MIDAS Webinar

July 26th, 2024

The Value of Environmental Surveillance for Pandemic Response

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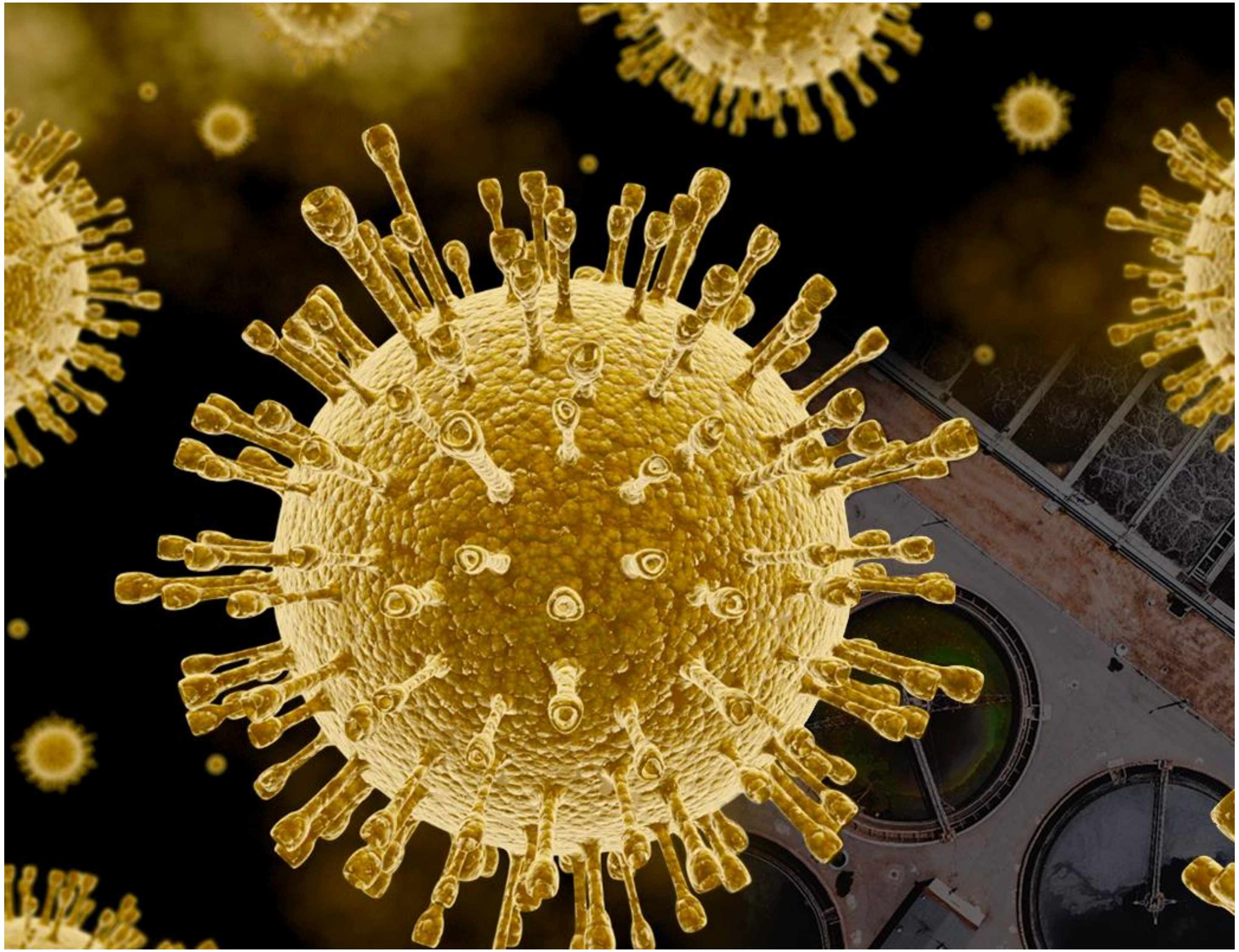
Working paper: https://www.rand.org/pubs/working_papers/WRA3263-1.html



Agenda

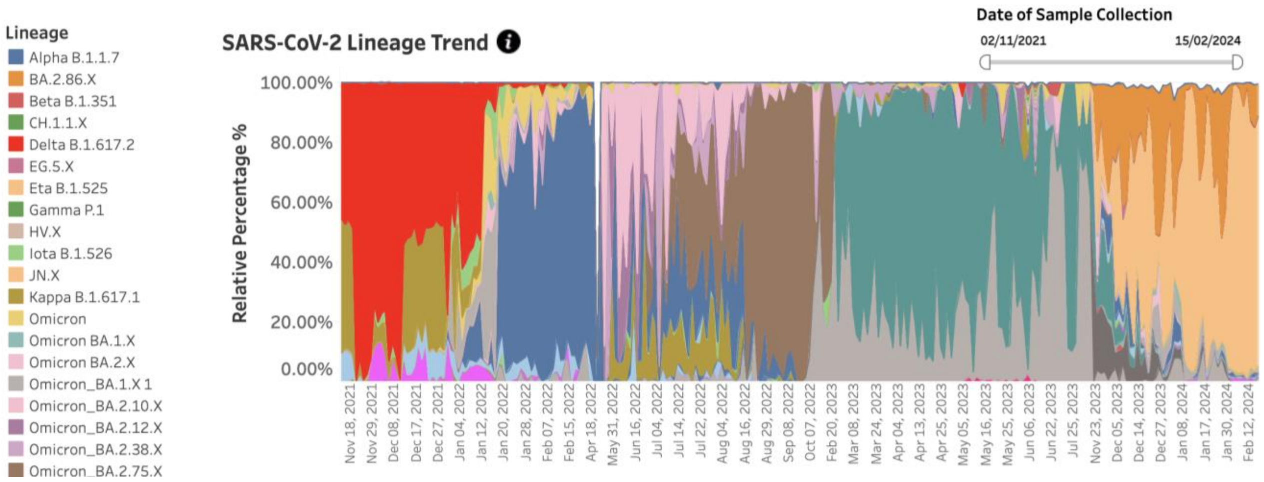
- Background: ESS
- Policy question
- Methods overview
- Results
- Conclusions
- Future work

Environmental sampling surveillance (ESS) goes mainstream

ESS via wastewater became widespread during the COVID-19 pandemic

In Sep 2020, the CDC launched the National Wastewater Surveillance System. Other countries also use wastewater systems to monitor diseases like SARS-Cov-2, H1N1, and influenza.

- **Benefits:** earlier warnings, more complete coverage



But progress cannot be taken for granted

- **COVID-19 surveillance efforts are being scaled back**
- **Unclear/unstable long-term funding mechanisms might hinder progress** (or cause inaction when public health action is warranted)
- **We propose an approach to quantify the value of environmental surveillance** using the first year of COVID-19 as an example

