The Backward Art of Slowing the Spread?
Congregation Efficiencies during COVID-19

January 2022

Disease Prevention as an Industry

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  - Home production = amateur hour

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- Economic theory of public goods: any set of individuals has MUCH more demand when they cooperate than act atomistically
  - Samuelson: per member WTP is proportional to membership
- Economies of scale in supply, esp. when markets are suppressed

Infectious disease especially harms large groups, but …

- x = prevention effort. n = group size

- Per member disease cost $f(n,x)$

$$f_n > 0, f_x < 0$$

- Per member prevention cost $c(n,x)/n$

$$c_x \geq 0, c(n,0) = 0$$

- Equilibrium: $\min_x \{s(n)f(n,x) + c(n,x)/n\}$

…large groups may take their harm in prevention cost

- Equilibrium: $E(n) = \min_x\{s(n)f(n,x) + c(n,x)/n\}$

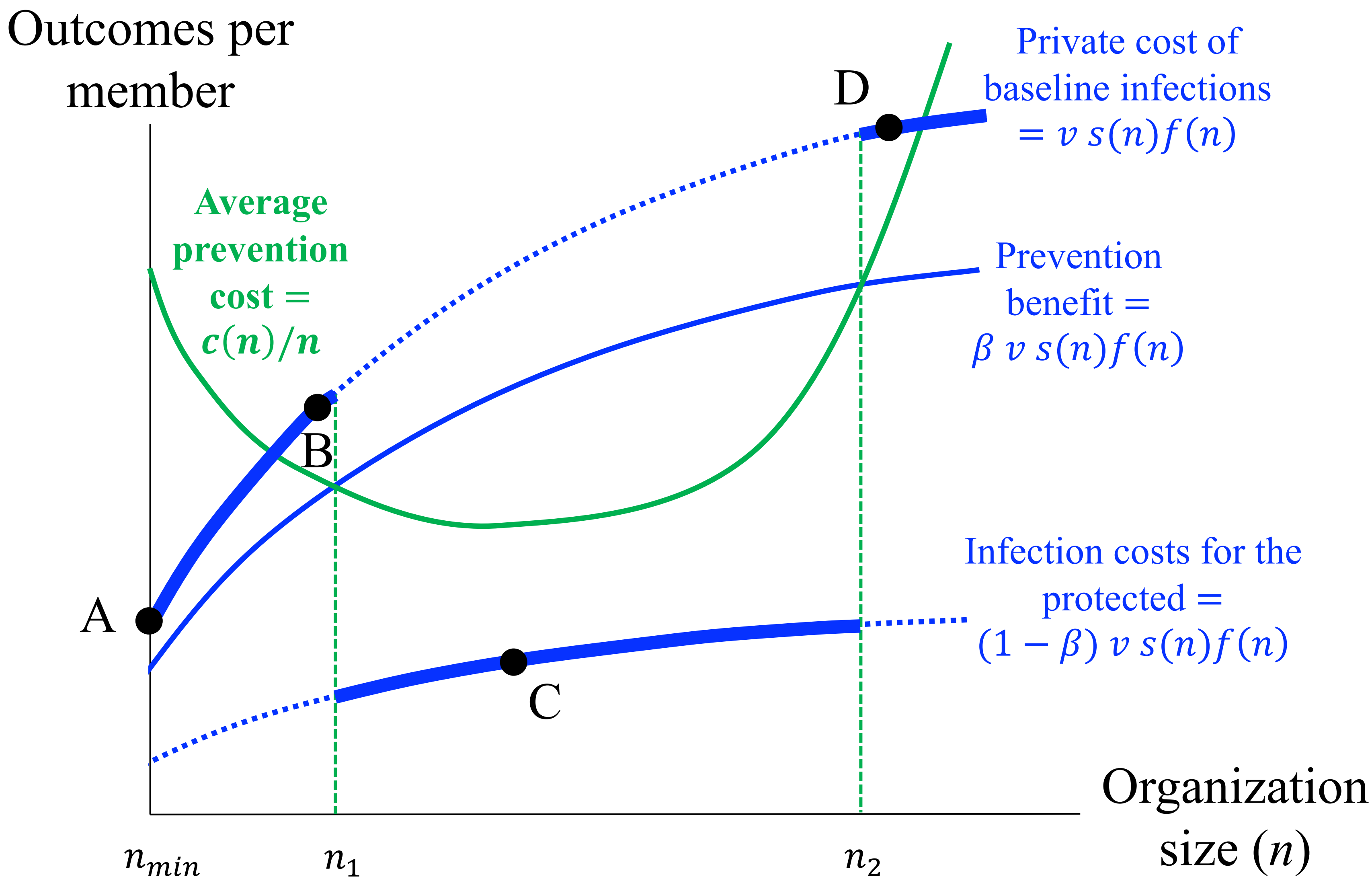
Epi **Econ**

- Equilibrium disease gradient: $\boxed{f_n} + f_x\boxed{dx/dn}$
  - Can have either sign. ie, "Epi fundamentals reversed"

