

# Causal Inference in Three-Wave Panel Designs

## with illustrations from the New Zealand Attitudes and Values Study

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

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

1

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<sup>1</sup>  $Y$  denotes the outcome;  $A$  denotes a treatment,  $Y(a)$  denotes the outcome when  $A = a$

# But Individuals Experience Only **One** Treatment

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

# Average Treatment Effect in Randomised Controlled Experiments Work From Assumptions

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

## Section 1

# The Three Fundamental Assumptions of Causal Inference

# The Three Fundamental 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 Exchangeability

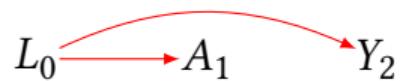
$$Y(a) \coprod_a A|L \quad \text{or equivalently} \quad A \coprod Y(a)|L$$

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<sup>a</sup> $L$  denotes measured covariates.

## Positivity

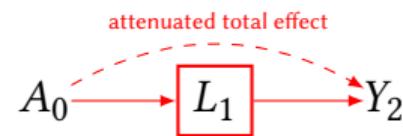
# The Typical Worry: Confounding by Common Cause



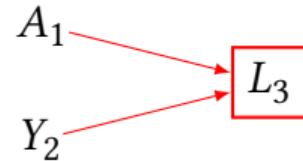
# However, There Are Other Worries: Reverse Causation

$$Y_1 \longrightarrow A_2$$

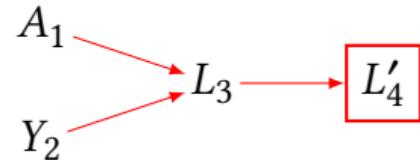
# Another Worry is Mediator Bias



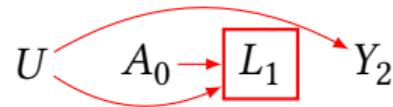
# Another **Worry** is Collider Bias



# Another **Worry** is Collider Bias Proxy



# Yet Another Worry is Post Exposure Collider Bias



2

<sup>2</sup>U denotes an unmeasured confounder of  $A \rightarrow Y$

# Another **Worry** are Unmeasured Common Causes ( $U$ )

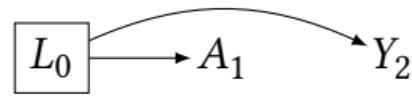
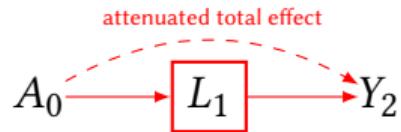


# Reverse Causation Strategy: Longitudinal Hygiene

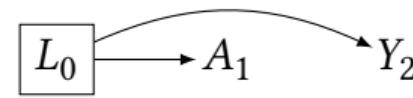
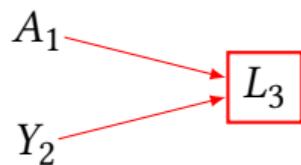
$$Y_1 \longrightarrow A_2$$

$$A_1 \qquad Y_2$$

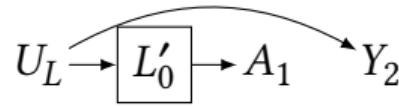
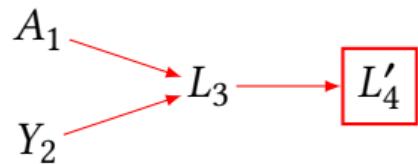
# Mediator Bias Strategy: Longitudinal Hygiene



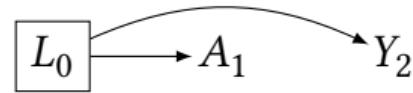
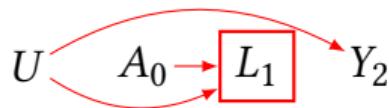
# Collider Bias Strategy: Longitudinal Hygiene



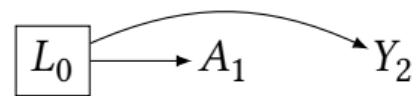
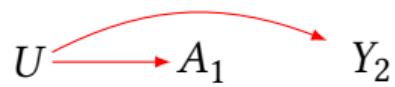
# Collider Bias Proxy Strategy: Longitudinal Hygiene



# Post Exposure Collider Bias Strategy: Longitudinal Hygiene



# Unmeasured Common Cause Strategy: Longitudinal Hygiene



## Section 2

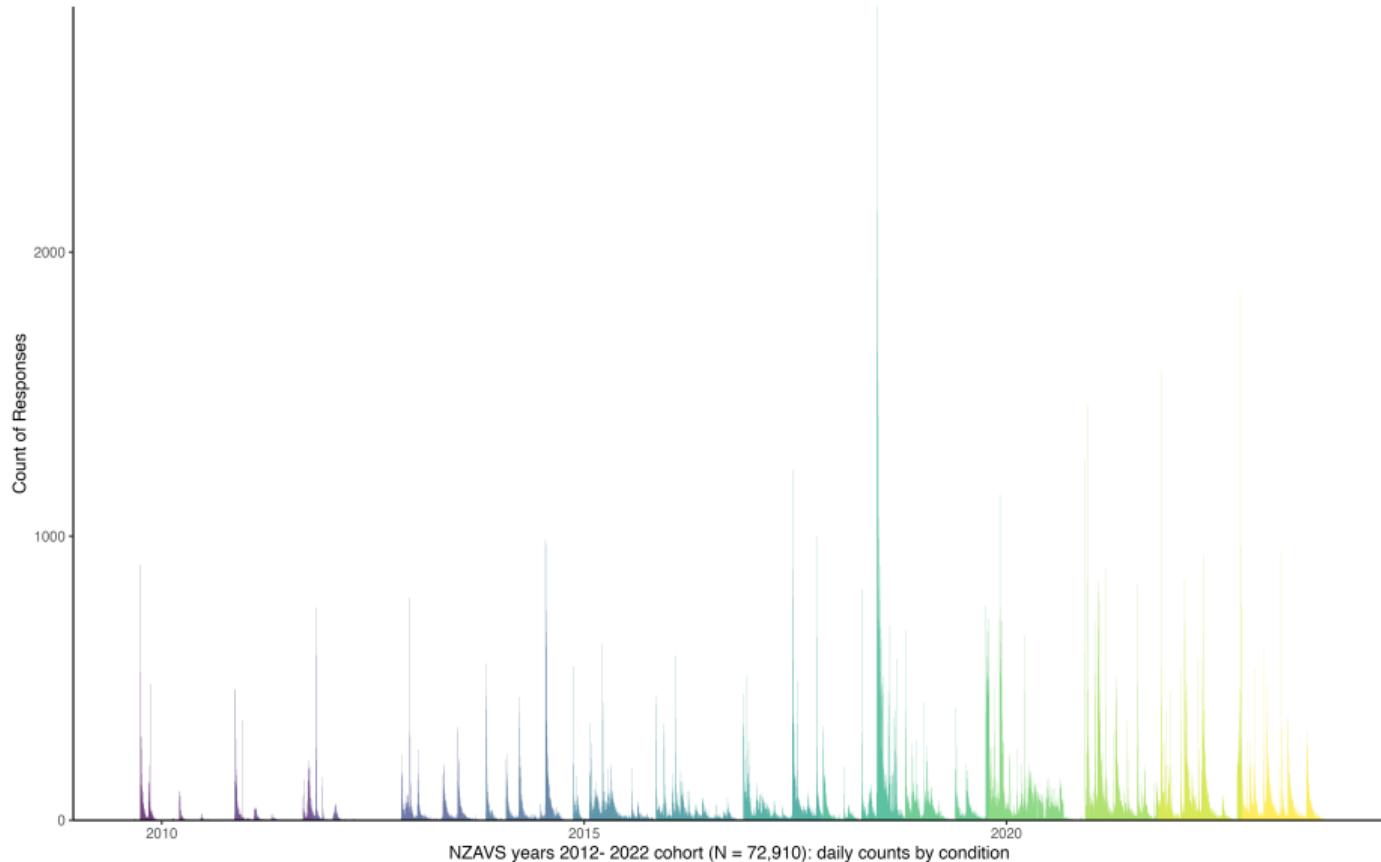
New Zealand Attitudes and Values Study (NZAVS)

# NZAVS Longitudinally Hygienic Data Collection

- Planned 20-year longitudinal study, currently in its 14<sup>th</sup> 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 72910 unique individuals, and ~ 38,000 in the longitudinal study

