Your Title

YOUR NAME

2025-05-23

Abstract

**Background**: (Brief few sentences) **Objectives**: 1. Estimate the causal effect of YOUR EXPOSURE on YOUR OUTCOMES measured one year later. 2. Evaluate whether these effects vary across the population. 3. Provide policy guidance on which individuals might benefit most. **Method**: We conducted a three-wave retrospective cohort study (waves XX-XXX, October XXXX–October XXXX) using data from the New Zealand Attitudes and Values Study, a nationally representative panel. Participants were eligible if they participated in the NZAVS in the baseline wave (XXXX, were under the age of 62, and were employed > 20 hours per week. We defined the exposure as (XXXX > NUMBER on a 1-7 Likert Scale (1 = yes, 0 = no)). To address attrition, we applied inverse probability of censoring weights; to improve external validity, we applied weighted to the population distribution of Age, Ethnicity, and Gender. We computed expected mean outcomes for the population in each exposure condition (high XXXX/low XXXXX). Under standard causal assumptions of unconfoundedness, the contrast provides an unbiased average treatment effect. We then used causal forests to detect heterogeneity in these effects and employed policy tree algorithms to identify individuals (“strong responders”) likely to experience the greatest benefits. **Results**: Increasing XXXXX leads to XXXXX. Heterogeneous responses to (e.g. *Forgiveness*, *Personal Well-Being*, and *Life-Satisfaction*…) reveal structural variability in subpopulations… **Implications**: (Brief few sentences) **Keywords**: *Causal Inference*; *Cross-validation*; *Distress*; *Employment*; *Longitudinal*; *Machine sLearning*; *Religion*; *Semi-parametric*; *Targeted Learning*.

## Introduction

**Your place to shine here**

## Method

### Sample

Data were collected as part of the New Zealand Attitudes and Values Study (NZAVS), an annual longitudinal national probability panel assessing New Zealand residents’ social attitudes, personality, ideology, and health outcomes. The panel began in 2009 and has since expanded to include over fifty researchers, with responses from 40,000 participants to date. The study operates independently of political or corporate funding and is based at a university. It employs prize draws to incentivise participation. The NZAVS tends to slightly under-sample males and individuals of Asian descent and to over-sample females and Māori (the Indigenous people of New Zealand). To enhance the representativeness of our sample population estimates for the target population of New Zealand, we apply census-based survey weights that adjust for age, gender, and ethnicity (New Zealand European, Asian, Māori, Pacific) (Sibley, 2021). For more information about the NZAVS, visit: [OSF.IO/75SNB](https://doi.org/10.17605/OSF.IO/75SNB).

### Target Population

The target population for this study comprises New Zealand residents as represented in the 2018 of the New Zealand Attitudes and Values Study (NZAVS) during the years 2018 weighted by New Zealand Census weights for age, gender, and ethnicity (refer to Sibley (2021)). The NZAVS is a national probability study designed to reflect the broader New Zealand population accurately. Despite its comprehensive scope, the NZAVS has some limitations in its demographic representation. Notably, it tends to under-sample males and individuals of Asian descent while over-sampling females and Māori (the indigenous peoples of New Zealand). To address these disparities and enhance the accuracy of our findings, we apply New Zealand Census survey weights to the sample data.

### Eligibility Criteria

To be included in the analysis of this study, participants needed to participate in the 2018 of the study and respond to the baseline measure of Extraversion.

Participants may have been lost to follow-up at the end of the study if they met eligibility criteria at 2018. We adjusted for attrition and non-response using censoring weights, described below.

A total of 39,635 individuals met these criteria and were included in the study.

### Average Treatment Effect

Researchers often want to know what might happen if we could change (or ‘intervene on’) a particular variable for everyone in a study—much like testing a new treatment in a randomised trial. Because we cannot always run an actual trial, we imagine a **target trial** (Hernán et al., 2016), a hypothetical experiment that clarifies exactly which cause-and-effect question we are trying to answer.

Here, we ask:

‘How would the outcomes of interest change if, for everyone in the population, we set the exposure to **>4, scale range 1-7**, compared with setting it to **<=4, scale range 1-7**, given each individual’s characteristics?’

Thus we compare two scenarios:

1. **1**: Everyone receives exposure level >4, scale range 1-7.
2. **0**: Everyone receives exposure level <=4, scale range 1-7.

The difference between these two population means is the **Average Treatment Effect (ATE)**. Because we evaluate several outcomes, ATE confidence intervals were corrected for multiplicity with bonferroni at = 0.05.

By combining time-series data with a rich baseline covariate set, we may, under the identifications assumptions described below, separate the causal effects of the exposure from spurious associations. Measuring demographics, personality traits, and other background factors at baseline helps ensure that, conditional on those covariates, assignment to the two exposure levels is ‘as good as random.’ (See Appendix [D](#appendix-assumptions_grf) for a full statement of the required assumptions.)

### Moderators and treatment policies

We pursued two complementary objectives: (i) to test whether personalised targeting, based on individual conditional average treatment effects , yields welfare gains, and (ii) to convert any such gains into transparent, practitioner‐ready decision rules.

#### Pre-processing and honest model training

Our protocol is as follows: in settings where the exposure is positive, outcomes for which lower is better are sign‐flipped so that larger values always index improvement. Similarly, where the exposure is negative, outcomes for which ‘higher is better’ are sign flipped.Here, we flipped: Anxiety, Depression, Rumination.

Each model estimate used an honest 70/30 split: the training fold built the causal forest with grf (Tibshirani et al., 2024), while the held-out fold powered all diagnostic checks and provided data for fitting policy trees. This separation curbs over-fitting yet keeps the workflow simple.

#### Budget-based screening with Qini curves.

Before constructing rules we asked a budget question: If resources allow treatment of only the top 20% or 50% of individuals ranked by , what uplift is purchased relative to treating everyone? Qini curves quantified the incremental gain; outcomes whose 95% confidence intervals excluded zero at either spend level were labelled actionable, signalling meaningful heterogeneity in benefit.

#### Deriving transparent decision rules.

For each actionable outcome we trained depth-2 policy trees with policytree (Athey & Wager, 2021a; Sverdrup et al., 2024) on the validation data. The resulting if–then statements maximise expected welfare under the same budget cap and remain auditable by domain experts.

#### Global heterogeneity tests (supplementary).

Appendix E reports RATE-AUTOC and RATE-Qini statistics, asking whether any covariate information can beat a uniform policy. These tests, controlled for false discovery at q=0.1 via Benjamini–Hochberg false-discovery-rate adjustment, are informative but not required for the budget-first pipeline.

Overall, combining Qini curves to screen and shallow policy trees to act isolates budget-relevant treatment heterogeneity and distils it into actionable rules, avoiding the chase for spurious complexity. Full technical details appear in Appendix D.

### Exposure Indicator

The New Zealand Attitudes and Values Study assesses Extraversion using the following question:

Mini-IPIP6 Extraversion dimension: (i) I am the life of the party. (ii) I don’t talk a lot. (r) (iii) I keep in the background. (r) (iv) I talk to a lot of different people at parties.(Refer to [Appendix A](#appendix-measures)).

