Presented at the ICEAA 2025 Professional Development & Training Workshop - www.iceaaonline.com/atl2025

Cost Vs. Contagion: Evaluating the Effect of Public Health Investment Strategies on Future Pandemics

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Delivering clarity from complexity

SIRIUS ANALYSIS

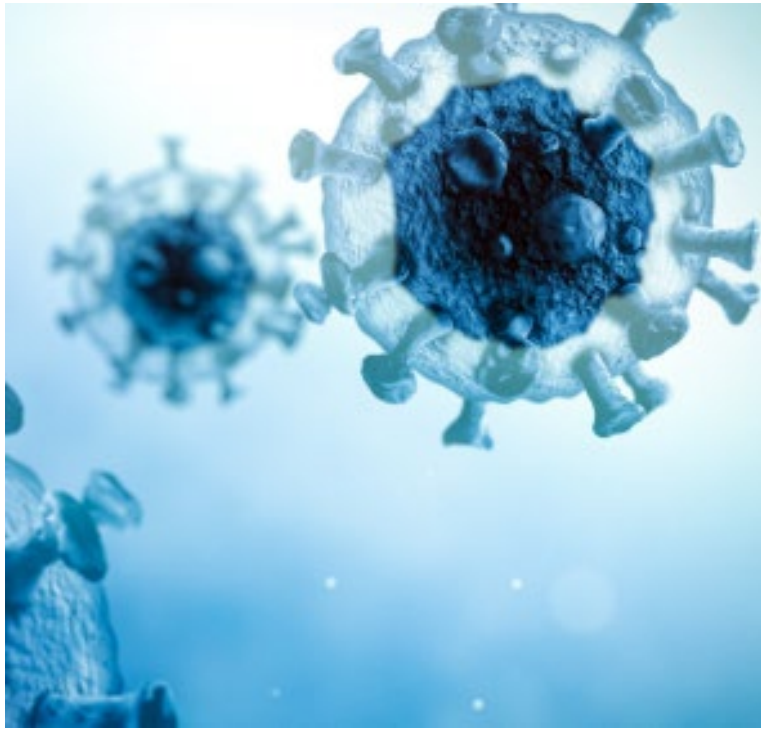
Contents

Company Overview

- **Established in 2020**
- **100 employees**, growing to 110 by the end of 2025
- **Sirius Analysis Inc** incorporated in Virginia, USA September 2024
- Turnover **more than trebled** in the past 2 years

Introduction

- Epidemiology blown into the spotlight during COVID-19 Pandemic
- Over 7 million confirmed deaths globally before April 2024. Just under the population of Hong Kong
- US federal government provided c. $4.6 trillion dollars to national COVID-19 response and relief
- Unprecidented global event
- Oxford dictionary defines epidemiology as “the scientific study of the spread and control of diseases”
- Assists in political decision making of interventions
- COVID-19 highlighted the importance of quick and decisive action
- How do we act effectively while minimising damage to the economy?



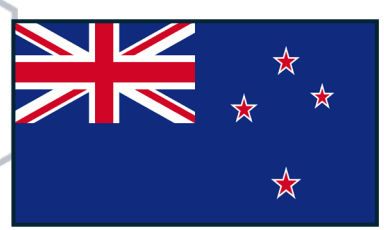
What Questions is This Study Answering?

- What measures did countries implement during the COVID-19 pandemic?
- In a city the size of New York City, in the year 2025:
  - How much would these countries have spent implementing their mitigation strategies?
  - How effective would they have been?
  - What is the economic effect?
- This study is **comparative** and seeks to explore these approaches on an even playing field.
- Complex, multi-dimensional problem!

Population of 8.48 million

Which Countries?

New Zealand



Strict, early action. Large economic investment. High intervention

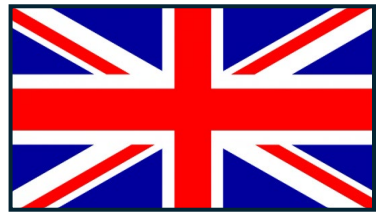
Sweden

Minimal action compared with Europe. Herd immunity strategy

USA

Quick vaccine rollout. Various responses over states. Average lockdown and testing

UK



Slow initial response. Strong vaccine rollout and major business support.

South Korea

Strict contact tracing, quarantine and border controls

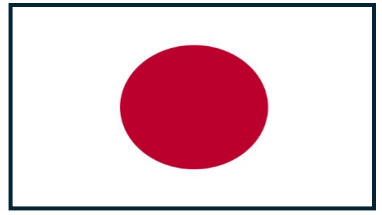
South Africa

Strict early response. Slow vaccine rollout.

Brazil

Inconsistent response across states. Low economic support. high case numbers

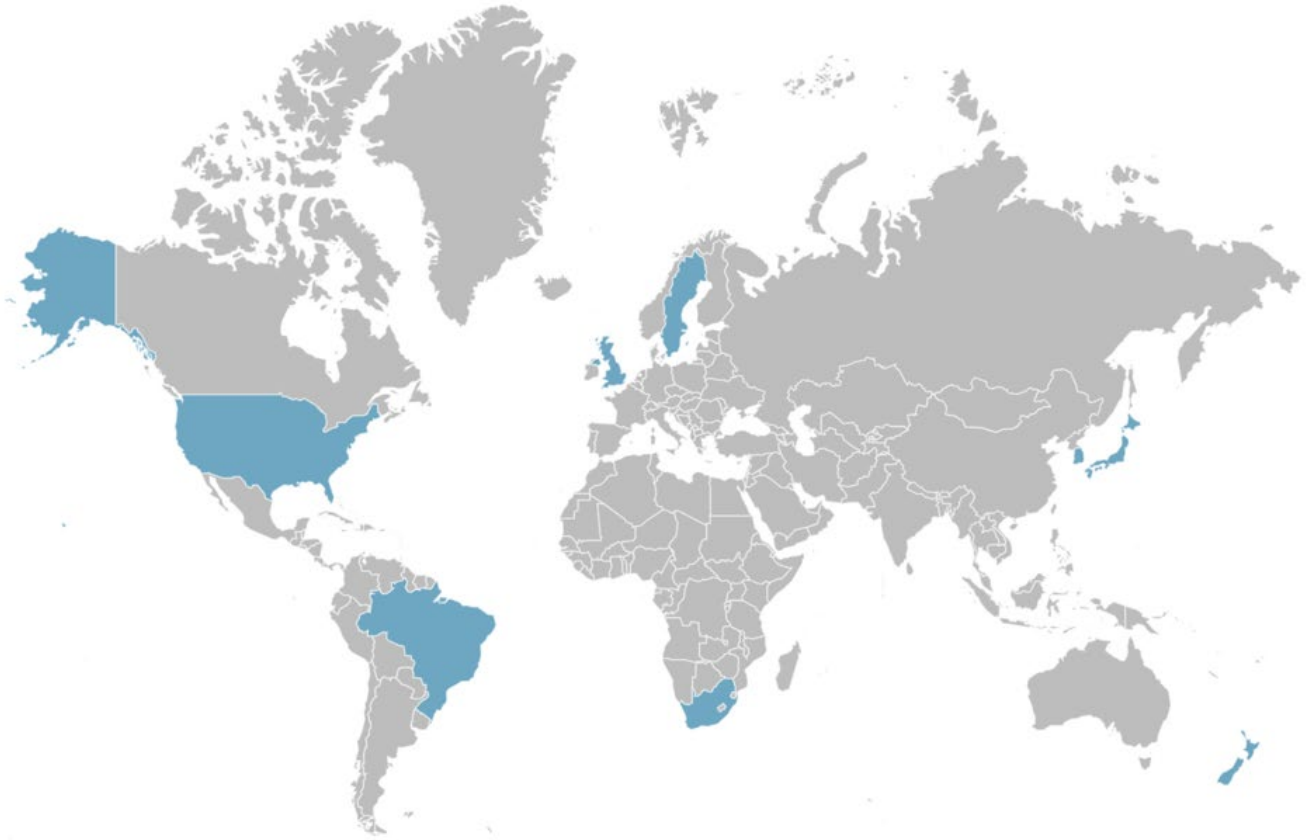
Japan



Less strict lockdowns but quick and effective action. Low track & trace

Why these countries?

