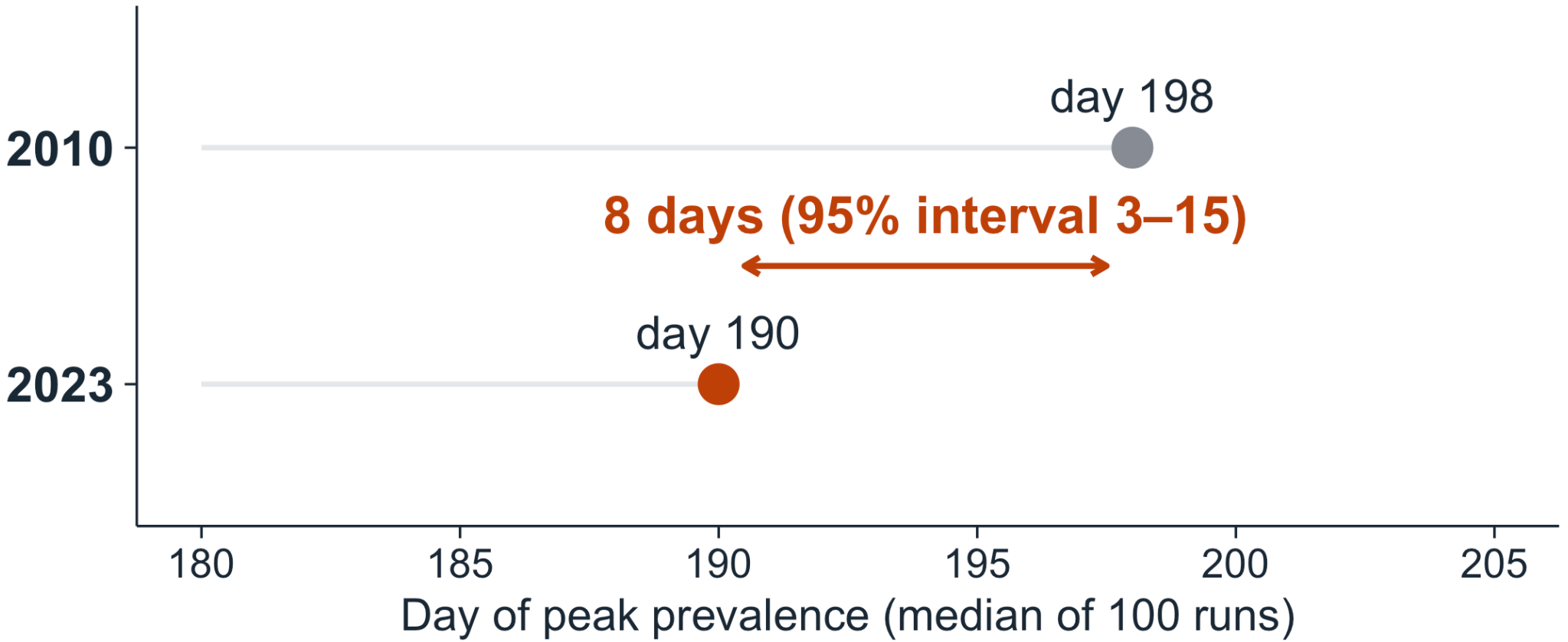
N_i is the population of catchment i, and z_i is its local final size.

$Z \approx z^*$ when nearly all people live in infected locations.

Pandemic size Z lies close to z^*, the Kermack–McKendrick value, for all four network years, so in this model R_0 alone sets how many people are infected.