## New Zealand Attitudes and Values Study (panel)

N = 72,910; years 2012-2022

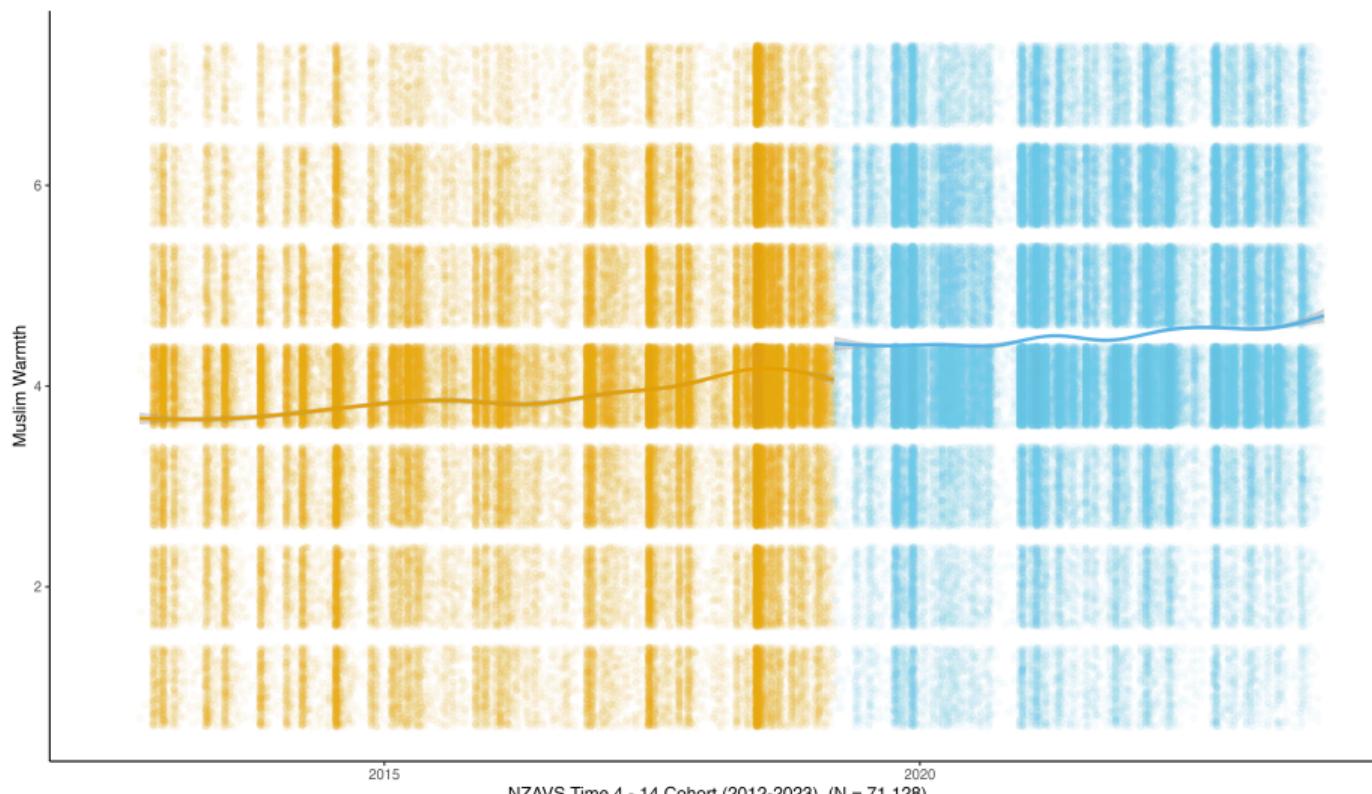


# BIG EVENTS

## Discontinuity at attacks (GAM)

Boost to Warmth increase in the years following the attacks: FULL SAMPLE

attack\_condition 0 1



# 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.”

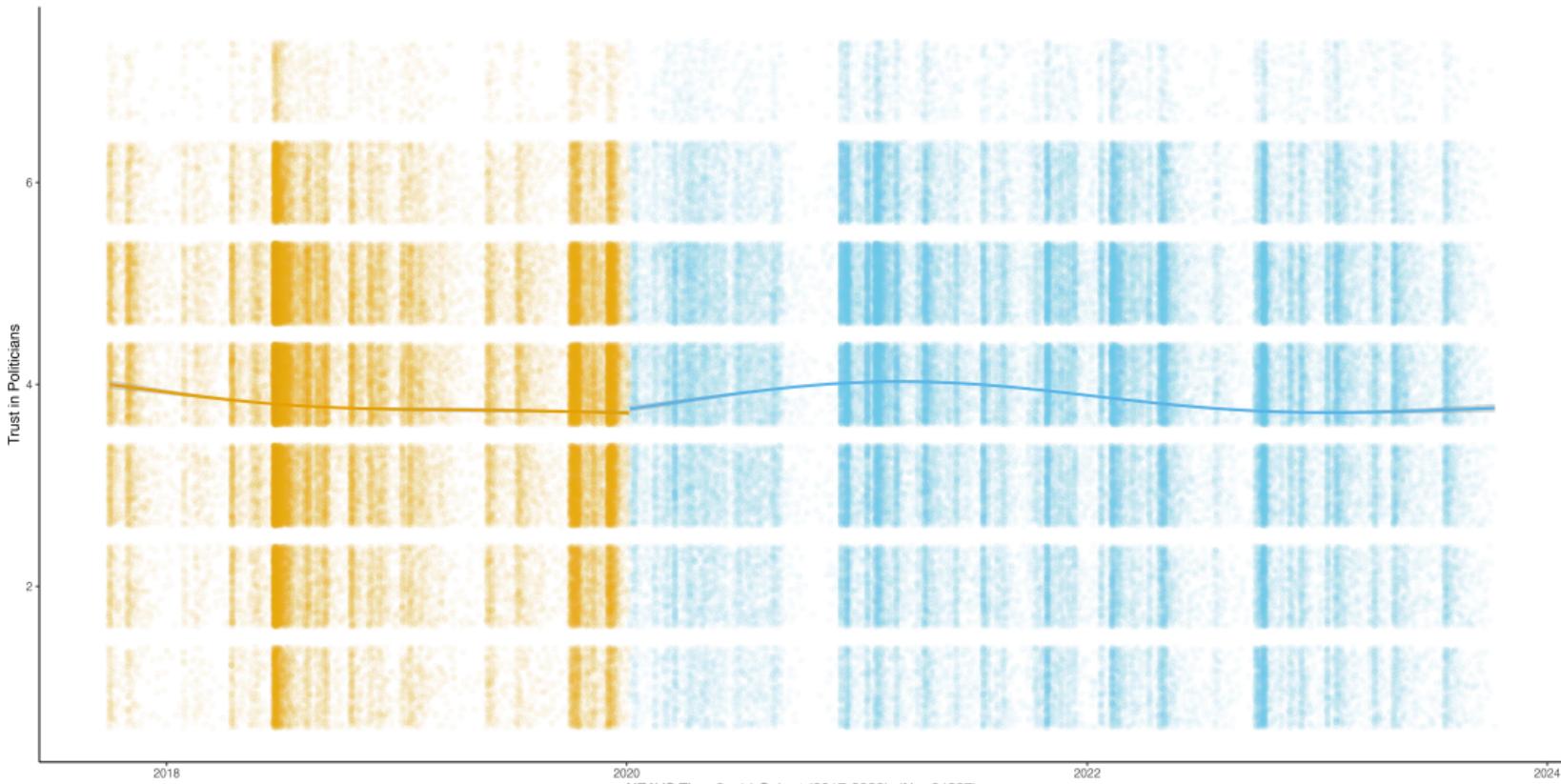
**Trust in politicians** - “Politicians in New Zealand can generally be trusted.”

**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.”

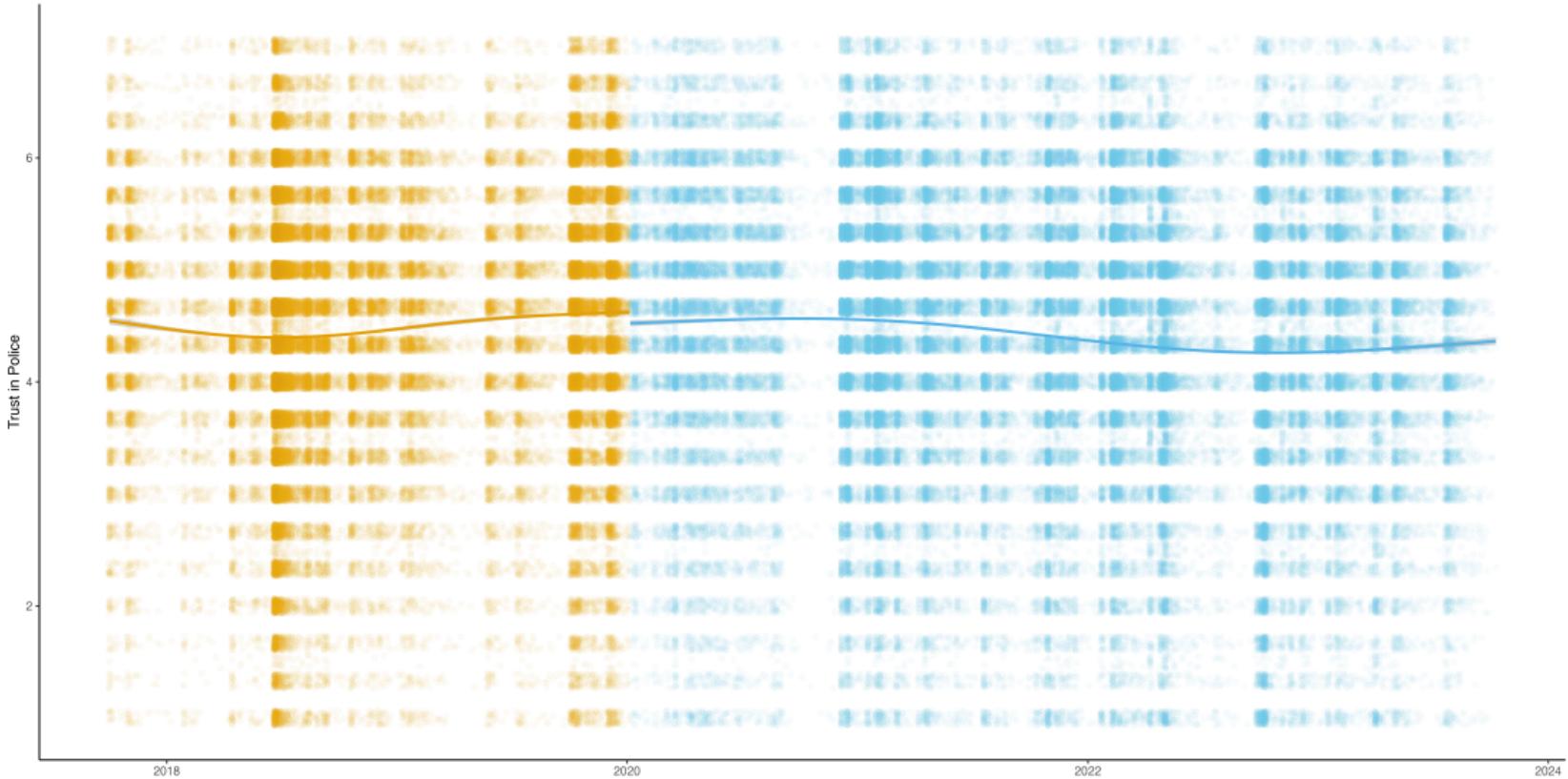
**General tendency to believe in conspiracies** - “I think that the official version of major world events given by authorities often hides the truth.”

