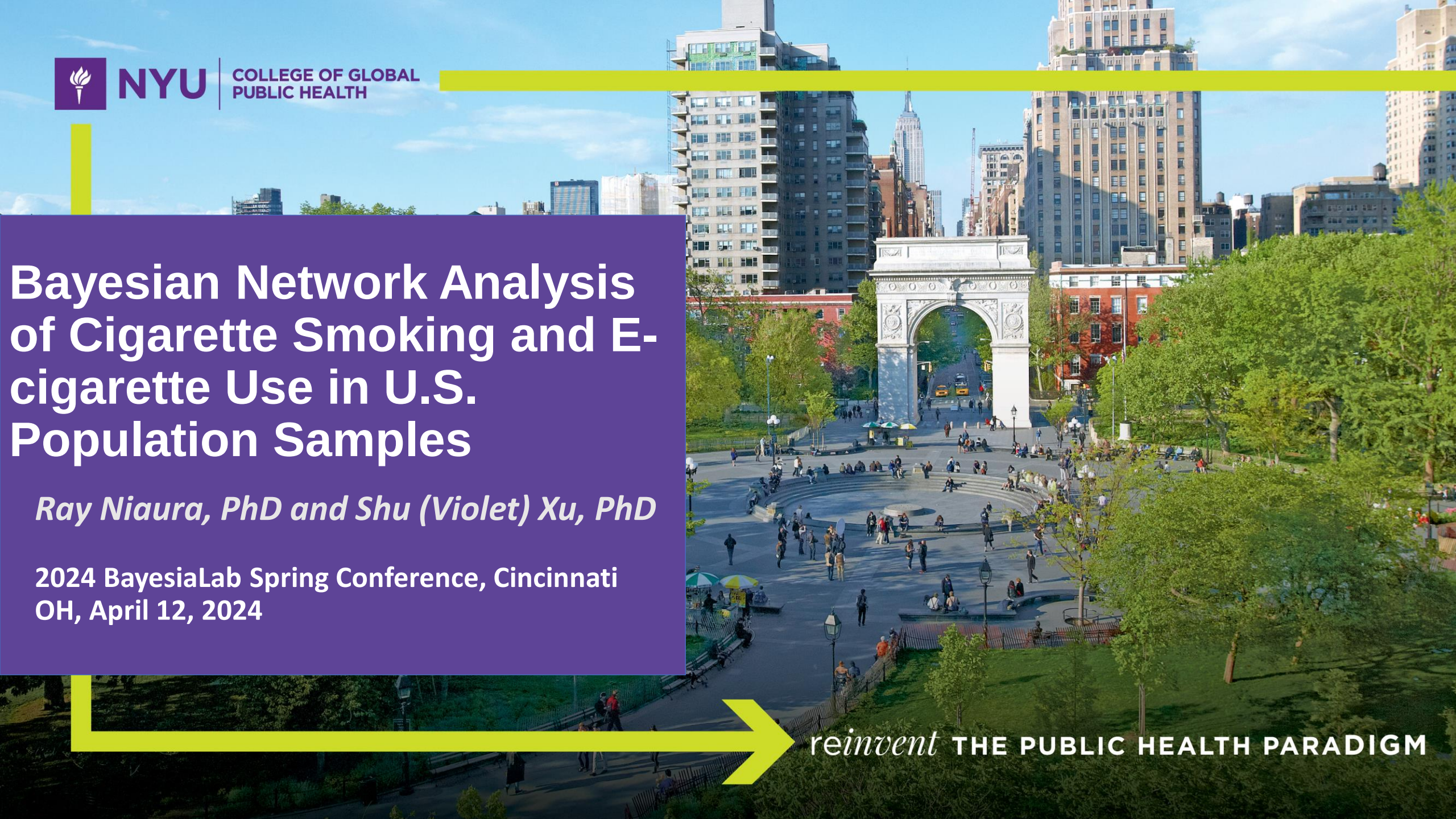


Bayesian Network Analysis of Cigarette Smoking and E-cigarette Use in U.S. Population Samples

Ray Niaura, PhD and Shu (Violet) Xu, PhD

2024 BayesiaLab Spring Conference, Cincinnati OH, April 12, 2024

DISCLOSURES

Niaura - Past 3 years: I do work with the FDA CTP via contractual mechanisms. I am a co-Investigator on several NIH grant awards.