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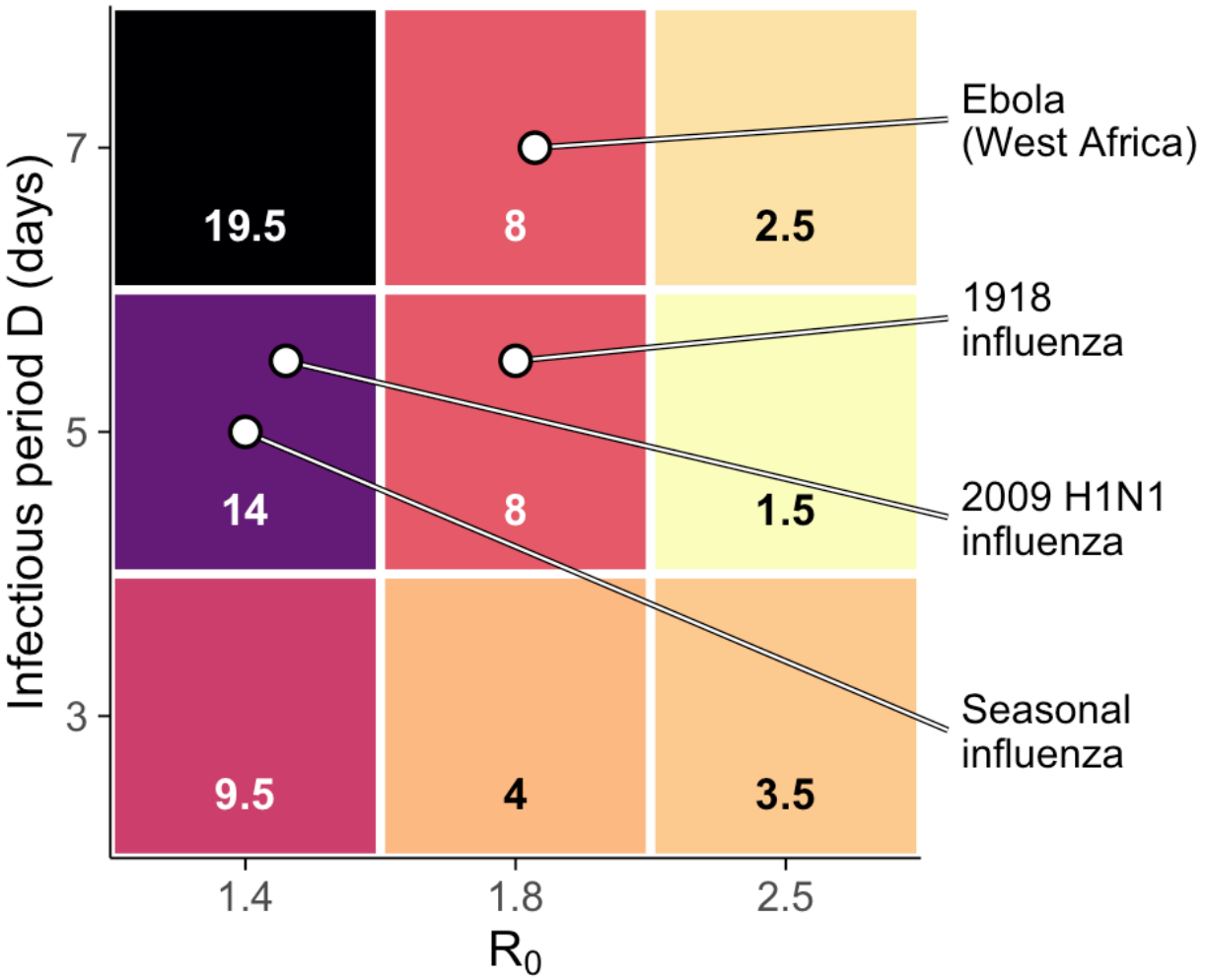
2023 network peaks about a week before the 2010 network

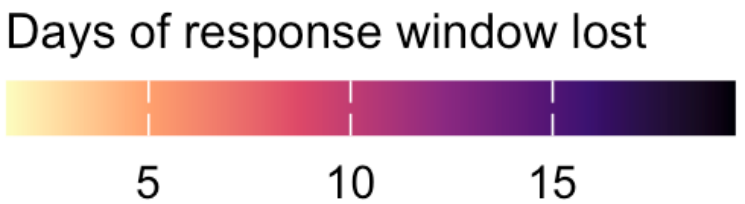


At R_0 = 1.8 and a five-day infectious period, the median peak falls on day 190 in 2023 and day 198 in 2010.

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The acceleration is largest at low R_0 and long infectious periods





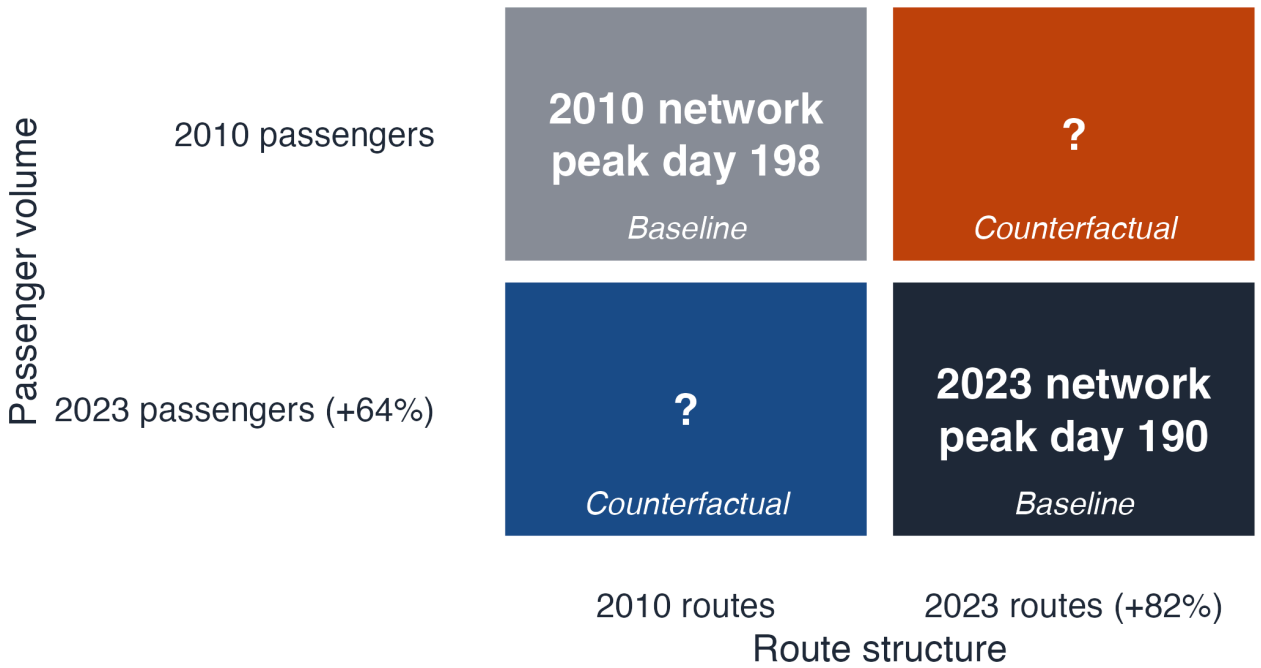
Days lost between the 2010 and 2023 networks range from 1.5 at high R_0 to 19.5 at low R_0 with a long infectious period. White dots mark real pathogens.