- Envelope theorem near $x = 0$:
  $$E'(n) = s(n)f_n(n,0) + s'(n)f(n,0) > 0$$

- i.e., private incentive to avoid large groups even when they are safer

Figure 1. Equilibrium Prevention and Organization Size



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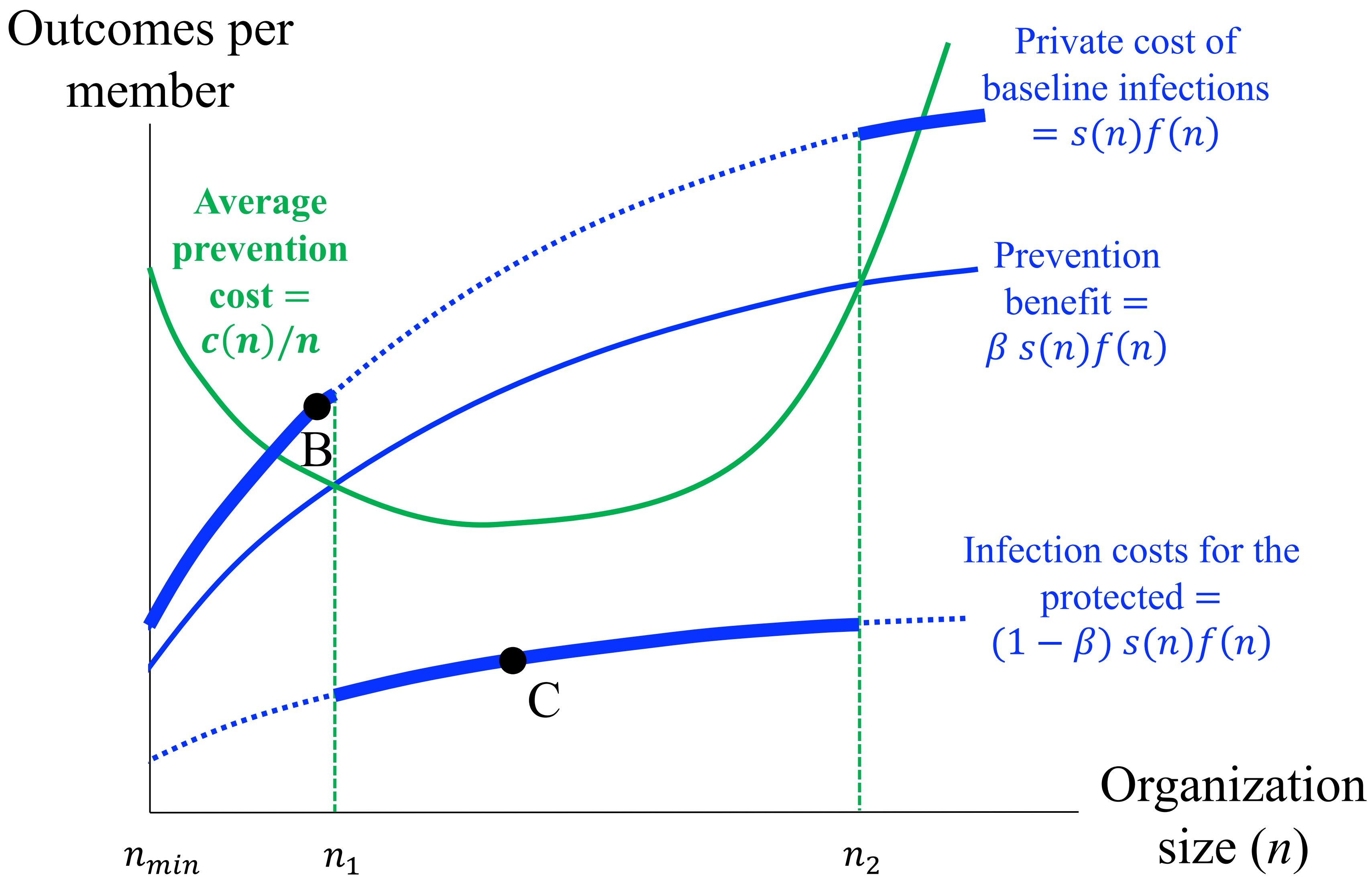


Figure 1. Equilibrium COVID Prevention and Organization Size

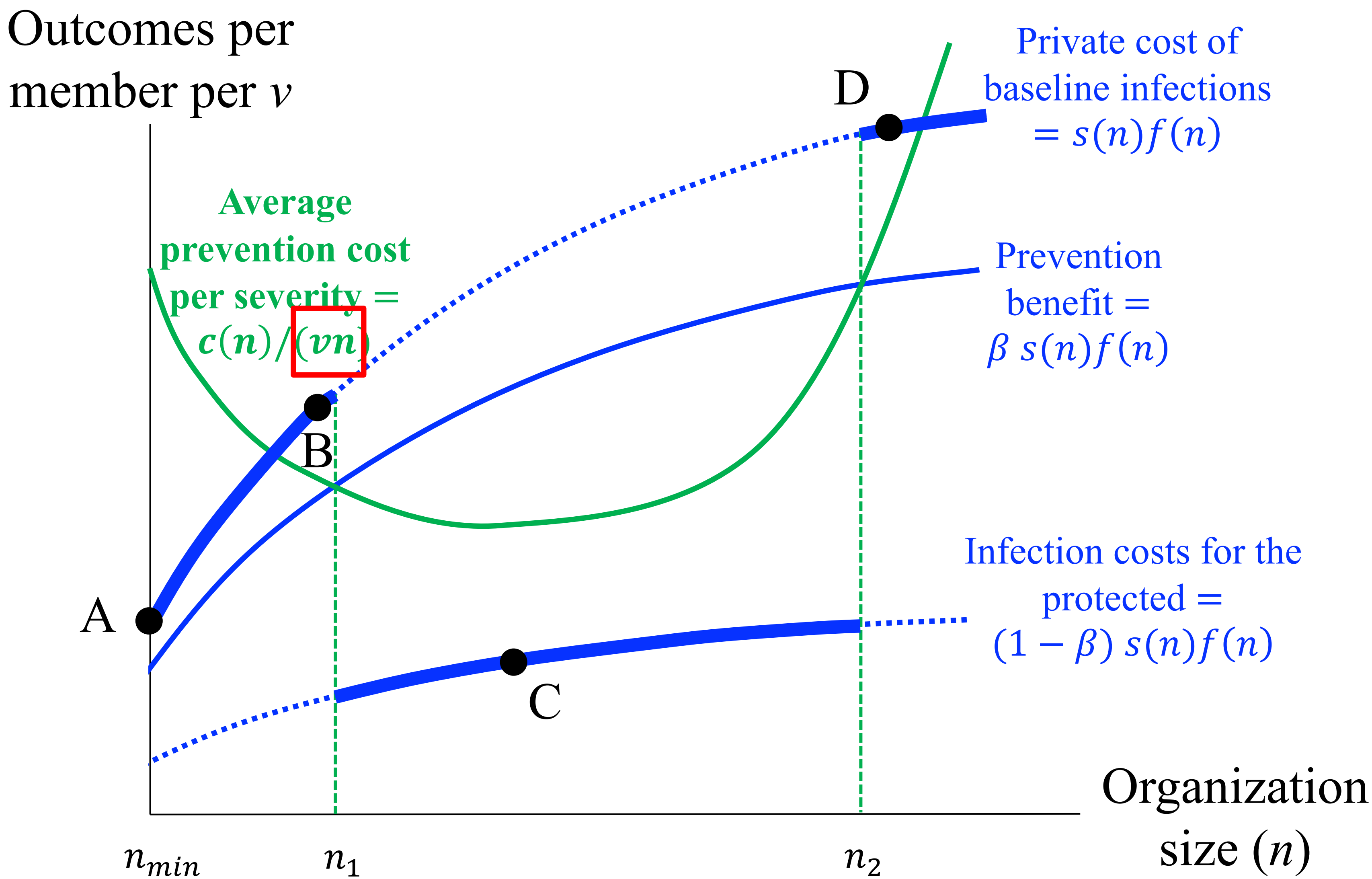
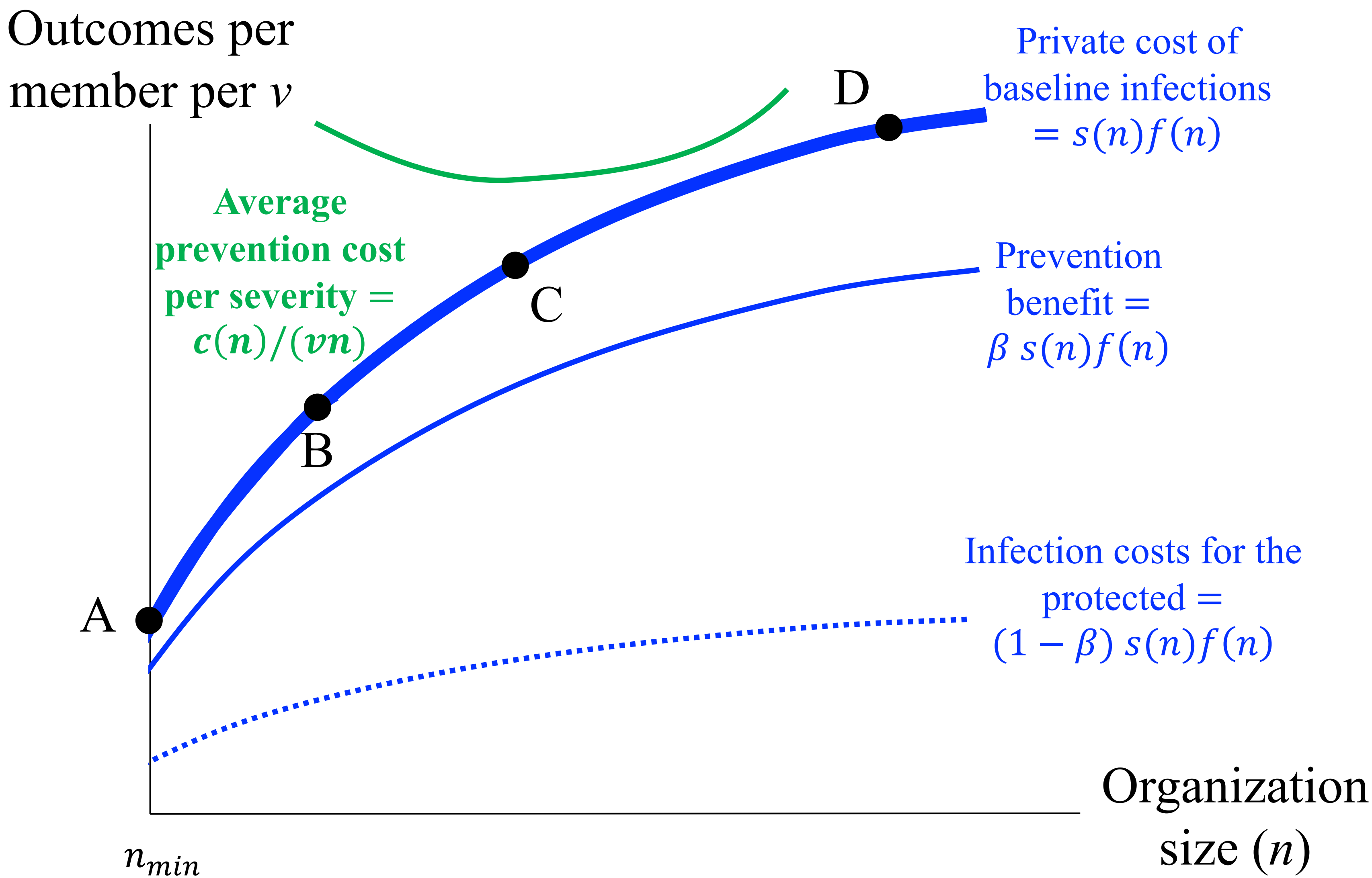