- More accurate data recording (Not perfect!)
- Variety of approaches
- Different economic investments
- Variety in the levels of success
- Geographical spread
- These 8 countries between them represent approaches taken by most of the world



Methodology

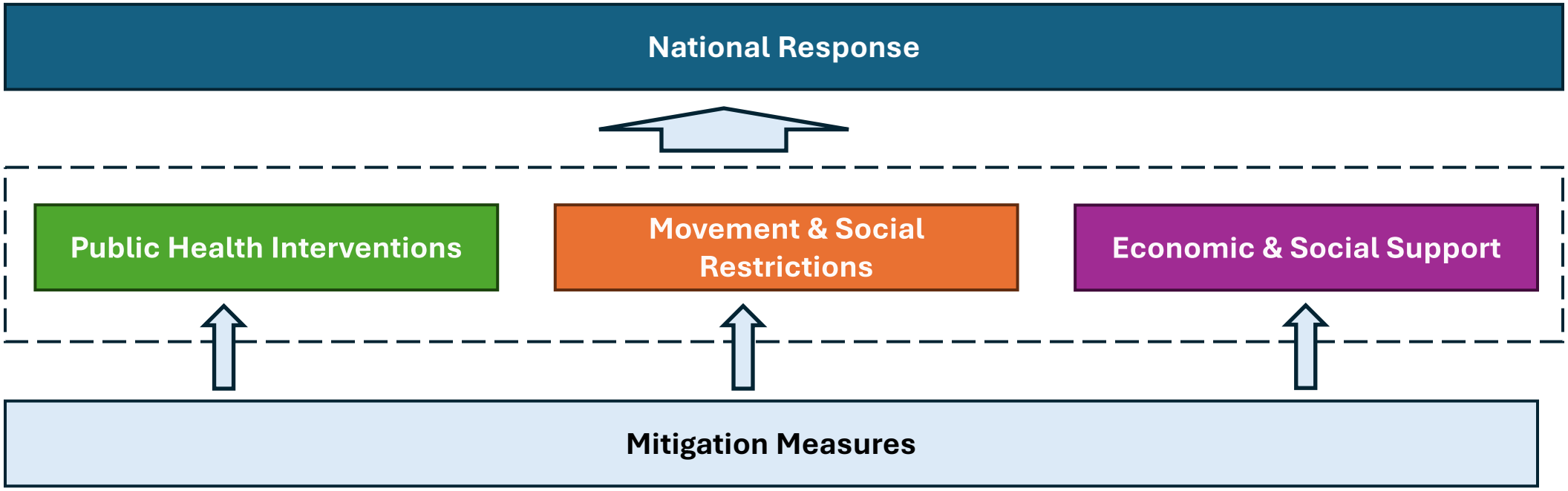
- Develop architecture and form assumptions
- **Cost:**
  - Develop cost breakdown structure, gather cost data and grade data readiness (Cost Data and Assumptions List)
  - Build up base minimum, most likely and maximum costs for the mitigation measures
  - Populate national mitigation matrix, scoring each countries effort at implementing the included mitigation measures. Assign cost scalars to these scores
  - Adjust costs for each country, run Monte Carlo simulation and output percentile costs
- **Effectiveness:**
  - Build SEIRS compartment model
  - Derive differential equations and solve for each country
  - Discuss nature and stability
- **Results and conclusions:**
  - Present results and compare Cost Effectiveness

Assumptions

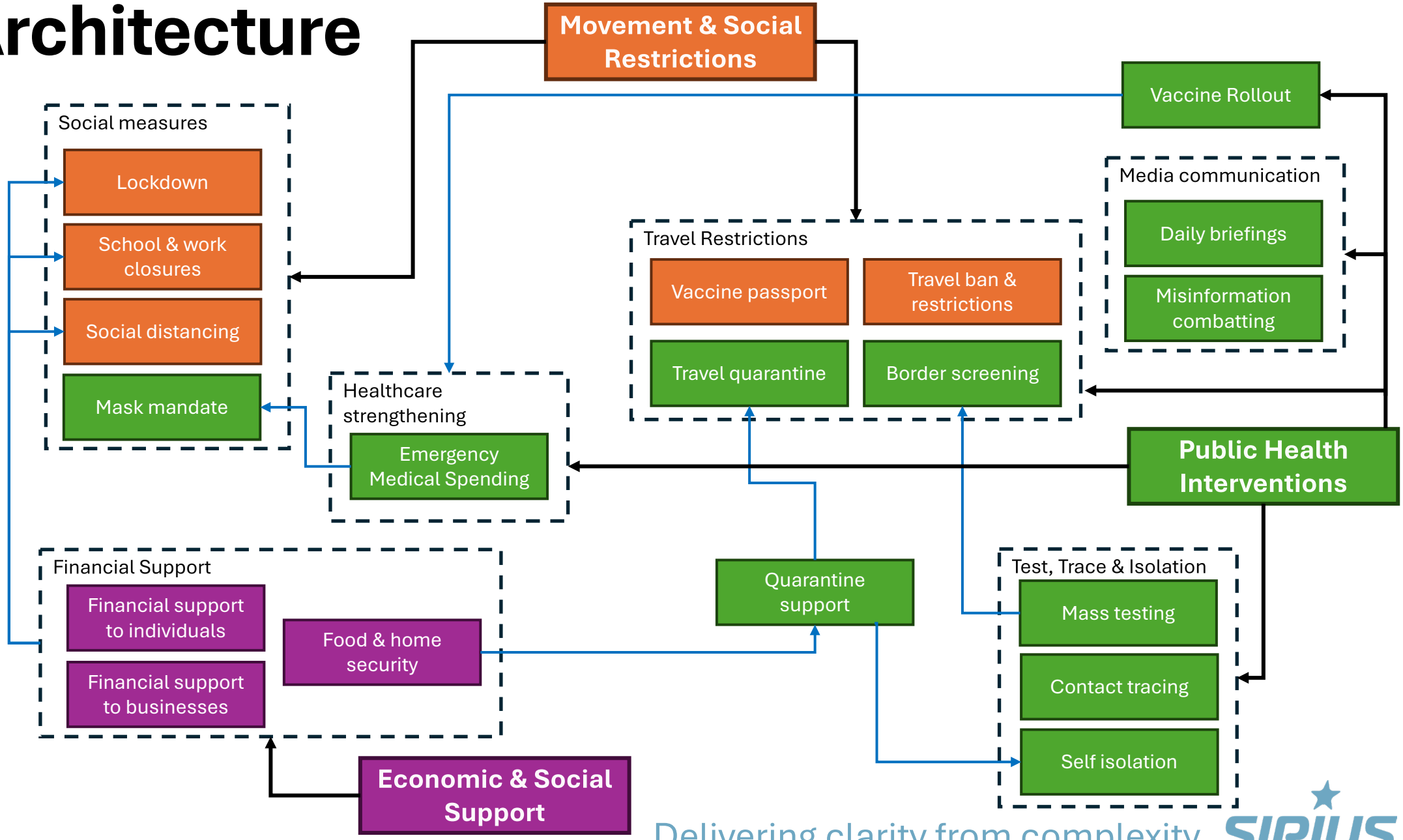
- Beginning in 2025, Spanning over a period of 1 year
- Measures implemented and disease acts over this year
- Costs will be presented in 2025 US dollars
- New outbreak will require minimal time to adjust vaccines and tests. Measures implemented immediately
- Measures implemented will be the same as those used in the COVID-19 pandemic
- Not all measures incur a direct cost. Others overlap in cost and are included in government emergency spending and financial and support
- Economic effect of measures will not be directly analysed but will be discussed in trade-off
- Measure relevant assumptions will noted in later slides

National Responses

- Individual **national responses** generally consisted of similar **mitigation measures** (e.g. lockdown, contact tracing etc), but varied massively in the severity and timing
- These **measures** can be grouped into 3 **categories**: Public Health Interventions, Movement & Social Restrictions and Economic & Social Support
- Constructing a detailed architecture will allow us to visualise relationships between **measures**, derive a general Cost Breakdown Structure (CBS) and form assumptions.



Architecture



Cost Breakdown

Public Health Interventions	Vaccine rollout	Vaccine rollout
	Test, Trace & Isolation	Mass testing
		Contact tracing
		Overheads
	Healthcare strengthening	Emergency medical spending
Economic & Social Support	Financial Support	Financial support

Vaccine Rollout

- Vaccine research, development and purchasing out of scope
- Costs built bottom up
- Vaccines administered at set sites or via outreach. Outreach is more expensive due to extra transport and facility requirements
- Cold supply chain and storage requirements. (2-8°C or 35-46°F)
- Fixed costs include planning & coordination, behavioural data collection, cold chain equipment.
- Variable on dose include recurring cold chain, transport, waste management and vaccine certificates
- Outreach specific costs include extra transport and per diem, variable on dose numbers

- Facility costs include pharmacovigilance, training and community awareness
- Low-mid DRL (80% min, 150% max). Previous cost estimate during 2020 pandemic
- Most Likely cost c. $194 million for New York City, 2025

Test & Trace

3 areas of consideration: Test, Trace and overheads (common costs)

Bottom-up cost build

Several types of testing: Mass testing (Rollout of lateral flow testing to the wider population), Tests processed for healthcare staff and patients with medical need, Lab tests for wider population (including care homes) and Antibody testing

Testing also includes Prevalence testing, extra lab costs and test specific supply and logistics

Tracing made up a smaller portion of the costs. Accounted for Track & Trace software

Common overheads included Joint Biosecurity Centre, corporate services, Contain (activities to identify local outbreaks and support local response), Digital and Data, Innovation and partnerships

Assumptions made on the distribution between variable on population and fixed. Variable costs normalised to New York City sized Population

Low-mid DRL (80% min, 150% max). Actuals taken, unaudited management data from 2020-21

Most Likely cost c. $8.6 billion for New York City, 2025

$2.7 Bn ML on Overheads

$5.0 Bn ML on Testing

$0.9 Bn ML on Tracing

Emergency Medical Spending and Financial Support

Flat injections into existing services

Abundance of data internationally, very reliant on previous infrastructure. Difficult to establish specific cost avenues

Emergency healthcare refers to extra funding required to deal with Pandemic. E.g. extra PPE, hospital capacity, extra personnel, equipment.