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Does route structure or passenger volume govern pandemic spread?

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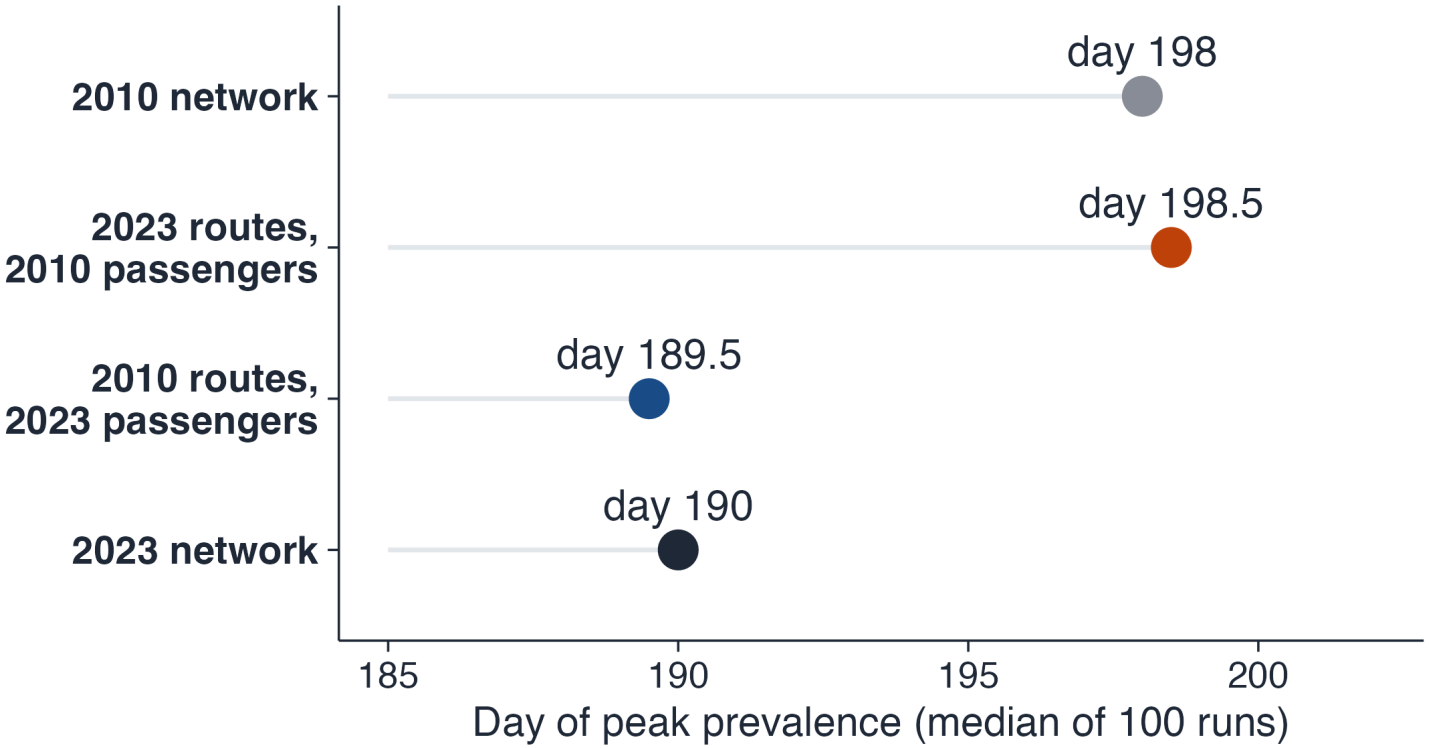
We swapped routes and passengers between years to separate them



Each counterfactual pairs one year's routes with the other year's passenger volume.