### Causal Identification Assumptions

This study relies on the following identification assumptions for estimating the causal effect of Extraversion:

1. **Consistency**: the observed outcome under the observed Extraversion is equal to the potential outcome under that exposure level. As part of consistency, we assume no interference: the potential outcomes for one individual are not affected by the Extraversion status of other individuals.
2. **No unmeasured confounding**: all variables that affect both Extraversion and the outcome have been measured and accounted for in the analysis.
3. **Positivity**: there is a non-zero probability of receiving each level of Extraversion for every combination of values of Extraversion and confounders in the population. Positivity is the only fundamental casual assumption that can be evaluated with data (refer to [Appendix G](#appendix-positivity)).

### Confounding Control

To manage confounding in our analysis, we implement VanderWeele (2019)’s *modified disjunctive cause criterion* by following these steps:

1. **Identified all common causes** of both the treatment and outcomes.
2. **Excluded instrumental variables** that affect the exposure but not the outcome. Instrumental variables do not contribute to controlling confounding and can reduce the efficiency of the estimates.
3. **Included proxies for unmeasured confounders** affecting both exposure and outcome. According to the principles of d-separation Pearl (2009), using proxies allows us to control for their associated unmeasured confounders indirectly.
4. **Controlled for baseline exposure** and **baseline outcome**. Both are used as proxies for unmeasured common causes, enhancing the robustness of our causal estimates, refer to VanderWeele et al. (2020).

### Statistical Estimation

We estimate heterogeneous treatment effects with Generalized Random Forests (GRF) (Tibshirani et al., 2024). GRF extends random forests for causal inference by focusing on conditional average treatment effects (CATE). It handles complex interactions and non-linearities without explicit model specification, and it provides ‘honest’ estimates by splitting data between model-fitting and inference. GRF is doubly robust because it remains consistent if either the outcome model or the propensity model is correct. We evaluate policies with the policytree package (Athey & Wager, 2021a; Sverdrup et al., 2024) and visualise results with margot (Bulbulia, 2024a). (Refer to [Appendix D](#appendix-explain-grf) for a detailed explanation of our approach.)

### Missing Data

The GRF package accepts missing values at baseline. To obtain valid inference for missing responses we computed inverse probability of censoring weights for censoring of the exposure, given that systematic censoring following the baseline wave may lead to selection bias that limit generalistion to the baseline target population (Bulbulia, 2024b). See [Appendix D](#appendix-explain-grf).

### Sensitivity Analysis

We perform sensitivity analyses using the E-value metric (Linden et al., 2020; VanderWeele & Ding, 2017). The E-value represents the minimum association strength (on the risk-ratio scale) that an unmeasured confounder would need with both exposure and outcome—after adjusting for measured covariates—to explain away the observed association (Linden et al., 2020; VanderWeele et al., 2020). Confidence intervals for each E-value were derived from the multiplicity-adjusted confidence intervals of the corresponding coefficient estimates (bonferroni, α = 0.05), so the sensitivity analysis obeys the same error-control framework as the main results.

## Results

### Average Treatement Effects

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| Figure 1: Average Treatment Effects on Multi-dimensional Wellbeing |

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| Table 1: Average Treatment Effects on Multi-dimensional Wellbeing   | Outcome | ATE | 2.5 % | 97.5 % | E-Value | E-Value bound | | --- | --- | --- | --- | --- | --- | | **Social Belonging** | **0.133** | **0.09** | **0.177** | **1.51** | **1.39** | | **Neighbourhood Community** | **0.114** | **0.07** | **0.159** | **1.458** | **1.328** | | **Self Esteem** | **0.099** | **0.06** | **0.139** | **1.415** | **1.299** | | **Social Support** | **0.098** | **0.055** | **0.141** | **1.413** | **1.284** | | **Meaning: Purpose** | **0.104** | **0.053** | **0.154** | **1.43** | **1.278** | | **Meaning: Sense** | **0.094** | **0.043** | **0.145** | **1.401** | **1.244** | | Depression | -0.065 | -0.112 | -0.017 | 1.315 | 1.146 | | Anxiety | -0.06 | -0.104 | -0.016 | 1.3 | 1.141 | | Life Satisfaction | 0.056 | 0.012 | 0.1 | 1.287 | 1.121 | | Personal Well-being Index | 0.055 | 0.013 | 0.098 | 1.284 | 1.116 | | Rumination | -0.051 | -0.102 | -0.001 | 1.271 | 1.012 | | Hours of Exercise (log) | -0.02 | -0.074 | 0.034 | 1.155 | 1 | |

Confidence intervals were adjusted for multiple comparisons using bonferroni correction ( = 0.05). E‑values were also adjusted using bonferroni correction ( = 0.05).

The following outcomes showed reliable causal evidence (E‑value lower bound > 1.2): - Social Belonging: 0.133(0.069,0.197); on the original scale, 0.145 (0.075,0.215). E‑value bound = 1.329 - Neighbourhood Community: 0.114(0.049,0.179); on the original scale, 0.179 (0.077,0.281). E‑value bound = 1.264 - Self Esteem: 0.099(0.041,0.157); on the original scale, 0.126 (0.052,0.2). E‑value bound = 1.238 - Social Support: 0.098(0.035,0.161); on the original scale, 0.11 (0.039,0.18). E‑value bound = 1.216

Confidence intervals were adjusted for multiple comparisons using bonferroni correction ( = 0.05). E‑values were also adjusted using bonferroni correction ( = 0.05). The following outcomes showed reliable causal evidence (E‑value lower bound > 1.2):

* **Social Belonging**: 0.125(0.064,0.186); on the original scale, 0.136 (0.07,0.203). E‑value bound = 1.311
* **Neighbourhood Community**: 0.119(0.052,0.186); on the original scale, 0.187 (0.082,0.292). E‑value bound = 1.273
* Social Support: 0.096(0.032,0.16); on the original scale, 0.107 (0.036,0.179). E‑value bound = 1.203.

### Heterogeneous Treatment Effects

#### Qini Curves: (How Much Do We Gain By Treating Using At Different Budgets?)

#### Qini Curves

The Qini curve shows the cumulative **gain** as we expand a targeting rule down the CATE ranking.

* **Beneficial exposure:** we add individuals from the top positive CATEs downward; the baseline is ‘expose everyone.’
* **Detrimental exposure:** we first flip outcome direction (so higher values represent **more harm**; see Anxiety, Depression, Rumination), then *add* the exposure starting with individuals whose CATEs show the **greated harm**, gradually including those predicted to be more resistant to harm; the baseline is ‘expose everyone.’ The curve therefore quantifies the harm by when those most suceptible to harm are exposed.

If the Qini curve stays above its baseline, a targeted policy increases the outcome more than a one-size-fits-all alternative. (Outcome directions were flipped where needed—Anxiety, Depression, Rumination—so the positively valenced exposures always have positively valanced outcomes and negative exposures always have negatively valenced outcomes.)

We computed cumulative gains from prioritising individuals by CATE at 20% and 50% spend levels, comparing against a no-prioritisation baseline.