Xu -

OUTLINE

- **Who are the (U.S.) smokers? What can national data can tell us (US National Health Interview Survey; Population Assessment of Tobacco and Health Study)?**

- **Tobacco harm reduction: Can e-cigarettes help cigarette smokers quit?**

Cigarette smoking is bad for you but quitting helps

Smoking Cessation and Short-and Longer-Term Mortality

https://evidence.nejm.org/doi/full/10.1056/EVIDoa2300272

Eo Rin Cho, Ilene K. Brill, Inger T. Gram, Patrick E. Brown, Prabhat Jha
Prabhat.jha@utoronto.ca
Twitter/X: @countthedead

cghr

ST. MICHAEL'S
UNITY HEALTH TORONTO

TEMERTY FACULTY OF MEDICINE
UNIVERSITY OF TORONTO

UNIVERSITY OF TORONTO
DALLA LANA SCHOOL OF PUBLIC HEALTH

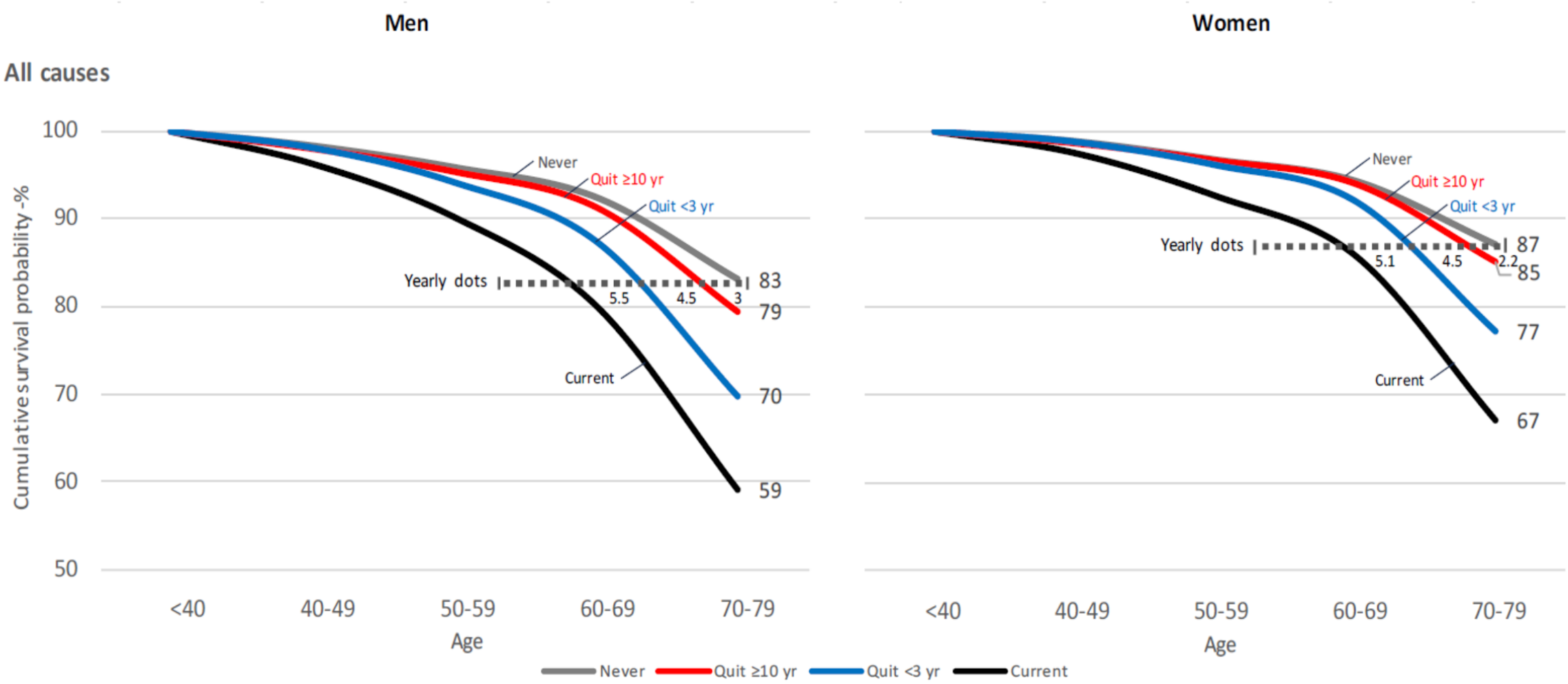
Worldwide no of smokers, drinkers and obese (B=billions, M=millions)