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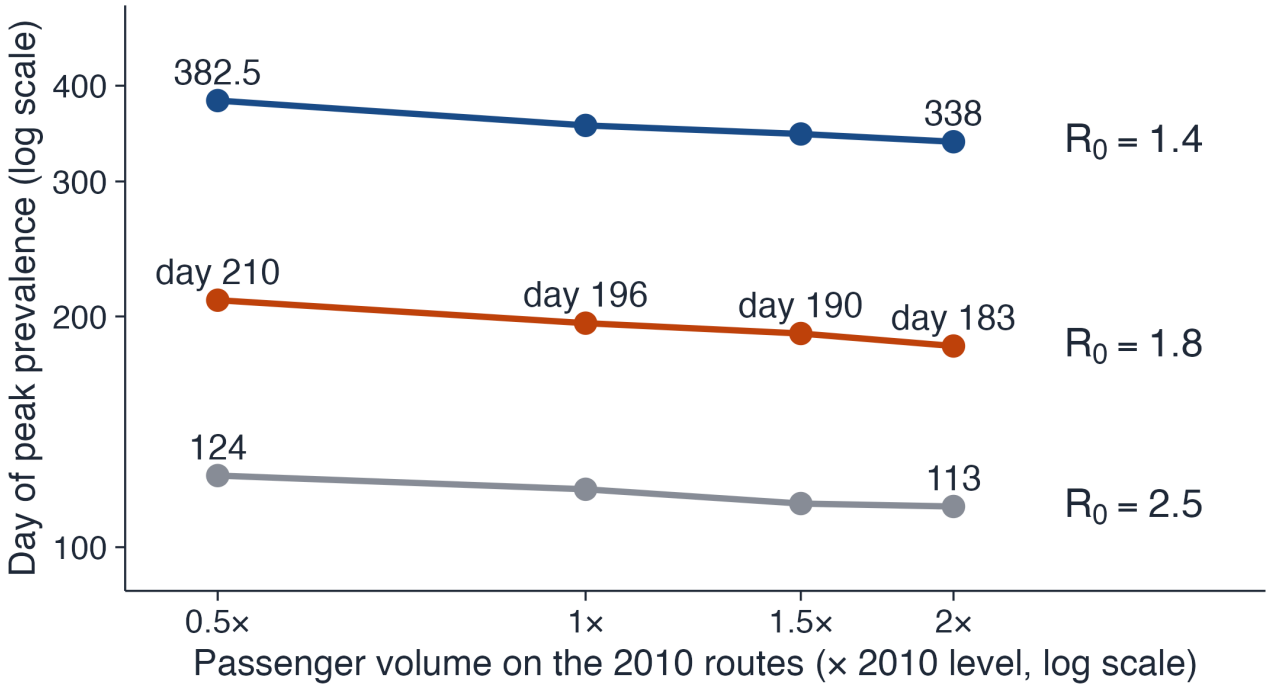
Passengers explain peak timing, not route geometry



Each counterfactual peaks beside the real network with the same passenger volume, not the one with the same routes (R_0 = 1.8, five-day infectious period).

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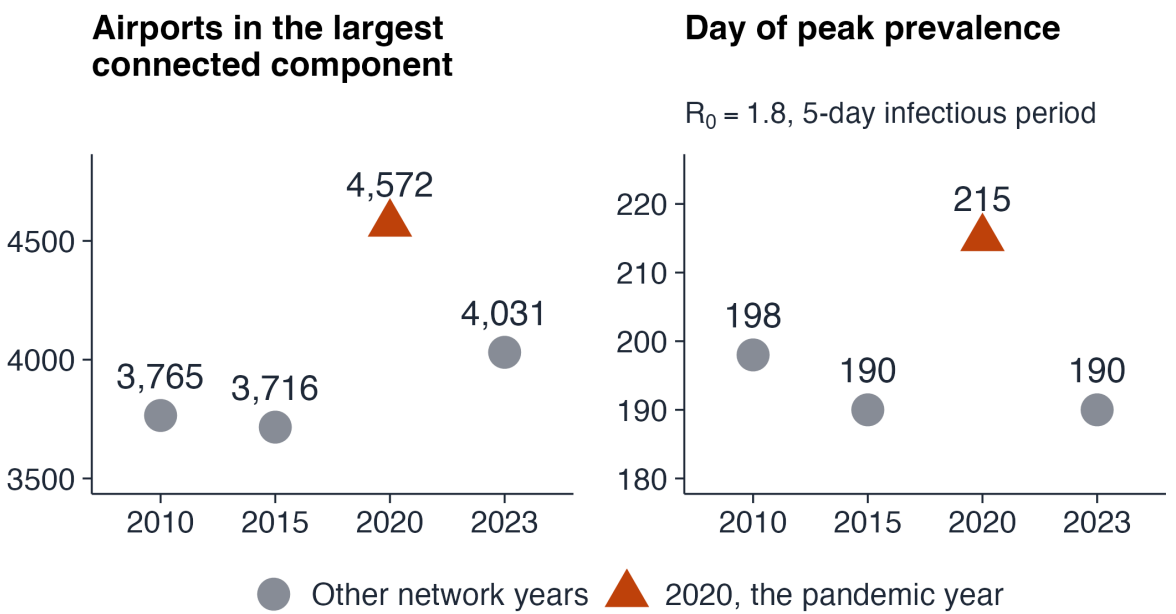
Each doubling of passengers brings the peak forward by about 6%



On the fixed 2010 routes, across all nine settings of R_0 and infectious period, each doubling brings the peak forward by 4.8% to 6.5%. For a notional novel influenza (R_0 = 1.8, five-day infectious period), that is about two weeks. Plotted: five-day infectious period.

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2020 connected the most airports and had the slowest pandemic



The 2020 network connected the most airports, yet its pandemic peaked on day 215, against days 190 to 198 in the other years (medians of 100 runs).