Figure 1. Equilibrium Flu Prevention and Organization Size



Allocating Time Among *L* Locations

- t_i = time spent at location i.

- $P_i(t_i)$ = Uninfected's probability of infection

$$P' > 0, P'' \leq 0$$

- Uninfected's all-location infection probability

$$1 - \prod_{i=1}^{L} [1 - P_i(t_i)]$$

$$MRT_{i,j} = \frac{P_i'(t_i)}{P_j'(t_j)} \frac{1 - P_j(t_j)}{1 - P_i(t_i)} \neq \frac{P_i(t_i)/t_i}{P_j(t_j)/t_j}$$

- Infections minimized at a corner

Measurement framework

- Specify a location and time interval
- (new infections) =

  (infectious members) *

  [1 – (screening rate)] *

  (avg number of close contacts/member) *

  (secondary attack rate per unit time) *

  (duration of gathering)

Measurement framework

- Specify a location and time interval

- (new infections/member–hour) =

    (initial infection rate) *

    [1 – (screening rate)] *

    (avg number of close contacts/member) *

    (secondary attack rate per unit time)

Large-org disadvantage

Prevention works on these

Comparing Marginal and Average

- Constant hazard within interaction

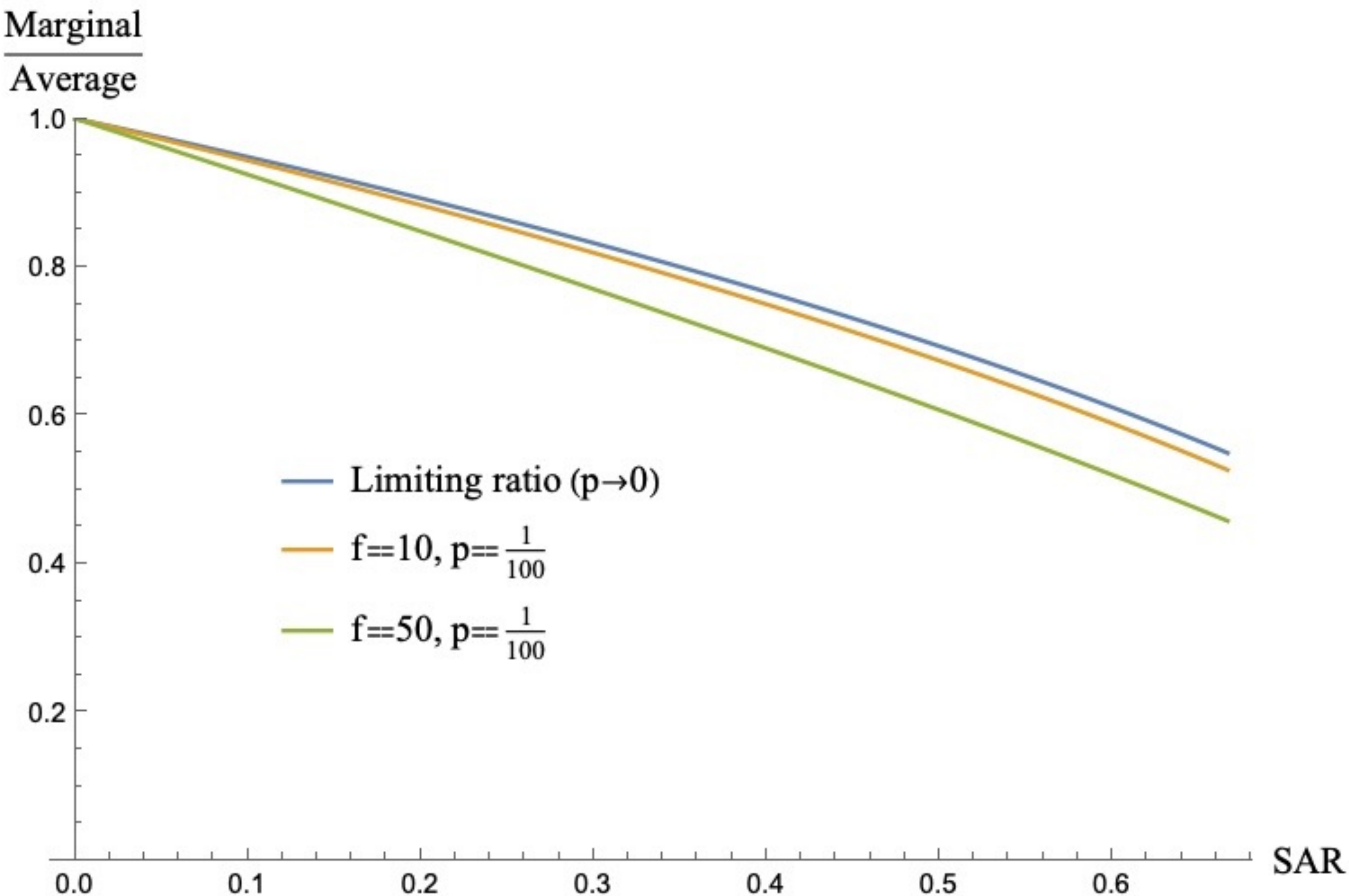
- p_i = prevalence of index cases at location i