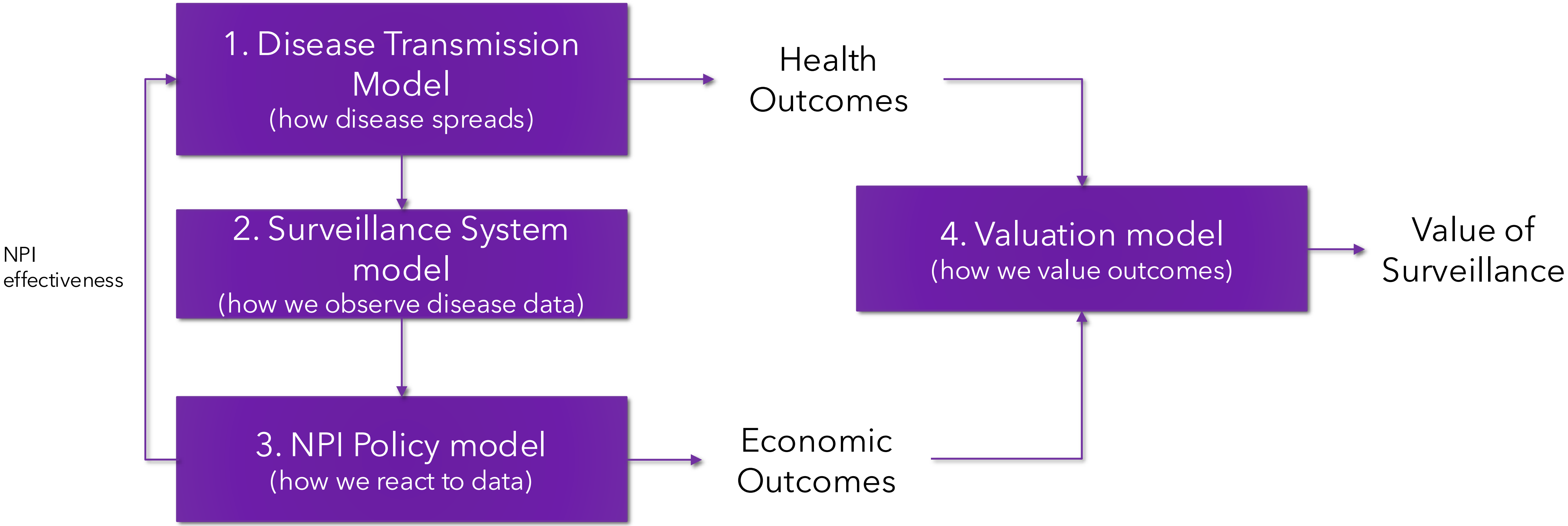
Policy Question:
What is the value of ESS for pandemic response?

ESS affects…

Total Pandemic Cost = Health Costs + Cost of NPIs + Cost of Surveillance

Value of Surveillance = Pandemic Cost without ESS - Pandemic Cost with ESS

Four ingredients needed to answer this question



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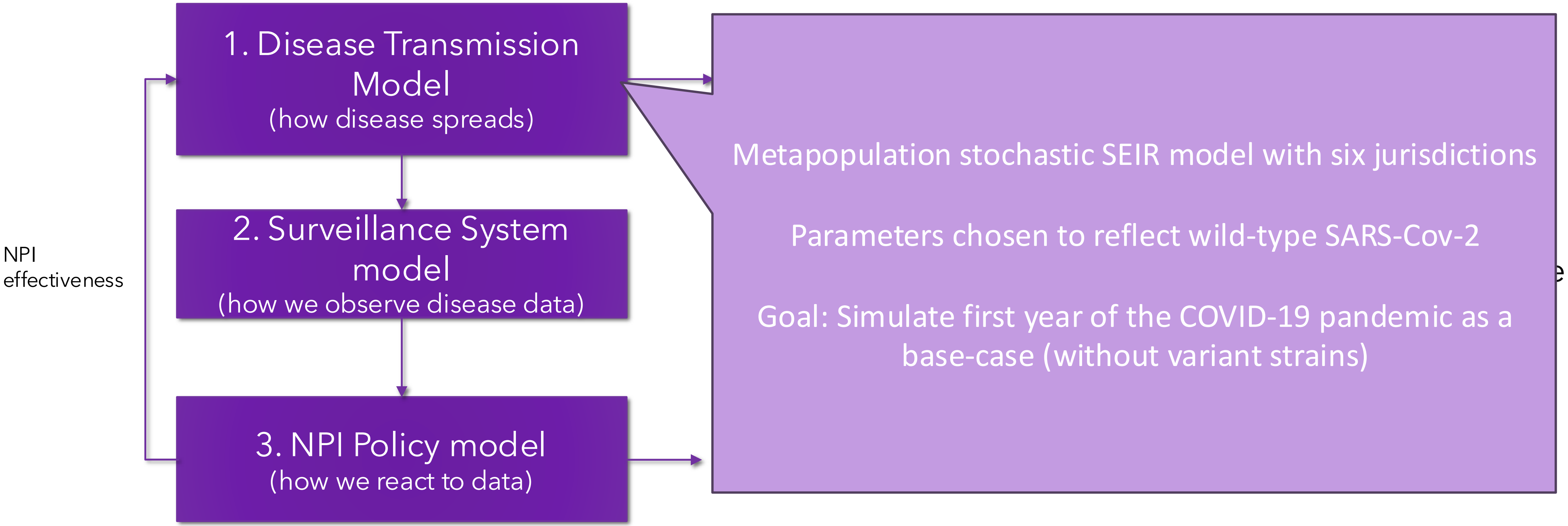

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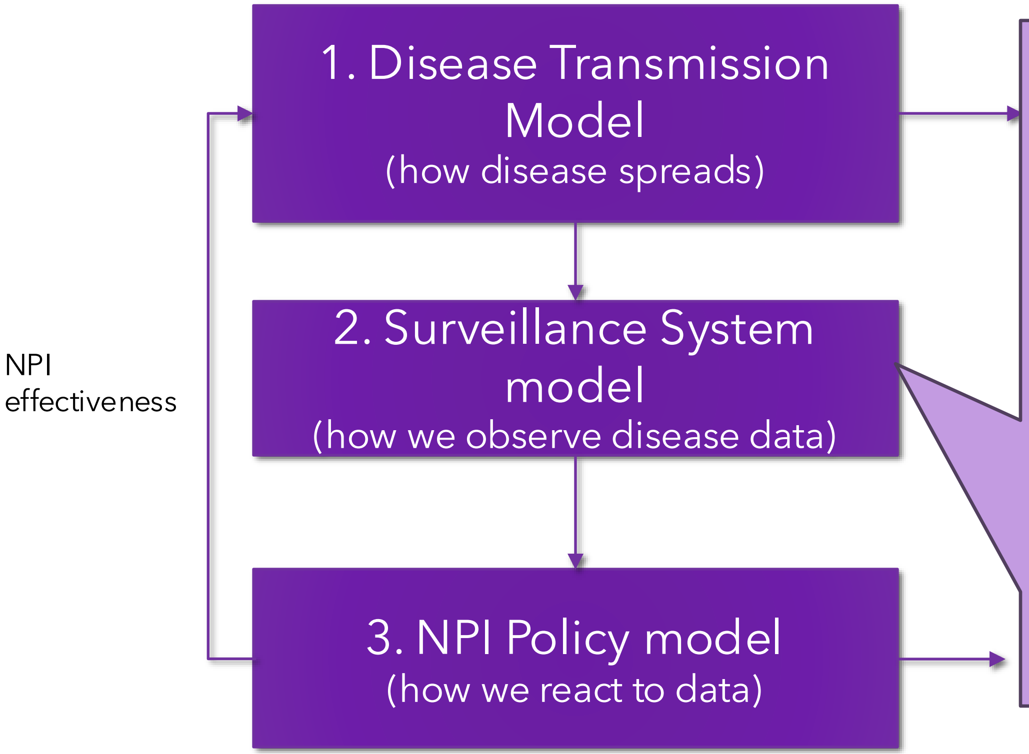
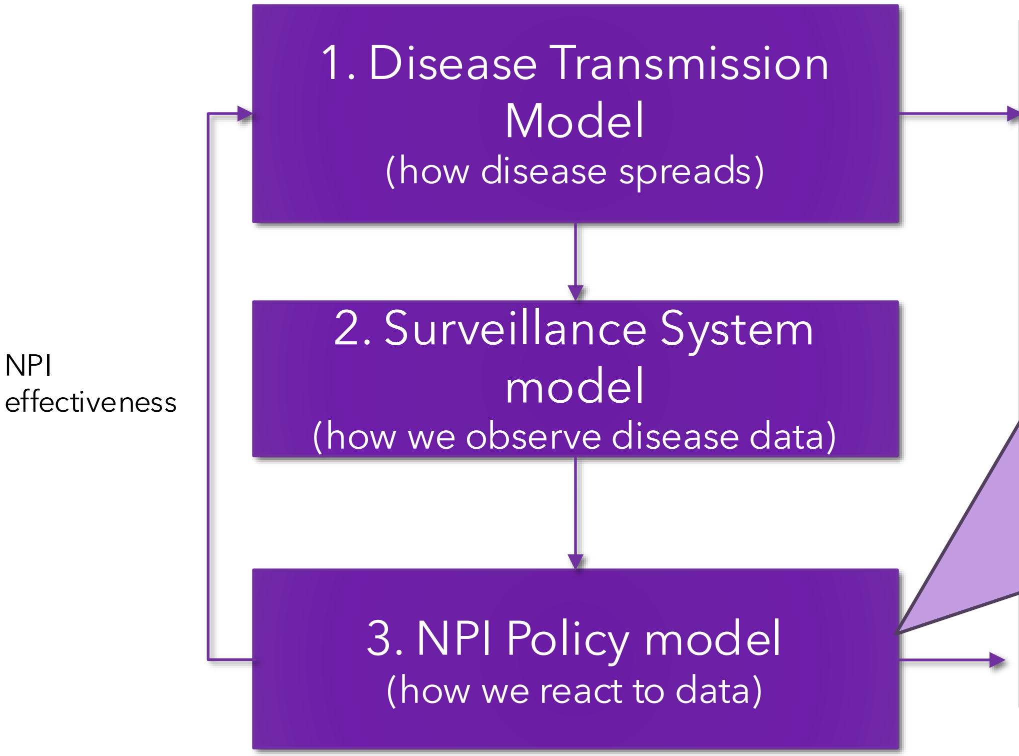