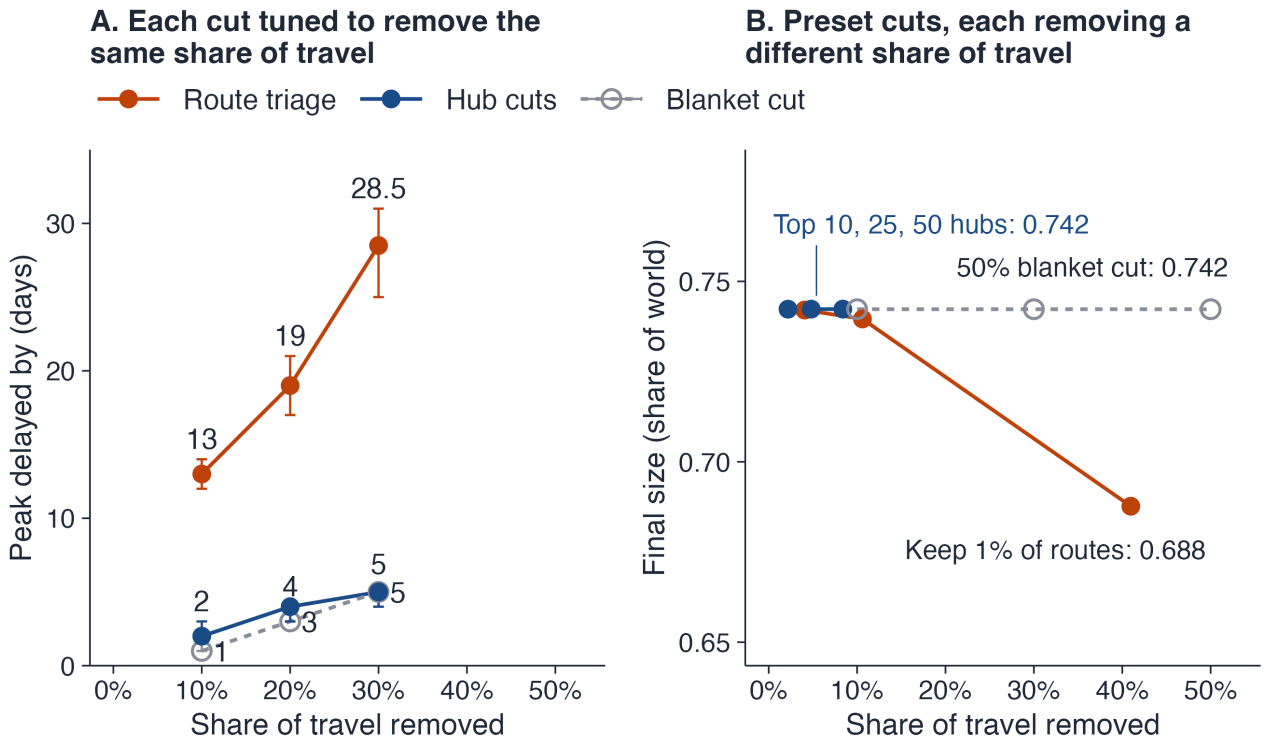
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Can we slow it down?

Three ways to cut the network

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Route triage delays the peak most per passenger removed



Route triage keeps only the highest-volume routes.

Hub cuts reduce outbound trips by 30% at the airports with the most departures. Connecting passengers are not cut.

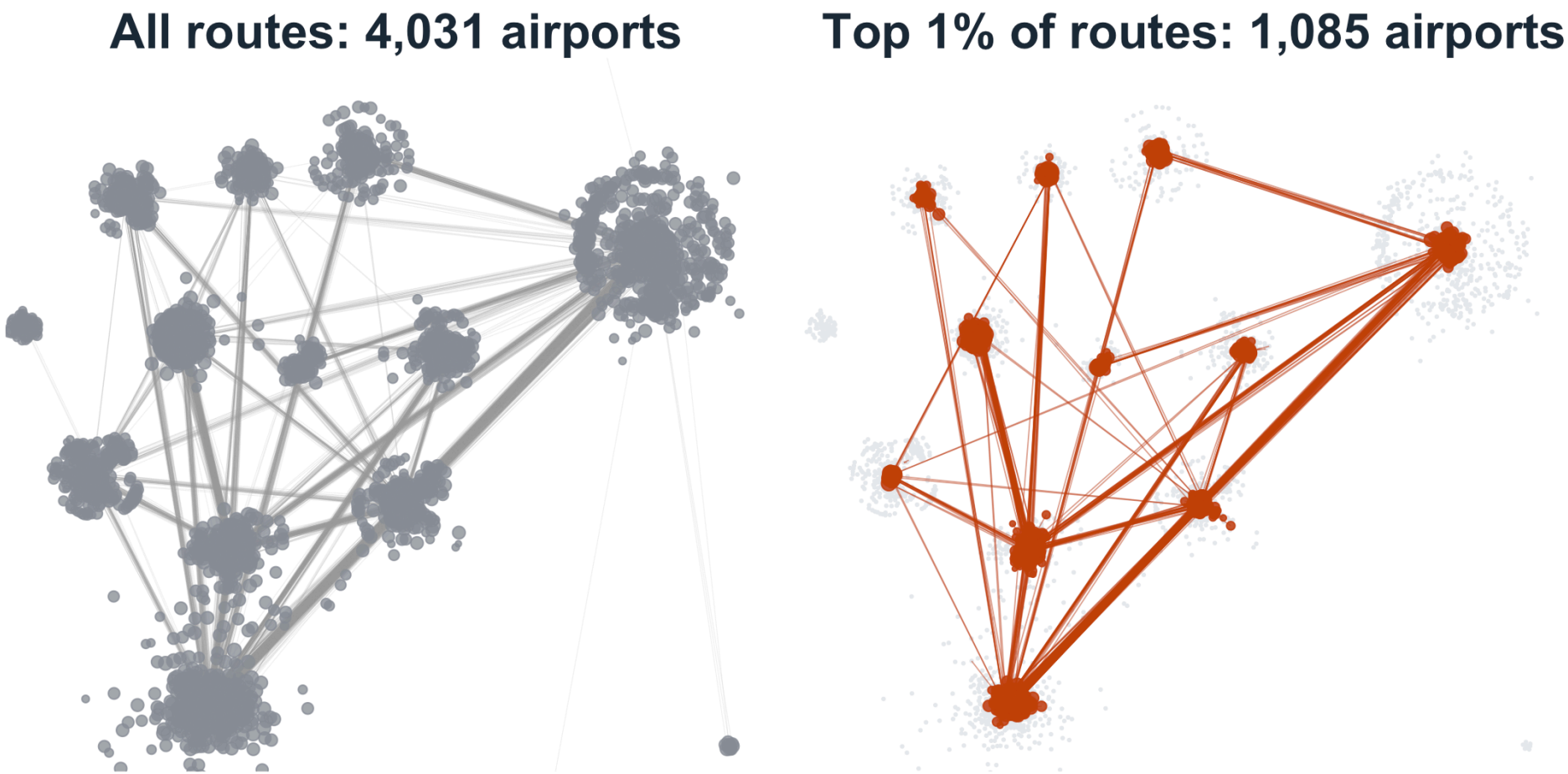
A blanket cut reduces every route by the same fraction.