$$P_i(t_i) = 1 - \left[1 - p_i + p_i e^{-h_i t_i / f(n_i)}\right]^{f(n_i)}$$

- $SAR_i(t_i)$ = Secondary attack rate

$$SAR_i(t_i) = (1 - p_i)\left[1 - e^{-\frac{h_i t_i}{f(n_i)}}\right]$$

$$\lim_{p_i \to 0} \frac{P_i'(t_i)}{P_i(t_i)} = \frac{1 - SAR_i}{SAR_i} \ln \frac{1}{1 - SAR_i} \in [0,1]$$



Marginal / Average
1.0
0.8
0.6
0.4
0.2
Limiting ratio (p→0)
f==10, p==1/100
f==50, p==1/100
0.0
0.1
0.2
0.3
0.4
0.5
0.6
SAR

Fighting the Flu at Work

- 60-70 percent of employers offer on-site flu shot
  - Among employed persons, the workplace is the most common place to receive it (doctor office close second)
  - Hardly any self-employed (= small business?) receive at work
  - Self employed much less likely to vax than employees

- 61 percent of workers have paid sick leave
  - 50 percent at small businesses (< 50)
  - 81 percent at large businesses (>499)

Table 1. Studies Measuring Setting-specific COVID-19 Infection or Transmission Rates

Studies have U.S. subjects unless noted otherwise

Description	Time Frame	Citation
	Worker/student infections traced to source (Figure 3)	
Duke Health workers	Mar 15 - Jun 6	Seidelman at al. (2020)
NC schools	Aug 15 - Oct 23	Zimmerman et al. (2021)
Wood County, WI schools	Aug 31 - Nov 29	Falk et al. (2021)
	Worker/student infection rates compared to local community (Table 3)	
Meat processing workers	Apr 1 - Jul 31	Hernstein et al. (2021)
On-campus university students	Sep 18 - Nov 20	[This paper]
Primary & secondary students & staff	Aug 31 - Nov 22	Mulligan (2021)
FEDEX pilots	Jan - Aug	Risher (2020)
Amazon/Whole Foods front-line workers	Mar 1 - Sep 19	Amazon Staff (2020)
	Secondary attack rates (Table 4)	
Hair stylists, masked	May 12 - May 20	Hendrix et al. (2020)
Healthcare with PPE	January	Burke et al. (2020)
Office workplace	January	Chu et al. (2020)
Households	March - April	Dawson et al. (2020)
Households	March 2 - 12	Rosenberg et al. (2020)
Households	March 22 - April 22	Yousaf et al. (2020)
Students & staff, Australia	March 5 - April 9	Mccartney et al. (2020)
Students & staff, France	Jan 24 - Feb 7	Danis et al. (2020)
Students & staff, Ireland	March 1 - 12	Heavey et al. (2020)
Students & staff, Italy	Sep 1 - Oct 15	Larosa et al. (2020)

Table 2. Prevention Measures Cited in Papers about Within-organization Spread

Physical barriers

Universal masking (all organizations studied)

Other PPE such as eye protection (hospitals)

Airflow or filtering (hospitals, airlines)

Other physical barriers (hospitals, food processors)

Positive assortative matching

Screening/quarantining potentially sick (hospitals, schools, food processors, airlines)

Pods or limits on interdepartmental contact (hospitals, schools)

Develop and administer its own testing service (University of Illinois, Amazon)

Video-based contact tracing (Amazon)