Financial support includes support to individuals and businesses. Taken from extra spending to economic affairs between 2020/21 in UK. Most attributed to financial support schemes

Cost for Emergency Healthcare derived from excess Healthcare spend in the UK above previous year during 2020/21

Low DRL (70% min and 170% max)

Financial Support

Most Likely cost c. $26.0Bn for 2025 New York City

Emergency Medical Spending

Most Likely cost c. $10.9Bn for 2025 New York City

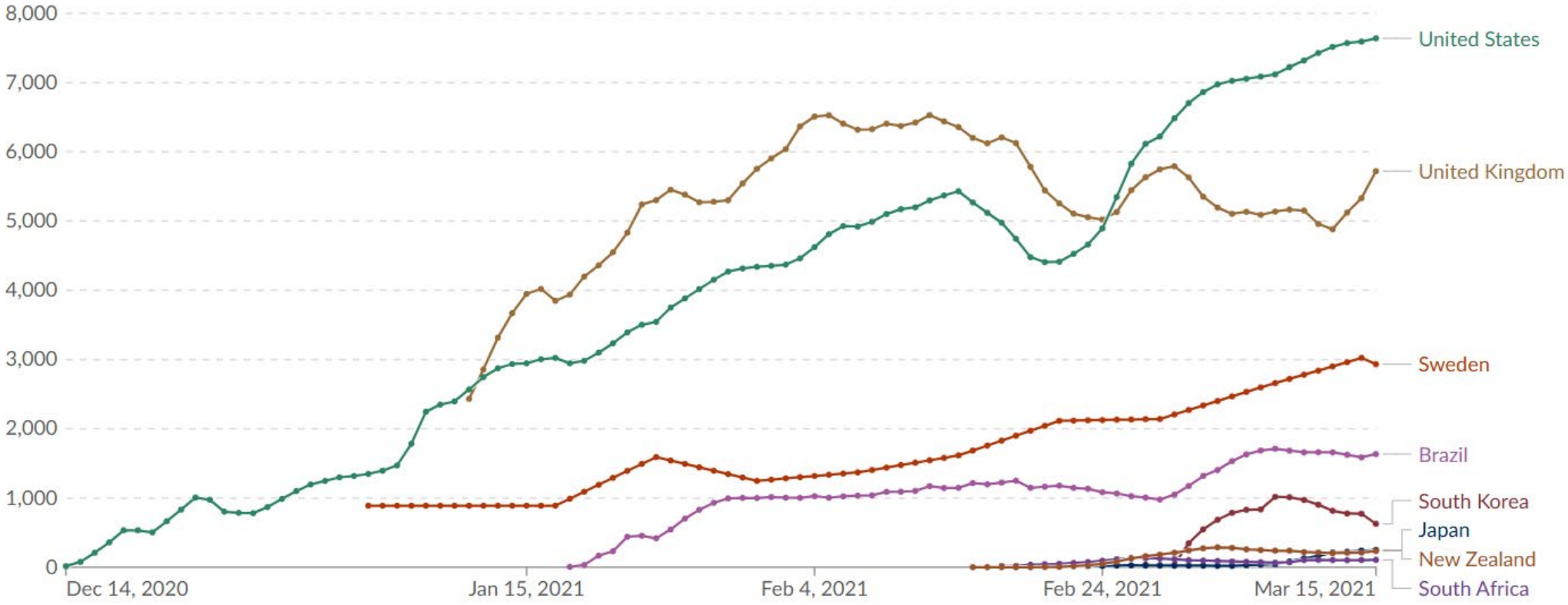
Mitigation Matrix

- Measures scored 1-5 for each country (minimal to substantial effort)
- Scores will be used to scale costs
- Lockdown and border restrictions will be used later

Measures	USA	UK	New Zealand	Sweden	South Korea	South Africa	Brazil	Japan
Lockdown	3	4	5	1	4	3	2	3
Border restrictions	3	3	5	1	4	3	1	4
Vaccine rollout	4	5	4	3	4	2	3	3
Test	3	3	3	2	5	3	3	2
Trace	2	3	4	2	5	3	2	3
Financial Support	3	5	4	3	3	2	2	4
Emergency Healthcare	3	4	5	3	4	2	2	3

Daily COVID-19 vaccine doses administered per million people

7-day rolling average. All doses, including boosters, are counted individually.



Graph from Our World in Data

Cost Scalar Tables

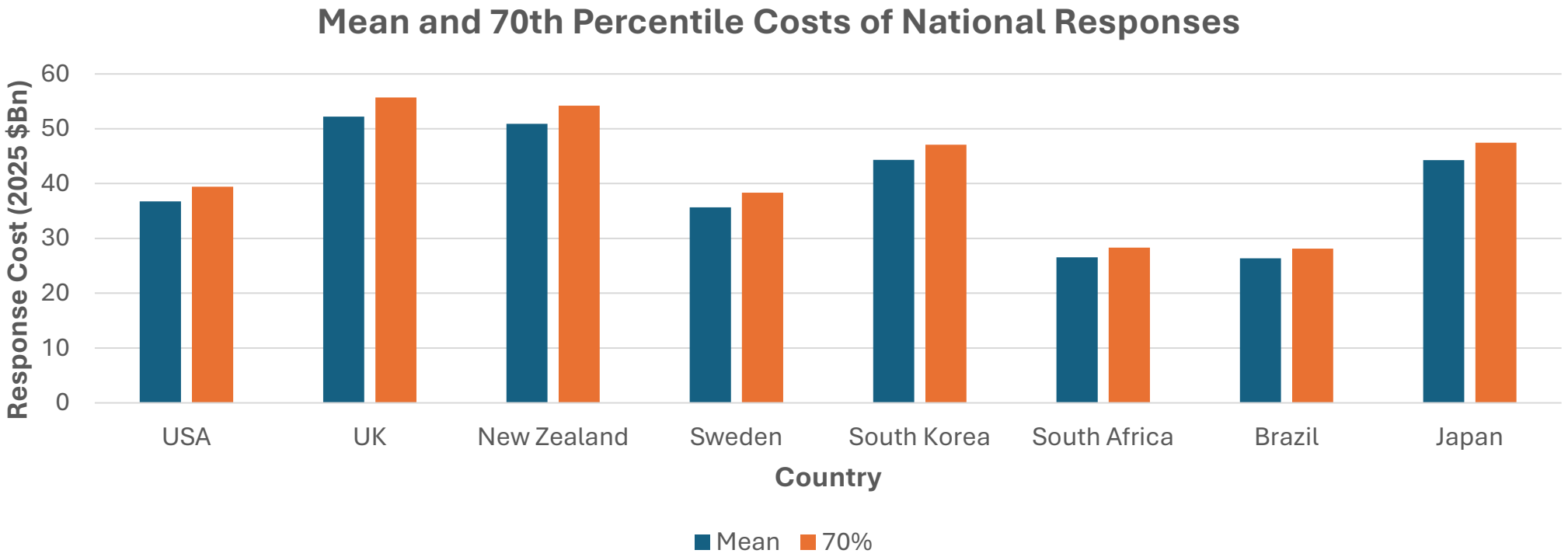
Score	Vaccine		
	Min	ML	Max
1	0.5	0.55	0.65
2	0.6	0.65	0.7
3	0.7	0.75	0.8
4	0.8	0.9	0.95
5	0.95	1	1.1

Score	Test & Trace		
	Min	ML	Max
1	0.67	0.73	0.87
2	0.80	0.87	0.93
3	0.93	1.00	1.07
4	1.07	1.20	1.27
5	1.27	1.33	1.47

Score	Financial Support		
	Min	ML	Max
1	0.15	0.2	2.5
2	0.3	0.35	0.45
3	0.5	0.6	0.7
4	0.85	0.9	0.95
5	0.95	1	1.05

Score	Emergency Healthcare		
	Min	ML	Max
1	0.17	0.22	2.78
2	0.33	0.39	0.50
3	0.56	0.67	0.78
4	0.94	1.00	1.06
5	1.06	1.11	1.17