Every cut starts on day 0 and stays in force.

A: each cut was tuned until it removed 10, 20 or 30% of passengers, so the delays compare equal disruption. B: final size at preset levels (a number of hubs, a share of routes kept, a blanket percentage), which remove different shares of travel. Medians of 100 runs, R_0 = 1.8, 5-day infectious period; error bars are 95% bootstrap intervals.

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Futility of route triage as an intervention: Cutting 99% of routes still leaves a connected backbone of 1,100 airports



The top 1% of routes carries 59% of passengers and still links about 1,100 airports in one connected piece.

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Key findings

- Final size set by R_0 at realistic epidemic and airline parameters
- Speed set mainly by passenger volume, not network structure
- Restrictions: delay the peak, without preventing spread

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Thank you

Earth at night, 2016. NASA Earth Observatory image by Joshua Stevens, using Suomi NPP VIIRS data from Miguel Román, NASA GSFC.

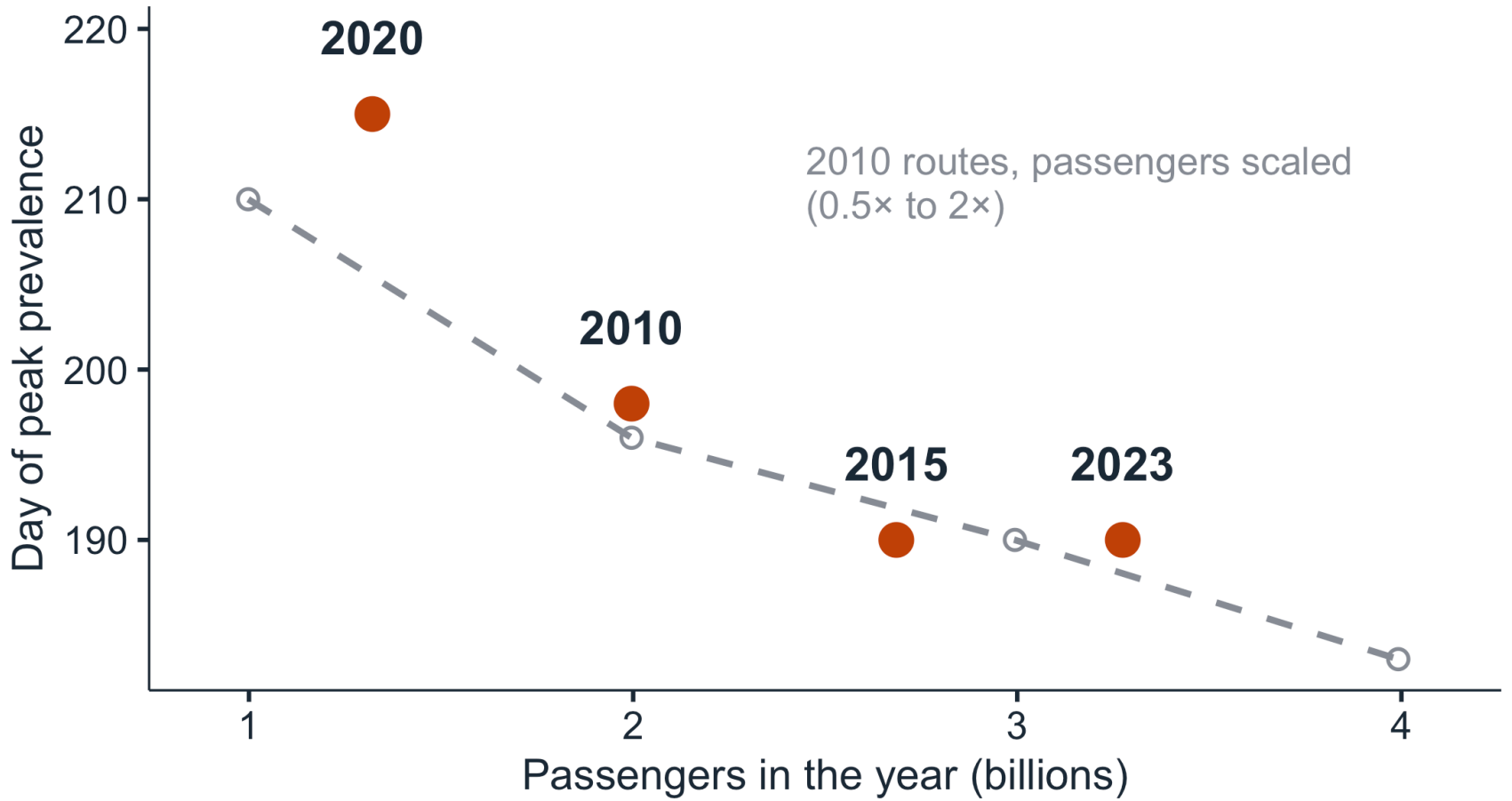
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Without 2020, network year explains almost none of the variation in peak time