## Trust in Politicians: Pre/Post Covid-19 Attack

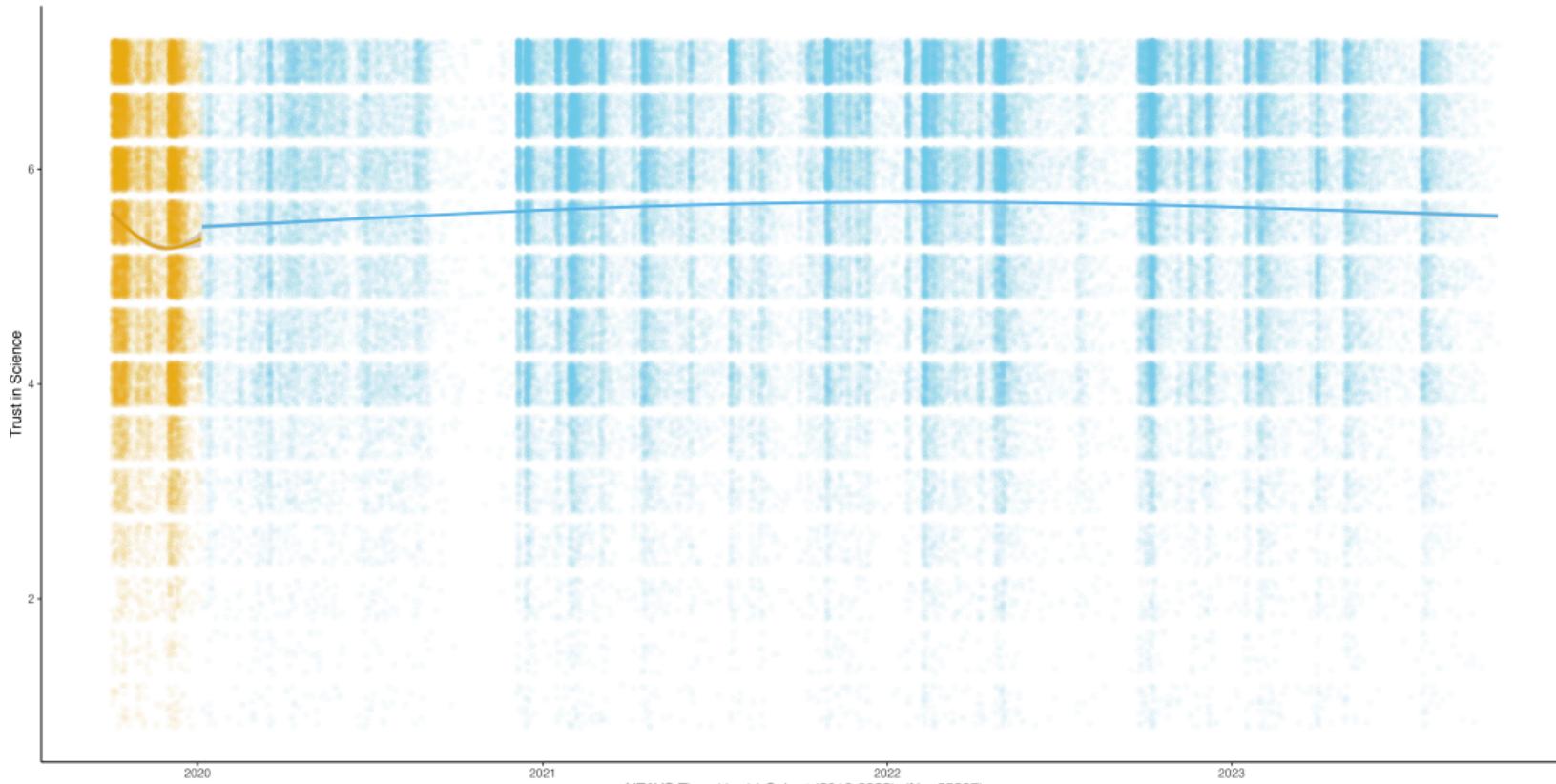
covid\_19\_attack 0 1



## Trust in Police: Pre/Post Covid-19 Attack

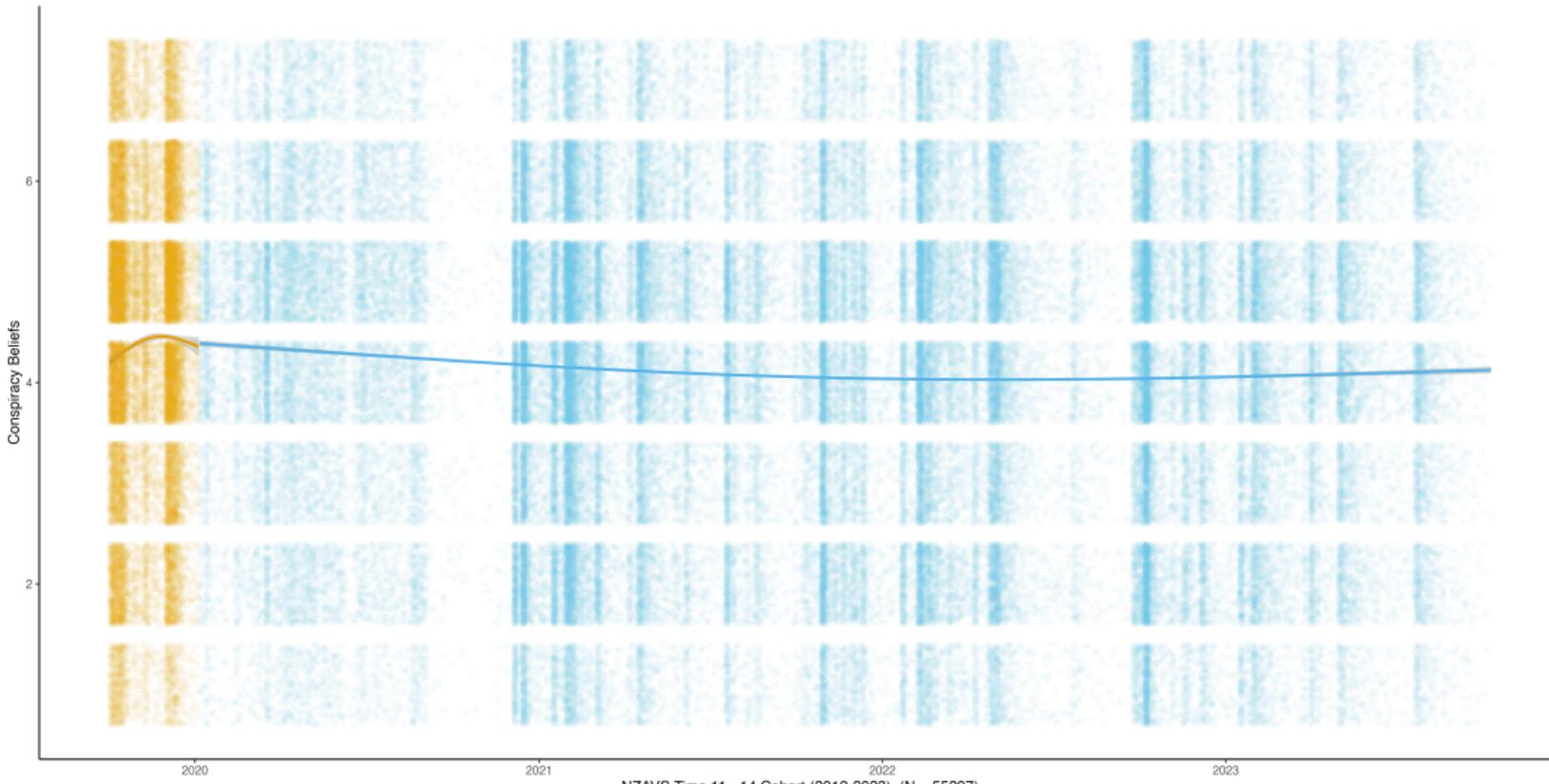
covid\_19\_attack 

## Trust in Science: Pre/Post Covid-19 Attacks

covid\_19\_attack 

NZAVS Time 11 - 14 Cohort (2012-2023), (N = 55297)

