Causal Inference in Three-Wave Panel Designs

with illustrations from the New Zealand Attitudes and Values Study

Joseph.Bulbulia@vuw.ac.nz (Victoria University)

The Fundamental Problem of Causal Inference: We Require a Counterfactual Contrast

$$Y_{\text{you}}(1) - Y_{\text{you}}(0)$$

But Individuals Experience Only **One** Exposure

$$Y_i|A_i = 1 \implies Y_i(0)|A_i = 1 \text{ is counterfactual}$$

Average Treatment Effect in Randomised Controlled Experiments Work From Assumptions

$$\text{Average Treatment Effect} = \left[\left(\underbrace{\mathbb{E}[Y(1)|A=1]}_{\text{observed}} + \underbrace{\mathbb{E}[Y(1)|A=0]}_{\text{unobserved}} \right) - \left(\underbrace{\mathbb{E}[Y(0)|A=0]}_{\text{observed}} + \underbrace{\mathbb{E}[Y(0)|A=1]}_{\text{unobserved}} \right) \right]$$

Section 1

The Three Fundemental Assumptions of Causal Inference

The Three Fundemental Assumptions of Causal Inference

Causal Consistency

$$Y_i^{observed}|A_i = \begin{cases} Y_i(a^*) & \text{if } A_i = a^* \\ Y_i(a) & \text{if } A_i = a \end{cases}$$

Conditional Exchangeabilty

$$Y(a) \coprod A|L \quad \text{or equivalently} \quad A \coprod Y(a)|L$$

Positivity

$$0 < Pr(A = a|L = l) < 1$$

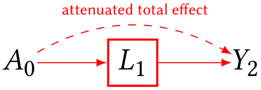
The Common Worry: Confounding by Common Cause

$$
\begin{tikzcd}
L_0 \arrow[r] \arrow[rr, bend left] & A_1 & Y_2
\end{tikzcd}
$$

However, There Are Other Worries: Reverse Causation

$$Y_1 \longrightarrow A_2$$

Another Worry is Mediator Bias



Another Worry is Collider Bias

$$
\begin{tikzcd}
A_1 \arrow[dr] & \\
 & \boxed{L_3} \\
Y_2 \arrow[ur] &
\end{tikzcd}
$$

Another Worry: Collider Bias Proxy

$$\begin{tikzcd} A_1 \arrow[dr] & & \\ & L_3 \arrow[r] & \boxed{L'_4} \\ Y_2 \arrow[ur] & & \end{tikzcd}$$

Post Exposure Collider Bias

$$\begin{tikzcd} U \arrow[rrr, bend left] \arrow[rr, bend right] & A_0 \arrow[r] & \boxed{L_1} & Y_2 \end{tikzcd}$$

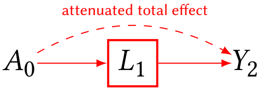
Another Worry: Unmeasured Common Cause

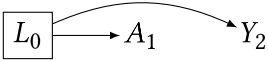
$$\begin{tikzcd} U \arrow[r] \arrow[rr, bend left] & A_1 & Y_2 \end{tikzcd}$$

Reverse Causation Solution: Longitudinal Hygiene

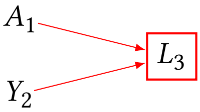
$$Y_1 \rightarrow A_2 \qquad\qquad\qquad A_1 \qquad Y_2$$

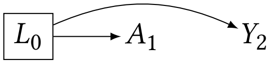
Mediator Bias Solution: Longitudional Hygiene



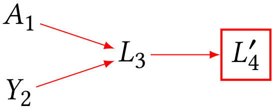


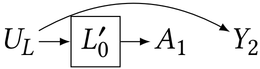
Collider Bias **Solution**: Longitudional Hygiene



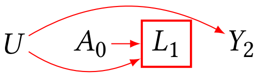


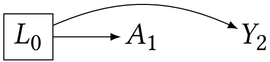
Collider Bias Proxy **Solution**: Longitudional Hygiene





Post Exposure Collider Bias **Solution**: Longitudional Hygiene





Unmeasured Common Cause **Solution**: Longitudional Hygiene

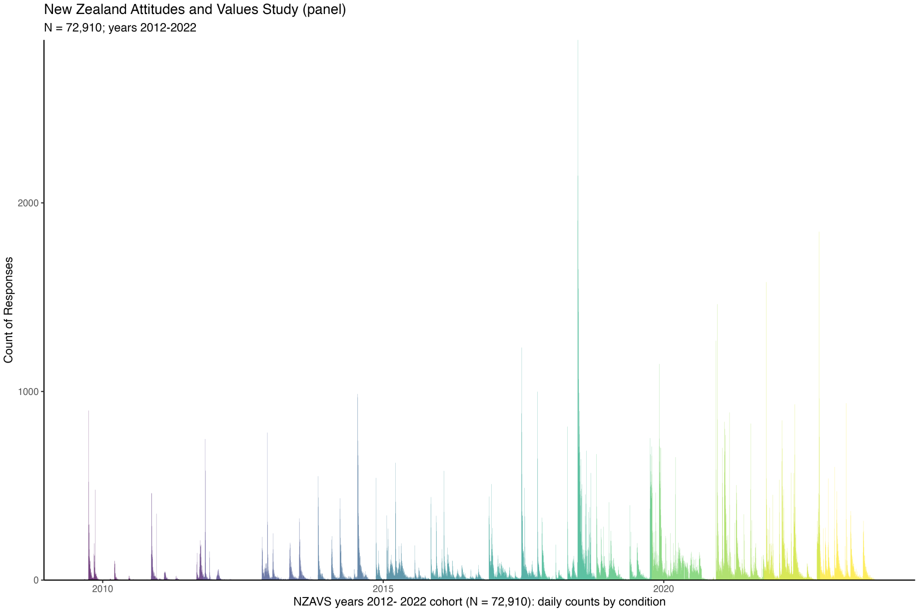
$$
\begin{tikzcd}
U \arrow[r] \arrow[rr, bend left] & A_1 & Y_2
\end{tikzcd}
\qquad\qquad
\begin{tikzcd}
\boxed{L_0} \arrow[r] \arrow[rr, bend left] & A_1 & Y_2
\end{tikzcd}
$$