**Social Belonging** No benefits for priority investments as measured by the Qini curve at the twenty or fifty percent spend levels.

**Anxiety (reversed)** No benefits for priority investments as measured by the Qini curve at the twenty or fifty percent spend levels.

**Depression (reversed)** No benefits for priority investments as measured by the Qini curve at the twenty or fifty percent spend levels.

**Life Satisfaction** At 20% spend: CATE prioritisation is beneficial (diff: 0.09 [95% CI 0.05, 0.13]). At 50% spend: CATE prioritisation is beneficial (diff: 0.09 [95% CI 0.03, 0.14]).

**Hours of Exercise (log)** No benefits for priority investments as measured by the Qini curve at the twenty or fifty percent spend levels.

**Meaning: Purpose** At 20% spend: CATE prioritisation is beneficial (diff: 0.08 [95% CI 0.05, 0.12]). At 50% spend: CATE prioritisation is beneficial (diff: 0.08 [95% CI 0.03, 0.13]).

**Meaning: Sense** At 20% spend: CATE prioritisation is beneficial (diff: 0.08 [95% CI 0.04, 0.12]). At 50% spend: CATE prioritisation is beneficial (diff: 0.07 [95% CI 0.02, 0.12]).

**Neighbourhood Community** At 20% spend: CATE prioritisation is beneficial (diff: 0.09 [95% CI 0.05, 0.12]). At 50% spend: No reliable benefits from CATE prioritisation.

**Personal Well-being Index** At 20% spend: CATE prioritisation is beneficial (diff: 0.10 [95% CI 0.06, 0.13]). At 50% spend: CATE prioritisation is beneficial (diff: 0.09 [95% CI 0.03, 0.14]).

**Rumination (reversed)** At 20% spend: No reliable benefits from CATE prioritisation. At 50% spend: CATE prioritisation worsens outcomes compared to ATE.

**Self Esteem** At 20% spend: CATE prioritisation is beneficial (diff: 0.06 [95% CI 0.03, 0.10]). At 50% spend: CATE prioritisation is beneficial (diff: 0.07 [95% CI 0.02, 0.11]).

**Social Support** At 20% spend: CATE prioritisation is beneficial (diff: 0.10 [95% CI 0.06, 0.13]). At 50% spend: CATE prioritisation is beneficial (diff: 0.07 [95% CI 0.02, 0.13]).

[Table 2](#tbl-qini) presents results for our Qini curve analysis at different spend rates.

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| Table 2: Qini Curve Results   | Model | Spend 20% | Spend 50% | | --- | --- | --- | | Social Belonging | 0.03 [-0.00, 0.07] | 0.00 [-0.05, 0.05] | | Anxiety (reversed) | -0.00 [-0.01, 0.01] | -0.00 [-0.01, 0.01] | | Depression (reversed) | -0.00 [-0.01, 0.01] | -0.00 [-0.01, 0.01] | | Life Satisfaction | **0.09 [0.05, 0.13]** | **0.09 [0.03, 0.14]** | | Hours of Exercise (log) | 0.01 [-0.02, 0.04] | -0.02 [-0.07, 0.03] | | Meaning: Purpose | **0.08 [0.05, 0.12]** | **0.08 [0.03, 0.13]** | | Meaning: Sense | **0.08 [0.04, 0.12]** | **0.07 [0.02, 0.12]** | | Neighbourhood Community | **0.09 [0.05, 0.12]** | 0.03 [-0.02, 0.08] | | Personal Well-being Index | **0.10 [0.06, 0.13]** | **0.09 [0.03, 0.14]** | | Rumination (reversed) | -0.01 [-0.03, 0.01] | *-0.04 [-0.06, -0.01]* | | Self Esteem | **0.06 [0.03, 0.10]** | **0.07 [0.02, 0.11]** | | Social Support | **0.10 [0.06, 0.13]** | **0.07 [0.02, 0.13]** | |

[Figure 2](#fig-qini-1) presents results for reliable Qini results

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| Figure 2: Qini Graphs |

#### Decision Rules (Who is Most Sensitive to Treatment?)

#### Policy Trees

We used policy trees (Athey & Wager, 2021b, 2021a; Sverdrup et al., 2024) to find straightforward ‘if-then’ rules for who benefits most from treatment, based on participant characteristics. Because we flipped some measures, a higher predicted effect always means greater improvement. Policy trees can uncover small but important subgroups whose treatment responses stand out, even when the overall differences might be modest.

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| Figure 3: Decision Tree: {glued\_policy\_names\_1} |

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| Figure 4: Decision Tree: {glued\_policy\_names\_2} |

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| Figure 5: Decision Tree: {glued\_policy\_names\_3} |

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| Figure 6: Decision Tree: {glued\_policy\_names\_4} |

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| Figure 7: Decision Tree: {glued\_policy\_names\_5} |

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| Figure 8: Decision Tree: {glued\_policy\_names\_6} |

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| Figure 9: Decision Tree: {glued\_policy\_names\_7} |

### Policy Tree Interpretations (depth 2)

A shallow policy tree recommends actions based on two splits for depth=2, or one split for depth=1. We trained on 50% of the data and evaluated on the rest.

**Findings for Life Satisfaction:**

Split 1: NZsei 13 l ≤ -0.121 (original: 52.05). Within that subgroup, split 2a: NZ Dep2018 ≤ 0.466 (original: 6.043), → **Control**; NZ Dep2018 > 0.466 (original: 6.043) → **Treated**.

Split 2: NZsei 13 l > -0.121 (original: 52.05). Within that subgroup, split 2b: Conscientiousness ≤ 1.528 (original: 6.719), → **Treated**; Conscientiousness > 1.528 (original: 6.719) → **Control**.

**Findings for Meaning: Purpose:**

Split 1: Meaning: Sense ≤ -0.586 (original: 4.996). Within that subgroup, split 2a: Meaning: Sense ≤ -0.617 (original: 4.959), → **Treated**; Meaning: Sense > -0.617 (original: 4.959) → **Control**.

Split 2: Meaning: Sense > -0.586 (original: 4.996). Within that subgroup, split 2b: NZ Dep2018 ≤ 1.552 (original: 9.007), → **Treated**; NZ Dep2018 > 1.552 (original: 9.007) → **Control**.

**Findings for Meaning: Sense:**

Split 1: log Household Inc ≤ 0.15 (original: 100000.015). Within that subgroup, split 2a: Age ≤ 0.612 (original: 57), → **Treated**; Age > 0.612 (original: 57) → **Control**.

Split 2: log Household Inc > 0.15 (original: 100000.015). Within that subgroup, split 2b: Hours of Exercise (log) ≤ -0.543 (original: 1.965), → **Control**; Hours of Exercise (log) > -0.543 (original: 1.965) → **Treated**.

**Findings for Neighbourhood Community:**

Split 1: log Hours Housework ≤ -0.083 (original: 6.96). Within that subgroup, split 2a: Life Satisfaction ≤ -1.515 (original: 3.481), → **Control**; Life Satisfaction > -1.515 (original: 3.481) → **Treated**.