## Conspiracy Beliefs: Pre/Post Covid-19 Attacks

covid\_19\_attack 

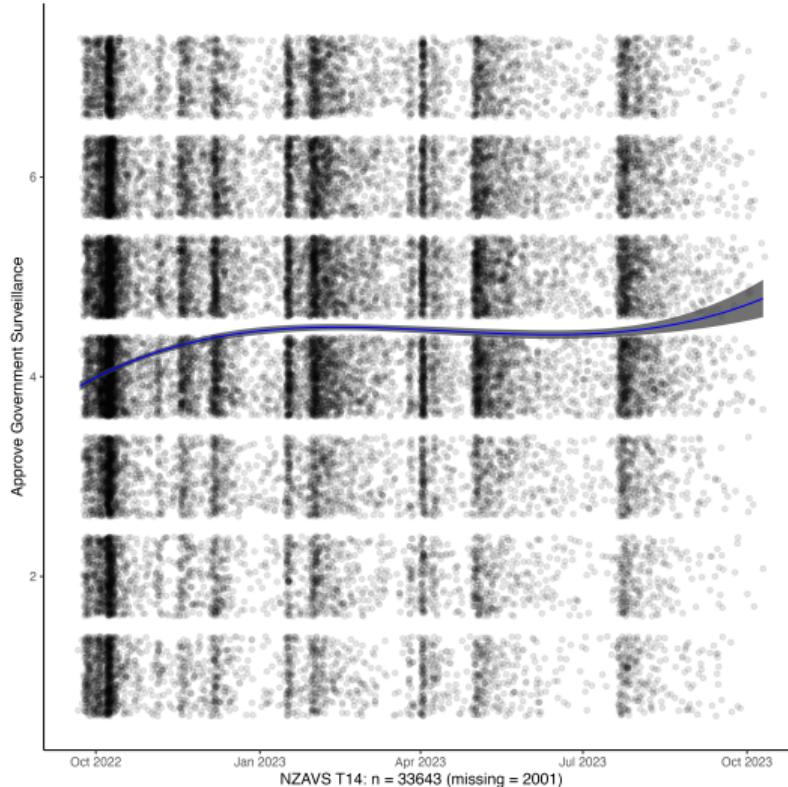
# Regulate Gov't Surveillance vs Regulate AI

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)

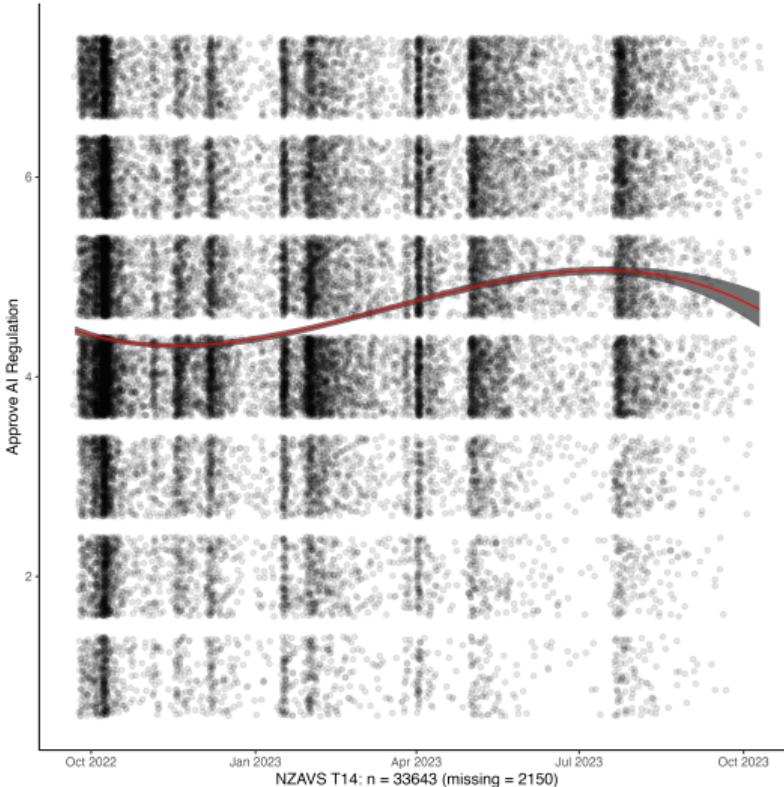
A

Collection of telephone and internet data by  
the New Zealand Government as part of anti-terrorism efforts



B

Strict regulation limiting the development and use of Artificial Intelligence

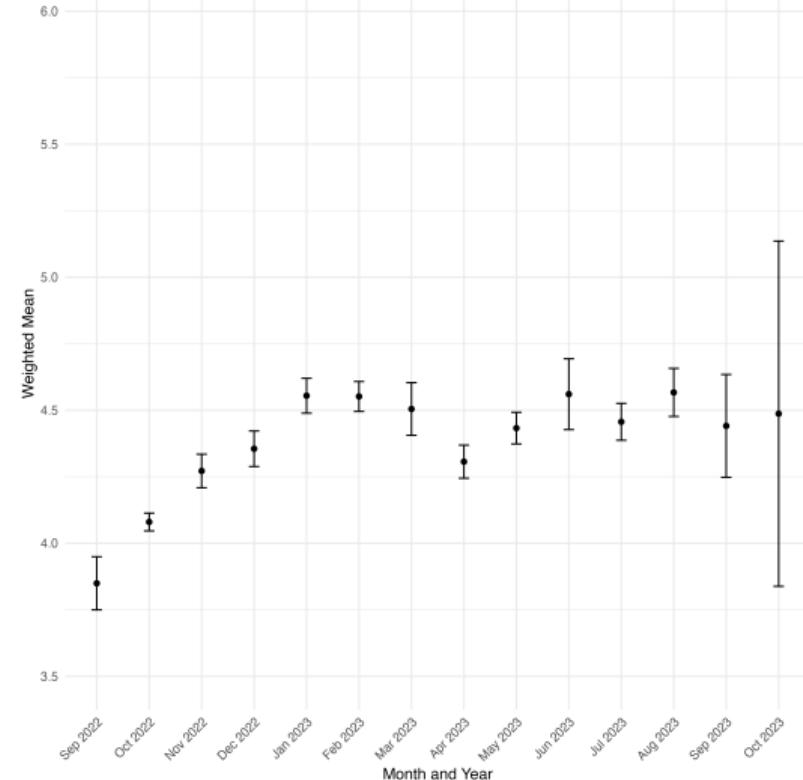


## Weighted Monthly Marginal Means: Comparisons of Attitudes to New Zealand Government Interventions

NZAJS Time 14 (n=33643)