- All four years: intraclass correlation 0.40 to 0.56
- Without 2020: 0.01 to 0.08
- 2010, 2015 and 2023 differ in mean peak day by 2 to 17 days across the nine parameter sets

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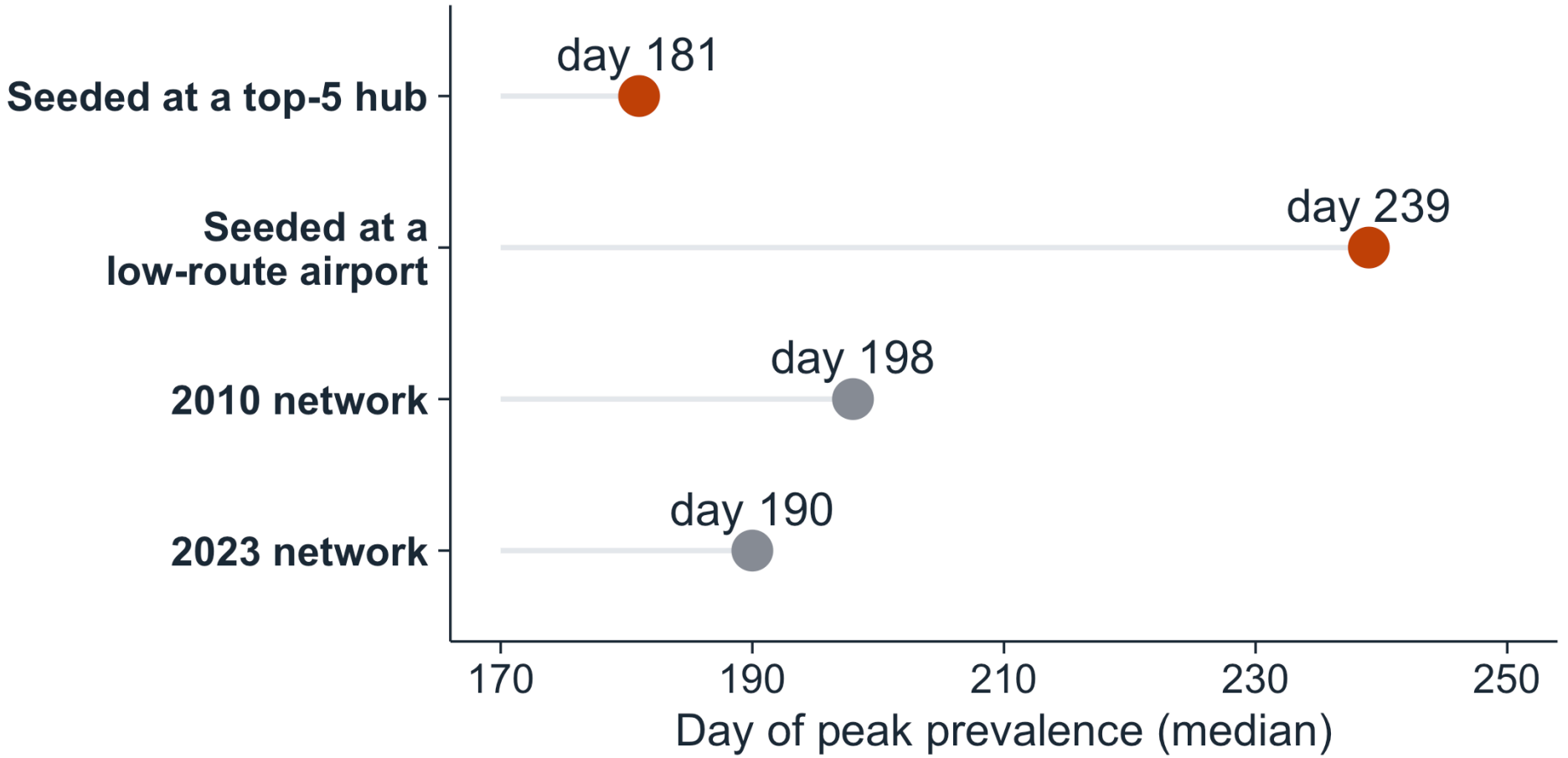
Peak day tracks passenger volume, with 2015 faster and 2020 slower than volume alone predicts



The real years sit close to the volume-only line except 2020, which peaks far later, and 2015, which peaks a little earlier.