Split 2: log Hours Housework > -0.083 (original: 6.96). Within that subgroup, split 2b: Neuroticism ≤ -1.328 (original: 1.963), → **Control**; Neuroticism > -1.328 (original: 1.963) → **Treated**.

**Findings for Personal Well-being Index:**

Split 1: Social Support ≤ 0.035 (original: 5.987). Within that subgroup, split 2a: Meaning: Sense ≤ -3.021 (original: 2.032), → **Control**; Meaning: Sense > -3.021 (original: 2.032) → **Treated**.

Split 2: Social Support > 0.035 (original: 5.987). Within that subgroup, split 2b: Age ≤ -0.108 (original: 47), → **Treated**; Age > -0.108 (original: 47) → **Control**.

**Findings for Self Esteem:**

Split 1: Neighbourhood Community ≤ -0.114 (original: 4.002). Within that subgroup, split 2a: Hours of Exercise (log) ≤ 1.011 (original: 10.038), → **Treated**; Hours of Exercise (log) > 1.011 (original: 10.038) → **Control**.

Split 2: Neighbourhood Community > -0.114 (original: 4.002). Within that subgroup, split 2b: log Hours Housework ≤ -0.953 (original: 3.035), → **Control**; log Hours Housework > -0.953 (original: 3.035) → **Treated**.

**Findings for Social Support:**

Split 1: Neighbourhood Community ≤ -0.134 (original: 3.968). Within that subgroup, split 2a: Hours of Exercise (log) ≤ 1.652 (original: 17.983), → **Treated**; Hours of Exercise (log) > 1.652 (original: 17.983) → **Control**.

Split 2: Neighbourhood Community > -0.134 (original: 3.968). Within that subgroup, split 2b: Age ≤ 0.468 (original: 55), → **Treated**; Age > 0.468 (original: 55) → **Control**.

## Planned Subgroup Comparisons (Optional)

Based on theoretical findings we expected that the effects of {name\_exposure} would vary by age…@fig-planned-comparison and [Table 3](#tbl-planned-comparison)

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| Figure 10: Planned Comparison Plot |

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| Table 3: Planned Comparison Table   | Outcomes | Group Differences | | --- | --- | | Social Support | **-0.144 [-0.269, -0.019]** | | Social Belonging | -0.069 [-0.194, 0.056] | | Self Esteem | -0.051 [-0.179, 0.077] | | Rumination | 0.108 [-0.043, 0.259] | | Personal Well-being Index | **-0.145 [-0.277, -0.013]** | | Neighbourhood Community | -0.011 [-0.146, 0.124] | | Meaning: Sense | -0.161 [-0.330, 0.008] | | Meaning: Purpose | -0.047 [-0.218, 0.124] | | Life Satisfaction | -0.081 [-0.225, 0.063] | | Hours of Exercise (log) | -0.017 [-0.188, 0.154] | | Depression | 0.014 [-0.125, 0.153] | | Anxiety | 0.051 [-0.070, 0.172] | |

We found reliable treatment-effect differences comparing People Over 62 Years Old to People Under 35 Years Old for Social Support (People Over 62 Years Old vs People Under 35 Years Old): = -0.144 [-0.269, -0.019] and Personal Well-being Index (People Over 62 Years Old vs People Under 35 Years Old): = -0.145 [-0.277, -0.013]. We did not find reliable differences for all other outcomes.

## Discussion

## Appendix A: Measures

### Measures

#### Baseline Covariate Measures

### Baseline Covariates

#### Age

*What is your date of birth?*

We asked participants’ ages in an open-ended question (“What is your age?” or “What is your date of birth”). (**string\_is?** Developed for the NZAVS.)

#### Agreeableness

*I sympathize with others’ feelings.* *I am not interested in other people’s problems.* *I feel others’ emotions.* *I am not really interested in others (reversed).*

Mini-IPIP6 Agreeableness dimension: (i) I sympathize with others’ feelings. (ii) I am not interested in other people’s problems. (r) (iii) I feel others’ emotions. (iv) I am not really interested in others. (r) (Sibley et al., 2011)

#### Alcohol Frequency

*“How often do you have a drink containing alcohol?”*

Participants could chose between the following responses: ‘(1 = Never - I don’t drink, 2 = Monthly or less, 3 = Up to 4 times a month, 4 = Up to 3 times a week, 5 = 4 or more times a week, 6 = Don’t know)’ (Health, 2013)

#### Alcohol Intensity

*“How many drinks containing alcohol do you have on a typical day when drinking alcohol? (number of drinks on a typical day when drinking)”*

Participants responded using an open-ended box. (Health, 2013)

#### Social Belonging

*Know that people in my life accept and value me.* *Feel like an outsider (reversed).* *Know that people around me share my attitudes and beliefs.*

We assessed felt belongingness with three items adapted from the Sense of Belonging Instrument (Hagerty & Patusky, 1995): (1) “Know that people in my life accept and value me”; (2) “Feel like an outsider”; (3) “Know that people around me share my attitudes and beliefs”. Participants responded on a scale from 1 (Very Inaccurate) to 7 (Very Accurate). The second item was reversely coded. (Hagerty & Patusky, 1995)

#### Born in Nz

*Where were you born? (please be specific, e.g., which town/city?)*

Coded binary (1 = New Zealand; 0 = elsewhere.) (**string\_is?** Developed for the NZAVS.)

#### Conscientiousness

*I get chores done right away.* *I like order.* *I make a mess of things.* *I often forget to put things back in their proper place.*

Mini-IPIP6 Conscientiousness dimension: (i) I get chores done right away. (ii) I like order. (iii) I make a mess of things. (r) (iv) I often forget to put things back in their proper place. (r) (Sibley et al., 2011)

#### Education Level

*What is your highest level of qualification?*

We asked participants, “What is your highest level of qualification?”. We coded participans highest finished degree according to the New Zealand Qualifications Authority. Ordinal-Rank 0-10 NZREG codes (with overseas school qualifications coded as Level 3, and all other ancillary categories coded as missing) (**string\_is?** Developed for the NZAVS.)

#### Employed

*Are you currently employed (This includes self-employed of casual work)?*

Binary response: (0 = No, 1 = Yes) (**string\_is?** Stats NZ Census Question)

#### Ethnicity

*Which ethnic group(s) do you belong to?*

Coded string: (1 = New Zealand European; 2 = Māori; 3 = Pacific; 4 = Asian) (**string\_is?** NZ Census coding.)

#### Disability Status

*Do you have a health condition or disability that limits you and that has lasted for 6+ months?*

We assessed disability with a one-item indicator adapted from Verbrugge (1997). It asks, “Do you have a health condition or disability that limits you and that has lasted for 6+ months?” (1 = Yes, 0 = No). (Verbrugge, 1997)

#### Log Hours with Children

*Hours spent…looking after children.*

We took the natural log of the response + 1. (Sibley et al., 2011)

#### Log Hours Commuting

*Hours spent…travelling/commuting.*

We took the natural log of the response + 1. (**string\_is?** Developed for the NZAVS.)