Exposure	No.	Annual deaths
Smoking	1.1 B	6-7 M
Drinking	2.0 B	2 M
Adiposity (BMI>30)	0.6 B	~ 1.5 M

cghr

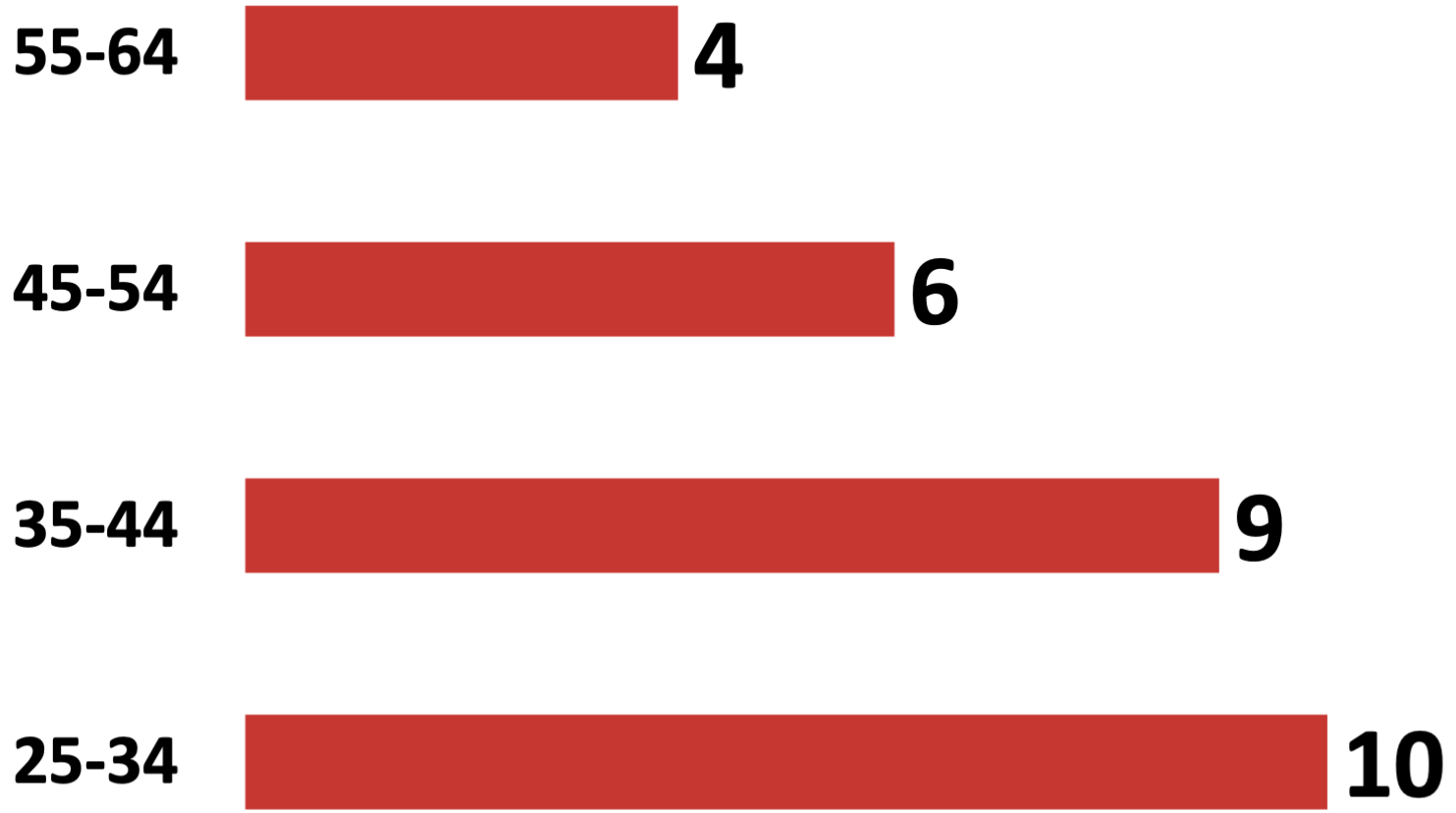
WHO 2022

Survival from ages 40 to 79 years of age by smoking status (never, cessation 10+ years or <3 years, and current) by sex: All causes mortality



Cho et al. NEJM Evidence 2024

US: Years gained by age at stopping smoking



Jha et al, NEJM 2013

WHO (still) SMOKES CIGARETTES?

Who are the smokers?

Priority populations

Key Disparities in Current Cigarette Smoking Among Adults and Youth According to Prevalence and/or Harm

- Low socioeconomic status
- Comorbid mental health or substance abuse diagnoses,
- Racial/ethnic minorities
- Individuals with physical disabilities,
- Sexual Orientation and Gender Identity
- Veterans/military
- Criminal justice populations
- Education (low)
- No health insurance
- Medicaid enrollees
- American Indians/Alaska Natives
- Chronic Disease Status
- Geographic Location
- Pregnant Women
- Adolescents
- Dual users
- Light/intermittent smokers

U.S. Department of Health and Human Services. Smoking Cessation. A Report of the Surgeon General. Atlanta, GA: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Center for Chronic Disease Prevention and Health Promotion, Office on Smoking and Health, 2020.

US NHIS

Centers for Disease Control and Prevention
CDC 24/7: Saving Lives, Protecting People™

Search | Search NCHS

National Center for Health Statistics

CDC > NCHS

- **National Health Interview Survey**
- About NHIS
- 2019 Redesign +
- What's New