Cost Results

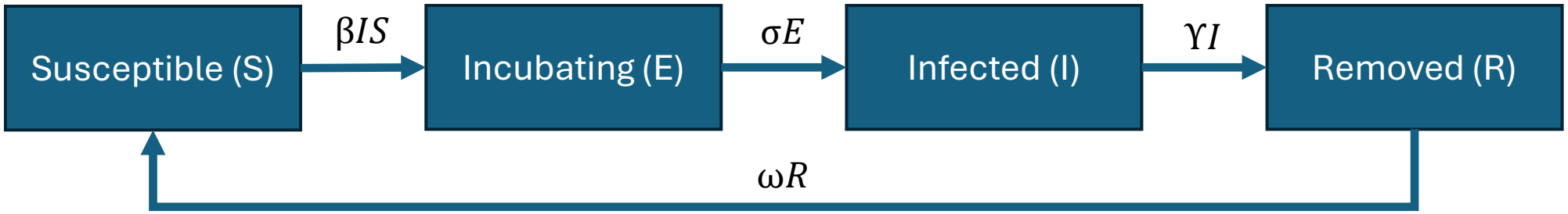


	Cost Outputs (2025 $Bn)							
	USA	UK	New Zealand	Sweden	South Korea	South Africa	Brazil	Japan
Mean	36.76	52.24	50.93	35.67	44.33	26.57	26.39	44.27
70%	39.45	55.73	54.19	38.35	47.09	28.32	28.15	47.47
90%	43.63	61.33	59.42	42.63	51.68	31.29	31.12	52.60

SIR Compartment Models

- We can visualise a disease by classifying the population by their infection status. Are they *Susceptible, Infected* or *Removed* (SIR)*?*
- Arrows indicate a movement from one category to another over time
- Categories represent a **proportion** of the population. Such that: $S + I + R = 1$
- We make assumptions to simplify the model:
  - No demography, immigration or emigration
  - Homogenous population
  - Individuals fall into **exactly** 1 of the compartments
  - Constant parameters
  - No external factors on disease

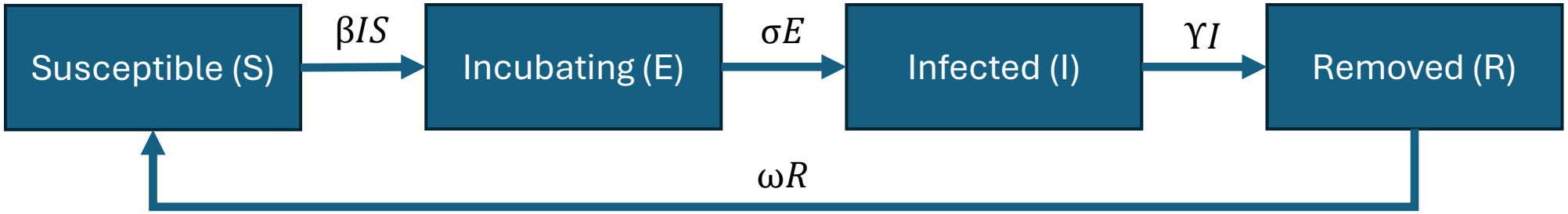
Constructing a Model for COVID 19



β	σ	Υ	ω
Infection	Incubation	Recovery	Waning Immunity

- Addition of a category for *Incubating* individuals. They are infected but haven't fully developed the disease
- *Incubating* individuals are asymptomatic, not infectious, and remain in the category for a period of time before becoming fully infectious.
- Individuals remain infected for a certain amount of time before moving to removed
- Addition of arrow connecting R to S. Waning immunity over time

Deriving Equations



From assumptions, we have $1 = S + E + I + R$ and $\frac{dS}{dt} + \frac{dE}{dt} + \frac{dI}{dt} + \frac{dR}{dt} = 0$

- $\frac{dS}{dt}$ =Waned immunity - Becoming initially infected
- $\frac{dE}{dt}$ =Becoming initially infected – Becoming fully infectec
- $\frac{dI}{dt}$ =Becoming fully infected –Recovering
- $\frac{dR}{dt}$ =Recovered – Waned immunity

- $\frac{dS}{dt} = -\beta SI + \omega R$
- $\frac{dE}{dt} = \beta SI - \sigma E$
- $\frac{dI}{dt} = \sigma E - \Upsilon I$
- $\frac{dR}{dt} = \Upsilon I - \omega R$

Solving the Equations

- We have: $\frac{dS}{dt} + \frac{dE}{dt} + \frac{dI}{dt} + \frac{dR}{dt} = 0$. Hence, we can set our equations to 0 and solve for our variables
- Trivial disease free solution exists at $(S, E, I, R) = (1,0,0,0)$
- Endemic Solution exists at

$$(S, E, I, R) = \left(\frac{\Upsilon}{\beta}, \frac{\Upsilon}{\sigma} I, \frac{1 - \frac{\Upsilon}{\beta}}{\frac{\Upsilon}{\sigma} + 1 + \frac{\Upsilon}{\omega}}, \frac{\Upsilon}{\omega} I\right)$$

- This is a little much to look at! We substitute in real values

Disease Parameters

- Wide variety in average estimated times from COVID exposure to symptom display
- Wide variety between variants. Omicron has an estimated incubation time of only 3 days. Shorter than the previous variants
- Assume we assess
  - Time spent incubating (E) is 4.5 days
  - Time spent Infected (I) is 7 days
  - Immunity wanes after 6 months

Parameter	Symbol	Value
Incubation	**σ**	1.56
Infection	**γ**	1.00
Immunity	**ω**	0.04

- Assessing time in weeks, we normalise these values to usable parameters
- Infection rate can be calculated from the infamous "$\boldsymbol{R_0}$" number. The average number of people a single person will infect at time 0. (No prior immunity. "Patient 0")
- Assume a base $\boldsymbol{R_0}$ value of **3**. We refer to the national mitigation matrix to scale this R to our countries

Calculating Infection Parameters

Measures	USA	UK	New Zealand	Sweden	South Korea	South Africa	Brazil	Japan
Lockdown	3	4	5	1	4	3	2	3
Border restrictions	3	3	5	1	4	3	1	4
Vaccine rollout	4	5	4	3	4	2	3	3
Test	3	3	3	2	5	3	3	2
Trace	2	3	4	2	5	3	2	3
Financial Support	3	5	4	3	3	2	2	4
Emergency Healthcare	3	4	5	3	4	2	2	3

- In a similar fashion to how we adapted the cost scalars, we scale the R_0 based on the measures implemented by the countries. From this we can calculate our infection parameters
- We assess the most prominent measures at controlling the virus

Measure Reduction Matrix

Measure					
Score	**Vaccine rollout**	**Test**	**Trace**	**Lockdown**	**Border restrictions**
1	5%	1%	1%	7%	1%
2	10%	3%	2%	14%	3%
3	20%	6%	4%	21%	6%
4	30%	10%	7%	28%	10%
5	40%	15%	10%	35%	15%

R_0 /β							
USA	**UK**	**New Zealand**	**Sweden**	**South Korea**	**South Africa**	**Brazil**	**Japan**
1.44	1.10	1.01	2.10	1.04	1.81	1.88	1.59

- Percentiles are multiplicative, **Not** additive
- Infective period is a week. In this case, $R_0 = \beta$.
- We can now calculate our Endemic Solutions and gain an insight into their stability

Disease Results

Country	S	E	I	R
USA	69.61%	0.71%	1.10%	28.58%
UK	90.96%	0.21%	0.33%	8.50%
New Zealand	98.59%	0.03%	0.05%	1.33%
Sweden	47.61%	1.22%	1.90%	49.28%
South Korea	96.06%	0.09%	0.14%	3.71%
South Africa	55.27%	1.04%	1.62%	42.07%
Brazil	53.13%	1.09%	1.70%	44.09%
Japan	62.93%	0.86%	1.34%	34.86%