#### Log Hours of Exercise

*Hours spent…exercising/physical activity.*

We took the natural log of the response + 1. (Sibley et al., 2011)

#### Log Hours on Housework

*Hours spent…housework/cooking.*

We took the natural log of the response + 1. (Sibley et al., 2011)

#### Log Household Income

*Please estimate your total household income (before tax) for the year XXXX.*

We took the natural log of the response + 1. (**string\_is?** Developed for the NZAVS.)

#### Male

*We asked participants’ gender in an open-ended question: “what is your gender?”*

Here, we coded all those who responded as Male as 1, and those who did not as 0. (Fraser et al., 2020)

#### Neuroticism

*I have frequent mood swings.* *I am relaxed most of the time (reversed).* *I get upset easily.* *I seldom feel blue (reversed).*

Mini-IPIP6 Neuroticism dimension: (i) I have frequent mood swings. (ii) I am relaxed most of the time. (r) (iii) I get upset easily. (iv) I seldom feel blue. (r) (Sibley et al., 2011)

#### Non Heterosexual

*How would you describe your sexual orientation? (e.g., heterosexual, homosexual, straight, gay, lesbian, bisexual, etc.)*

Open-ended question, coded as binary (not heterosexual = 1). (Greaves et al., 2017)

#### Nz Deprivation Index

*New Zealand Deprivation - Decile Index - Using 2018 Census Data*

Numerical: (1-10) (Atkinson et al., 2019)

#### Occupational Prestige Index

*We assessed occupational prestige and status using the New Zealand Socio-economic Index 13 (NZSEI-13).*

This index uses the income, age, and education of a reference group, in this case, the 2013 New Zealand census, to calculate a score for each occupational group. Scores range from 10 (Lowest) to 90 (Highest). This list of index scores for occupational groups was used to assign each participant a NZSEI-13 score based on their occupation. (Fahy et al., 2017)

#### Openness

*I have a vivid imagination.* *I have difficulty understanding abstract ideas (reversed).* *I do not have a good imagination (reversed).* *I am not interested in abstract ideas (reversed).*

Mini-IPIP6 Openness to Experience dimension: (i) I have a vivid imagination. (ii) I have difficulty understanding abstract ideas. (r) (iii) I do not have a good imagination. (r) (iv) I am not interested in abstract ideas. (r) (Sibley et al., 2011)

#### Parent

*If you are a parent, in which year was your eldest child born?*

Parents were coded as 1, while the others were coded as 0. (**Developed?** for the NZAVS.)

#### Has Partner

*What is your relationship status? (e.g., single, married, de-facto, civil union, widowed, living together, etc.)*

Coded as binary (has partner = 1). (**string\_is?** Developed for the NZAVS.)

#### Political Conservatism

*Please rate how politically liberal versus conservative you see yourself as being.*

Ordinal response: (1 = Extremely Liberal, 7 = Extremely Conservative) (Jost, 2006)

#### Major Religions

*Do you identify with a religion and/or spiritual group? –> (If yes…)–> What religion or spiritual group?*

Open-ended (string). Coded from New Zealand Census Categories. Levels are: “Not Religious”,“Anglican”,“Buddhist”, “Catholic”, “Christian (Non-Denominational)”, “Christian (Other Denominations)”,“Hindu”, “Jewish”, “Muslim”,“Presbyterian, Congregational, Reformed”, “Other Religions”. (**coded?** for the NZAVS.)

#### Religious Identification

*How important is your religion to how you see yourself?*

Ordinal response: (1 = Not Important, 7 = Very Important) (**string\_is?** Developed for the NZAVS.)

#### Rural Classification

*High Urban Accessibility = 1, Medium Urban Accessibility = 2, Low Urban Accessibility = 3, Remote = 4, Very Remote = 5.*

“Participants residence locations were coded according to a five-level ordinal categorisation ranging from Urban to Rural.” (Whitehead et al., 2023)

#### Sample Frame Opt in

*Participant was not randomly sampled from the New Zealand Electoral Roll.*

Code string (Binary): (0 = No, 1 = Yes) (**string\_is?** Developed for the NZAVS.)

#### Short Form Health

*In general, would you say your health is…*

Ordinal response: (1 = Poor, 7 = Excellent) (Instrument Ware Jr & Sherbourne, 1992)

#### Smoker

*Do you currently smoke tobacco cigarettes?*

Binary smoking indicator (0 = No, 1 = Yes). (**string\_is?** Developed for NZAVS.)

#### Exposure Measures

### Exposure Variable

#### Extraversion

*I am the life of the party.* *I don’t talk a lot (reversed).* *I keep in the background (reversed).* *I talk to a lot of different people at parties.*

Mini-IPIP6 Extraversion dimension: (i) I am the life of the party. (ii) I don’t talk a lot. (r) (iii) I keep in the background. (r) (iv) I talk to a lot of different people at parties. (Sibley et al., 2011)

#### Outcome Measures

### Outcome Variables

#### Social Belonging

*Know that people in my life accept and value me.* *Feel like an outsider (reversed).* *Know that people around me share my attitudes and beliefs.*

We assessed felt belongingness with three items adapted from the Sense of Belonging Instrument (Hagerty & Patusky, 1995): (1) “Know that people in my life accept and value me”; (2) “Feel like an outsider”; (3) “Know that people around me share my attitudes and beliefs”. Participants responded on a scale from 1 (Very Inaccurate) to 7 (Very Accurate). The second item was reversely coded. (Hagerty & Patusky, 1995)

#### Anxiety

*During the past 30 days, how often did…you feel restless or fidgety?* *During the past 30 days, how often did…you feel that everything was an effort?* *During the past 30 days, how often did…you feel nervous?*

Ordinal response: (0 = None Of The Time; 1 = A Little Of The Time; 2= Some Of The Time; 3 = Most Of The Time; 4 = All Of The Time) (Kessler et al., 2002)

#### Depression

*During the past 30 days, how often did…you feel hopeless?* *During the past 30 days, how often did…you feel so depressed that nothing could cheer you up?* *During the past 30 days, how often did…you feel you feel restless or fidgety?*

Ordinal response: (0 = None Of The Time; 1 = A Little Of The Time; 2= Some Of The Time; 3 = Most Of The Time; 4 = All Of The Time) (Kessler et al., 2002)

#### Life Satisfaction

*I am satisfied with my life.* *In most ways my life is close to ideal.*

Ordinal response (1 = Strongly Disagree to 7 = Strongly Agree). (Diener et al., 1985)

#### Log Hours of Exercise

*Hours spent…exercising/physical activity.*

We took the natural log of the response + 1. (Sibley et al., 2011)

#### Meaning Purpose

*My life has a clear sense of purpose*

Ordinal response (1 = Strongly Disagree to 7 = Strongly Agree). (Steger et al., 2006)

#### Meaning Sense

*I have a good sense of what makes my life meaningful.*

Ordinal response (1 = Strongly Disagree to 7 = Strongly Agree). (Steger et al., 2006)

#### Neighbourhood Community

*I feel a sense of community with others in my local neighbourhood.*

Ordinal response (1 = Strongly Disagree to 7 = Strongly Agree). (Sengupta et al., 2013)

#### Personal Well Being Index

no information available for this variable.