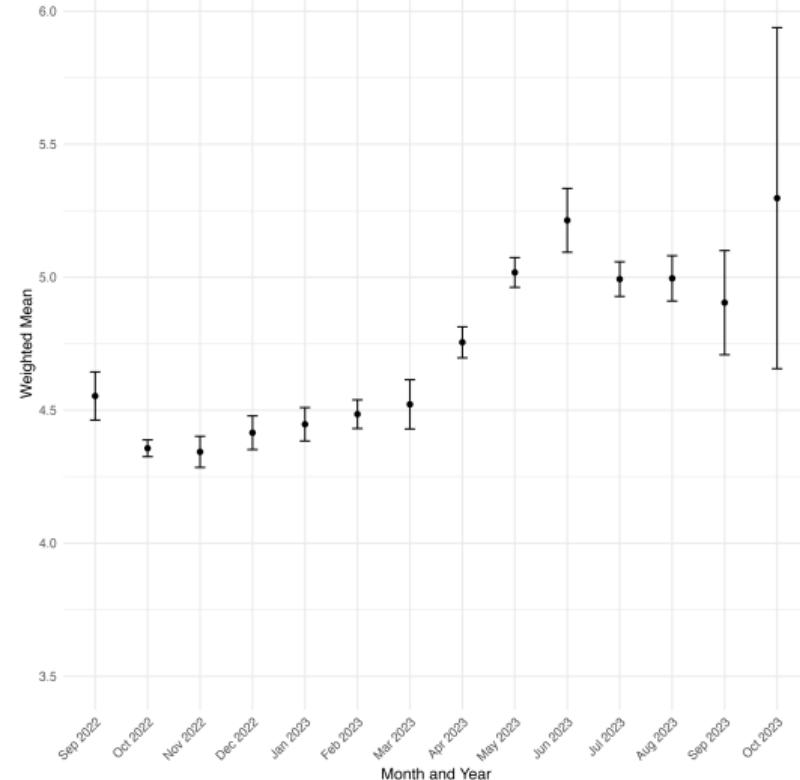
A

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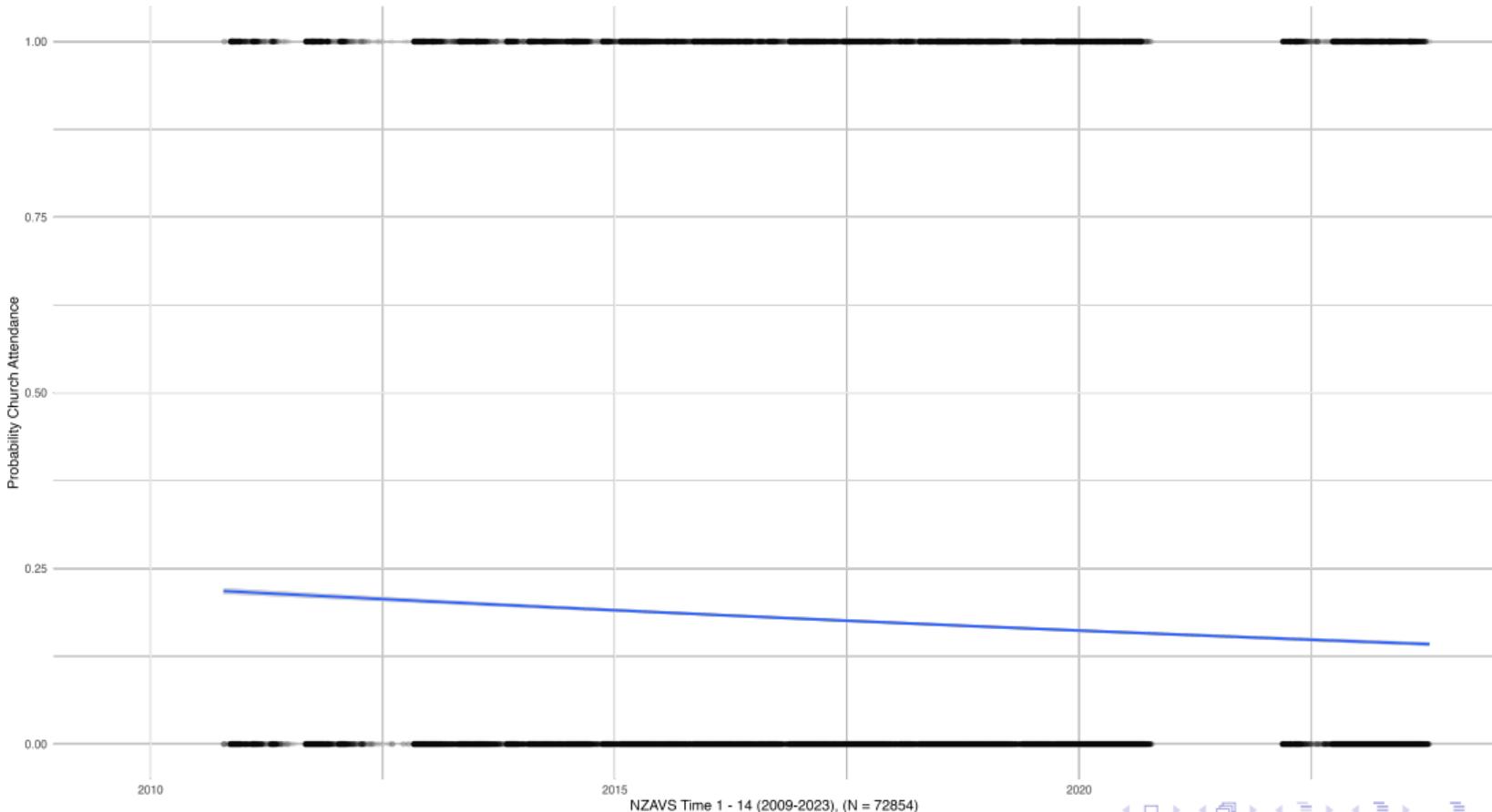
B

Self-regulation limiting the development and use of Artificial Intelligence



## Consider Gradual Events

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



# Worked Example: causal 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

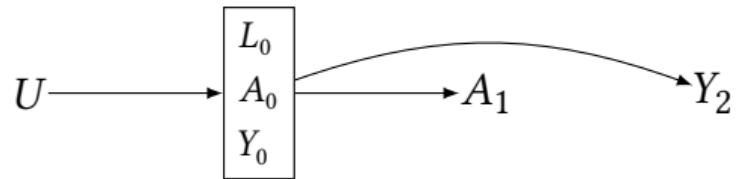
Intervention

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

Contrast:

$$f(A) = 0$$

# Key Graph

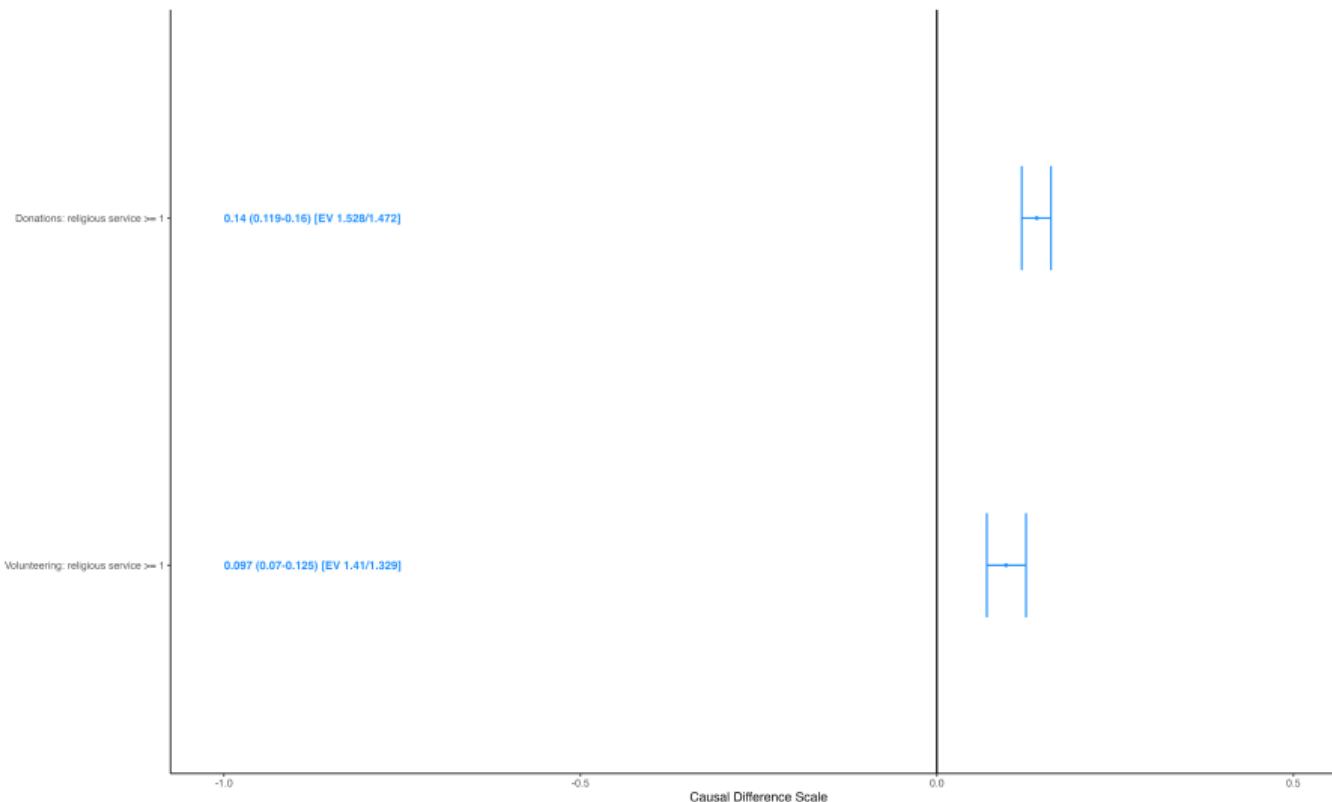


# Religious Service Outcomes

## Religious service effect on reported donations and volunteering

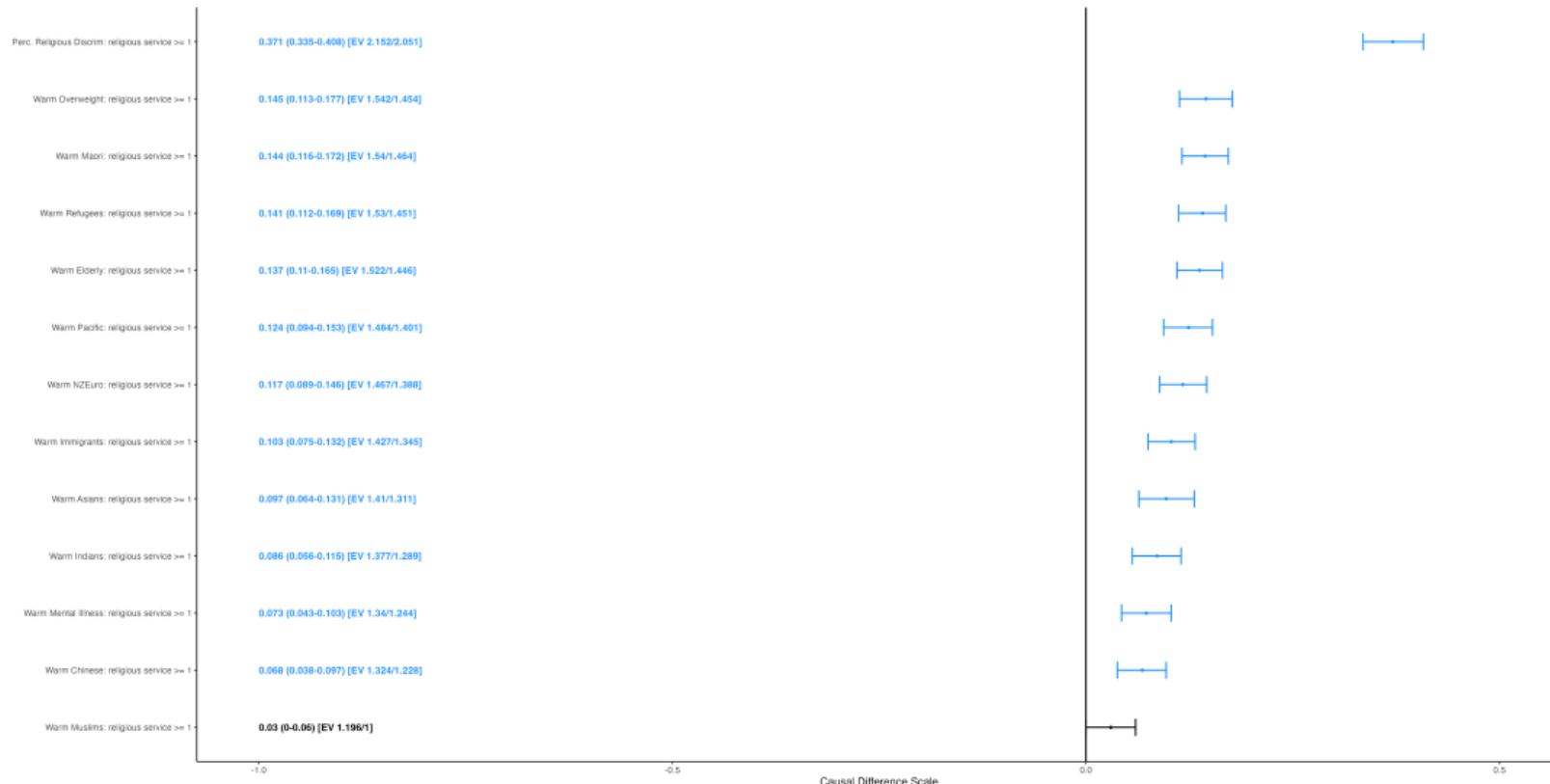
 $\geq 1 \times$  weekly religious service attendance

Reliability positive



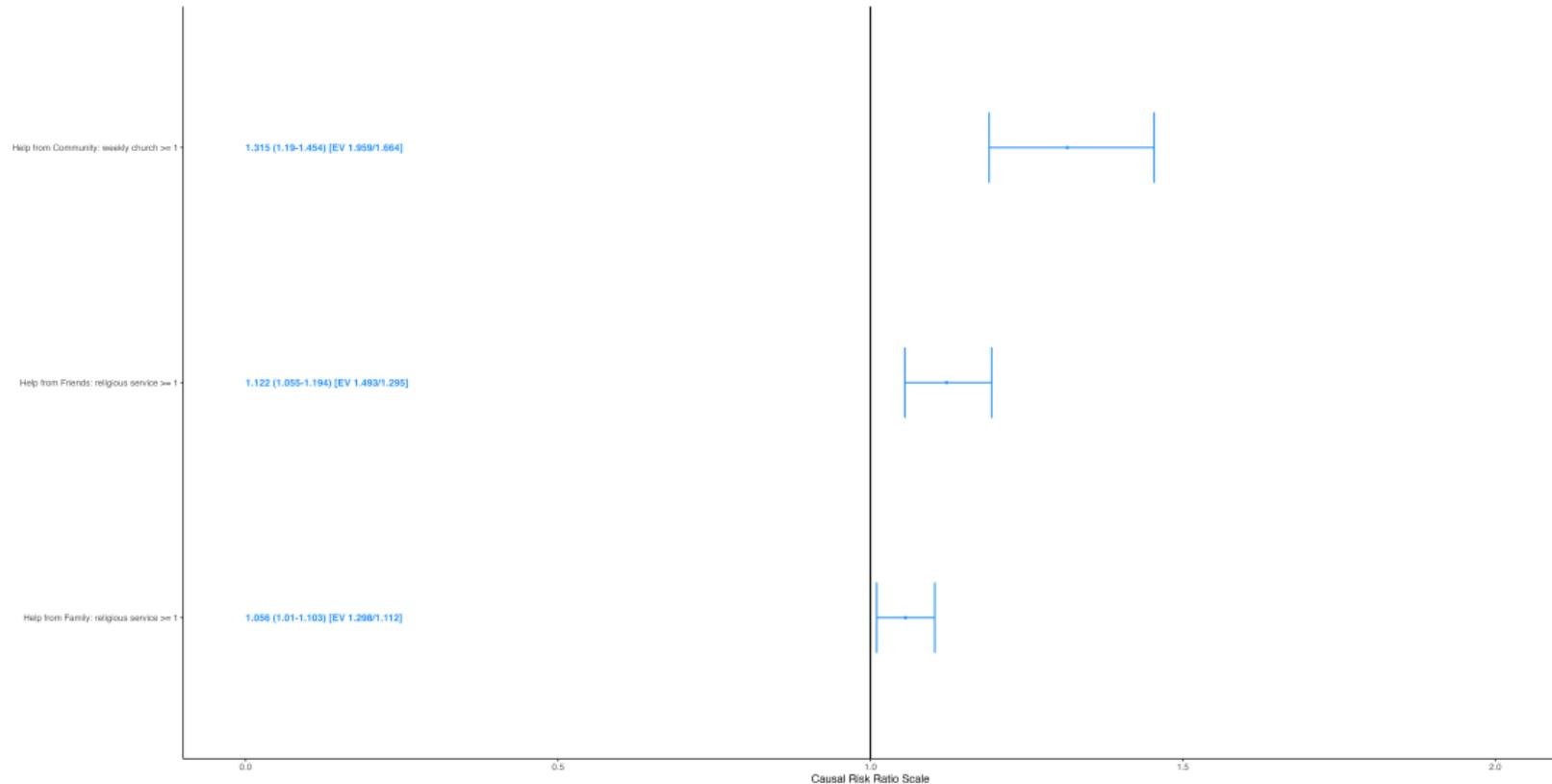
**Religious service effect on minority-group attitudes**  
 **$\geq 1 \times$  weekly religious service attendance**