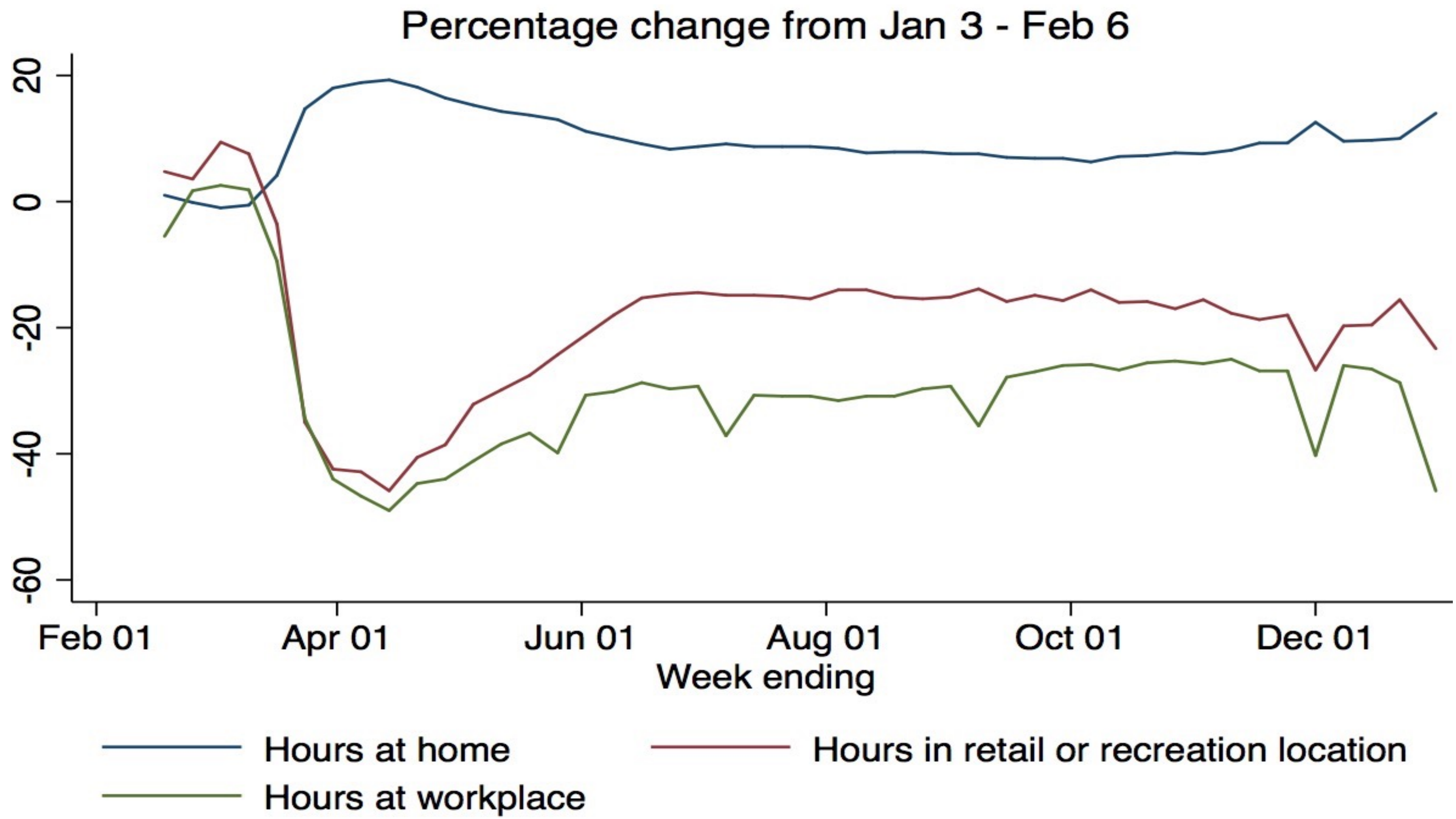
Social distancing

Spacing (hospitals, schools, airlines, Amazon)

Closed lunch rooms (hospitals)

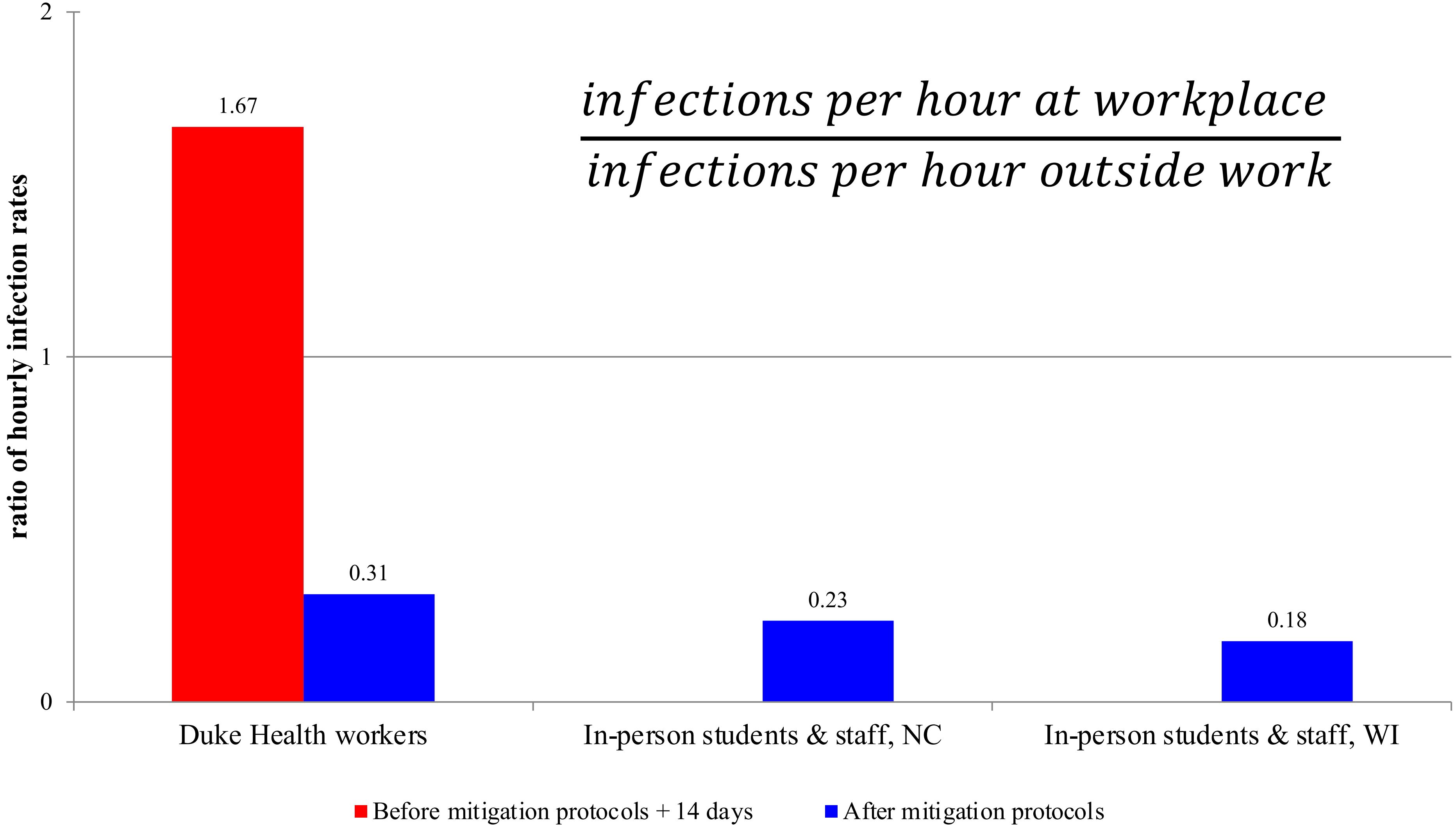
Handshakes prohibited (hospitals)