Section 2

New Zealand Attitudes and Values Study

The New Zealand Attitudes and Values Study: Longitudinally Hygeinic Data Collection

- Planned 20-year longitudinal study, currently in its 14^{th} year.
- Sample frame is drawn randomly from NZ Electoral Roll.
- Postal questionnaire (coverage; retention ~ 80%)
- Large multidisciplinary research team (40 +)
- Focus on personality, social attitudes, values, religion, employment, prejudice …
- Current sample contains > 72,290,000 unique people, and ~ 38,000 in the longitudinal study


New Zealand Attitudes and Values Study (panel)
N = 72,910; years 2012-2022
Count of Responses
2000
1000
0
2010
2015
2020
NZAVS years 2012- 2022 cohort (N = 72,910): daily counts by condition

BIG EVENTS


Discontinuity at attacks (GAM)
Boost to Warmth increase in the years following the attacks: FULL SAMPLE
attack_condition
0
1
Muslim Warmth
6
4
2
2015
2020
NZAVS Time 4 - 14 Cohort (2012-2023), (N = 71,128)

Institutional Trust

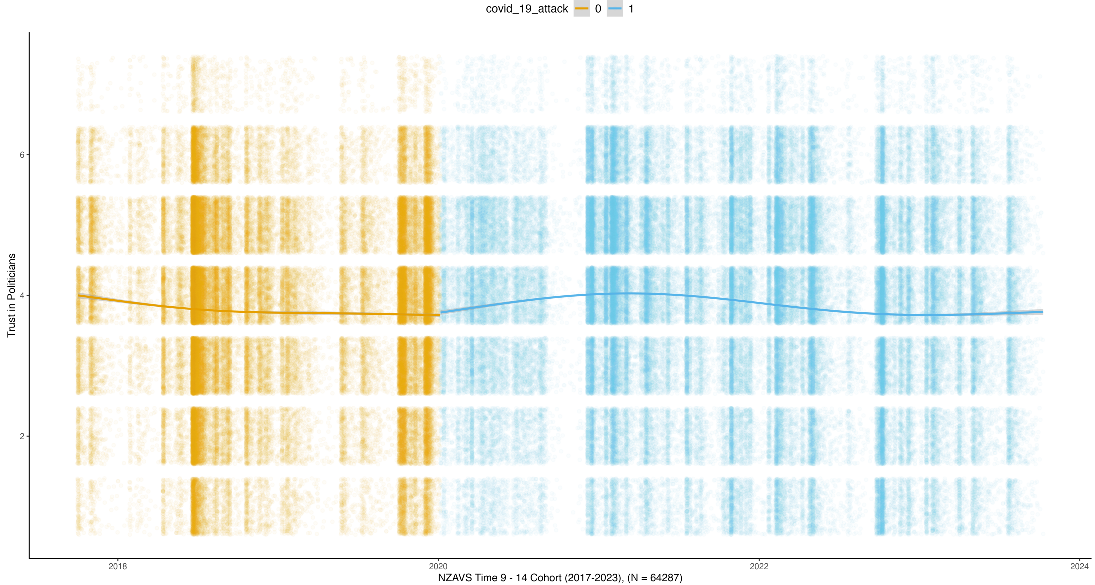
COVID-19 Government response - "I trust the Government to make sensible decisions about how to best manage COVID-19 in New Zealand." - "The New Zealand government response to COVID-19."

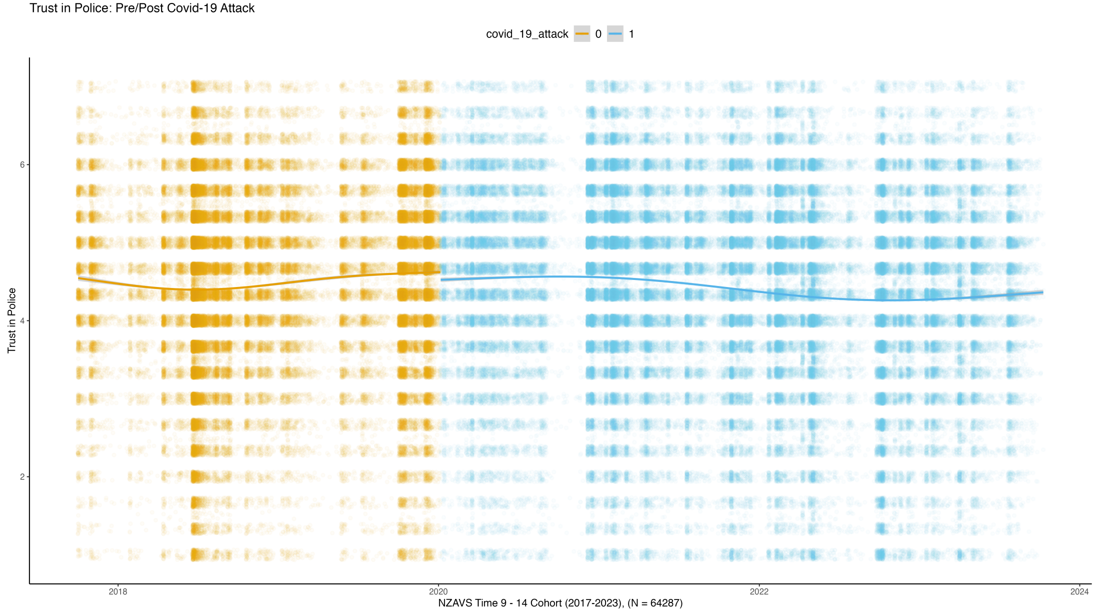
Trust in politicians - "Politicians in New Zealand can generally be trusted."