Most parsimonious representation of surveillance:

$$\hat{C}_{i,t} \sim B\left(-\Delta S_{i,t-l_i}, p_i\right)$$

$-\Delta S$: unobserved daily rate of new infections.
parameter $p_i \in (0,1)$: case ascertainment rate
l_i: surveillance lag, expressed as the number of days from infection to

Four ingredients needed to answer this question



NPI Policy*:

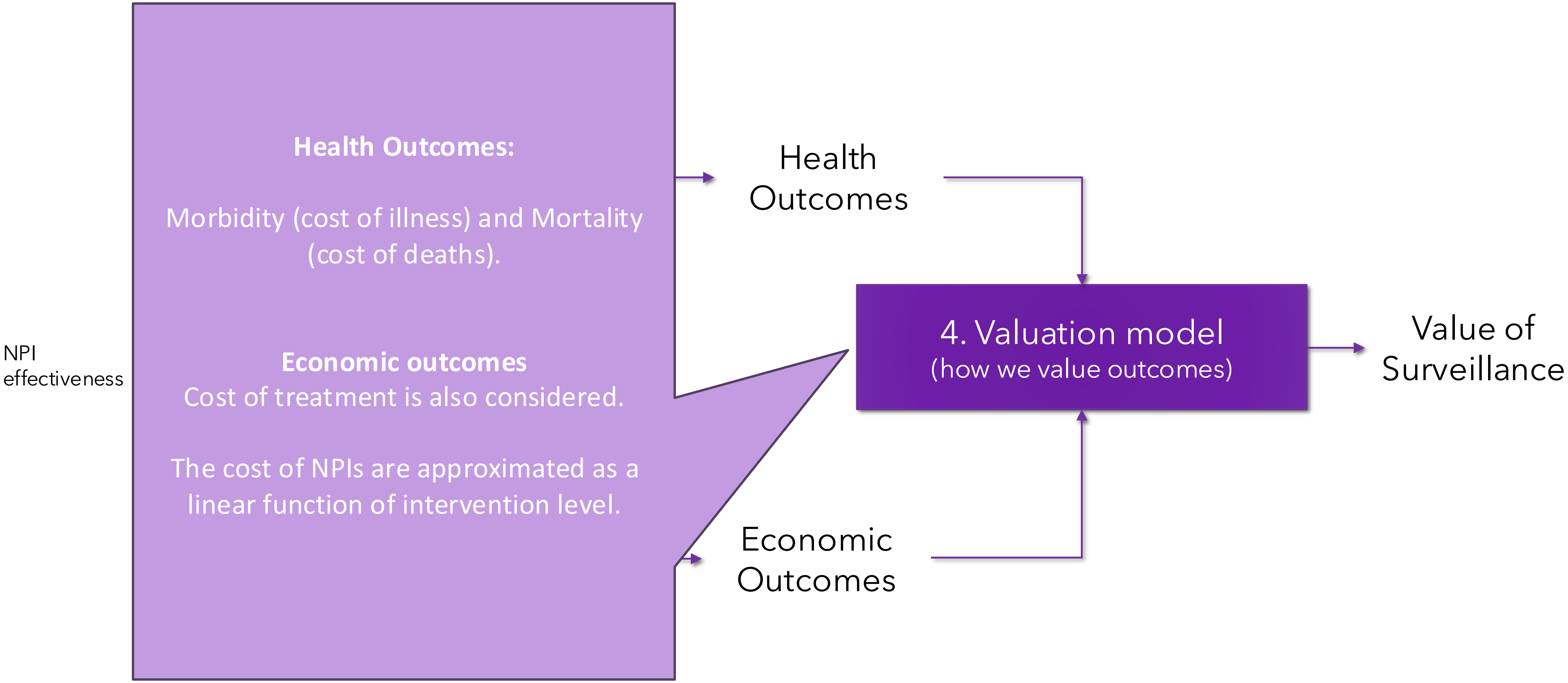
$$x^*_{i,t} = \min\left(\frac{10^5\ \hat{C}_{i,t}}{N_i p_i d_i}, x_{max}\right)$$

$\hat{C}_{i,t}$: Disease incidence (lagged, imperfect) signal.

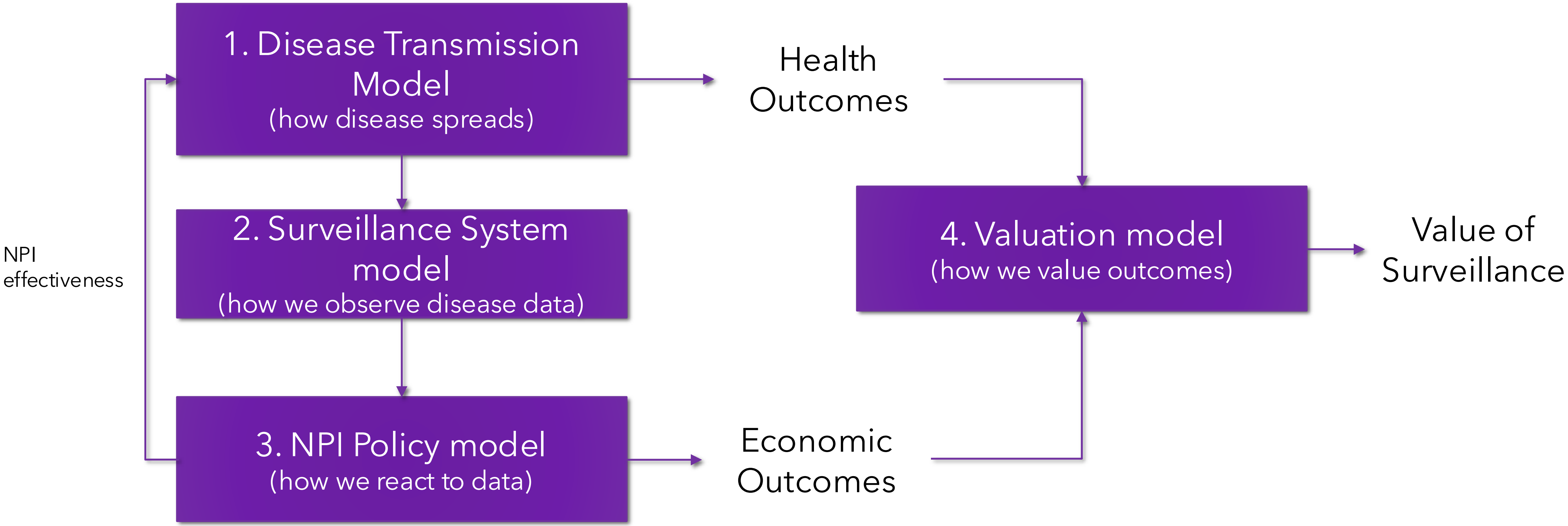
d_i: Disease incidence threshold needed to introduce interventions

*See appendix, the model is a little more complicated, includes decision lags.