National Health Interview Survey

Print

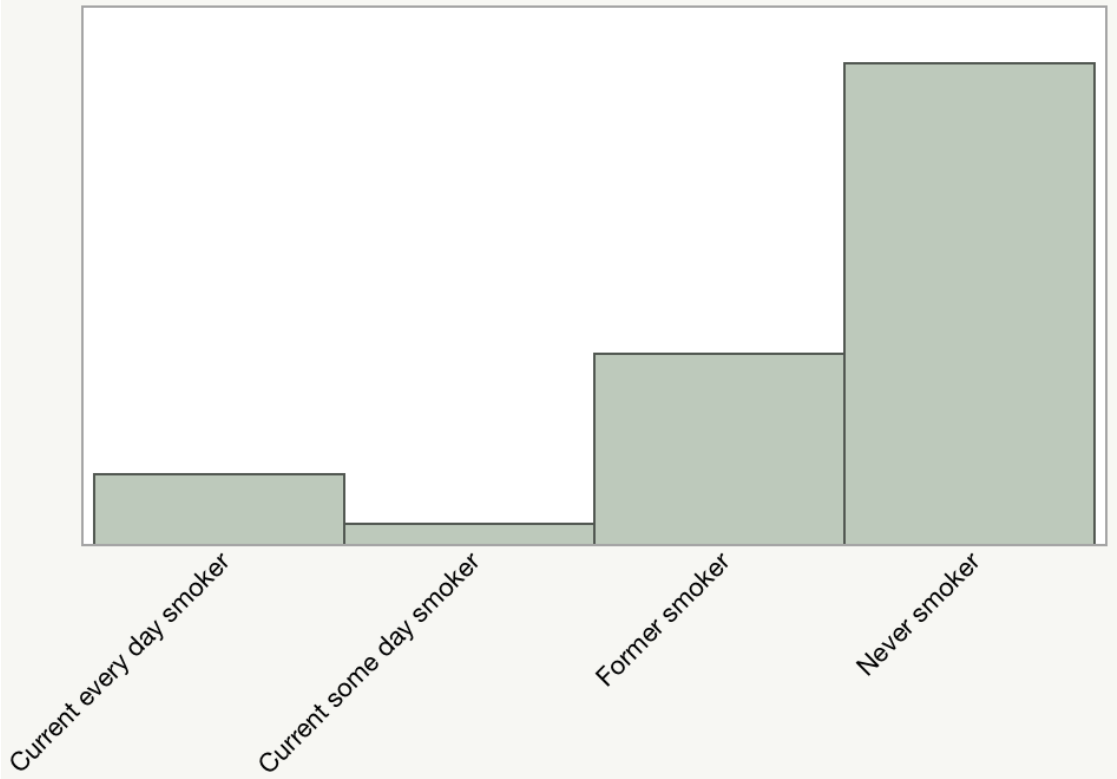
The National Health Interview Survey (NHIS) has monitored the health of the nation since 1957. NHIS data on a broad range of health topics are collected through personal household interviews. Survey results have been instrumental in providing data to track health status, health care access, and progress toward achieving national health objectives.

US National Health Interview Survey – 2022

Population Outcome: Smoking status- 4 categories

Distributions

SMOKE STATUS



Frequencies

Level	Count	Prob
Current every day smoker	2430	0.09023
Current some day smoker	714	0.02651
Former smoker	6744	0.25041
Never smoker	17044	0.63285
Total	26932	1.00000

N Missing 719

4 Levels

Regression model predicting smoking status via various sociodemographic and other characteristics