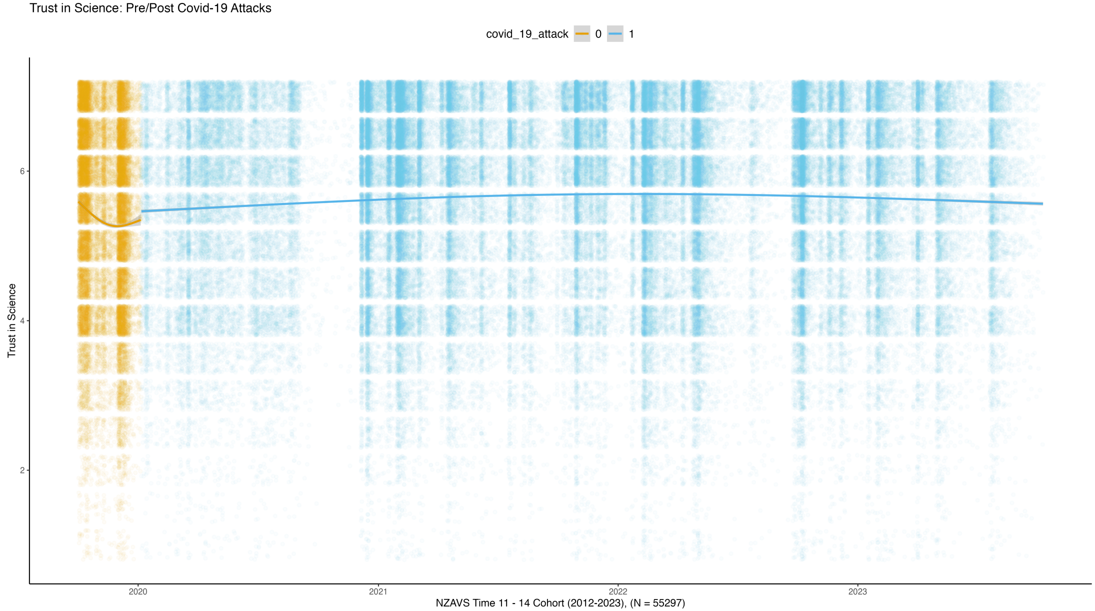
Institutional trust in police - "People's basic rights are well protected by the New Zealand Police." - "There are many things about the New Zealand Police and its policies that need to be changed." - "The New Zealand Police care about the well-being of everyone they deal with."

General tendency to believe in conspiracies - "I think that the official version of major world events given by authorities often hides the truth."

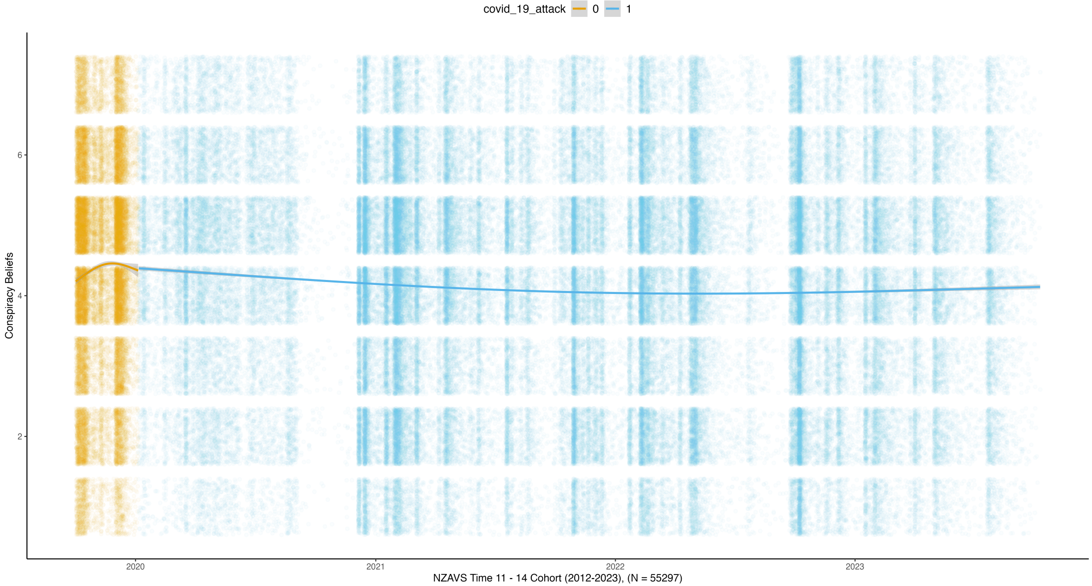
Trust in Politicians: Pre/Post Covid-19 Attack




Trust in Police: Pre/Post Covid-19 Attack
covid_19_attack
0
1
Trust in Police
6
4
2
2018
2020
2022
2024
NZAVS Time 9 - 14 Cohort (2017-2023), (N = 64287)


Trust in Science: Pre/Post Covid-19 Attacks
covid_19_attack
0
1
Trust in Science
6
4
2
2020
2021
2022
2023
NZAVS Time 11 - 14 Cohort (2012-2023), (N = 55297)

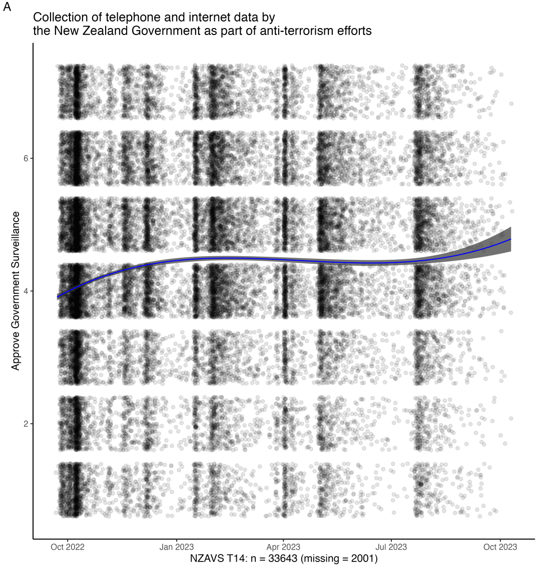
Conspiracy Beliefs: Pre/Post Covid-19 Attacks

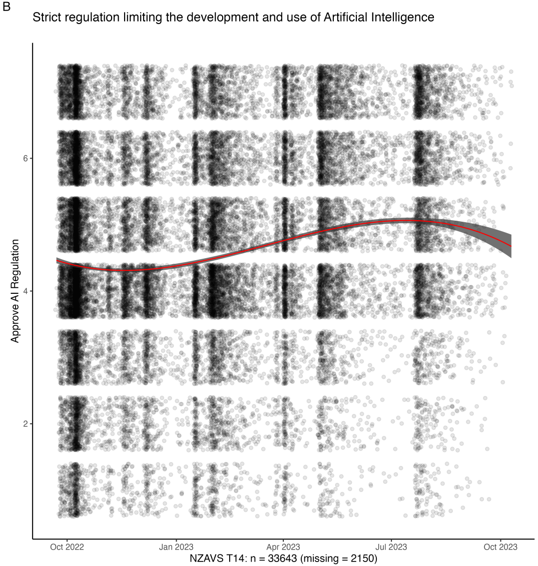


Regulate Artificial Intelligence?