Four ingredients needed to answer this question



All four components are needed to establish the value of ESS



Results

How valuable would ESS systems be

in the first year of a new COVID-19-like pandemic?

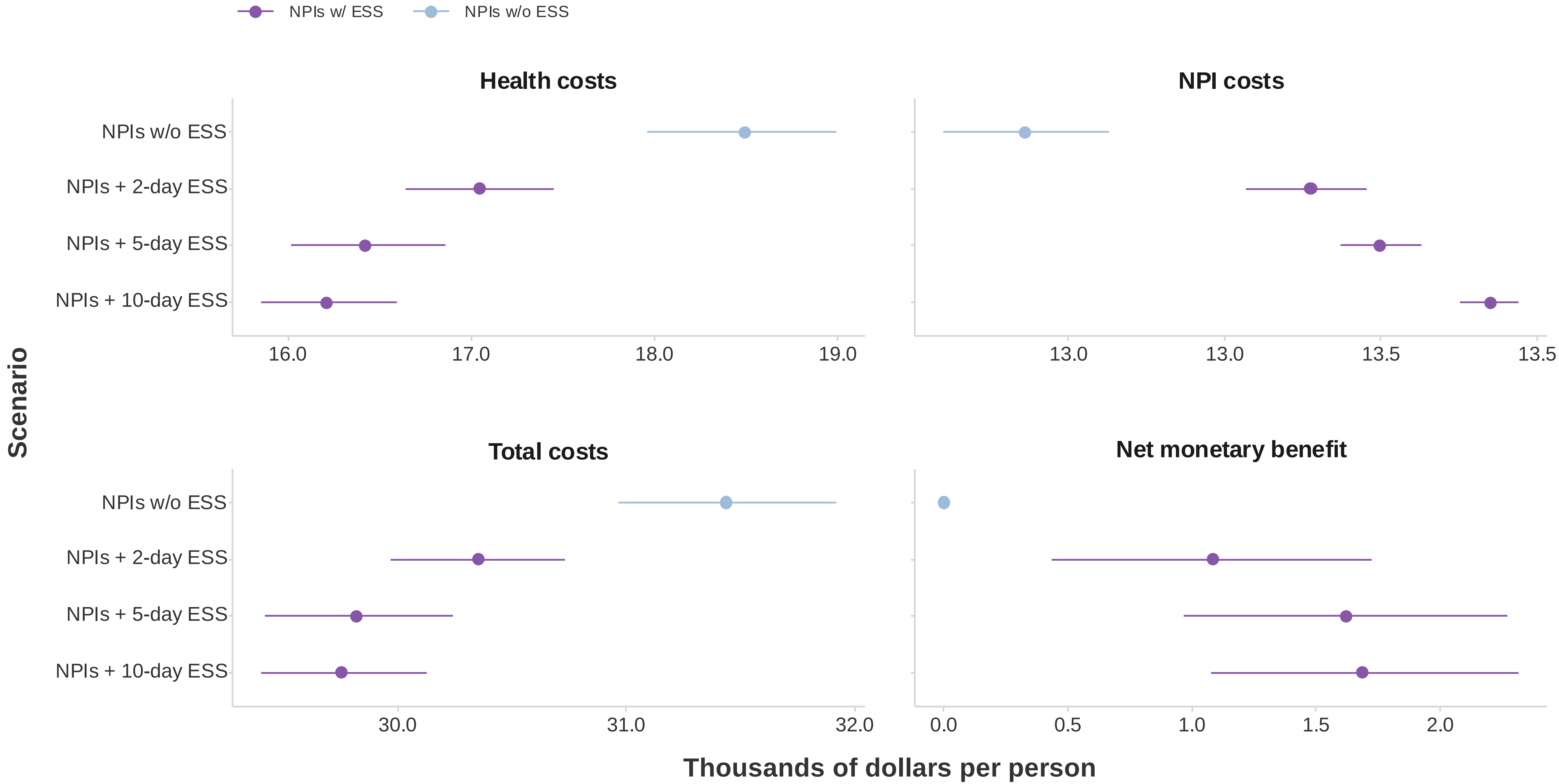
Value of ESS under base-case assumptions: ~ $ 1,600 per person*

Assuming a 5-day early warning relative to syndromic surveillance in the first year of a new COVID-19-like pandemic

Outcome	No NPIs	NPIs w/o ESS	NPIs + 2-day ESS	NPIs + 5-day ESS	NPIs + 10-day ESS
Epidemic size	92.0 (92.0-92.0)	29.0 (28.5-29.5)	27.1 (26.8-27.4)	26.2 (25.9-26.6)	26.1 (25.8-26.5)
Cost of illness	4,730 (4,730-4,730)	1,490 (1,460-1,520)	1,390 (1,380-1,410)	1,350 (1,330-1,360)	1,340 (1,320-1,360)
Deaths per 100,000 people	542 (536-548)	149 (145-153)	137 (134-141)	132 (129-136)	130 (127-134)
Deaths averted per 100,000 people	-393 (-400--385)	0 (0-0)	11.8 (6.05-17.4)	16.9 (11.0-22.4)	18.7 (13.3-24.1)
Cost of deaths	61,800 (61,100-62,500)	17,000 (16,500-17,500)	15,700 (15,300-16,000)	15,100 (14,700-15,500)	14,900 (14,500-15,200)
Health costs	66,500 (65,800-67,200)	18,500 (18,000-19,000)	17,000 (16,600-17,500)	16,400 (16,000-16,900)	16,200 (15,900-16,600)
Days of any NPI	0 (0-0)	325 (323-328)	329 (328-330)	330 (330-330)	337 (336-337)
Days of max NPI	0 (0-0)	113 (100-127)	71.2 (58.3-85.2)	70.8 (63.0-79.3)	51.1 (44.3-57.2)
NPI costs	0 (0-0)	12,900 (12,800-13,100)	13,300 (13,200-13,400)	13,400 (13,300-13,500)	13,500 (13,500-13,600)
Total costs	66,500 (65,800-67,200)	31,400 (31,000-31,900)	30,400 (30,000-30,700)	29,800 (29,400-30,200)	29,800 (29,400-30,100)
Net monetary benefit	-35,000 (-35,900--34,200)	0 (0-0)	1,080 (437-1,720)	1,620 (967-2,270)	1,690 (1,080-2,310)

Notes: All outcomes are computed at the end of the pandemic. Costs are expressed as 2020 dollars per person. Epidemic size is expressed as a percent of the population. Columns represents scenarios without NPIs (No NPIs), NPIs without ESS systems (NPIs w/o ESS), and NPIs informed by ESS systems with varying disease incidence detection lead times relative to syndromic surveillance (NPIs + n-day ESS). For instance, scenario NPIs + 5-day ESS represents an early warning system that produces a disease incidence measure that leads syndromic surveillance by five days.