#### Rumination

*During the last 30 days, how often did…you have negative thoughts that repeated over and over?*

Ordinal responses: 0 = None of The Time, 1 = A little of The Time, 2 = Some of The Time, 3 = Most of The Time, 4 = All of The Time. (Nolen-hoeksema & Morrow, 1993)

#### Self Esteem

*On the whole am satisfied with myself.* *Take a positive attitude toward myself.* *Am inclined to feel that I am a failure (reversed).*

Ordinal response (1 = Very inaccurate to 7 = Very accurate). (Rosenberg, 1965)

#### Social Support

*There are people I can depend on to help me if I really need it.* *There is no one I can turn to for guidance in times of stress (reversed).* *I know there are people I can turn to when I need help.*

Ordinal response: (1 = Strongly Disagree, 7 = Strongly Agree) (Cutrona & Russell, 1987)

## Appendix B: Sample Characteristics

#### Sample Statistics: Baseline Covariates

[Table 4](#tbl-appendix-baseline) presents sample demographic statistics.

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| Table 4: Demographic statistics for New Zealand Attitudes and Values Cohort: {baseline\_wave\_glued}.   |  | 2018 | | --- | --- | |  | (N=39635) | | **Age** |  | | Mean (SD) | 48.5 (13.9) | | Median [Min, Max] | 51.0 [18.0, 99.0] | | **Agreeableness** |  | | Mean (SD) | 5.35 (0.988) | | Median [Min, Max] | 5.47 [1.00, 7.00] | | Missing | 9 (0.0%) | | **Alcohol Frequency** |  | | Mean (SD) | 2.16 (1.34) | | Median [Min, Max] | 2.00 [0, 5.00] | | Missing | 1342 (3.4%) | | **Alcohol Intensity** |  | | Mean (SD) | 2.15 (2.09) | | Median [Min, Max] | 2.00 [0, 15.0] | | Missing | 2348 (5.9%) | | **Belong** |  | | Mean (SD) | 5.14 (1.07) | | Median [Min, Max] | 5.31 [1.00, 7.00] | | Missing | 7 (0.0%) | | **Born in NZ** |  | | 0 | 8510 (21.5%) | | 1 | 30670 (77.4%) | | Missing | 455 (1.1%) | | **Conscientiousness** |  | | Mean (SD) | 5.10 (1.06) | | Median [Min, Max] | 5.23 [1.00, 7.00] | | **Education Level** |  | | no\_qualification | 1003 (2.5%) | | cert\_1\_to\_4 | 13801 (34.8%) | | cert\_5\_to\_6 | 4953 (12.5%) | | university | 10400 (26.2%) | | post\_grad | 4220 (10.6%) | | masters | 3297 (8.3%) | | doctorate | 930 (2.3%) | | Missing | 1031 (2.6%) | | **Employed** |  | | 0 | 8111 (20.5%) | | 1 | 31475 (79.4%) | | Missing | 49 (0.1%) | | **Ethnicity** |  | | euro | 31454 (79.4%) | | maori | 4561 (11.5%) | | pacific | 971 (2.4%) | | asian | 2124 (5.4%) | | Missing | 525 (1.3%) | | **Disability Status** |  | | Mean (SD) | 0.223 (0.416) | | Median [Min, Max] | 0 [0, 1.00] | | Missing | 745 (1.9%) | | **Log Hours with Children** |  | | Mean (SD) | 1.18 (1.61) | | Median [Min, Max] | 0.0341 [0, 5.13] | | Missing | 1242 (3.1%) | | **Log Hours Commuting** |  | | Mean (SD) | 1.50 (0.832) | | Median [Min, Max] | 1.61 [0, 4.40] | | Missing | 1242 (3.1%) | | **Log Hours Exercising** |  | | Mean (SD) | 1.55 (0.846) | | Median [Min, Max] | 1.61 [0, 4.40] | | Missing | 1242 (3.1%) | | **Log Hours on Housework** |  | | Mean (SD) | 2.14 (0.782) | | Median [Min, Max] | 2.20 [0, 5.13] | | Missing | 1242 (3.1%) | | **Log Household Income** |  | | Mean (SD) | 11.4 (0.765) | | Median [Min, Max] | 11.5 [0.685, 14.9] | | Missing | 3067 (7.7%) | | **Male** |  | | 0 | 24766 (62.5%) | | 1 | 14767 (37.3%) | | Missing | 102 (0.3%) | | **Neuroticism** |  | | Mean (SD) | 3.49 (1.15) | | Median [Min, Max] | 3.48 [1.00, 7.00] | | Missing | 10 (0.0%) | | **Non-heterosexual** |  | | 0 | 35100 (88.6%) | | 1 | 2562 (6.5%) | | Missing | 1973 (5.0%) | | **NZ Deprivation Index** |  | | Mean (SD) | 4.77 (2.73) | | Median [Min, Max] | 4.05 [1.00, 10.0] | | Missing | 255 (0.6%) | | **Occupational Prestige Index** |  | | Mean (SD) | 54.1 (16.5) | | Median [Min, Max] | 54.0 [10.0, 90.0] | | Missing | 536 (1.4%) | | **Openness** |  | | Mean (SD) | 4.96 (1.12) | | Median [Min, Max] | 5.00 [1.00, 7.00] | | Missing | 3 (0.0%) | | **Parent** |  | | 0 | 11539 (29.1%) | | 1 | 27776 (70.1%) | | Missing | 320 (0.8%) | | **Has Partner** |  | | Mean (SD) | 0.752 (0.432) | | Median [Min, Max] | 1.00 [0, 1.00] | | Missing | 1244 (3.1%) | | **Political Conservatism** |  | | Mean (SD) | 3.59 (1.38) | | Median [Min, Max] | 3.97 [1.00, 7.00] | | Missing | 2682 (6.8%) | | **Major Religions** |  | | not\_rel | 24886 (62.8%) | | anglican | 2087 (5.3%) | | buddist | 332 (0.8%) | | catholic | 3123 (7.9%) | | christian\_nfd | 4534 (11.4%) | | christian\_others | 1738 (4.4%) | | hindu | 206 (0.5%) | | jewish | 80 (0.2%) | | muslim | 90 (0.2%) | | presby\_cong\_reform | 875 (2.2%) | | the\_others | 1068 (2.7%) | | Missing | 616 (1.6%) | | **Religious Identification** |  | | Mean (SD) | 2.36 (2.18) | | Median [Min, Max] | 1.00 [1.00, 7.00] | | Missing | 1050 (2.6%) | | **Rural Classification** |  | | High Urban Accessibility | 24406 (61.6%) | | Medium Urban Accessibility | 7431 (18.7%) | | Low Urban Accessibility | 4818 (12.2%) | | Remote | 2241 (5.7%) | | Very Remote | 486 (1.2%) | | Missing | 253 (0.6%) | | **Sample Frame Opt-In** |  | | 0 | 38485 (97.1%) | | 1 | 1150 (2.9%) | | **Short Form Health** |  | | Mean (SD) | 5.05 (1.17) | | Median [Min, Max] | 5.04 [1.00, 7.00] | | Missing | 6 (0.0%) | | **Smoker** |  | | 0 | 35771 (90.3%) | | 1 | 2880 (7.3%) | | Missing | 984 (2.5%) | |