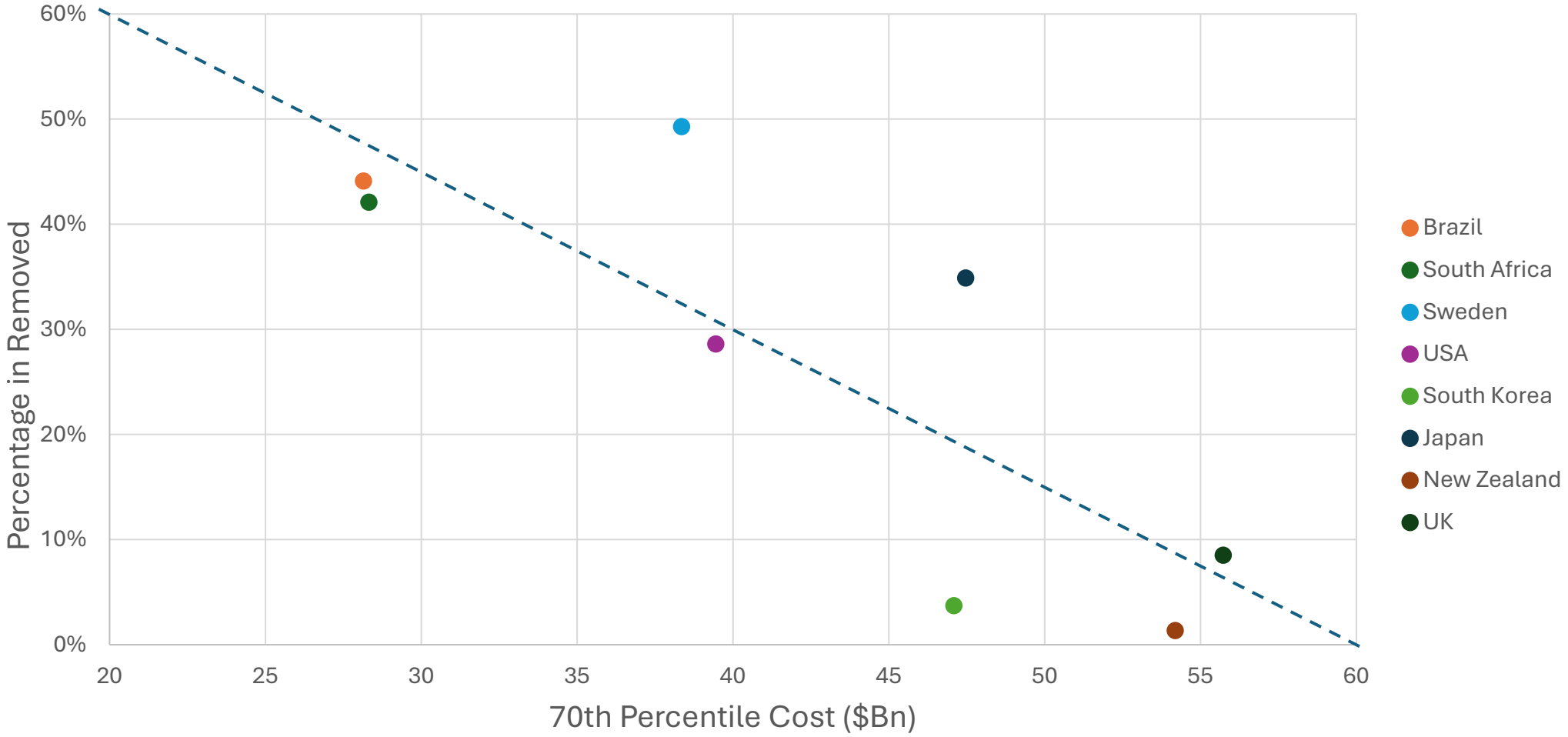
Rank	Country
1	New Zealand
2	South Korea
3	UK
4	USA
5	Japan
6	South Africa
7	Brazil
8	Sweden

- Definition of “Effectiveness” was left deliberately ambiguous!
- R includes deaths. $E + I$ is the proportion of with the virus. By any metric, New Zealand are most effective at containing the virus
- All these Endemic states have an “**Unstable element**”.

Results & Conclusions

Country	70th Percentile Cost ($Bn)	Removed Percentage
USA	39.45	28.58%
UK	55.73	8.50%
New Zealand	54.19	1.33%
Sweden	38.35	49.28%
South Korea	47.09	3.71%
South Africa	28.32	42.07%
Brazil	28.15	44.09%
Japan	47.47	34.86%

Cost Effectiveness results



Score Table

Country	Cost Rank	Effectiveness Rank	Potential Economic Impact
	1-8 (Cheapest-Expensive)	1-8 (Best-Worst)	Very low- Very High
USA	4	4	mid
UK	8	3	high
New Zealand	7	1	v.high
Sweden	3	8	v.low
South Korea	5	2	high
South Africa	2	6	mid
Brazil	1	7	low
Japan	6	5	high

- This study excluded economic effect. We can take a high-level look by assessing the stringency of measures which restrict trade and local economy
- I leave it to the audience to determine Cost-Effectiveness!

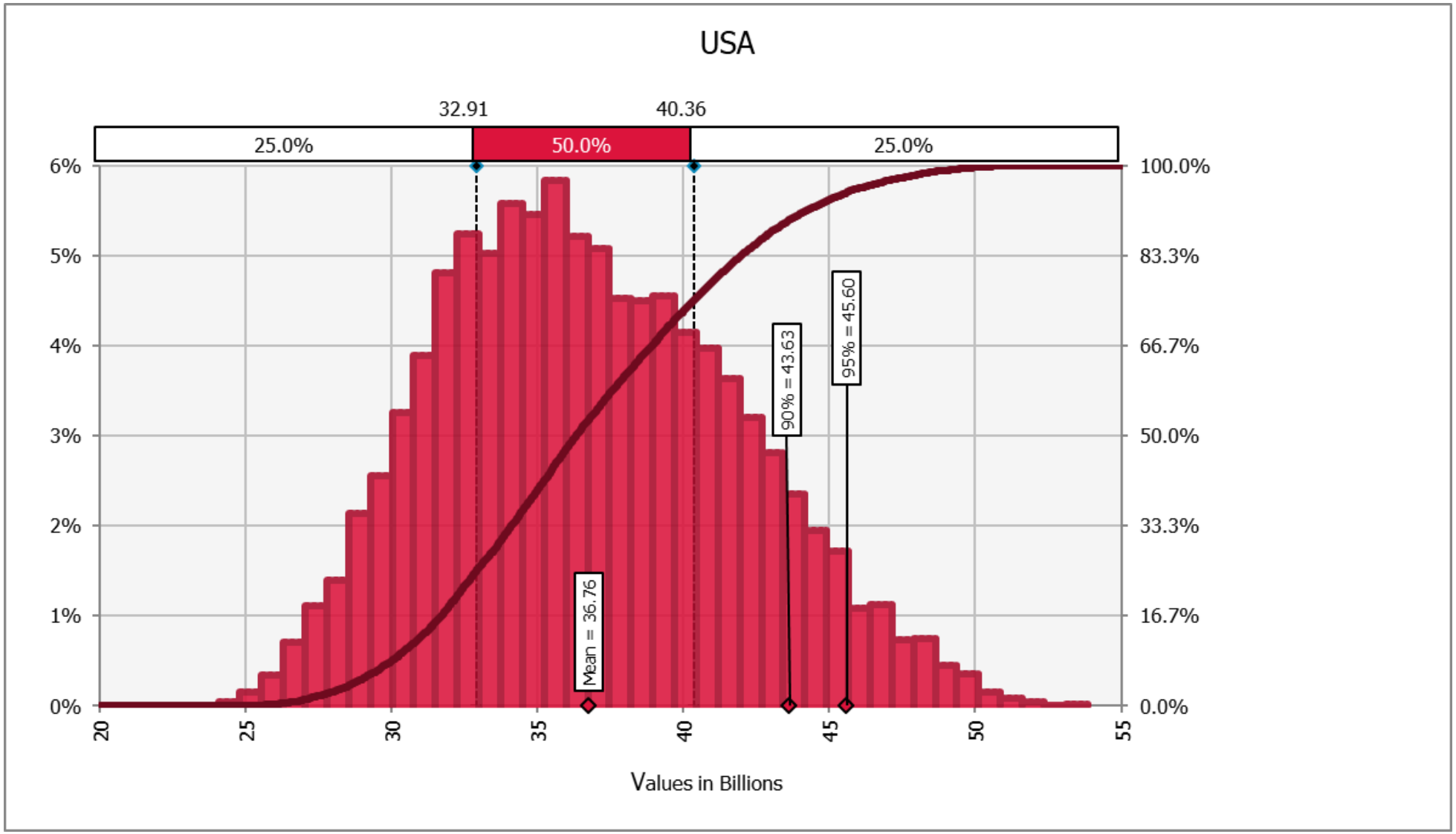
What next?

Thank you for your time. Any questions?