A little early warning goes a long way, but benefits are not linear



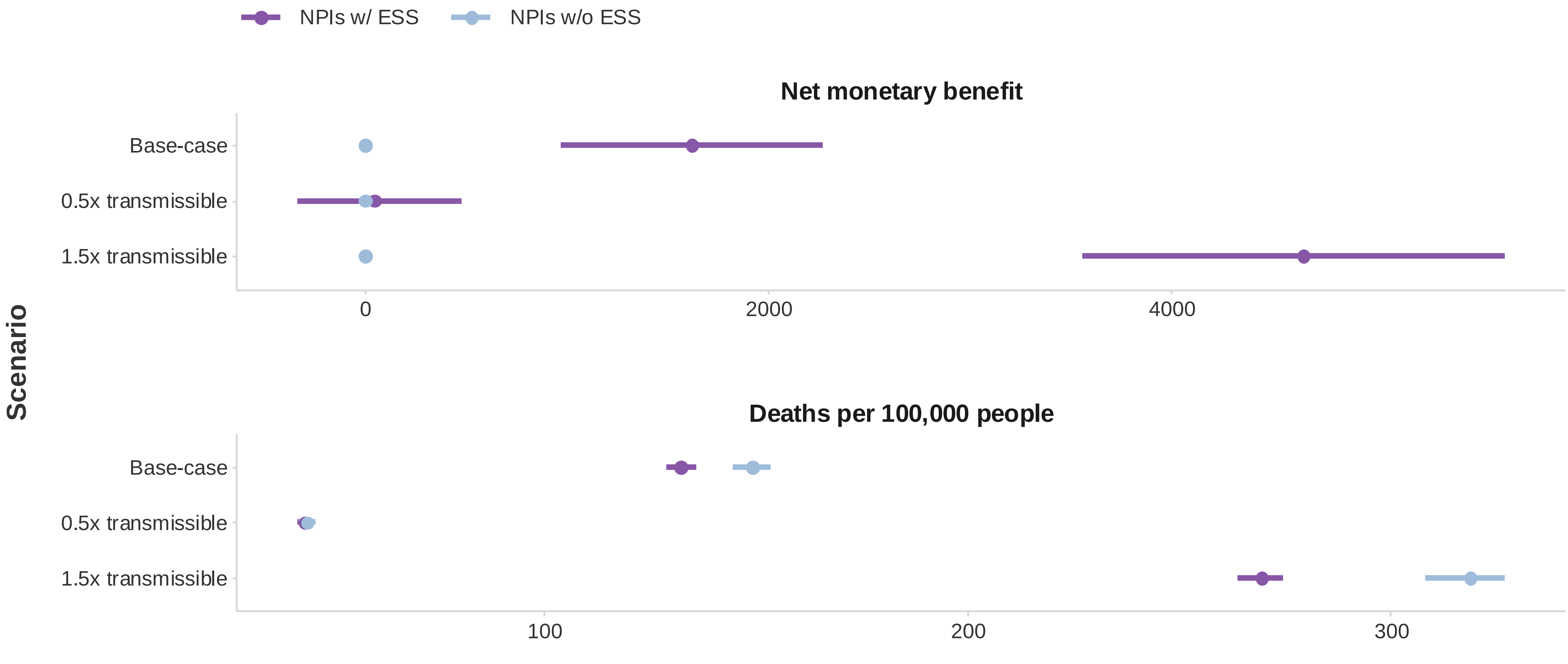
Notes: Dots represent the average value of each outcome across 1,000 replications, and 95% of the stochastic replications fall within the range represented by lines.

But how robust is this result?

what if…

the pathogen is more or less transmissible than SARS-Cov-2?

ESS value depends on transmissibility



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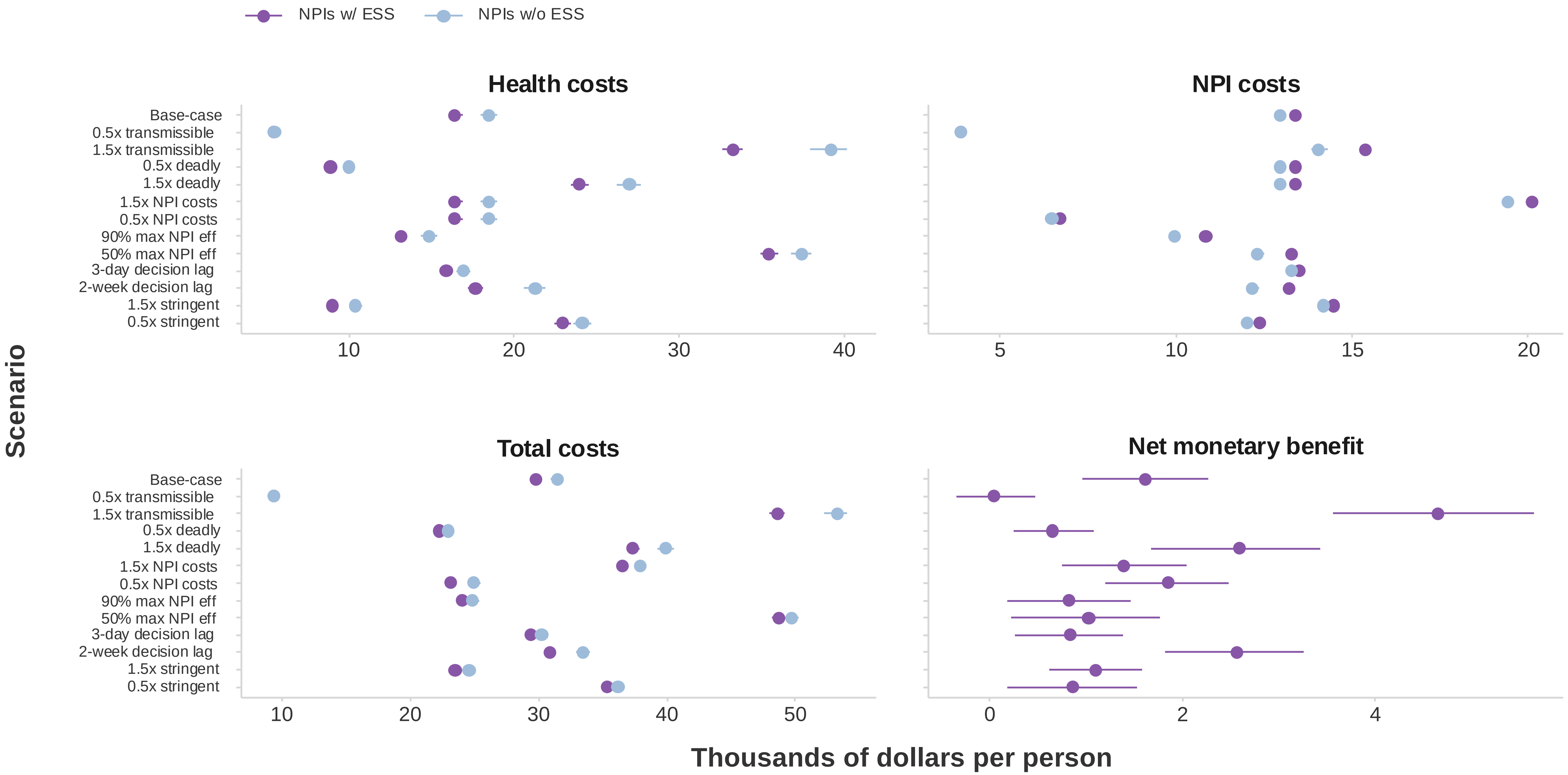
But how robust is this result?

what if…

- **transmissibility** is different
- **mortality** is different
- **NPI costs** are higher than assumed
- **NPIs are not as effective** as assumed
- **Decision makers take longer** to make decisions
- **Policymakers are not as stringent**