### Sample Statistics: Exposure Variable

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
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| Table 5: Demographic statistics for New Zealand Attitudes and Values Cohort waves 2018.   |  | 2018 | 2019 | | --- | --- | --- | |  | (N=39635) | (N=39635) | | **Extraversion** |  |  | | Mean (SD) | 3.91 (1.20) | 3.86 (1.19) | | Median [Min, Max] | 3.96 [1.00, 7.00] | 3.79 [1.00, 7.00] | | Missing | 0 (0%) | 11117 (28.0%) | | **Extraversion (binary)** |  |  | | [1.0,4.0] | 21138 (53.3%) | 15637 (39.5%) | | (4.0,7.0] | 18497 (46.7%) | 12881 (32.5%) | | Missing | 0 (0%) | 11117 (28.0%) | |

### Sample Statistics: Outcome Variables

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
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| Table 6: Outcome variables measured at   |  | 2018 | 2020 | Overall | | --- | --- | --- | --- | |  | (N=39635) | (N=39635) | (N=79270) | | **Social Belonging** |  |  |  | | Mean (SD) | 5.14 (1.07) | 5.06 (1.09) | 5.11 (1.08) | | Median [Min, Max] | 5.31 [1.00, 7.00] | 5.05 [1.00, 7.00] | 5.30 [1.00, 7.00] | | Missing | 7 (0.0%) | 13278 (33.5%) | 13285 (16.8%) | | **Anxiety** |  |  |  | | Mean (SD) | 1.21 (0.774) | 1.17 (0.756) | 1.19 (0.767) | | Median [Min, Max] | 1.00 [0, 4.00] | 1.00 [0, 4.00] | 1.00 [0, 4.00] | | Missing | 51 (0.1%) | 13275 (33.5%) | 13326 (16.8%) | | **Depression** |  |  |  | | Mean (SD) | 0.584 (0.751) | 0.550 (0.723) | 0.571 (0.740) | | Median [Min, Max] | 0.333 [0, 4.00] | 0.333 [0, 4.00] | 0.333 [0, 4.00] | | Missing | 54 (0.1%) | 13273 (33.5%) | 13327 (16.8%) | | **Life Satisfaction** |  |  |  | | Mean (SD) | 5.30 (1.20) | 5.25 (1.23) | 5.28 (1.21) | | Median [Min, Max] | 5.50 [1.00, 7.00] | 5.50 [1.00, 7.00] | 5.50 [1.00, 7.00] | | Missing | 260 (0.7%) | 13560 (34.2%) | 13820 (17.4%) | | **Hours of Exercise (log)** |  |  |  | | Mean (SD) | 1.55 (0.846) | 1.63 (0.839) | 1.58 (0.844) | | Median [Min, Max] | 1.61 [0, 4.40] | 1.78 [0, 4.40] | 1.61 [0, 4.40] | | Missing | 1242 (3.1%) | 13770 (34.7%) | 15012 (18.9%) | | Meaning: Purpose |  |  |  | | Mean (SD) | 5.20 (1.41) | 5.15 (1.44) | 5.18 (1.42) | | Median [Min, Max] | 5.05 [1.00, 7.00] | 5.04 [1.00, 7.00] | 5.04 [1.00, 7.00] | | Missing | 1010 (2.5%) | 13650 (34.4%) | 14660 (18.5%) | | Meaning: Sense |  |  |  | | Mean (SD) | 5.71 (1.22) | 5.71 (1.19) | 5.71 (1.20) | | Median [Min, Max] | 5.99 [1.00, 7.00] | 5.99 [1.00, 7.00] | 5.99 [1.00, 7.00] | | Missing | 128 (0.3%) | 13162 (33.2%) | 13290 (16.8%) | | **Neighbourhood Community** |  |  |  | | Mean (SD) | 4.19 (1.66) | 4.38 (1.57) | 4.27 (1.63) | | Median [Min, Max] | 4.03 [1.00, 7.00] | 4.95 [1.00, 7.00] | 4.04 [1.00, 7.00] | | Missing | 212 (0.5%) | 13202 (33.3%) | 13414 (16.9%) | | **Personal Well-being Index** |  |  |  | | Mean (SD) | 7.09 (1.66) | 7.18 (1.63) | 7.12 (1.65) | | Median [Min, Max] | 7.29 [0, 10.0] | 7.47 [0, 10.0] | 7.46 [0, 10.0] | | Missing | 41 (0.1%) | 13120 (33.1%) | 13161 (16.6%) | | **Rumination** |  |  |  | | Mean (SD) | 0.853 (1.00) | 0.797 (0.959) | 0.831 (0.987) | | Median [Min, Max] | 0.955 [0, 4.00] | 0.0495 [0, 4.00] | 0.953 [0, 4.00] | | Missing | 135 (0.3%) | 13335 (33.6%) | 13470 (17.0%) | | **Self Esteem** |  |  |  | | Mean (SD) | 5.14 (1.28) | 5.13 (1.27) | 5.14 (1.28) | | Median [Min, Max] | 5.34 [1.00, 7.00] | 5.34 [1.00, 7.00] | 5.34 [1.00, 7.00] | | Missing | 11 (0.0%) | 13280 (33.5%) | 13291 (16.8%) | | **Social Support** |  |  |  | | Mean (SD) | 5.95 (1.12) | 5.94 (1.12) | 5.95 (1.12) | | Median [Min, Max] | 6.30 [1.00, 7.00] | 6.29 [1.00, 7.00] | 6.30 [1.00, 7.00] | | Missing | 30 (0.1%) | 13112 (33.1%) | 13142 (16.6%) | |

## Appendix C: Transition Matrix to Check The Positivity Assumption

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| Table 7: Transition Matrix Showing Change   | From / To | State 0 | State 1 | Total | | --- | --- | --- | --- | | State 0 | 17572 | 2271 | 19843 | | State 1 | 2400 | 6275 | 8675 | |

These transition matrices capture shifts in states between consecutive waves. Each cell shows the count of individuals transitioning from one state to another. Rows are the initial state (From), columns the subsequent state (To). **Diagonal entries** (in **bold**) mark those who stayed in the same state.

## Appendix D: Approach to Heterogeneous Treatment Effects

## Appendix X. Estimating and Interpreting Heterogeneous Treatment Effects with **grf**

Here we explain a heterogeneous‐treatment‐effect (HTE) analysis using causal forests (Tibshirani et al., 2024). In our workflow, we move from the average treatment effect (ATE) to individualised effects, quantify the practical value of targeting, and finish with interpretable decision rules.

### 1 Average Treatment Effect (ATE)

The ATE answers: *‘What would happen, on average, if everyone received treatment versus no one?’*

Using the grf package, we estimate the ATE doubly-robustly. Because we analyse several outcomes, we adjust ATE *p*-values with bonferroni ( = 0.05) to control the family-wise error rate.