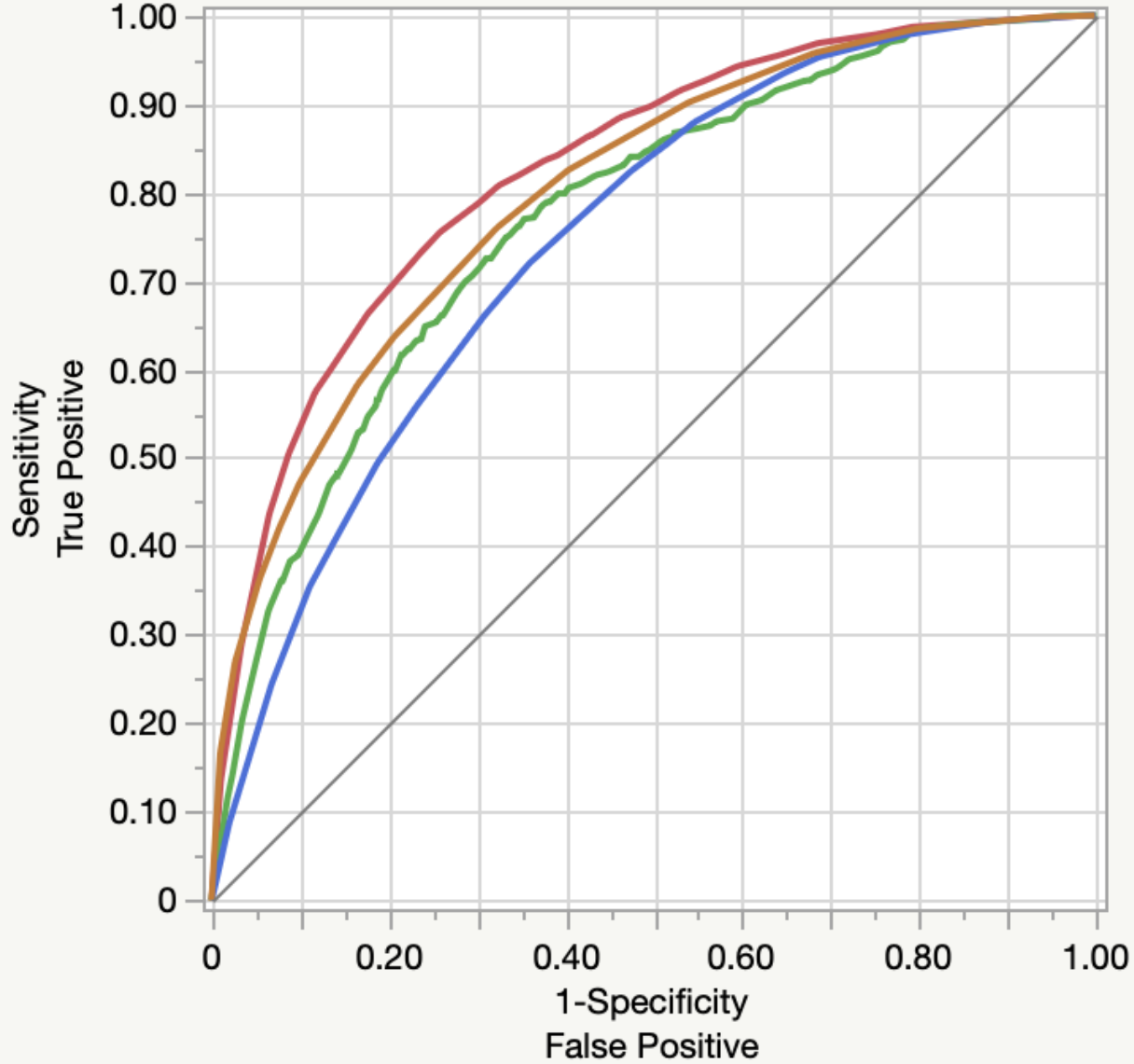
Nominal Logistic Fit for SMOKE STATUS

Effect Summary

Source	FDR LogWorth	FDR PValue
ECIG	415.960	0.00000
AGE CAT	210.432	0.00000
ALCOHOL	208.418	0.00000
EDUCATION	119.349	0.00000
POVERTY RATIO	31.451	0.00000
SEX	25.302	0.00000
MARITAL	21.534	0.00000
ETHNICITY	13.778	0.00000
VETERAN	9.135	0.00000
DISABILITY	3.769	0.00017
DEPRESSION	3.104	0.00079
ANXIETY	2.542	0.00287
SEX ORIENT	2.065	0.00860
ANXIETY MEDS	1.154	0.07009
EMPLOYMENT	1.143	0.07202
US BORN	0.879	0.13212
DEPRESS MEDS	0.290	0.51323
RACE	0.087	0.81845

Remove Add Edit ☑ FDR

Receiver Operating Characteristic on Training Data



SMOKE STATUS	Area
Current every day smoker	0.8259
Current some day smoker	0.7723
Former smoker	0.7478
Never smoker	0.8023