ESS's net monetary benefit remained positive in most scenarios



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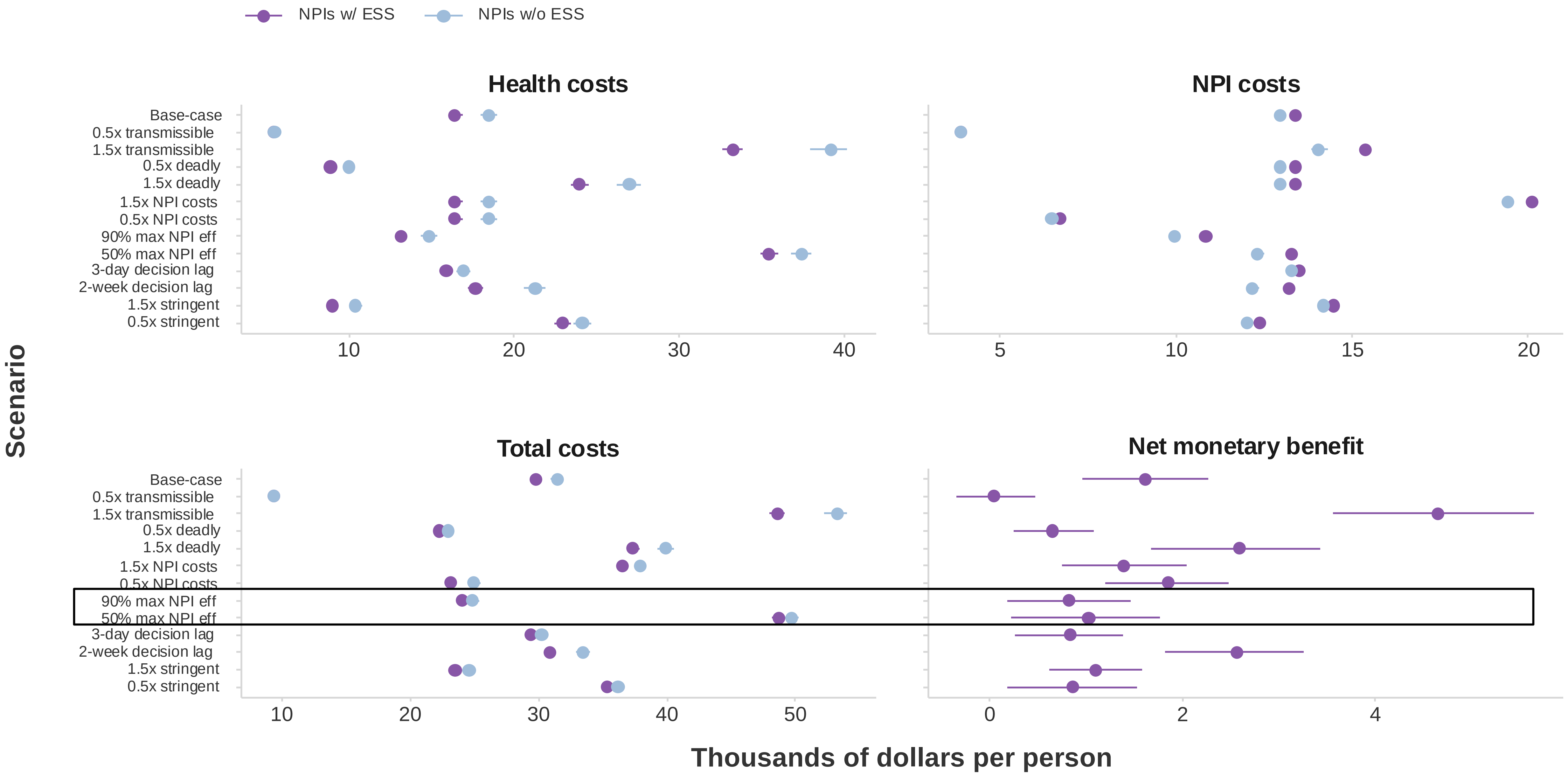

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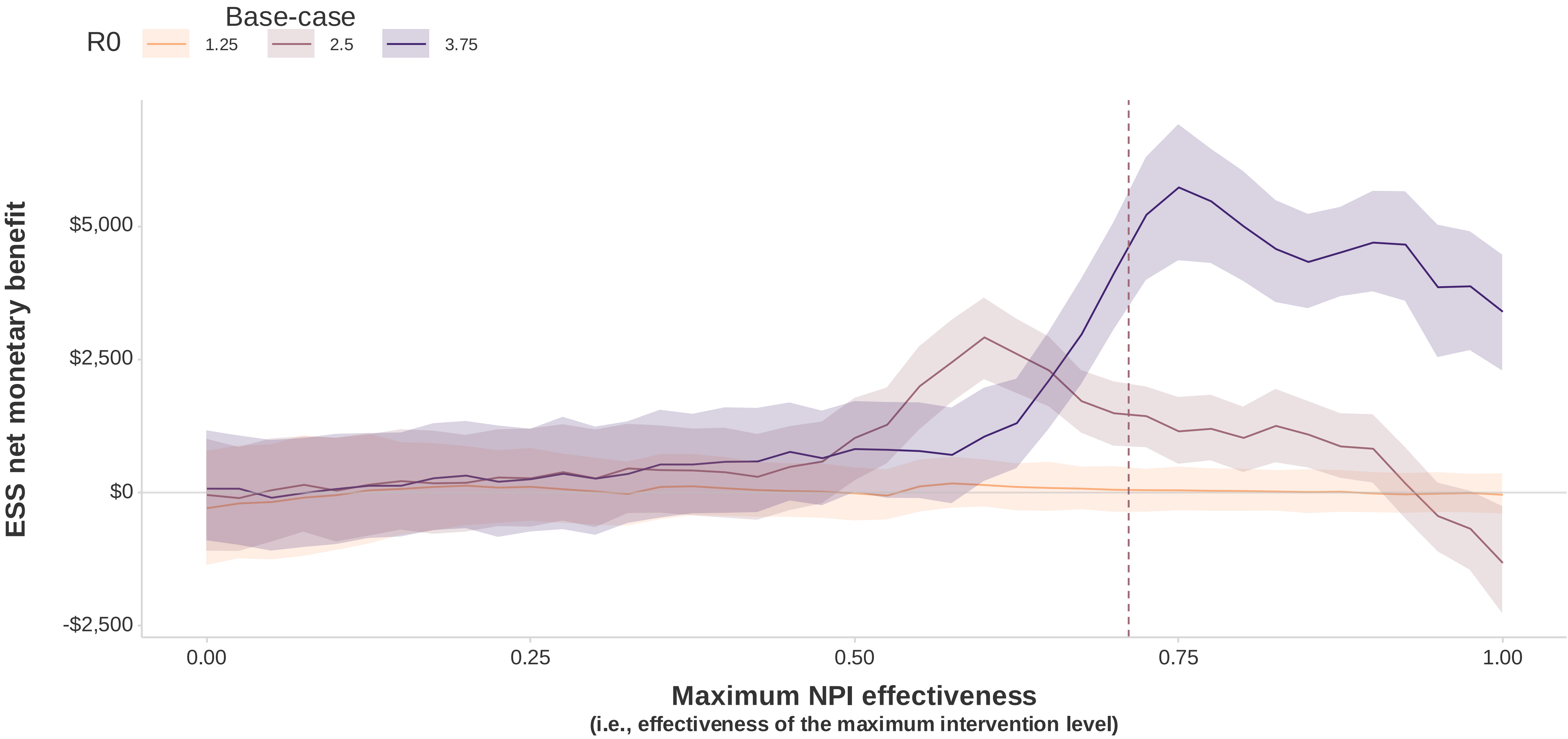
What is going on with NPI effectiveness?

Why does more *and* less NPI effectiveness implies lower ESS value?