Data Sources

- World Health Organisation (WHO)
- Foreign Policy
- Centers for Disease Control and Prevention (CDC)
- Worldometer
- Respective Government Treasury and Policy Pages
- World Bank & International Monetary Fund

- Many more. Full list on CDAL


USA
32.91
40.36
25.0%
50.0%
25.0%
6%
5%
4%
3%
2%
1%
0%
100.0%
83.3%
66.7%
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33.3%
16.7%
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Mean = 36.76
90% = 43.63
95% = 45.60
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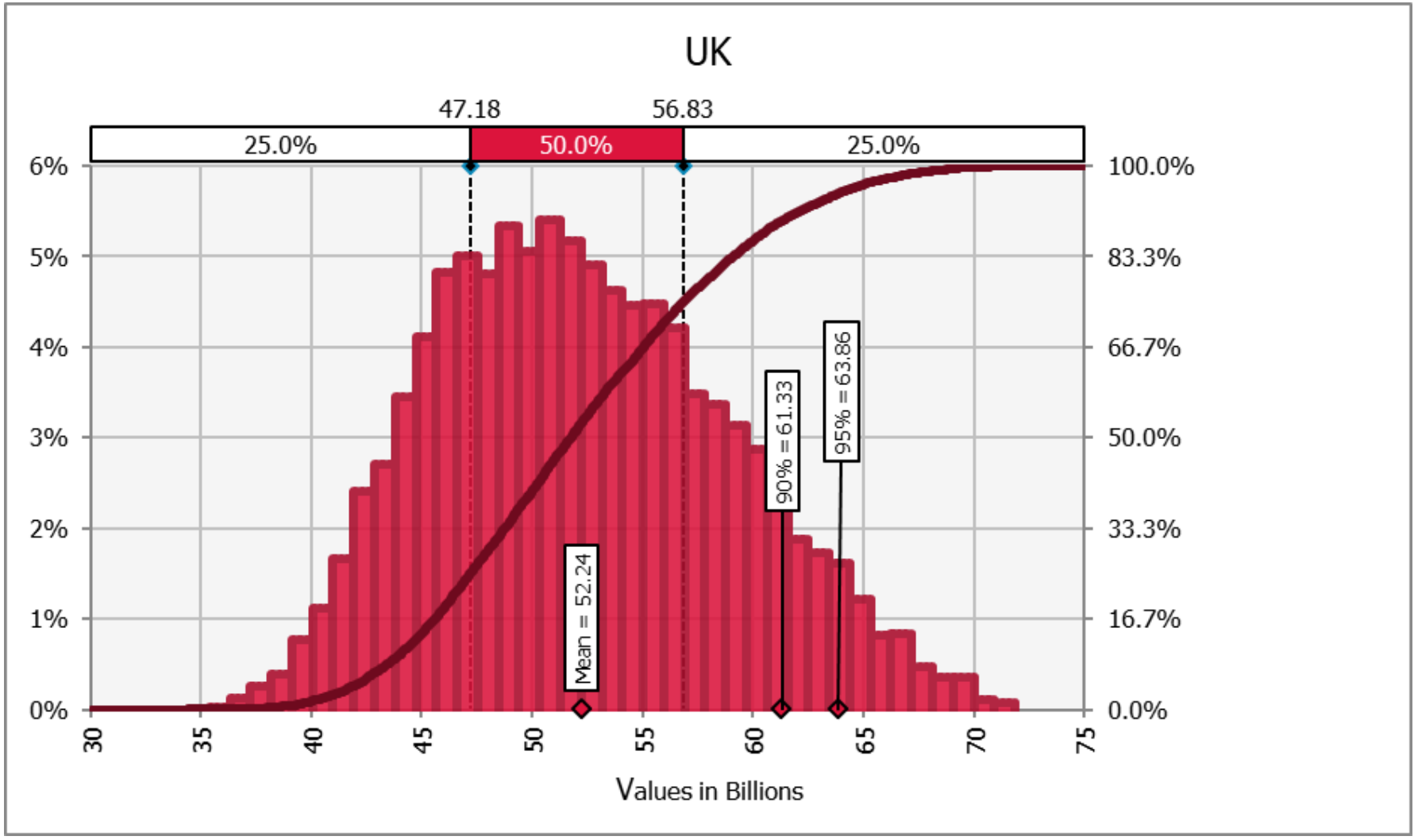
Values in Billions


UK
47.18
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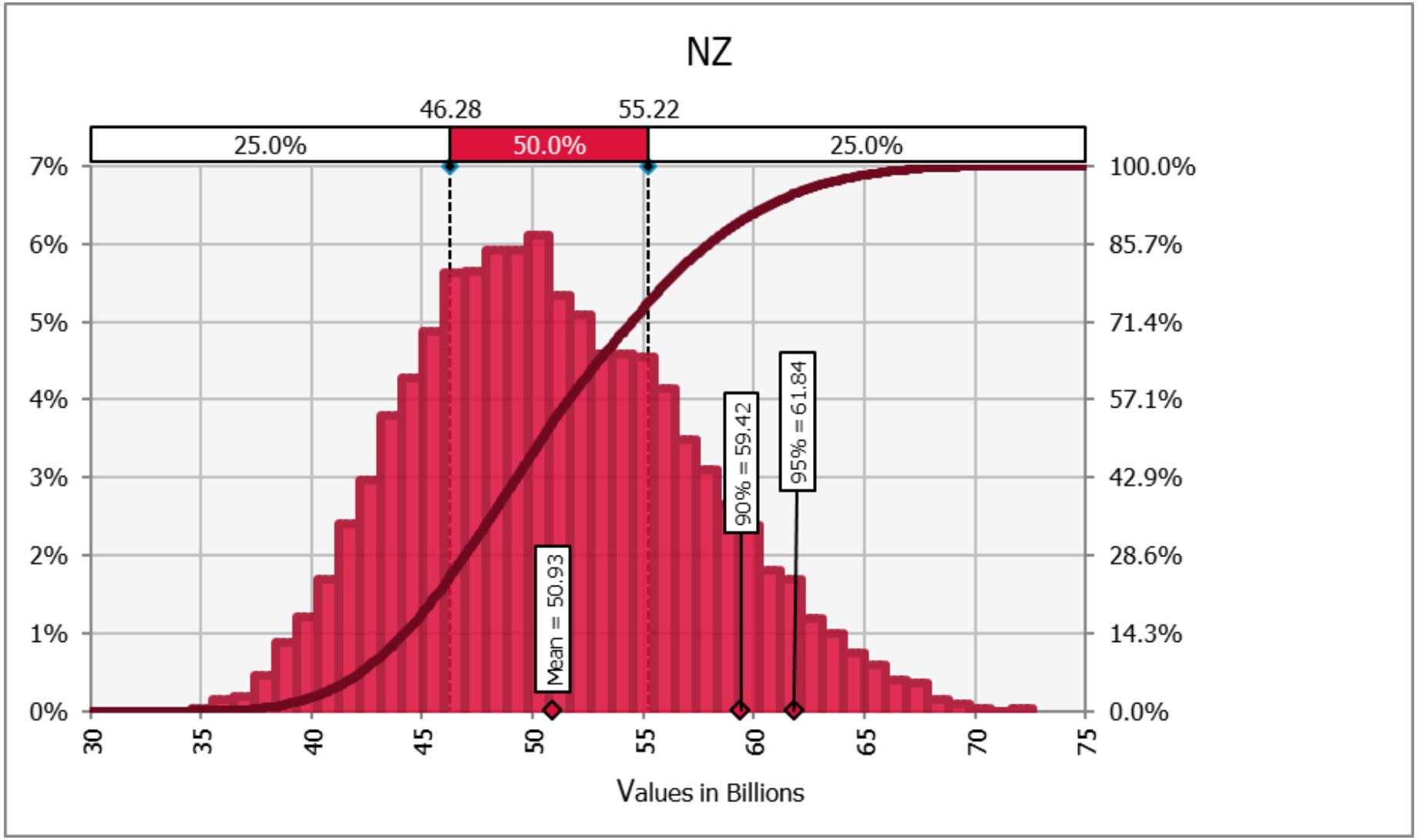
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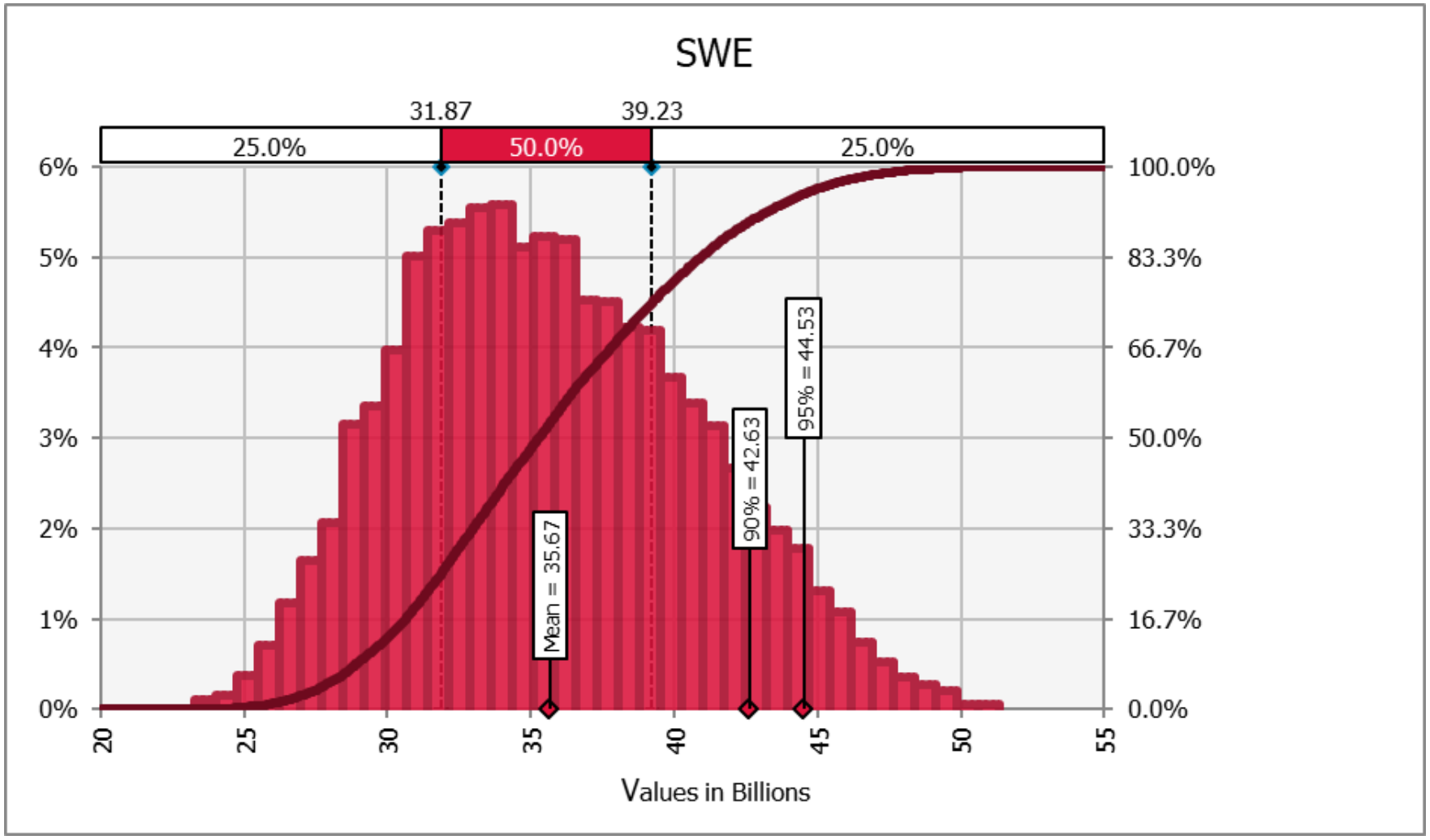
Values in Billions