Figure 2. U.S. Weekly Mobility, 2020



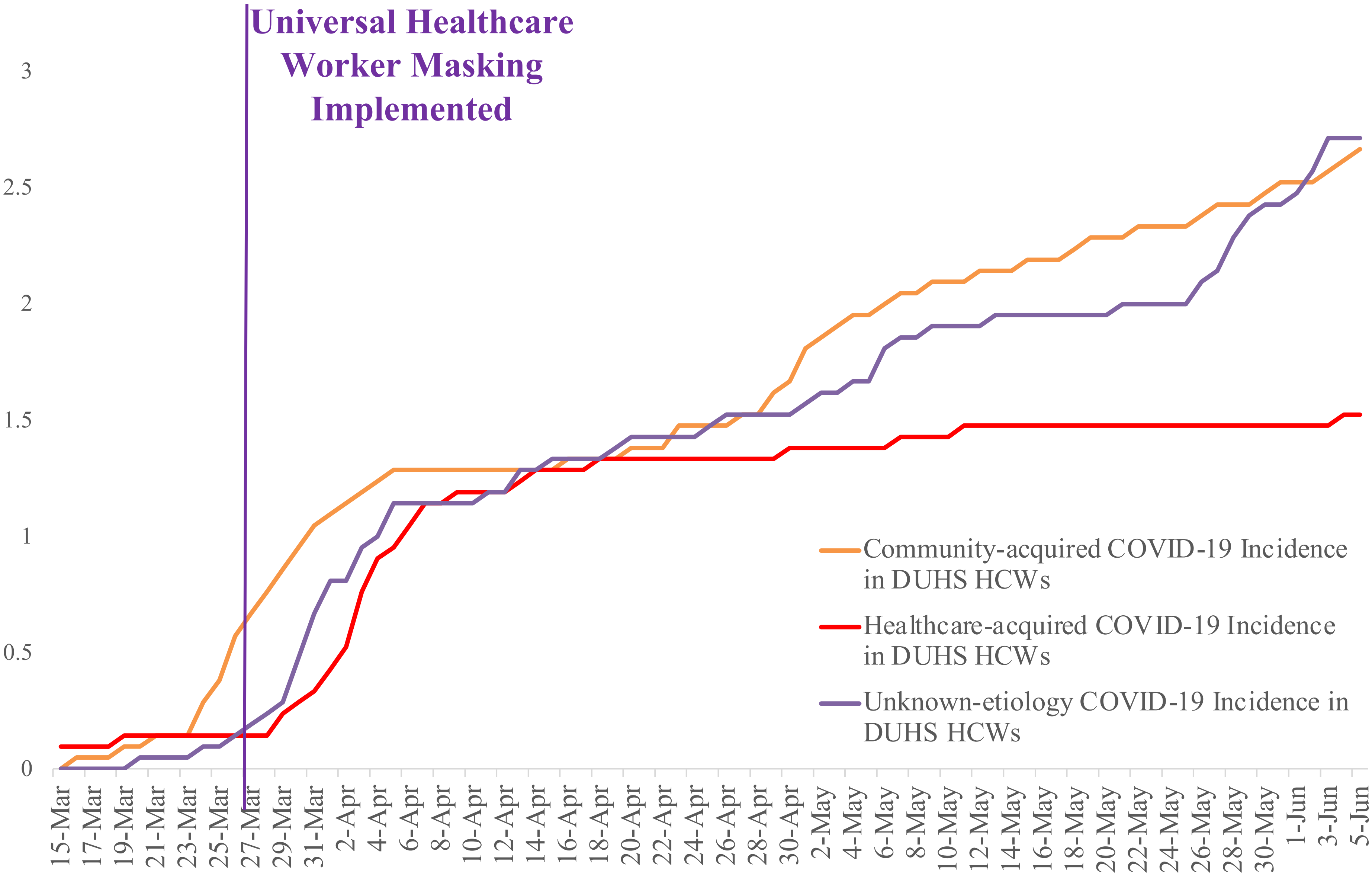
Source: Google Mobility

Figure 3. COVID-19 Infections Acquired at Work or School as a Ratio to those Acquired in the Community



Sources: Seidelman et al (2020), Zimmerman et al (2021), Falk et al (2021), Mulligan (2021), author's hours calculations.
Notes: Before-mitigation school data unavailable. Each of the four ratios in the chart has the same sample for its numerator as its denominator.

Cumulative Incidence of COVID-19 cases per 1000 population from 3/15/20-6/5/20 from Seidelman et al.



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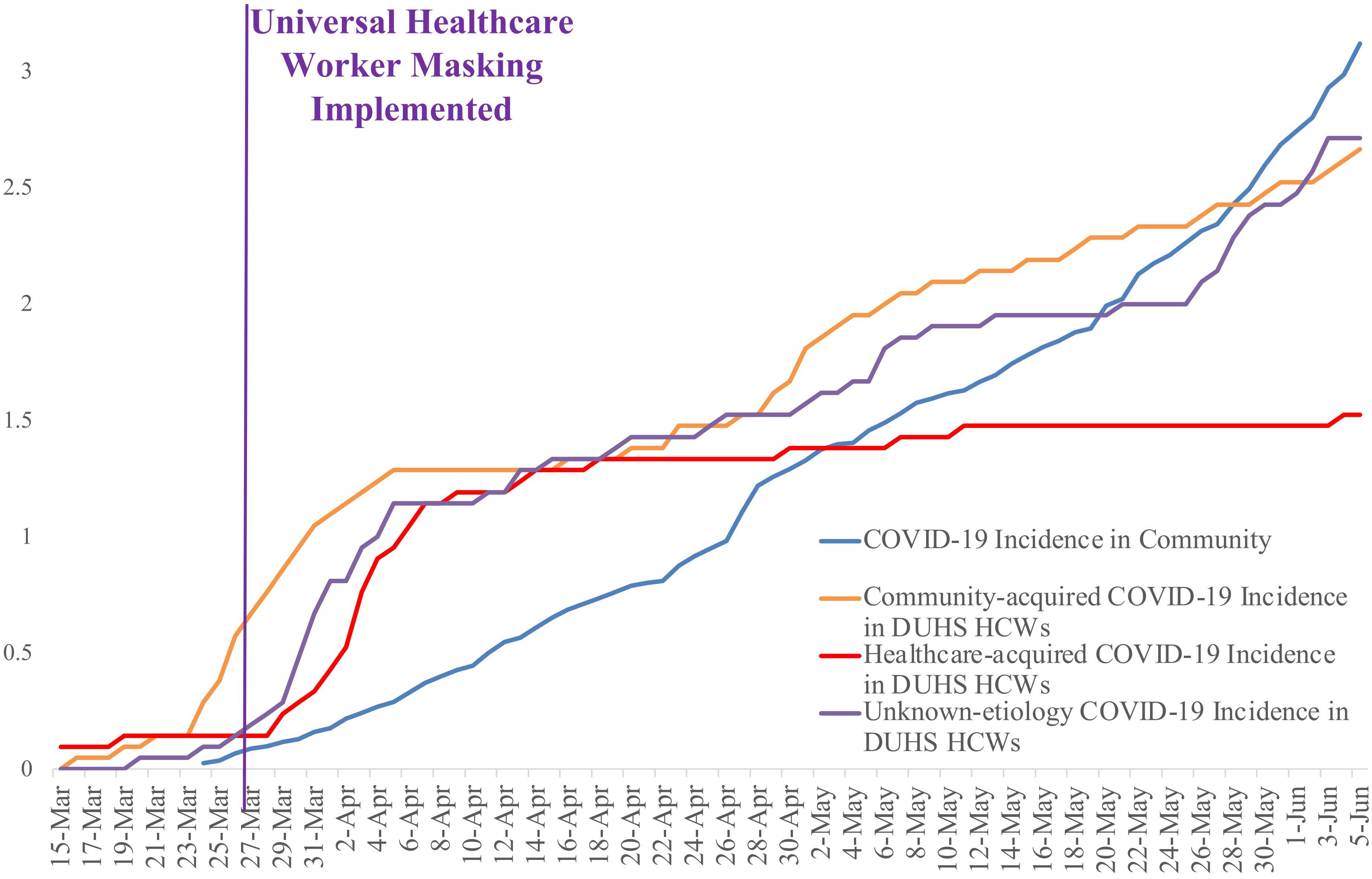