Reliability positive zero\_crossing



**Religious service effect on help received**  
≥ 1 x weekly service attendance

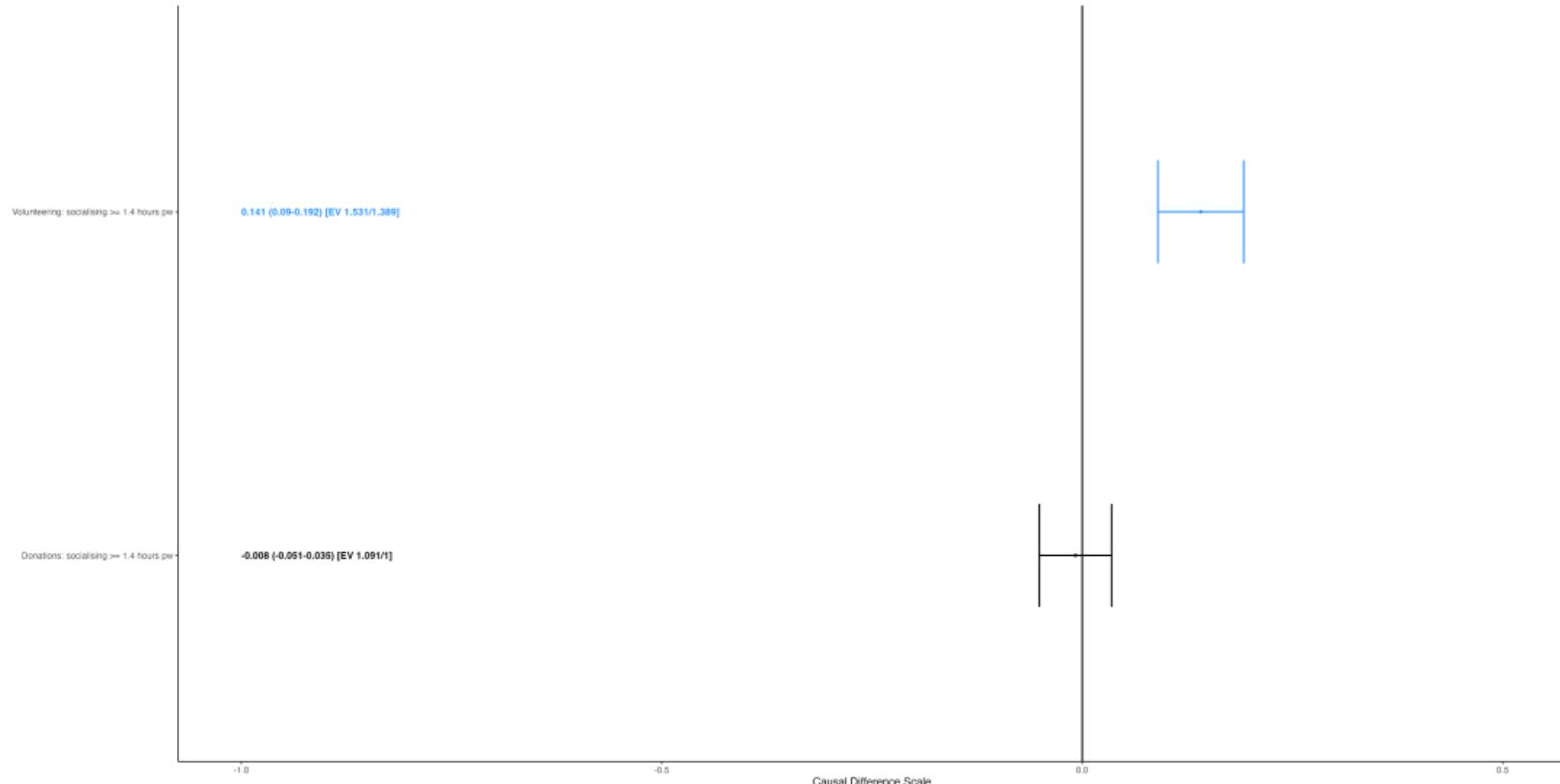
Reliability ← positive



# Socializing Outcomes

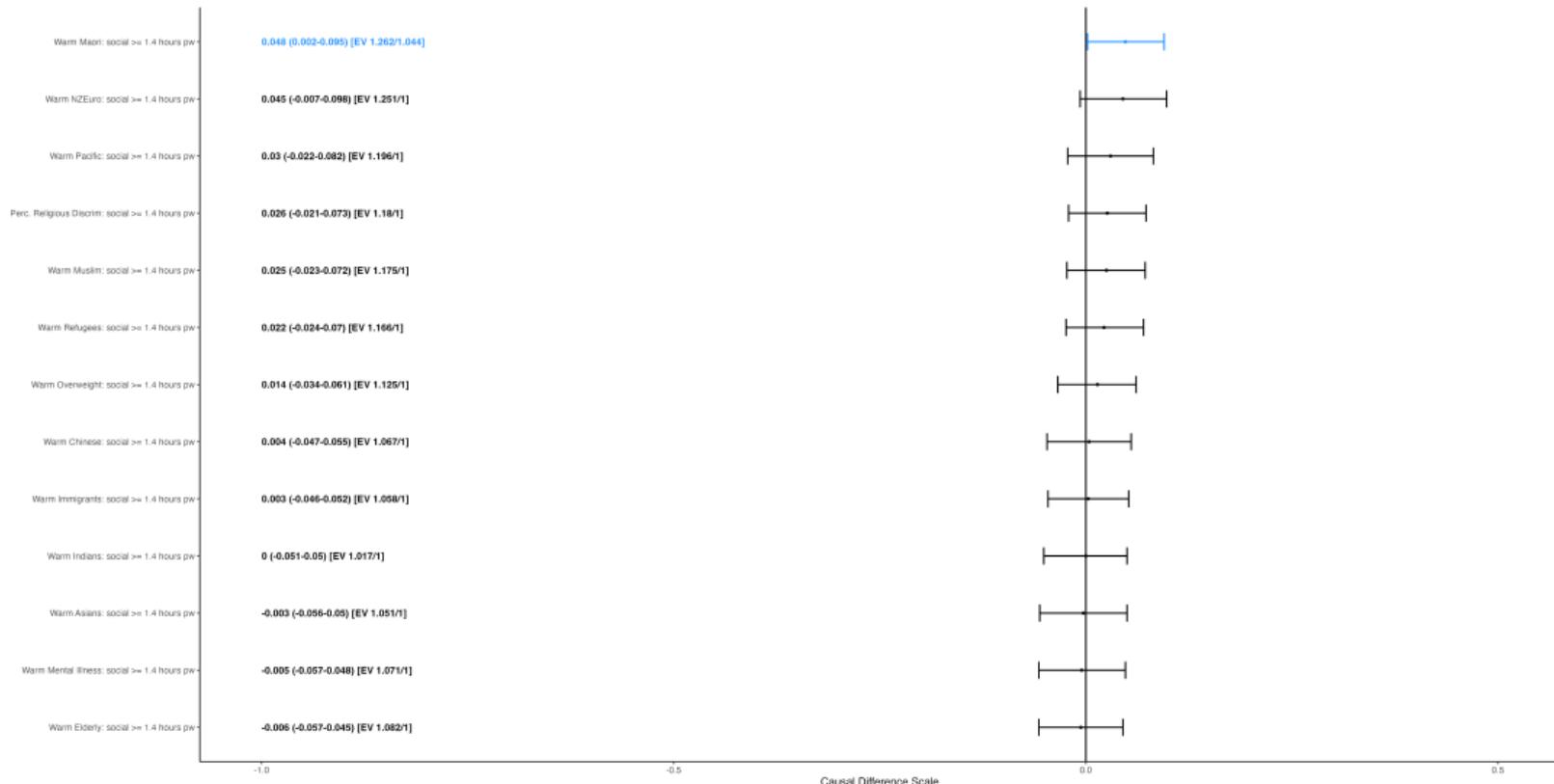
**Socialising effect on charity**  
 $\geq 1.4 \times$  weekly hours socialising

Reliability ↗ positive ⚡ zero\_crossing



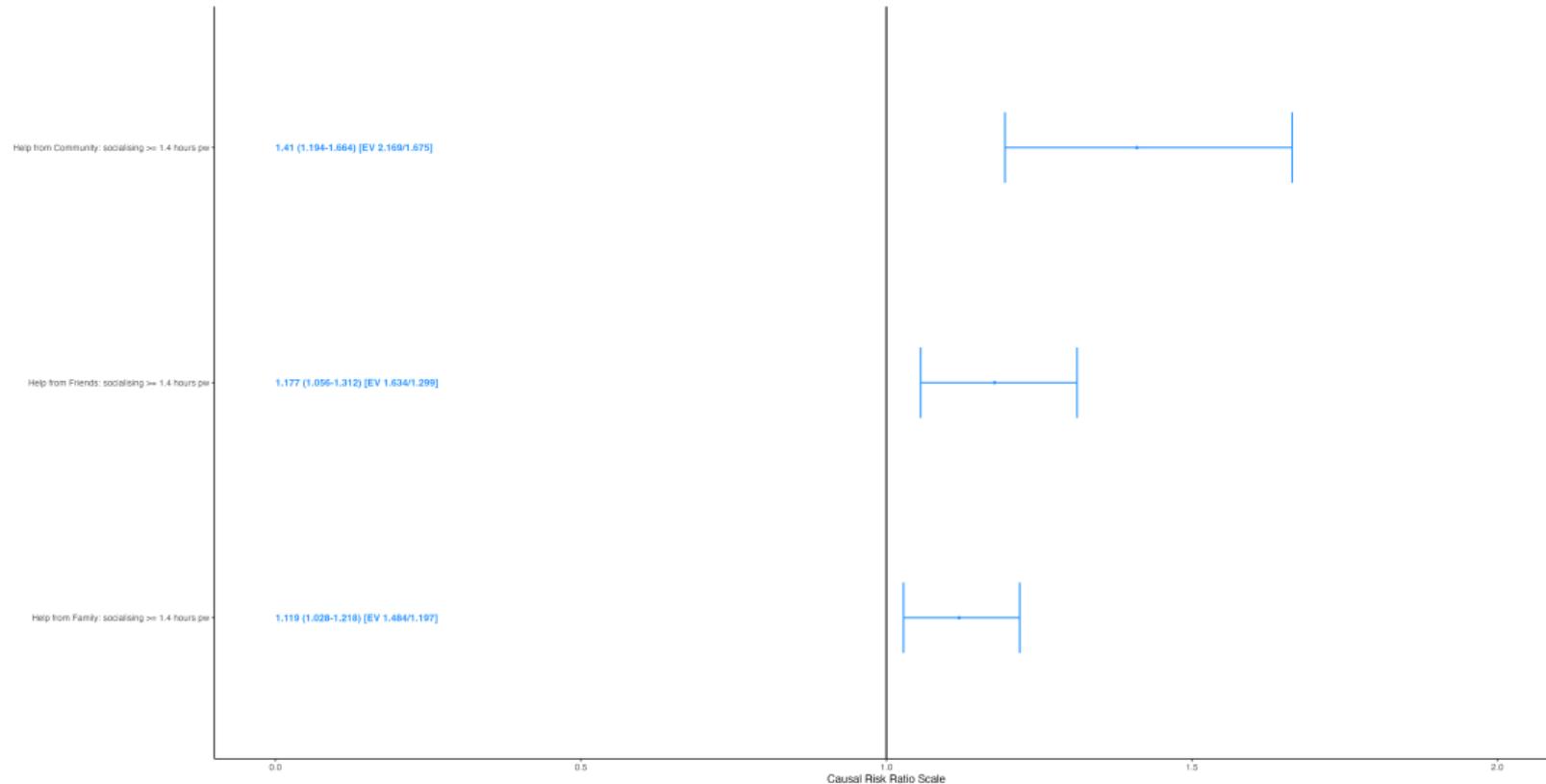
**Socializing effect on prejudice/acceptance**  
 **$\geq 1.4 \times$  weekly hours socialising**

Reliability positive zero\_crossing



**Socialising effect on help received**  
 $\geq 1.4 \times \text{weekly hours socialising}$

Reliability positive



# 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.
- Notably, cross-sectional associations are four times stronger, but these associations are **uninterpretable**
- Results underscore the importance of investigating gradual cultural change.