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Where an epidemic starts matters more than how the network changed



Seeding at a peripheral airport delays the peak by 58 days compared with seeding at a top hub, several times the 8 days between the 2010 and 2023 networks.

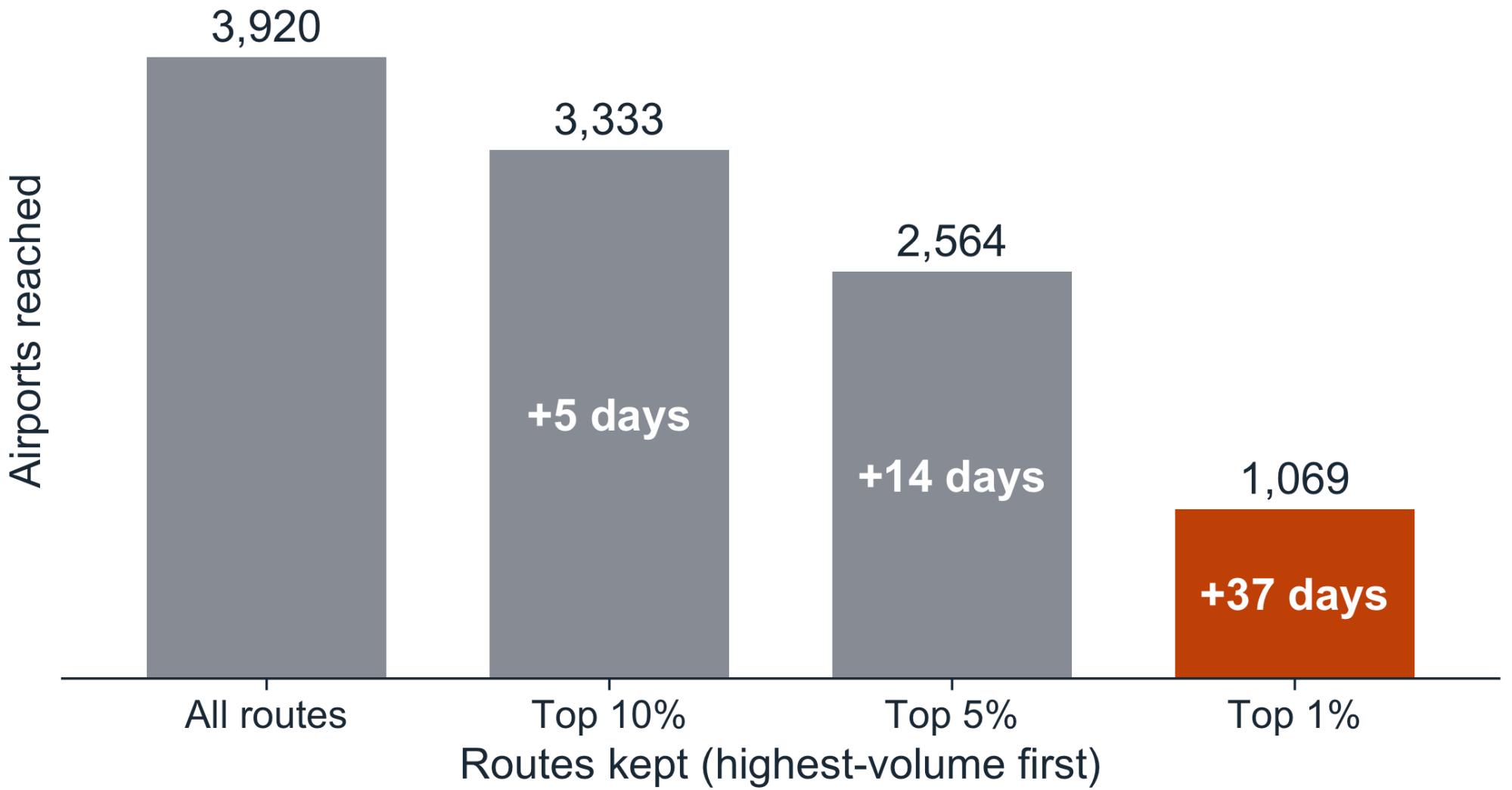
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Counting connecting passengers raises the hub-cut delay to under a week

- Outbound-only cuts at 10, 25 and 50 hubs: delays of 0, 1 and 1 days
- Adding approximated connecting itineraries: delays of 1, 3 and 5.5 days
- Volume removed roughly doubles (15% against 8% for 50 hubs)

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Delay and reach by how many routes are kept



Keeping fewer routes delays the peak more and reaches fewer airports, but even the top 1% reaches 1,069.

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