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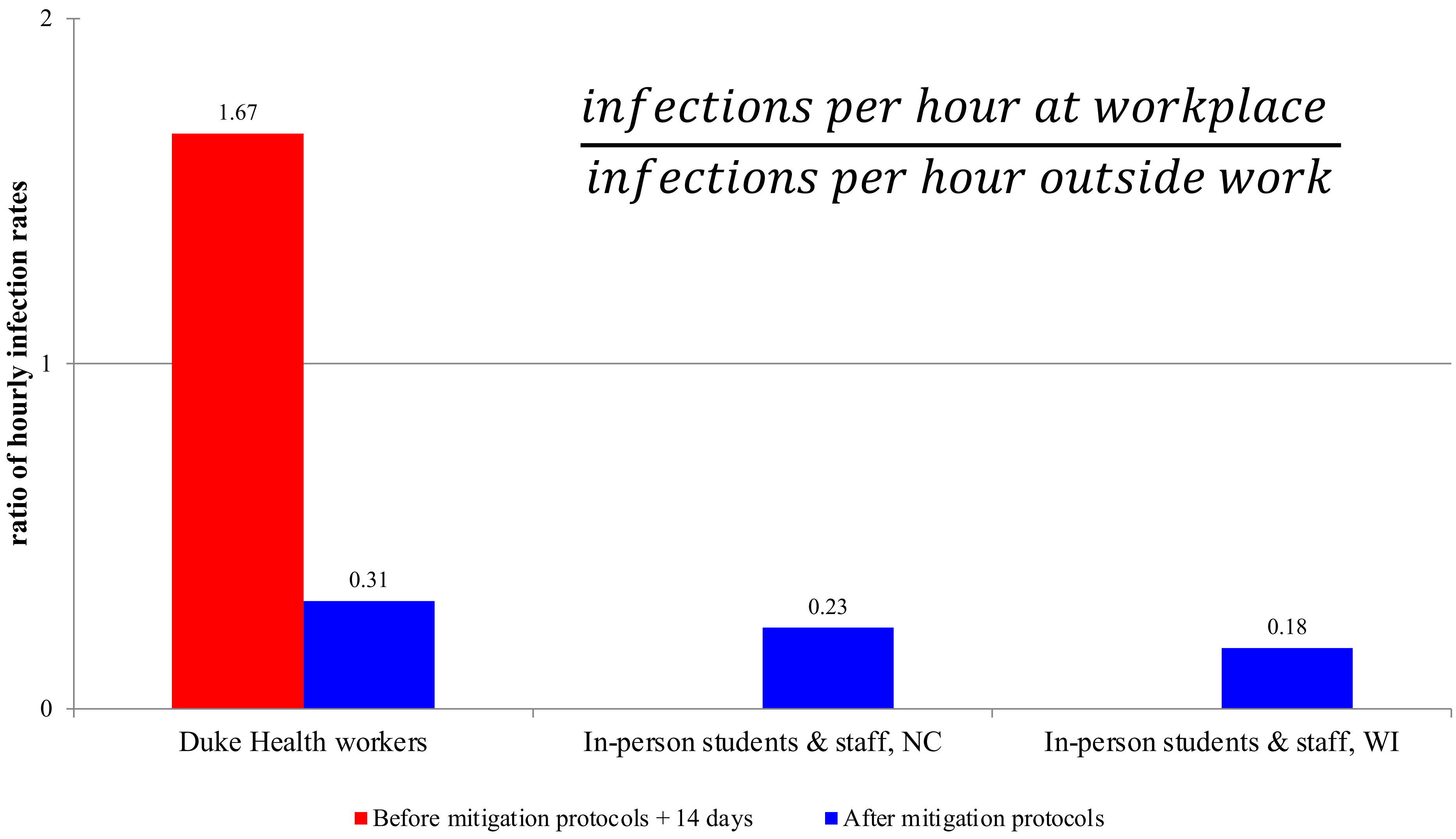

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Nursing-home orders

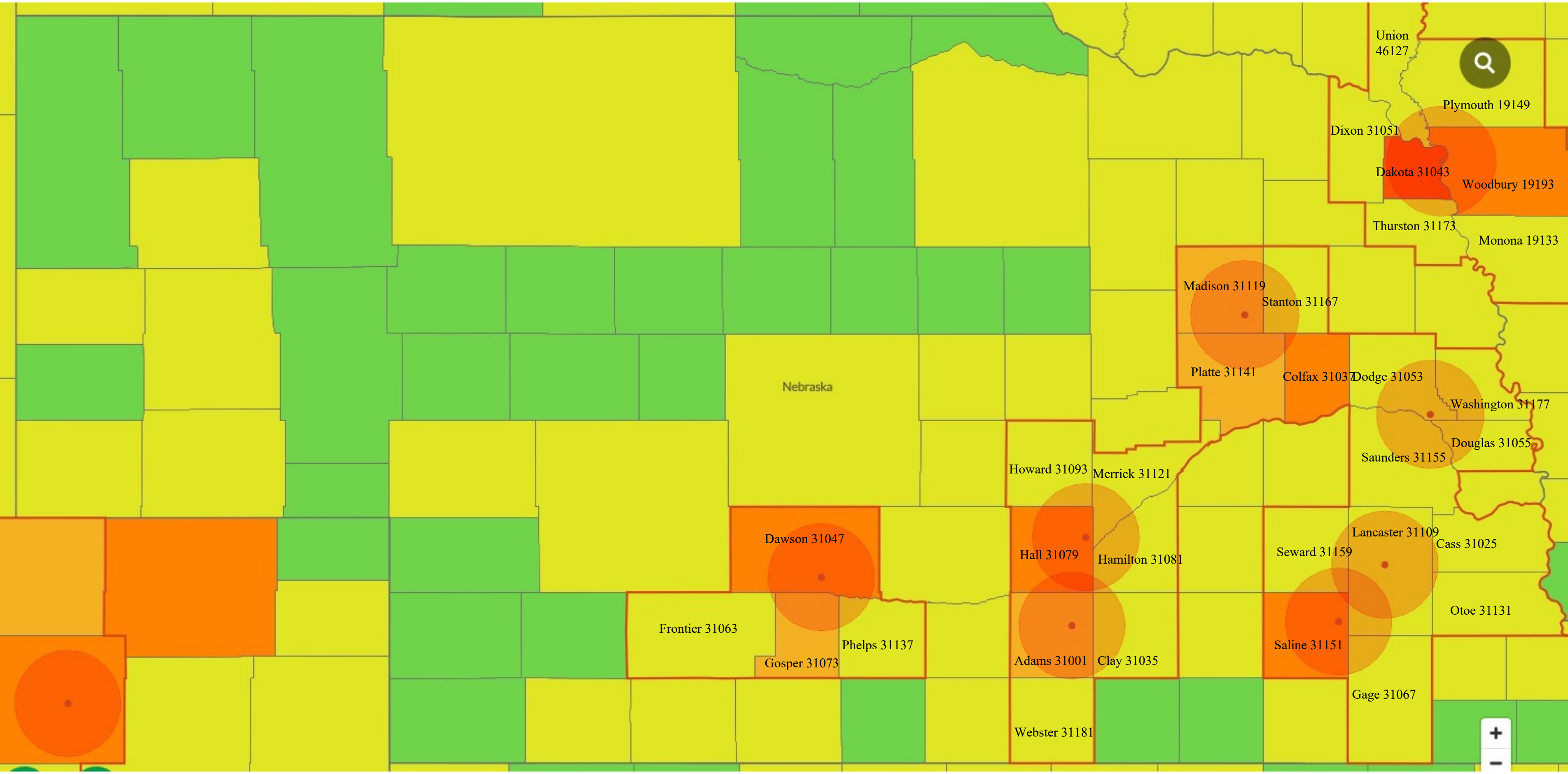
- Hospitals are larger than nursing homes
- Hospitals have scale economies in prevention
  - PPE, testing, negative pressure rooms
  - Monitor/limit cross-department contacts
- Governors order patients from hospital to nursing home
  - Contrary to the comparative advantage in prevention