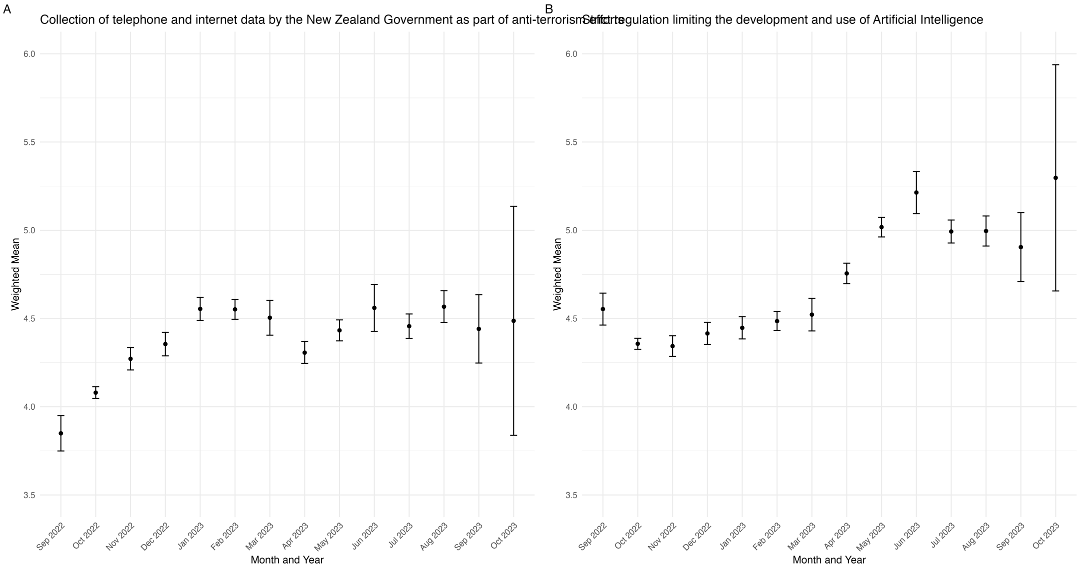
Comparison of Attitudes to New Zealand Government Interventions from 2022-SEP-22 to 2023-OCT-10

Generalised Additive Model: 3-knot splines weighted to NZ Census Age/Gender/Ethnicity, NZAVS (n=33643)



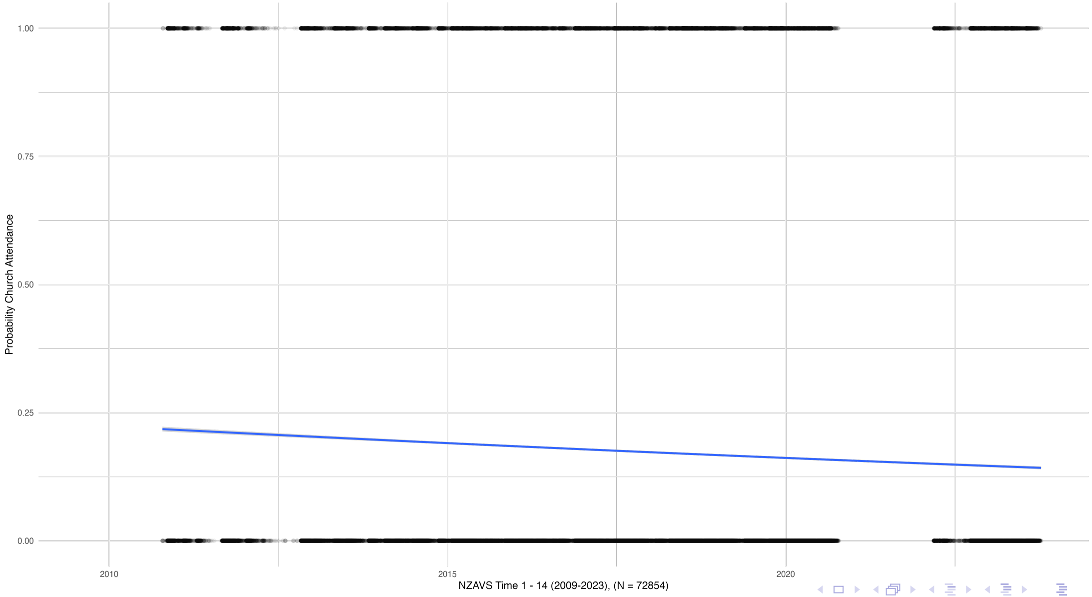


Weighted Monthly Marginal Means: Comparisons of Attitudes to New Zealand Government Interventions
NZAVS Time 14 (n=33643)



Consider Gradual Events

Probability of Church Attendance in New Zealand: Years 2009 - 2023



Worked Example: Casual Effects of Religious Service on Prosociality

Intervention

$$f(A = a*) = \begin{cases} 4 & \text{if } A < 4 \text{ monthly religious service attendance} \\ \tilde{A} & \text{if } A \geq 4 \text{ monthly religious service attendance} \end{cases}$$

Contrast

$$f(A) = 0$$

Shift Intervention: Socializing

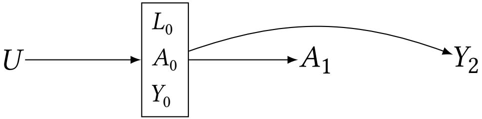
Intervention

$$f(A) = \begin{cases} 1.4 & \text{if } A \leq 1.4 \text{ hours socialising with community} \\ \tilde{A} & \text{if } A > 1.4 \text{ hours socialising with community} \end{cases}$$