This is not so trivial: results are not linear and not monotonic.

NPI effectiveness had a non-monotonic relationship with net monetary benefit



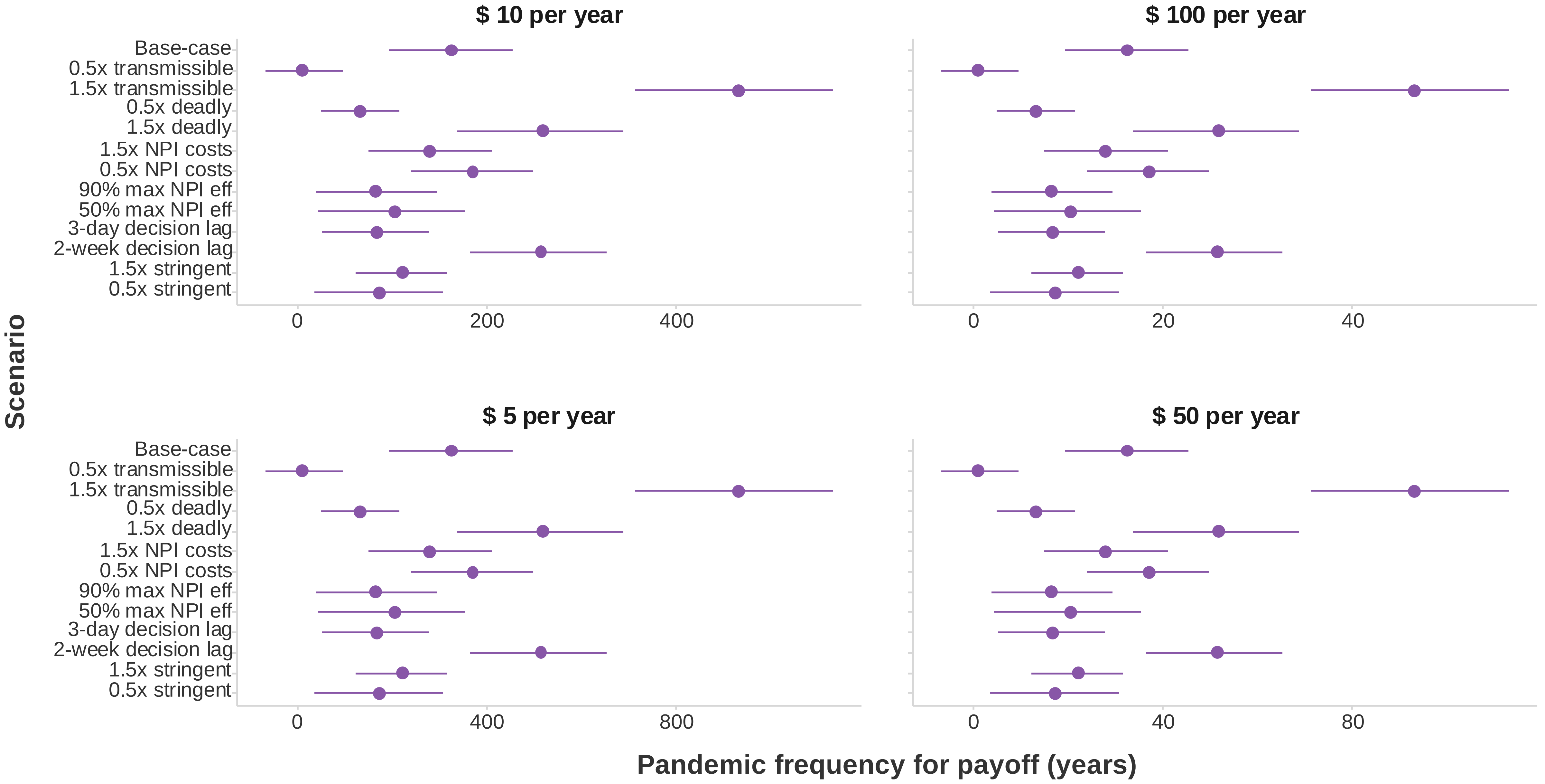
Notes: The vertical dashed line represents the NPI effectiveness in our base-case scenario (see Supplementary Methods). Lines represent the average net monetary benefit of a 5-day early warning system, and shaded areas represent 95% prediction intervals computed over 1,000 stochastic replications.

But we don’t get a new pandemic every year…

How likely does a pandemic need to be so that maintaining an ESS system operating would make sense?

ESS systems would have net-positive value even for rare pandemic events

An ESS system costing $10/yr per person can provide net-positive benefits even if a COVID-19-like pandemic happened only every ~150 years



Notes: Dots represent the minimum pandemic frequency so that the system provides net monetary benefits. The average value of each outcome across 1,000 replications, and 95% of the stochastic replications fall within the range represented by lines.

Conclusions

ESS systems provide meaningful net benefits under baseline assumptions and almost all alternative scenarios we explored. ESS…

1. Provide valuable early warning in worst-case pandemic scenarios
2. Help mitigate the effects of slow or lenient policy decisions
3. Rely on the effectiveness of the NPIs they inform
4. Deliver decreasing marginal benefits as early warning periods lengthen
5. Can have positive net benefits if permanently maintained and SARS-Cov-2-like pandemics were rare

Limitations and future work in this stream

- **Limitations:** Purposefully parsimonious model. Needs tailoring for more specific use cases.
- **What else do we want to do with this model?**
- Clarify the value of ESS systems under alternative time horizons and regimes
  - endemic vs pandemic vs elimination regimes.
  - Investigate marginal vs. total value (i.e., the value of surveilling uncovered populations).
  - Inform more practical decisions: Clarify how to respond to a specific pathogen/scenarios (i.e., H5N1 spillover) policy to a new specific pathogen.

Q: What kind of work would *you* like to see?

RAND’s work in this area is growing

Examples:

- **Ethics of ESS:** Using a structured stakeholder engagement process to develop an international ethical framework for wastewater surveillance, then testing the framework in diverse contexts (US and non-US). (If interested, please contact Laura Faherty: lfaherty@rand.org)
- **Robust Decision Making and Policy Responses**: Identify robust combinations of surveillance and policy responses (with Jonathan Ozik and others at U Chicago).
- **Interested in collaborating?** Reach out to plima@rand.org

Key Takeaways

- ESS systems could yield thousands of dollars of value per person in a new pandemic.
- The value of ESS must be evaluated in the context of the costs and benefits of the interventions it triggers.
- The value of early warning hinges on the effectiveness of the public health interventions it informs.

Questions?

plima@rand.org

Paper:

Sensitivity Analysis Results

Scenario	EWS	Deaths per 100,000 people	Health costs	NPI costs	Total costs	Net monetary benefit
Base-case	N	149 (145-153)	18,500 (18,000-19,000)	12,900 (12,800-13,100)	31,400 (31,000-31,900)	0 (0-0)
Base-case	Y	132 (129-136)	16,400 (16,000-16,900)	13,400 (13,300-13,500)	29,800 (29,400-30,200)	1,620 (967-2,270)
0.5x transmissible	N	43.9 (41.9-45.9)	5,490 (5,260-5,720)	3,880 (3,780-3,980)	9,370 (9,090-9,650)	0 (0-0)
0.5x transmissible	Y	43.4 (41.5-45.3)	5,430 (5,200-5,650)	3,900 (3,810-3,990)	9,330 (9,040-9,610)	43.5 (-341-478)
1.5x transmissible	N	319 (308-327)	39,200 (38,000-40,200)	14,000 (13,800-14,300)	53,300 (52,300-54,100)	0 (0-0)
1.5x transmissible	Y	269 (264-275)	33,300 (32,600-33,900)	15,400 (15,300-15,500)	48,600 (48,000-49,200)	4,660 (3,560-5,660)
0.5x deadly	N	74.6 (71.9-77.2)	9,990 (9,670-10,300)	12,900 (12,800-13,100)	22,900 (22,600-23,200)	0 (0-0)
0.5x deadly	Y	66.1 (63.9-68.4)	8,880 (8,620-9,150)	13,400 (13,300-13,500)	22,300 (22,000-22,500)	657 (248-1,080)
1.5x deadly	N	224 (218-229)	27,000 (26,300-27,700)	12,900 (12,800-13,100)	39,900 (39,300-40,600)	0 (0-0)
1.5x deadly	Y	198 (194-203)	24,000 (23,400-24,500)	13,400 (13,300-13,500)	37,400 (36,800-37,900)	2,590 (1,680-3,430)
1.5x NPI costs	N	149 (145-153)	18,500 (18,000-19,000)	19,400 (19,300-19,600)	37,900 (37,400-38,400)	0 (0-0)
1.5x NPI costs	Y	132 (129-136)	16,400 (16,000-16,900)	20,100 (20,000-20,200)	36,500 (36,100-36,900)	1,390 (744-2,050)
0.5x NPI costs	N	149 (145-153)	18,500 (18,000-19,000)	6,470 (6,420-6,530)	25,000 (24,500-25,500)	0 (0-0)
0.5x NPI costs	Y	132 (129-136)	16,400 (16,000-16,900)	6,700 (6,670-6,730)	23,100 (22,700-23,600)	1,850 (1,190-2,490)
90% max NPI eff	N	120 (115-124)	14,900 (14,300-15,400)	9,970 (9,840-10,100)	24,800 (24,300-25,400)	0 (0-0)
90% max NPI eff	Y	106 (103-109)	13,200 (12,800-13,500)	10,800 (10,800-10,900)	24,000 (23,700-24,400)	826 (185-1,460)
50% max NPI eff	N	303 (297-308)	37,400 (36,800-38,000)	12,300 (12,200-12,500)	49,700 (49,200-50,300)	0 (0-0)
50% max NPI eff	Y	286 (281-291)	35,400 (34,900-36,000)	13,300 (13,200-13,400)	48,700 (48,200-49,300)	1,030 (223-1,770)
3-day decision lag	N	137 (133-140)	16,900 (16,500-17,300)	13,300 (13,200-13,400)	30,200 (29,800-30,600)	0 (0-0)
3-day decision lag	Y	128 (125-131)	15,900 (15,500-16,300)	13,500 (13,400-13,600)	29,400 (29,000-29,800)	837 (259-1,390)
2-week decision lag	N	172 (166-177)	21,300 (20,600-21,900)	12,200 (12,000-12,400)	33,500 (32,900-34,000)	0 (0-0)
2-week decision lag	Y	142 (139-146)	17,700 (17,200-18,100)	13,200 (13,200-13,300)	30,900 (30,500-31,300)	2,570 (1,820-3,260)
1.5x stringent	N	83.9 (80.6-87.1)	10,400 (10,000-10,800)	14,200 (14,100-14,300)	24,600 (24,200-25,000)	0 (0-0)
1.5x stringent	Y	72.7 (70.3-75.2)	9,020 (8,740-9,320)	14,500 (14,400-14,500)	23,500 (23,200-23,800)	1,100 (616-1,580)
0.5x stringent	N	195 (190-199)	24,100 (23,600-24,700)	12,000 (11,900-12,100)	36,200 (35,700-36,700)	0 (0-0)
0.5x stringent	Y	185 (181-189)	22,900 (22,500-23,400)	12,400 (12,300-12,500)	35,300 (34,900-35,800)	860 (178-1,530)

Notes: All outcomes are computed at the end of the first year of the pandemic. Costs are expressed as 2020 dollars per person. Epidemic size is expressed as a percent of the population. Uncertainty intervals encompass 95% of stochastic replications.

Baseline Parameter Values

Parameter	Description	Value
σ	Time from exposed to pre-symptomatic (latent period) [1/days]	3.3^{-1} days
δ	Time from pre-symptomatic to infected (incubation period – latent period) [1/days]	3.5^{-1} days
γ	Time from infected to removed [1/days]	7^{-1} days
ρ	Proportion of asymptomatic cases	35%
r_{t0}	Age-adjusted IFR at pandemic onset	0.733%
p_{r^*}	Percent reduction in the IFR at time t_{r^*}	40%
t_{r^*}	Time at which IRR reaches pre-vaccine plateau (days after pandemic onset).	150
R_0	Basic Reproductive number	2.5
$VLSY$	Value of a statistical life year (2020 US dollars)	$240,676
VSL	Value of a statistical life (millions of 2020 US dollars)	11.4
C_{max_npi}	Cost of the most-stringent NPI level as a fraction of GDP per capita	25%
Y	GDP per capita (used to approximate economic costs of NPIs).	$76,000
c_{lag}	Baseline time from symptom onset to case confirmation (days)	6
p	Case ascertainment rate for conventional surveillance.	30%
τ	Incremental reduction in transmission rates per non-pharmaceutical intervention level	14.2%
d	Incidence rate per 100,000 people (adjusted for case ascertainment rate) necessary for the introduction of nonpharmaceutical interventions	17.9
k_h	Proportion of mixing at home	0.18
k_{wt}	Proportion of mixing at work and travel, which may cross county lines	0.46
k_o	Proportion of mixing at other modes (not crossing county lines)	0.36
a_{up}	Time lag (in days) to increase NPI intervention levels, which accounts for decision and implementation delays (3 minimum)	7
a_{down}	Time lag (in days) to decrease NPI intervention levels, which accounts for decision and implementation delays	14
L_{max}	Maximum intervention level	5

Notes: Parameter values reflect the COVID-19 pandemic assumptions.

[i] Age-adjusted IFR estimate at the outset of the pandemic for the United States. We use age-adjusted IFR estimates as to reflect the current population distribution, which is consistent with the use of VSL for valuing the costs of interventions.

[ii] Virtually all the 40% reduction in IFR observed during the first months of the COVID-19 pandemic in the US was observed during the first six months. IRR is assumed to evolve following at logistic function set to start at r at the beginning of the pandemic, reaches $(1-p_{r^*})r$ at time t_{r^*}, and passes at $(1-0.5p_{r^*})$ at time $t_{r^*}/2$.

[iii] Median of estimates for most-stringent intervention level from Welburn and Strong across all US states.

[iv] Assuming case confirmation is the epidemiological indicator used for decisionmaking. A study comparing the timeliness of alternative epidemiological signals found that case data leads hospital admissions data by about one day, hence the use of hospitalization data would not meaningfully change these results.

[v] Held constant throughout the simulation. Although the case ascertainment rate is not constant, it has been estimated between 20% and 40% throughout the pandemic in the United States.

[vi] See the calibration section. The calibrated middle point is also consistent with the middle range of a literature review that found the effectiveness of the most-stringent NPIS in the US to be in the 70%-80% range.

Methods overview

- **Method:** Simulate a COVID-19-like pandemic for one year across multiple jurisdictions using a discrete-time stochastic model
  - Progression across S, E, P, I, A, R states with binomial outflows
  - Parameters based on the first year of COVID-19 in the US when possible
    - Population and mixing, disease progression, transmissibility, fatality (and decreasing fatality rates), policy decision lags, NPI costs
- **Outcomes:** mortality and illness (VSLY), NPI economic costs

Additional assumptions

- **ESS systems** reduce estimated incidence lags and case ascertainment bias
- **NPIs** can be set at 5 levels at fixed decision frequencies
  - NPI effectiveness and thresholds are calibrated based on number of deaths per 100,000 and median number of days spent at the highest intervention level
- **Sensitivity analyses:** test parameters at baseline (mostly US COVID-19 levels) and at levels 0.5x and 1.5x the baseline