### 2 Do Effects Vary? Formal Test of Heterogeneity

Define the conditional average treatment effect (CATE)

If is constant, effects are homogeneous; otherwise they vary. Classical interaction models impose strong forms; **grf** uses *causal forests* to discover complex, nonlinear heterogeneity (Wager & Athey, 2018). We assess heterogeneity with RATE *p*-values corrected via Benjamini–Hochberg false-discovery-rate adjustment (q = 0.1), controlling the false-discovery rate (Benjamini & Hochberg, 1995).

### 3 Causal Forests for Individualised Estimates

A causal forest is an ensemble of ‘honest’ causal trees that split on covariates to maximise treated–control contrasts. For each unit we obtain

Strengths are flexibility, orthogonalisation, and per-person estimates.

### 4 Built-in Protection Against Over-fitting

Honesty (split half/estimate half) plus out-of-bag (OOB) predictions yield unbiased and standard errors without manual hyper-tuning.

### 5 Missing Data Handling

**grf** deploys ‘Missing Incorporated in Attributes’ (MIA): missingness is a valid split, so cases stay in the analysis – no ad-hoc imputation required.

### 6 Testing for **Actionable** Heterogeneity: the TOC & RATE Metrics

Ranking units by defines a **Targeting Operator Characteristic** (TOC) curve: the cumulative gain from treating the top fraction of predicted responders. Two scalar summaries:

* **RATE AUTOC** – area under the entire TOC; emphasises the very highest responders.
* **RATE Qini** – weighted area with weight ; rewards sustained gains across larger coverage (Yadlowsky et al., 2021).

Under constant, both equal 0. grf::rank\_average\_treatment\_effect() supplies point estimates, standard errors, and -tests.

**Multiplicity control**: We adjust AUTOC and Qini *p*-values with Benjamini–Hochberg false-discovery-rate adjustment (q = 0.1) before declaring actionable heterogeneity.

Here is an **interpretation tip**:

* AUTOC answers *‘How sharply can we prioritise?’*
* Qini answers *‘How valuable is targeting when budgets are modest but not tiny?’*

### 7 Visualising Policy Value: the Qini Curve

Plotting the Qini curve (cumulative gain vs ) reveals where returns plateau. Investigators (and policy audiences) can see at a glance whether benefits concentrate in, say, the top 20 % or persist up to 50 %.

### 8 Valid Inference for RATE / Qini

Although OOB predictions are out-of-sample per tree, they inherit forest-level dependence. We use an explicit **sample split**:

1. **Train set**: fit the causal forest and compute .
2. **Test set**: compute RATE AUTOC/Qini and run tests.

This second split yields honest policy evaluation and guards against optimistic bias (Tibshirani et al., 2024).

### 9 From Black Box to Simple Rules: Policy Trees

Stakeholders value transparent criteria. The **policytree** algorithm takes or doubly-robust scores and learns a shallow decision tree that maximises expected welfare (Sverdrup et al., 2024).

*Advantages*: interpretability, the possibility of fairness constraints, and easy communication (e.g., *‘treat if age < 25 and baseline severity high’*).

Training mirrors the split above: learn the tree on one fold, evaluate welfare on another.

**Caveat** Splits identify predictors of *effect variation*, not causal levers. Changing a covariate in the tree does **not** guarantee an effect on .

### 10 Ethical and Practical Considerations

Statistical optimisation rarely aligns perfectly with equity or political feasibility. Decisions about who *should* receive treatment belong to democratic processes that weigh fairness, cost, and broader social values.

### Putting it together

The sequence—ATE, causal-forest CATEs, RATE/Qini diagnostics, Qini curve, and finally a shallow policy tree—delivers both rigorous evidence and a defensible targeting rule. Researchers learn **how large** heterogeneity is, **where** targeting pays off under budget constraints, and **which** simple covariate splits capture most of the welfare gain, all while guarding against over-fitting and multiplicity.

## Appendix E: RATE AUTOC and RATE Qini

#### Rate Test

The RATE metric shows how much extra gain (or avoided loss) we achieve by **targeting** instead of treating everyone identically.

**Technical note**: In code we always set policy = "treat\_best"; for harmful exposures this is interpreted as *‘treat-those-most-sensitive’* (i.e., prioritise protection or withholding).

* **Beneficial exposure:** we rank by positive CATEs and deliver the exposure to those predicted to **benefit most**.
* **Detrimental exposure:** we rank by increasingly **positive** CATEs (more predicted harm) and identify those who should be protected or withheld from the exposure.

Either way, a larger **absolute** RATE shows that a CATE-based targeting rule ‘outperforms’ a one-size-fits-all policy—by boosting outcomes for beneficial exposures or – in the case where we are explore sensitivity to harm – evaluating increasing harms for detrimental ones.

Recall we flipped Anxiety, Depression, Rumination so **‘higher’ always tracks the analysis goal: higher = more benefit for beneficial exposures, higher = more harm for detrimental exposures.**

Because we test several outcomes, RATE *p*-values are adjusted with Benjamini–Hochberg false-discovery-rate adjustment (q = 0.1) before we decide whether heterogeneity is actionable.

### Comparison of targeting operating characteristic (TOC) by rank average treatment effect (RATE): AUTOC vs QINI

We applied two TOC by RATE methods to the same causal-forest estimates:

* **AUTOC** intensifies focus on top responders via logarithmic weighting.
* **QINI** balances effect size and prevalence via linear weighting.

Exploratory RATE analysis; controlled FDR at q=0.20 over 12 outcomes.

Both methods yield positive RATE estimates for: **Hours of Exercise (log)**.

This concordance indicates robust heterogeneity evidence.

When methods disagree (only QINI yields positive RATE for Anxiety (reversed)), choose **QINI** for overall benefit or **AUTOC** to focus top responders.

Refer to [Appendix E](#appendix-cate-validation) for details.

##### RATE AUTOC Results

### Evidence for heterogeneous treatment effects (policy = treat best responders) using AUTOC

AUTOC uses logarithmic weighting to focus treatment on top responders.

Note: The following outcomes were inverted during preprocessing because higher values of the exposure correspond to worse outcomes: Anxiety, Depression, Rumination.

Positive RATE estimates for: **Hours of Exercise (log)**.

Estimates (**Hours of Exercise (log)**: 0.084 (95% CI 0.035, 0.133)) show robust heterogeneity.

Negative RATE estimates for: Neighbourhood Community.

Estimates (Neighbourhood Community: -0.076 (95% CI -0.137, -0.015)) caution against CATE prioritisation.

For outcomes with adjusted p-values not meeting the FDR threshold of q = 0.20 (Meaning: Sense, Anxiety (reversed), Rumination (reversed), Self Esteem, Social Support, Life Satisfaction, Meaning: Purpose, Depression (reversed), Social Belonging, Personal Well-being Index), evidence is inconclusive.

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| Figure 11: RATE AUTOC Graphs |

[Figure 11](#fig-rate-1) presents the RATE AUTOC curve for Hours of Exercise (log)

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