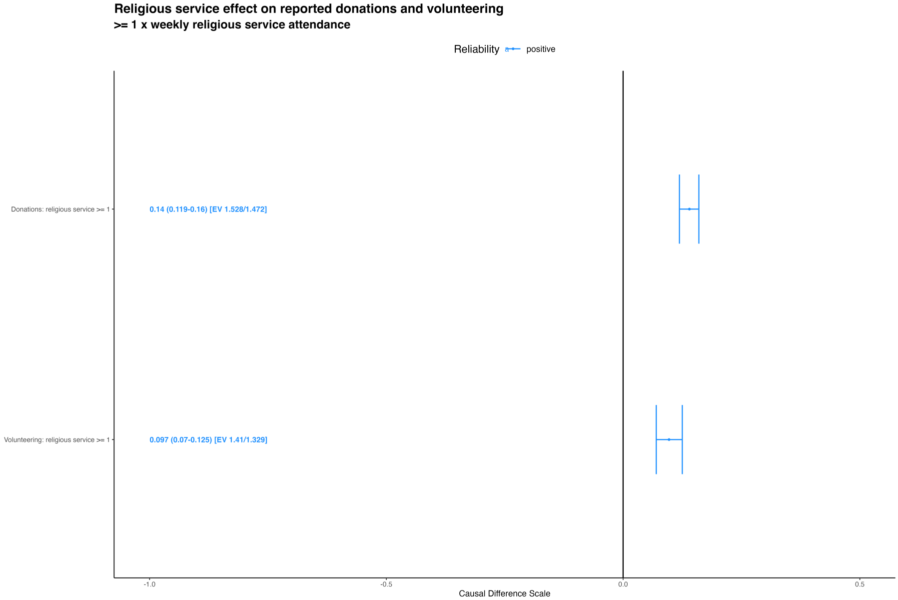
Contrast:

$$f(A) = 0$$

Key Graph

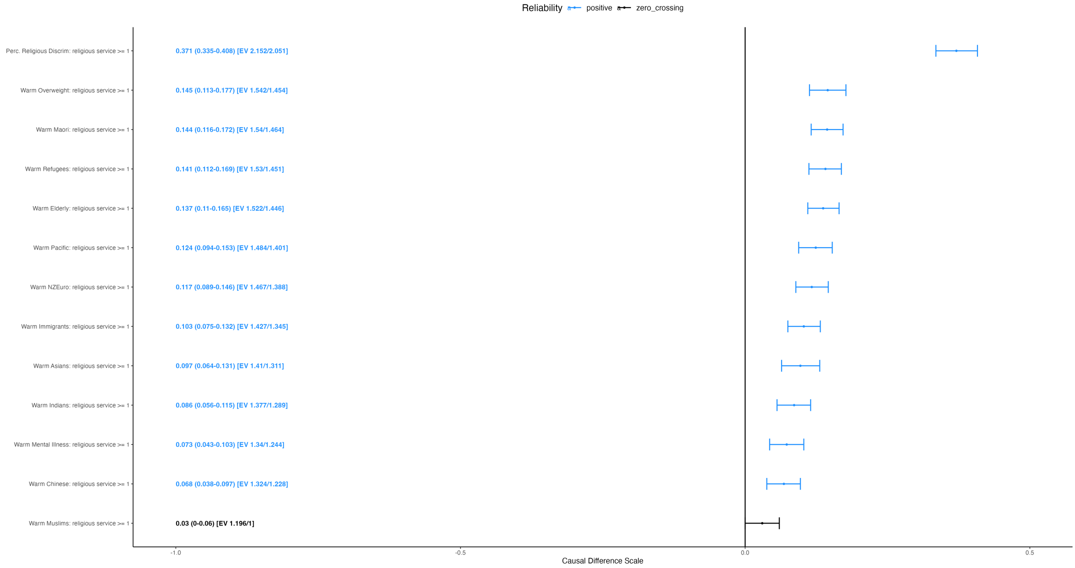


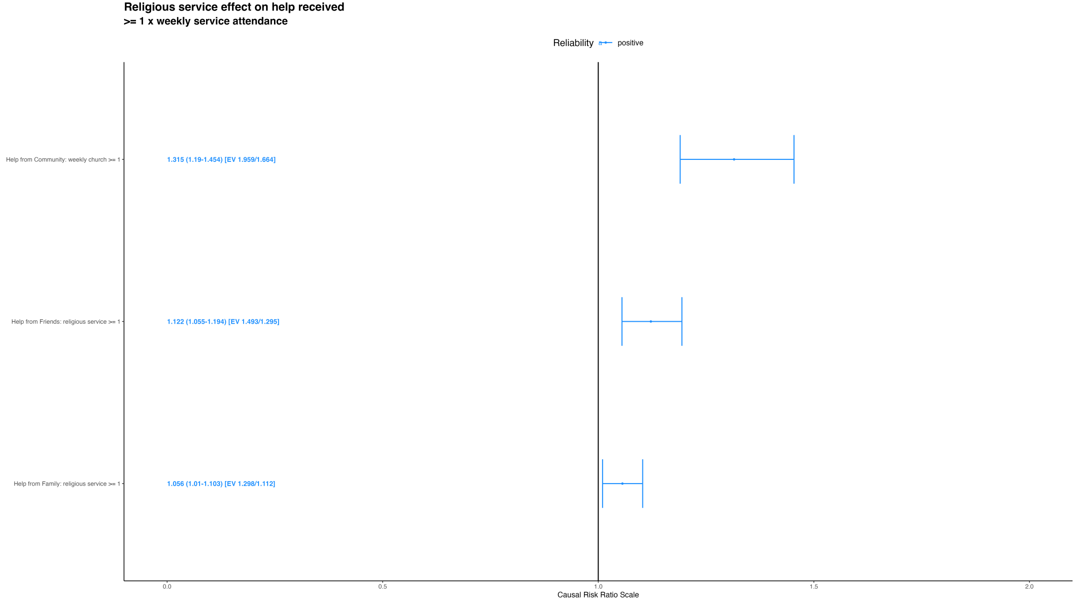
Religious Service Outcomes



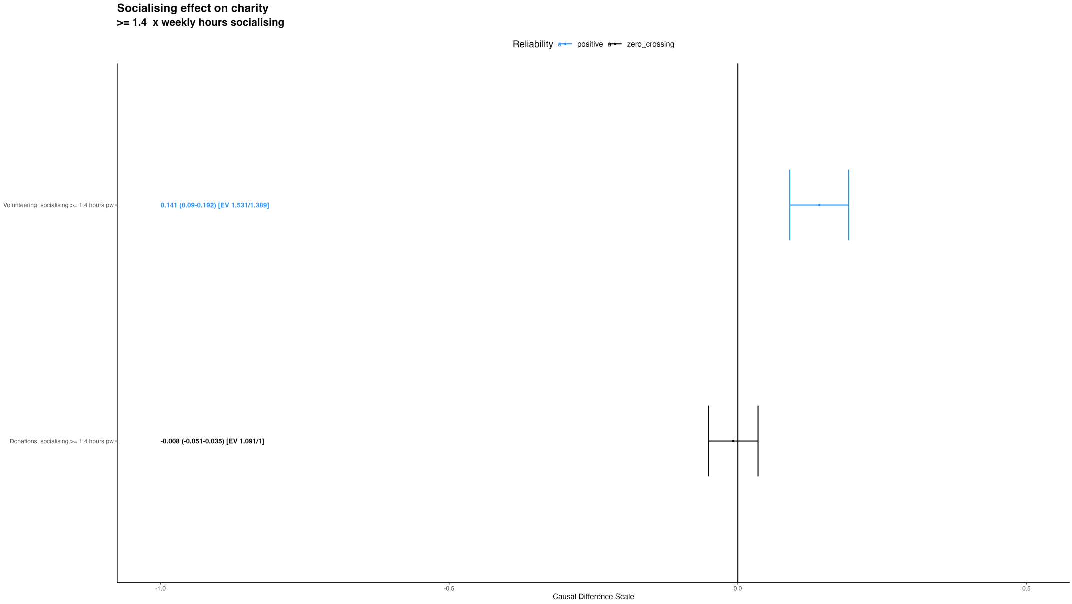
Religious service effect on reported donations and volunteering
>= 1 x weekly religious service attendance
Reliability
positive
Donations: religious service >= 1
0.14 (0.119-0.16) [EV 1.528/1.472]
Volunteering: religious service >= 1
0.097 (0.07-0.125) [EV 1.41/1.329]
-1.0
-0.5
0.0
0.5
Causal Difference Scale

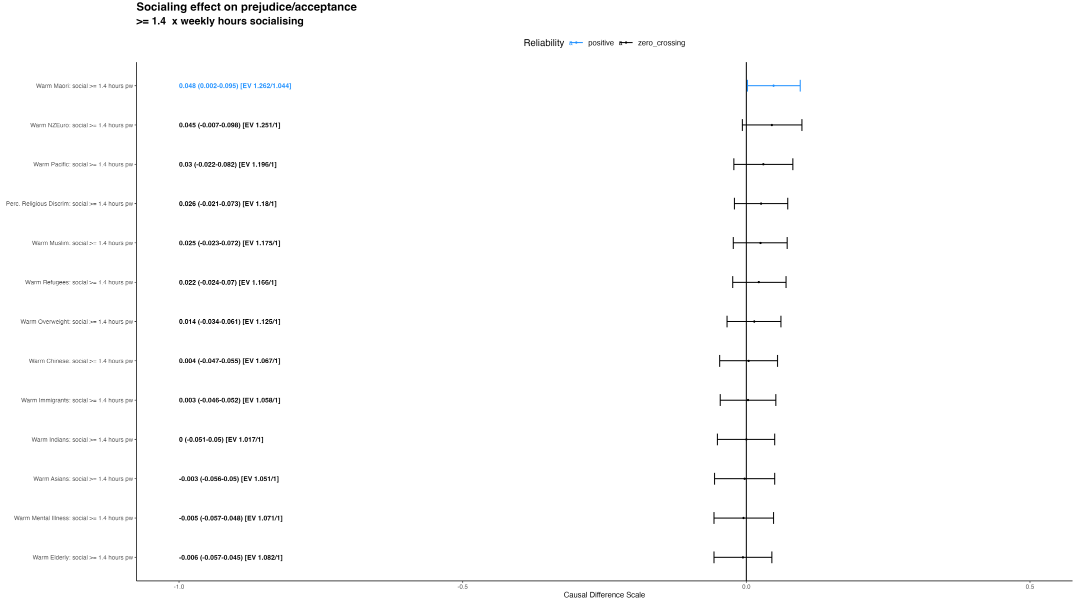
Religious service effect on minority-group attitudes
>= 1 x weekly religious service attendance