SWE
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95% = 44.53
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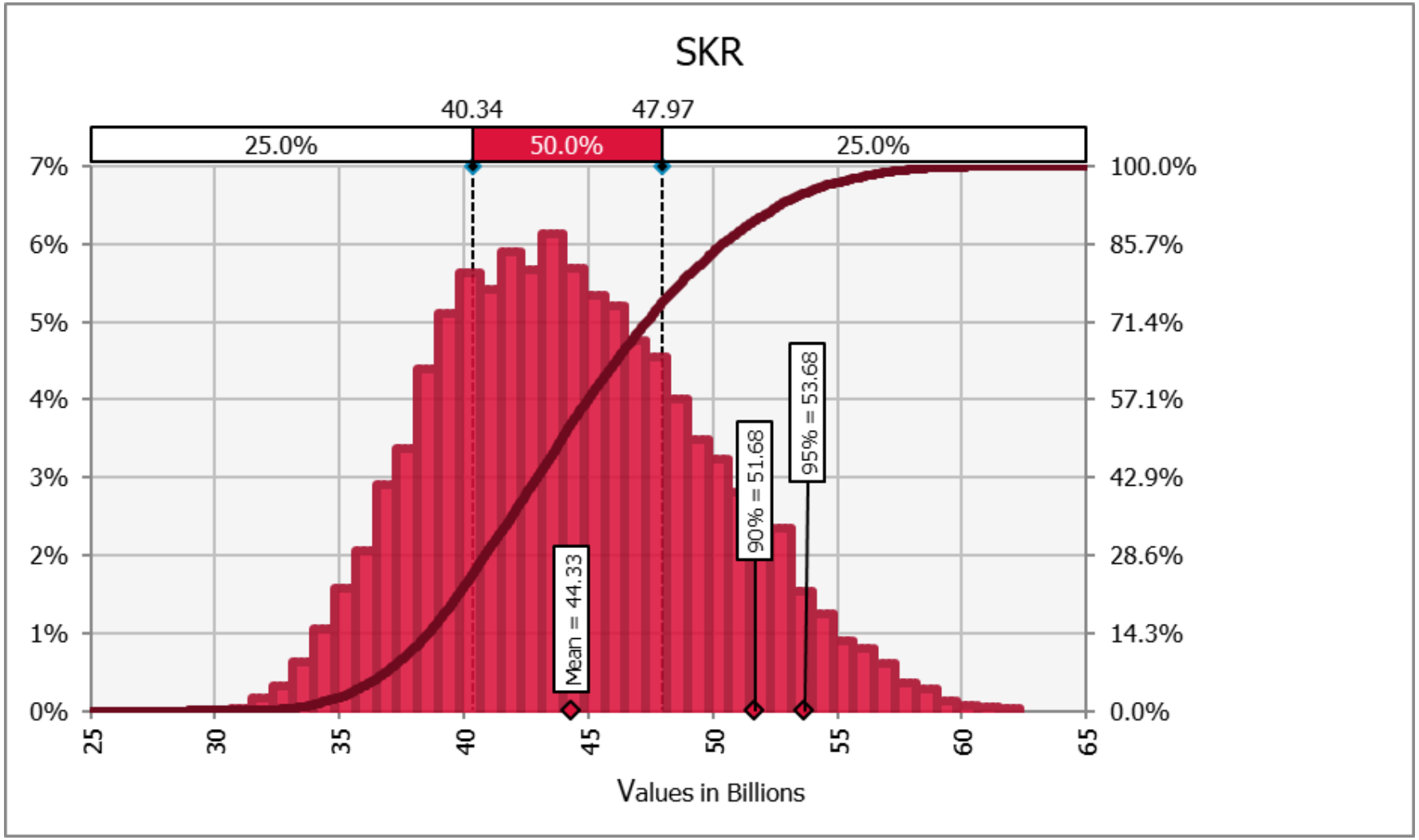
Values in Billions