Table 3. COVID-19 Prevalence Among Employees or Students Compared to the Surrounding Community

Employer/organization	Time frame	Community definition	Infection rate as ratio to community's
Nebraska meat processors, before mitigation	Apr 1 - May 17	Other residents of surrounding counties	15.1
Nebraska meat processors, after mitigation	May 18 - July 31		2.8
Univ. of Chicago on-campus students	Sep 18 - Nov 20	Chicago	0.09
Primary and secondary in-person students	Aug 31 - Nov 22	U.S. ages 5-17	0.77
Primary and secondary in-person staff	Aug 31 - Nov 22	Reweighted U.S. age-specific infections	0.81
FEDEX pilots	Jan - Aug	Reweighted U.S. age-specific infections	0.92
Amazon/Whole Foods front-line workers	Mar 1 - Sep 19	Reweighted state and age-specific infections	0.58

Sources: See Table 1.

Note: Each numerator includes infections that employees or students acquired in the community. Age-specific infection rates are from CDC. State and age-specific baseline for Amazon/Whole Foods was calculated by Amazon Staff (2020). Occupation-specific age distributions are from Jan - Mar Current Population Survey hosted by IPUMS. Both numerators and denominators are expressed per capita.


Union
46127
Plymouth 19149
Dixon 31051
Dakota 31043
Woodbury 19193
Thurston 31173
Monona 19133
Madison 31119
Stanton 31167
Platte 31141
Colfax 31037
Dodge 31053
Washington 31177
Nebraska
Douglas 31055
Saunders 31155
Howard 31093
Merrick 31121
Dawson 31047
Lancaster 31109
Cass 31025
Hall 31079
Hamilton 31081
Seward 31159
Otoe 31131
Frontier 31063
Phelps 31137
Saline 31151
Gosper 31073
Adams 31001
Clay 31035
Gage 31067
Webster 31181

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Measurement framework: SAR Studies

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  (infectious members) *
  [1 – (screening rate)] *
  (avg number of close contacts/member) *
  (secondary attack rate per unit time) *
  (duration of gathering)

Index cases

Table 4. Secondary Attack Rates in Various Settings

Numerator is secondary cases

denominator

Occupation/location	Country	Time Frame	Index cases	Close contacts per index	Reproduction rate	SAR Raw	SAR per 8 hours
Hair stylists, masked	U.S.	May 12 - May 20	2	69.5	0	0	0
Healthcare with PPE	U.S.	January	2	81.5	0	0	0
Office workplace	U.S.	January	1	11	0	0	0
Households	U.S.	March - April	26	2.5	0.62	25.0%	0.89%
Households	U.S.	March 2 - 12	155	2.2	0.85	38.2%	1.36%
Households	U.S.	March 22 - April 22	N/A	[195 contacts]	N/A	24.1%	0.86%
Students	Australia	March 5 - April 9	9	62.7	0.11	0.2%	0.01%
School staff	Australia	March 5 - April 9	9	7.3	0.11	1.5%	0.07%
Students & staff	France	Jan 24 - Feb 7	1	86	0	0	0
Students & staff	Ireland	March 1 - 12	6	154	0	0	0
Students	Italy	Sep 1 - Oct 15	48	20.75	0.79	3.8%	0.19%
School staff	Italy	Sep 1 - Oct 15	48	4.25	0	0	0

Sources: See Table 1.

Note: All school subjects are in person. The reproduction rate is the product of close contacts per index and raw SAR. Household contact hours are assumed to be 14 days times 16 hours per day. School contact hours are assumed to be 3.4 days (avg. presence of index case) times 6 hours per day.

"households show the highest transmission rates" and that "households are high-risk settings for the transmission of [COVID-19]."

Measurement framework

- Specify a location and time interval

- (new infections/member–hour) =

  (initial infection rate) *

  [1 – (screening rate)] *

  (avg number of close contacts/member) *

  (secondary attack rate per unit time)

Large-org disadvantage

Prevention works on these

Transmission components: schools vs. households

Row	Rate	Units	School	Remote	Remote/School
A	Infectious days per student or staff infected and present	Days	3.4	10?	
B	[1-screening rate]	Share	0.34	1	2.9
C	Close-contact rate	Contacts per infected	15.8	2.4	0.1
D	SAR	Infections per 1000 contact days	0.61	10.4	17.0
B*C*D	Infections per person-day				7.4

Note: School parameters B, C, and D from Australia study. Remote parameters are from household SAR studies.

Conclusions

- Organizations implemented prevention protocols
  - They worked
  - Maybe policy should not undermine private prevention
- Hourly infection rates in workplaces < off-site rates, despite potentially more close contacts
  - Workplaces screen
  - Workplaces have low SARs
- Such work has a positive externality
  - Private incentives to stay home and avoid prevention
- Large employers are safer than small ones?
  - Hospital vs. nursing home