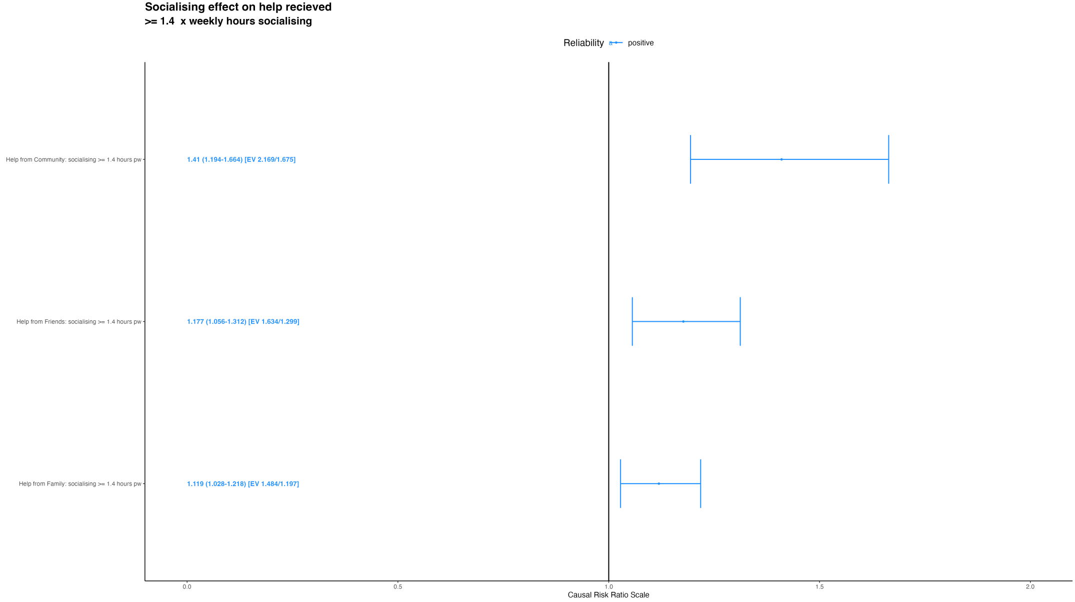



Religious service effect on help received
>= 1 x weekly service attendance
Reliability
positive
Help from Community: weekly church >= 1
1.315 (1.19-1.454) [EV 1.959/1.664]
Help from Friends: religious service >= 1
1.122 (1.055-1.194) [EV 1.493/1.295]
Help from Family: religious service >= 1
1.056 (1.01-1.103) [EV 1.298/1.112]
0.0
0.5
1.0
1.5
2.0
Causal Risk Ratio Scale

Socializing Outcomes


Socialising effect on charity
>= 1.4 x weekly hours socialising
Reliability
positive
zero_crossing
Volunteering: socialising >= 1.4 hours pw
0.141 (0.09-0.192) [EV 1.531/1.389]
Donations: socialising >= 1.4 hours pw
-0.008 (-0.051-0.035) [EV 1.091/1]
-1.0
-0.5
0.0
0.5
Causal Difference Scale


Socialing effect on prejudice/acceptance
>= 1.4 x weekly hours socialising
Reliability positive zero_crossing
Warm Maori: social >= 1.4 hours pw
0.048 (0.002-0.095) [EV 1.262/1.044]
Warm NZEuro: social >= 1.4 hours pw
0.045 (-0.007-0.098) [EV 1.251/1]
Warm Pacific: social >= 1.4 hours pw
0.03 (-0.022-0.082) [EV 1.196/1]
Perc. Religious Discrim: social >= 1.4 hours pw
0.026 (-0.021-0.073) [EV 1.18/1]
Warm Muslim: social >= 1.4 hours pw
0.025 (-0.023-0.072) [EV 1.175/1]
Warm Refugees: social >= 1.4 hours pw
0.022 (-0.024-0.07) [EV 1.166/1]
Warm Overweight: social >= 1.4 hours pw
0.014 (-0.034-0.061) [EV 1.125/1]
Warm Chinese: social >= 1.4 hours pw
0.004 (-0.047-0.055) [EV 1.067/1]
Warm Immigrants: social >= 1.4 hours pw
0.003 (-0.046-0.052) [EV 1.058/1]
Warm Indians: social >= 1.4 hours pw
0 (-0.051-0.05) [EV 1.017/1]
Warm Asians: social >= 1.4 hours pw
-0.003 (-0.056-0.05) [EV 1.051/1]
Warm Mental Illness: social >= 1.4 hours pw
-0.005 (-0.057-0.048) [EV 1.071/1]
Warm Elderly: social >= 1.4 hours pw
-0.006 (-0.057-0.045) [EV 1.082/1]
-1.0
-0.5
0.0
0.5
Causal Difference Scale


Socialising effect on help recieved
>= 1.4 x weekly hours socialising
Reliability
positive
Help from Community: socialising >= 1.4 hours pw
1.41 (1.194-1.664) [EV 2.169/1.675]
Help from Friends: socialising >= 1.4 hours pw
1.177 (1.056-1.312) [EV 1.634/1.299]
Help from Family: socialising >= 1.4 hours pw
1.119 (1.028-1.218) [EV 1.484/1.197]
0.0
0.5
1.0
1.5
2.0
Causal Risk Ratio Scale

Results

- Causal effects of religious service attendance on the economy are considerable, in expectation they represent ~ **0.048%** of New Zealand's 2021 annual government budget.
- These results underscores the importance of investigating the consequences of gradual change in cultural engagement.
- **What do you think we should be focussing on?**

Summary

1. To move beyond association to causality requires time, literally.

Summary

1. To move beyond association to causality requires time, literally.
2. Big events $\neq$ big effect sizes.

Summary

1. To move beyond association to causality requires time, literally.
2. Big events $\neq$ big effect sizes.
3. Long-term effects unclear.

Summary

1. To move beyond association to causality requires time, literally.
2. Big events $\neq$ big effect sizes.
3. Long-term effects unclear.
4. Long-term change might be more important for planning.

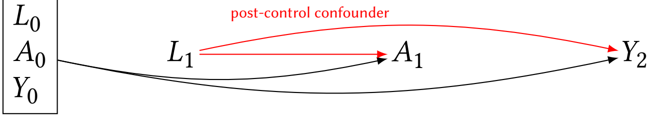
Thanks

- Chris G. Sibley (NZAVS lead Investigator)
- TRT Grant 0418
- Max Planck Institute for Evolutionary Anthropology
- Victoria University
- University of Canterbury
- 72,290 NZAVS participants