SKR
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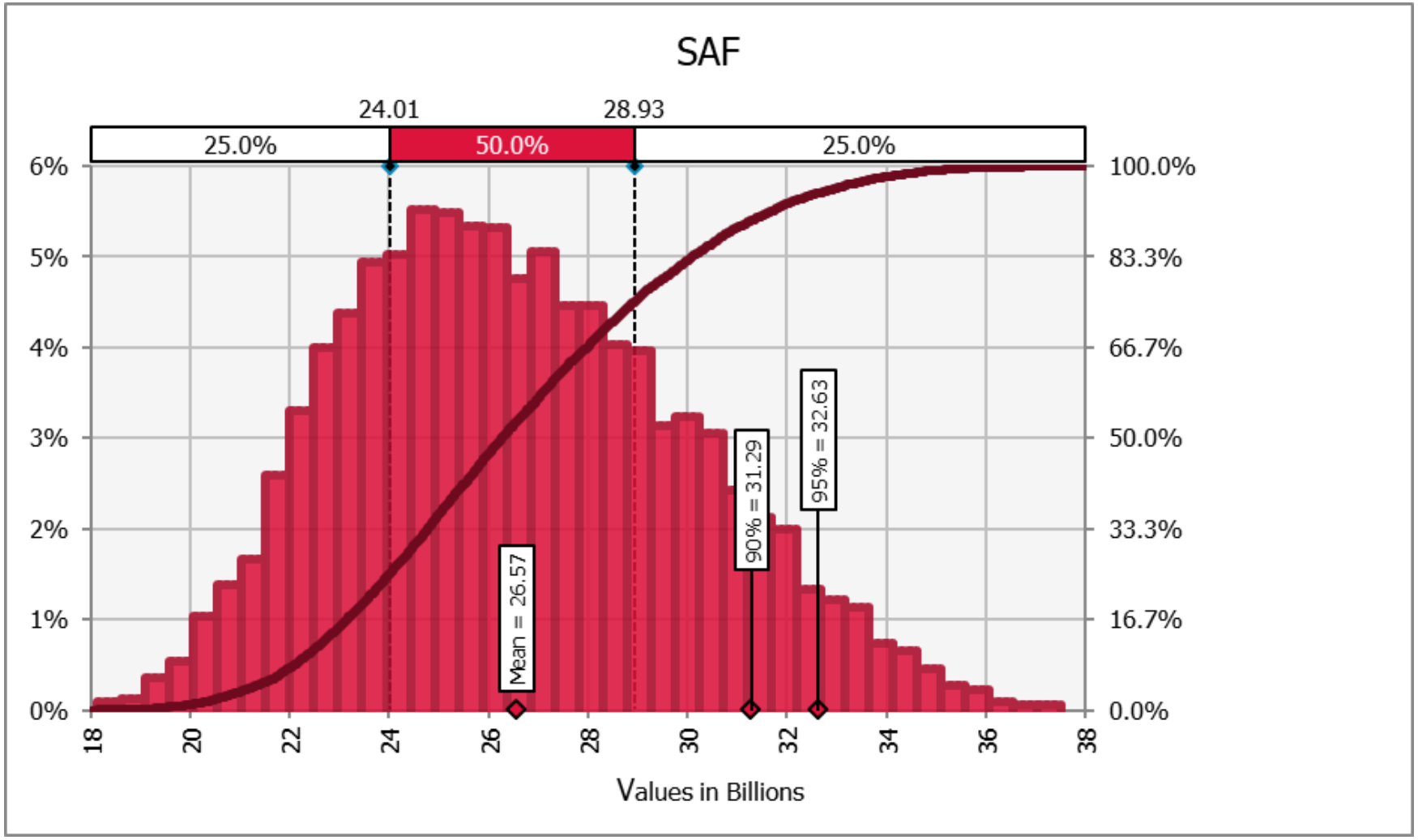
SAF
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95% = 32.63
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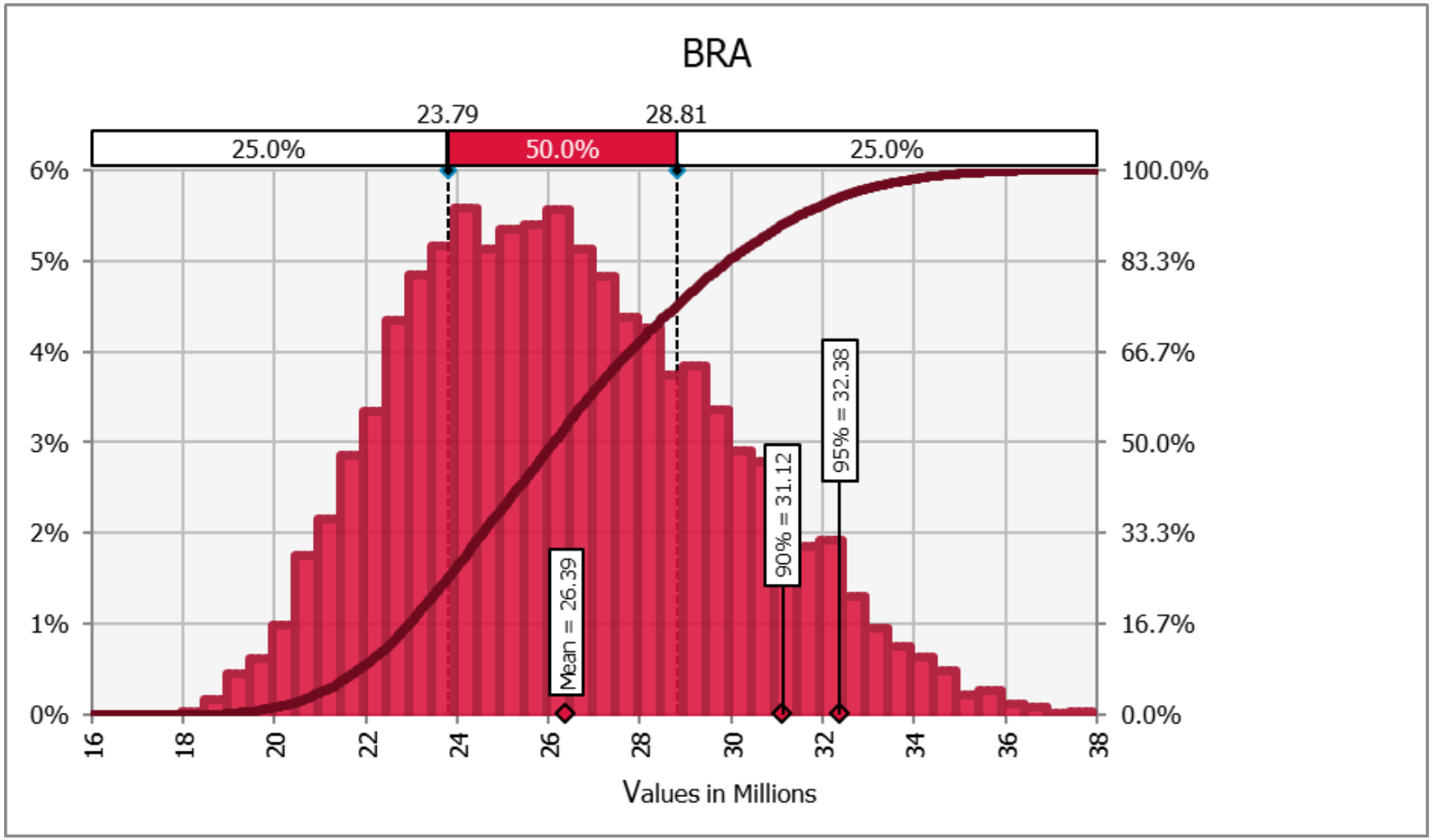
Values in Billions


BRA
23.79
28.81
25.0%
50.0%
25.0%
6%
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4%
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2%
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0%
100.0%
83.3%
66.7%
50.0%
33.3%
16.7%
0.0%
Mean = 26.39
90% = 31.12
95% = 32.38
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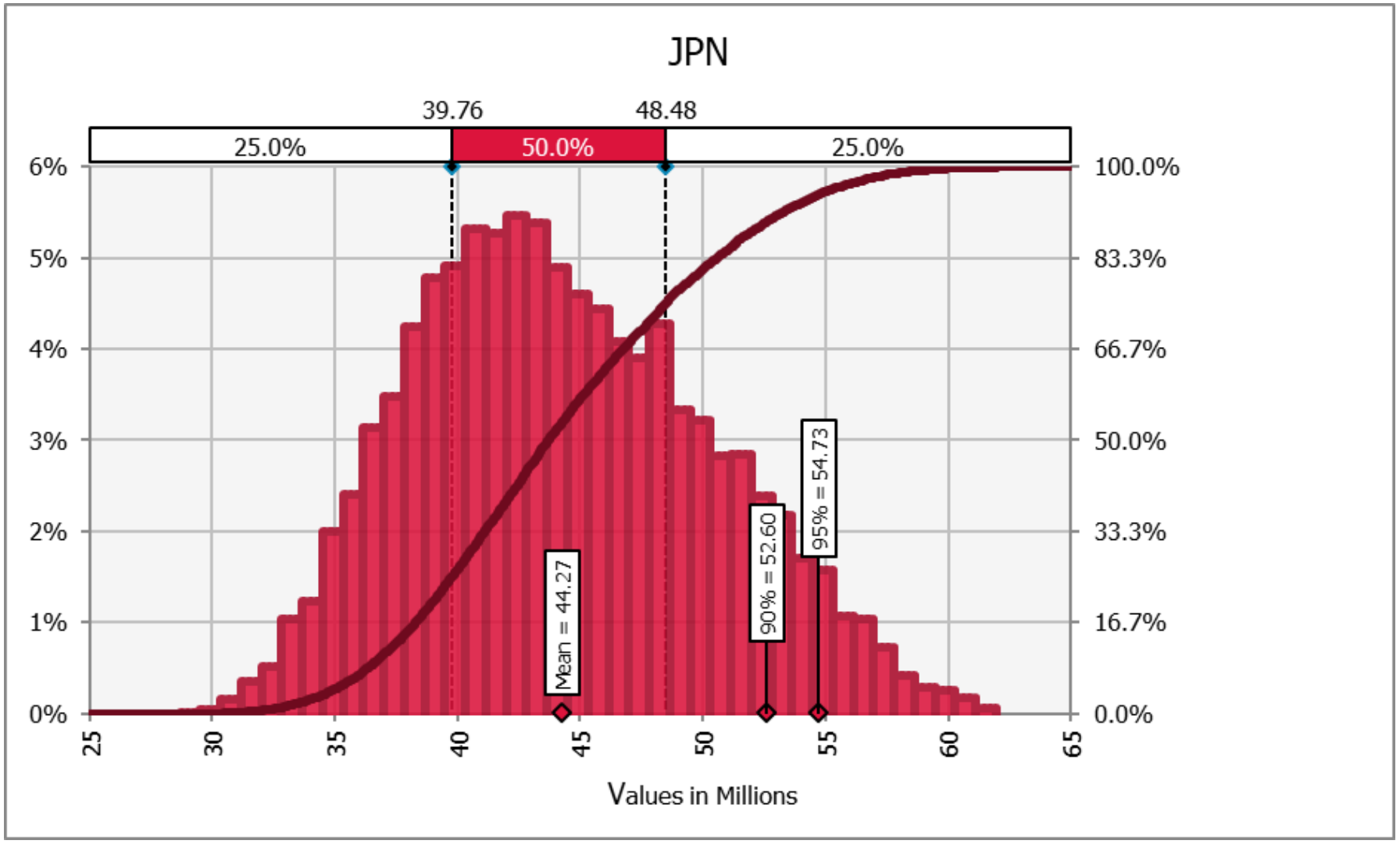
38
Values in Millions


JPN
39.76
48.48
25.0%
50.0%
25.0%
6%
5%
4%
3%
2%
1%
0%
100.0%
83.3%
66.7%
50.0%
33.3%
16.7%
0.0%
Mean = 44.27
90% = 52.60
95% = 54.73
25
30
35
40
45
50
55
60
65
Values in Millions