# Summary

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- ① To move beyond association to causality requires time, literally.
- ② Big events ≠ 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)
- Templeton Religion Trust Grant 0418
- Max Planck Institute for Evolutionary Anthropology: Department Linguistic and Cultural Evolution
- Victoria University
- University of Canterbury
- 72,910 NZAVS participants

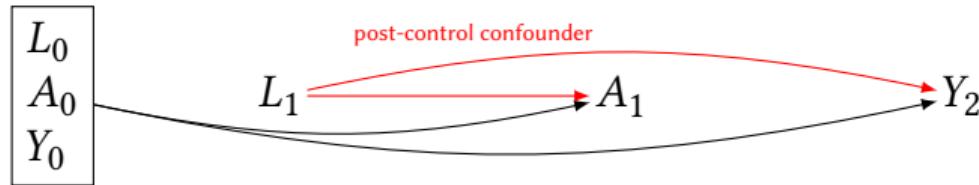




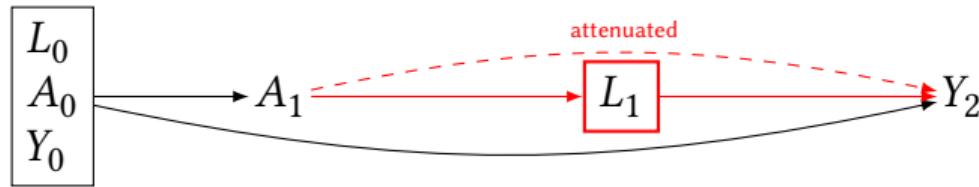
# Extra Slides

# Longitudinal Data Bring Their Own Problems

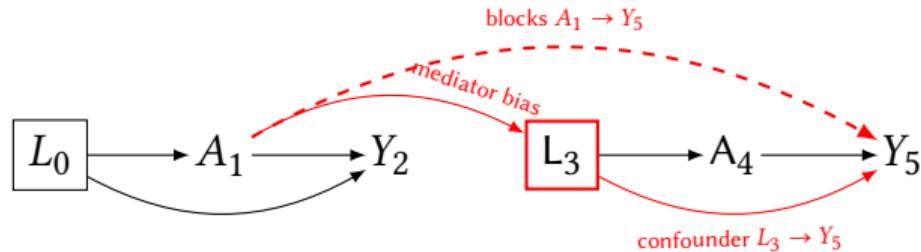
# Timing of Confounder



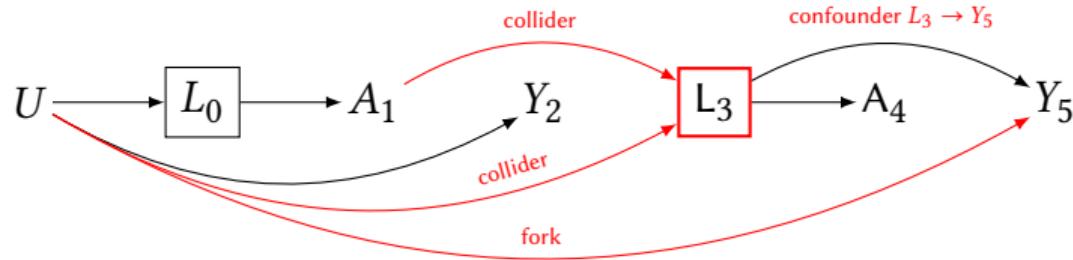
# Timing of Mediator



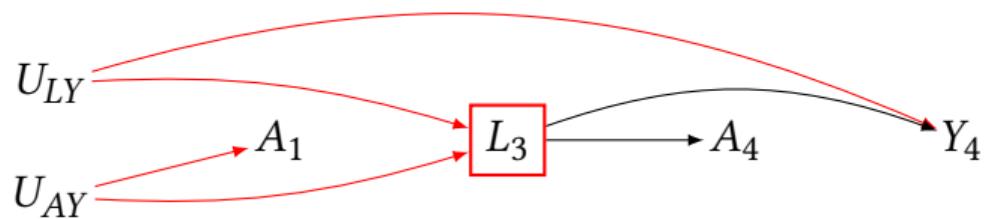
# Treatment Confounder Bias



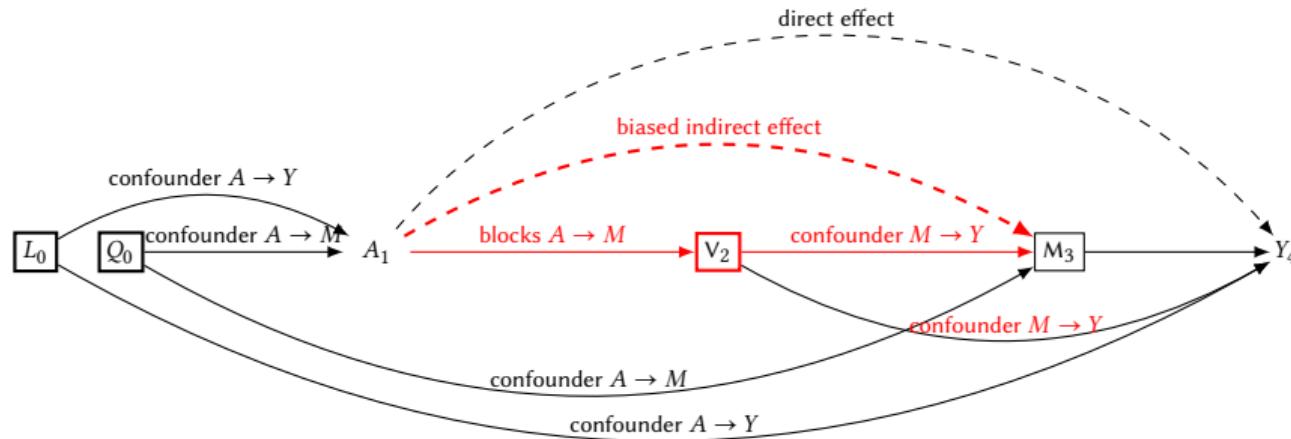
# Treatment Confounder Feedback



# Treatment Confounder Feedback Variation



# Mediation



# 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

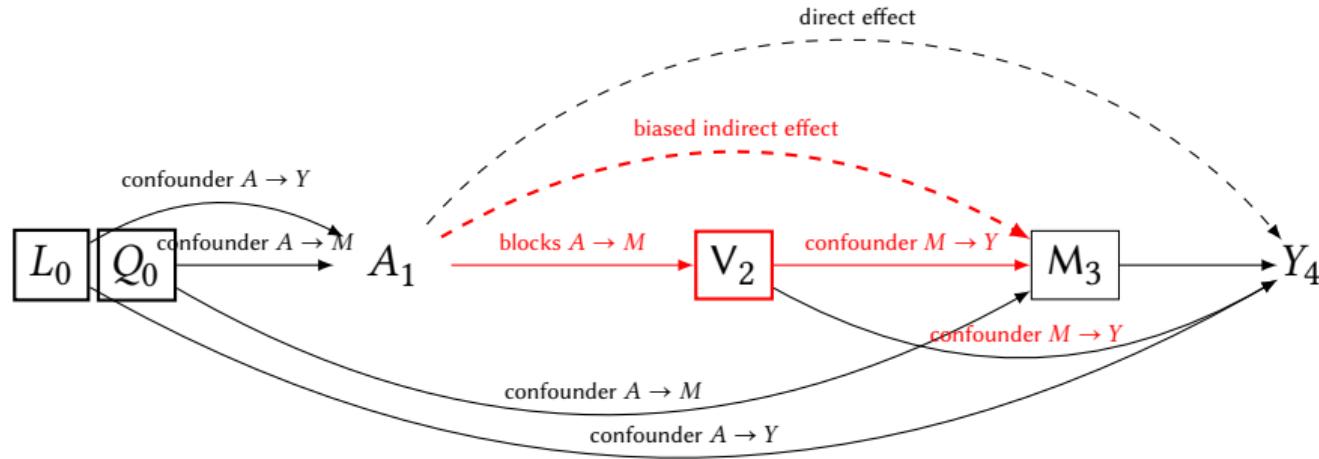
**Natural Indirect Effect (NIE):** is the effect of the exposure on the outcome that is mediated. To obtain these quantities we must compare the potential outcome  $Y$  under treatment, where the mediator assumes its natural level under treatment with the potential outcome when the mediator assumes its 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

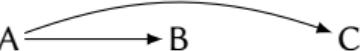
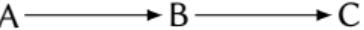
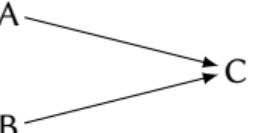
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$X$	Any variable.
$A$	The treatment or, equivalently, the exposure.
$Y$	The outcome.
$Y(a)$	The potential outcome when $A = a$ .
$L$	Measured confounder(s): typically comprises a set of variables.
$U$	Unmeasured confounder.
$Z$	Effect-modifier (or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

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1	<b>Causality Absent</b>	A      B	A and B have no causal effect on each other.	$A \perp\!\!\!\perp B$ (independent)
2	<b>Causality</b>	$A \longrightarrow B$	A causally affects B, and they are associated.	$A \not\perp\!\!\!\perp B$ (dependent)

**Three variables**

3	<b>Fork</b>		A causally affects both B and C; B and C are conditionally independent given A.	$B \perp\!\!\!\perp C   A$
4	<b>Chain</b>		C is affected by B which is, in turn, affected by A; A and C are conditionally independent given B.	$A \perp\!\!\!\perp C   B$
5	<b>Collider</b>		C is affected by both A and B, which are independent; conditioning on C induces association between A and B.	$A \not\perp\!\!\!\perp B   C$