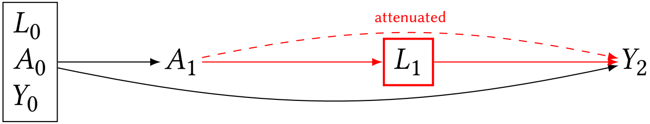
Extra Slides

Longitudinal Data Bring Their Own Problems

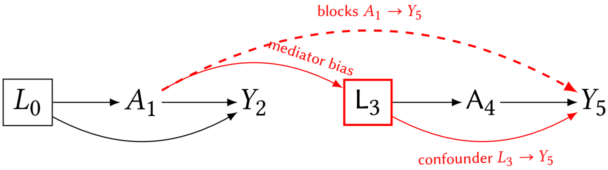
Timing of Confounder



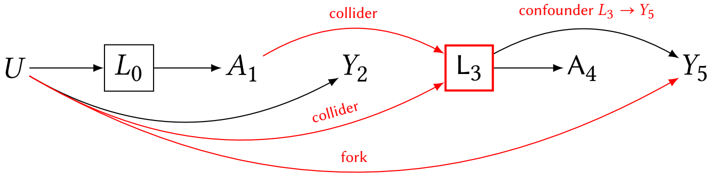
Timing of Mediator



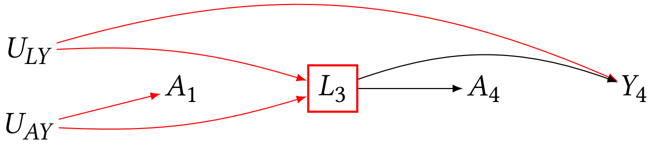
Treatment Confounder Bias



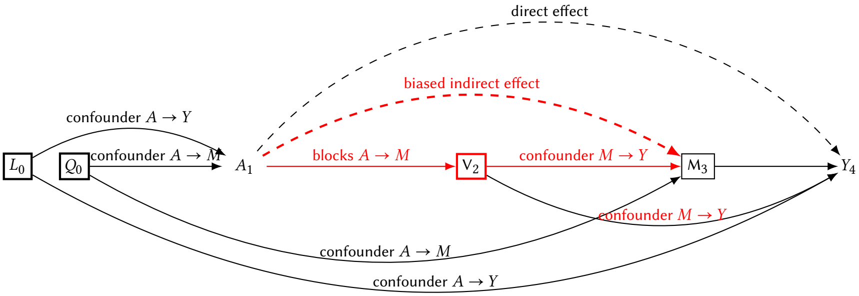
Treatment Confounder Feedback



Treatment Confounder Feedback Variation



Mediation


direct effect
biased indirect effect
confounder $A \rightarrow Y$
confounder $A \rightarrow M$
L_0
Q_0
A_1
blocks $A \rightarrow M$
V_2
confounder $M \rightarrow Y$
M_3
Y_4
confounder $M \rightarrow Y$
confounder $A \rightarrow M$
confounder $A \rightarrow Y$

Mediation

Total Effect

$$TE = \mathbb{E}[Y(1)] - \mathbb{E}[Y(0)]$$

Total Effect Considering Mediator

$$TE = \mathbb{E}[Y(1)] - \mathbb{E}[Y(0)]$$

$$\mathbb{E}[Y(1)] = \mathbb{E}[Y(1, M(1))]$$

Natural Direct Effect

Natural Direct Effect (NDE) is the effect of the treatment on the outcome while maintaining the mediator at the level it would have been if the treatment had *not* been applied:

$$NDE = \mathbb{E}[Y(1, M(0))] - \mathbb{E}[Y(0, M(0))]$$

Natural Indirect Effect

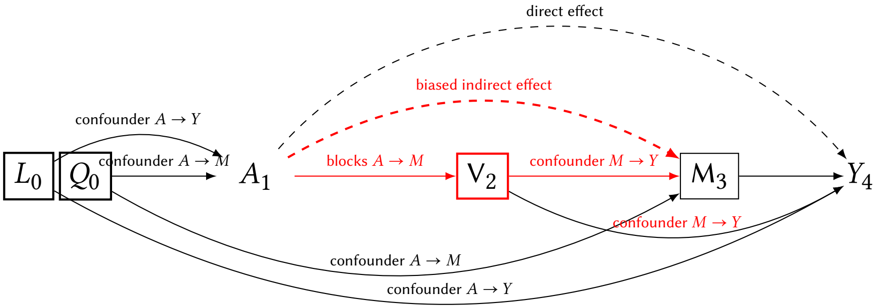
Natural Indirect Effect (NIE): is the effect of the exposure on the outcome that is mediated. To obtain these quantities we must compare the potential outcome Y under treatment, where the mediator assumes its natural level under treatment with the potential outcome when the mediator assumes its natural value under no treatment is given:

$$NIE = \mathbb{E}[Y(1, M(1))] - \mathbb{E}[Y(1, M(0))]$$

Decomposition

$$\text{Total Effect (TE)} = \underbrace{\left\{\mathbb{E}[Y(1, M(1))] - \mathbb{E}[Y(1, M(0))]\right\}}_{\text{Natural Indirect Effect (NIE)}} + \underbrace{\left\{\mathbb{E}[Y(1, M(0))] - \mathbb{E}[Y(0, M(0))]\right\}}_{\text{Natural Direct Effect (NDE)}}$$

Why Mediation is Difficult



Interaction

Interaction: simplifies to

$$\underbrace{\mathbb{E}[Y(1,1)]}_{\text{joint exposure}} - \underbrace{\mathbb{E}[Y(1,0)]}_{\text{only A exposed}} - \underbrace{\mathbb{E}[Y(0,1)]}_{\text{only B exposed}} + \underbrace{\mathbb{E}[Y(0,0)]}_{\text{neither exposed}} \neq 0$$

Key

Symbol	
X	Any variable.
A	The treatment or, equivalently, the exposure.
Y	The outcome.
$Y(a)$	The potential outcome when $A = a$.
L	Measured confounder(s): typically comprises a set of variables.
U	Unmeasured confounder.
Z	Effect-modifier (or 'moderator') of A on Y.
M	Mediator of A on Y.
$\bar{X}$	Sequential variables, e.g. $\bar{A} = \{A_1, A_2, A_3\}$; $\bar{L} = \{L_0, L_1, L_2\}$.
$\mathscr{R}$	Denotes randomisation into treatment event.

		Two variables		
1	**Causality Absent**	A B	A and B have no causal effect on each other.	$A \coprod B$ (independent)
2	**Causality**	A → B	A causally affects B, and they are associated.	$A \not\coprod B$ (dependent)
		Three variables		
3	**Fork**	A → B, A → C	A causally affects both B and C; B and C are conditionally independent given A.	$B \coprod C \mid A$
4	**Chain**	A → B → C	C is affected by B which is, in turn, affected by A; A and C are conditionally independent given B.	$A \coprod C \mid B$
5	**Collider**	A → C ← B	C is affected by both A and B, which are independent; conditioning on C induces association between A and B.	$A \not\coprod B \mid C$