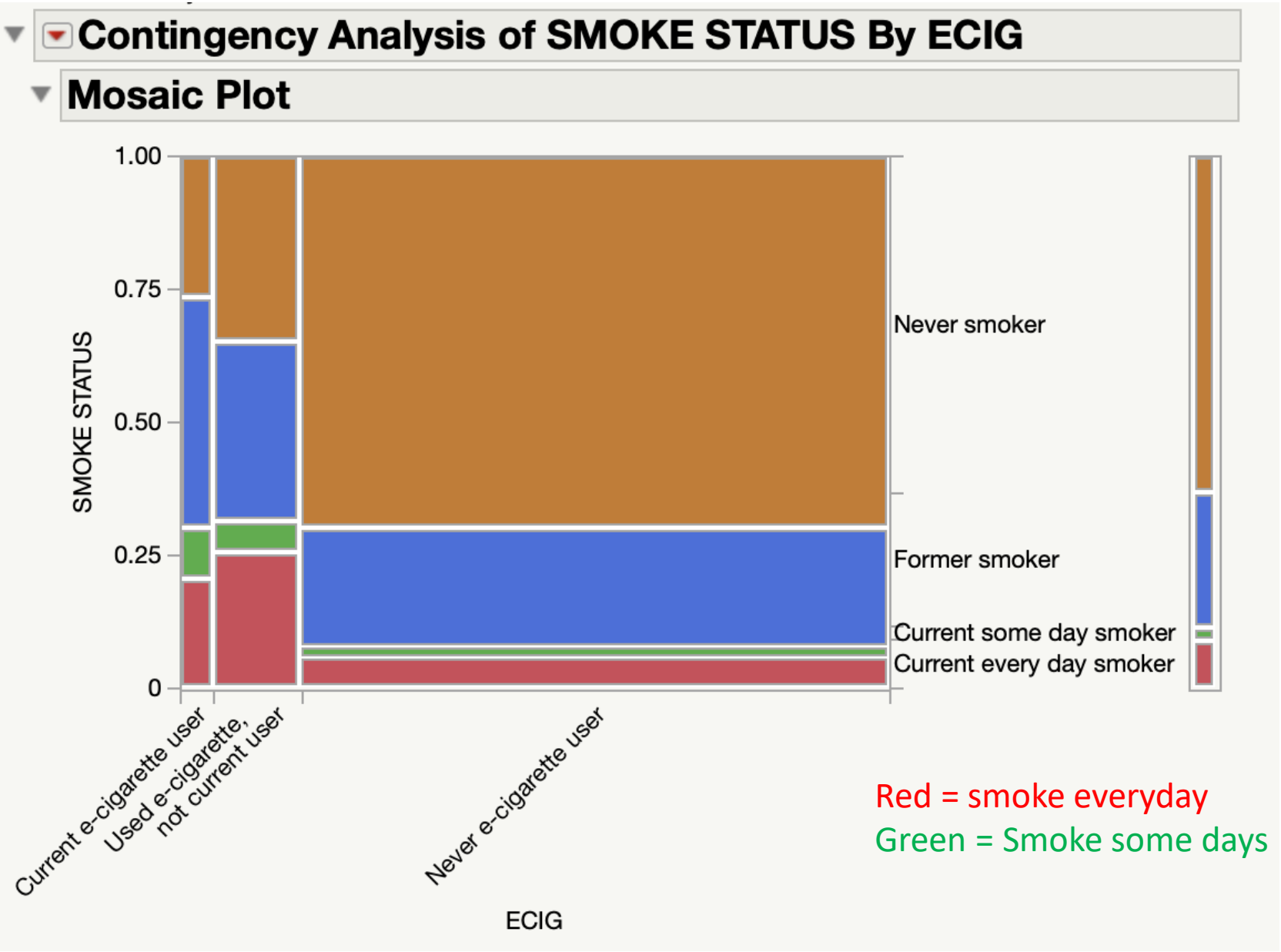
Confusion Matrix

Training

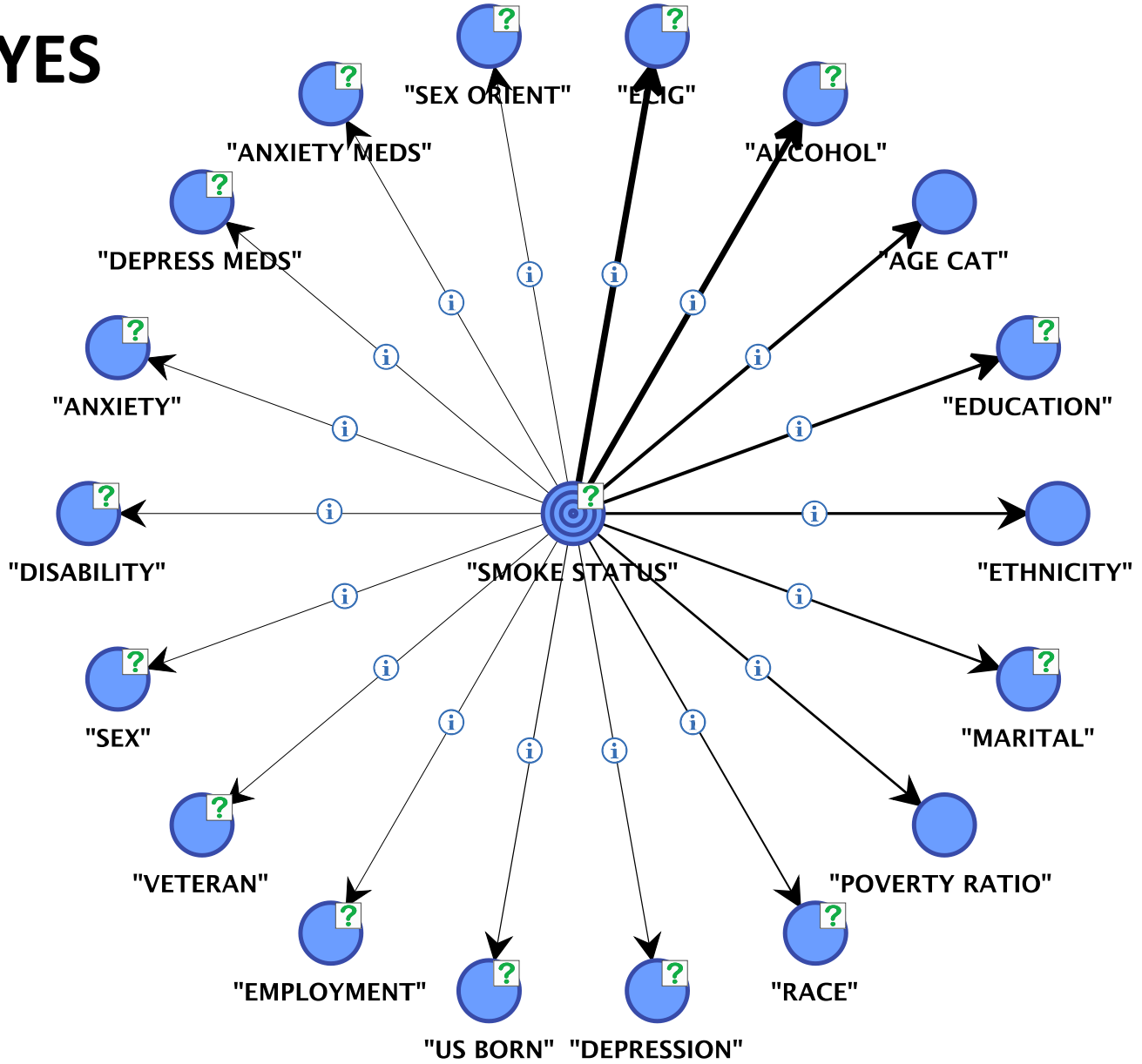
Actual SMOKE STATUS	Predicted Count			
	Current every day smoker	Current some day smoker	Former smoker	Never smoker
Current every day smoker	533	0	684	1013
Current some day smoker	75	1	174	376
Former smoker	322	0	2119	3777
Never smoker	174	1	1133	13784

Actual SMOKE STATUS	Predicted Rate			
	Current every day smoker	Current some day smoker	Former smoker	Never smoker
Current every day smoker	0.239	0.000	0.307	0.454
Current some day smoker	0.120	0.002	0.278	0.601
Former smoker	0.052	0.000	0.341	0.607
Never smoker	0.012	0.000	0.075	0.913

Cigs and E-cigs co-occurrence: NHIS 2022



NAIVE BAYES



Naive learning on "SMOKE STATUS":
Delete All Arcs
Variable Selection: false

Missing values treated with Structural EM
Total Weight: 27,651
Initial MDL score: 745,005.421
Final MDL score: 735,828.106
Total learning time: 0s

Target Evaluation - "SMOKE STATUS"

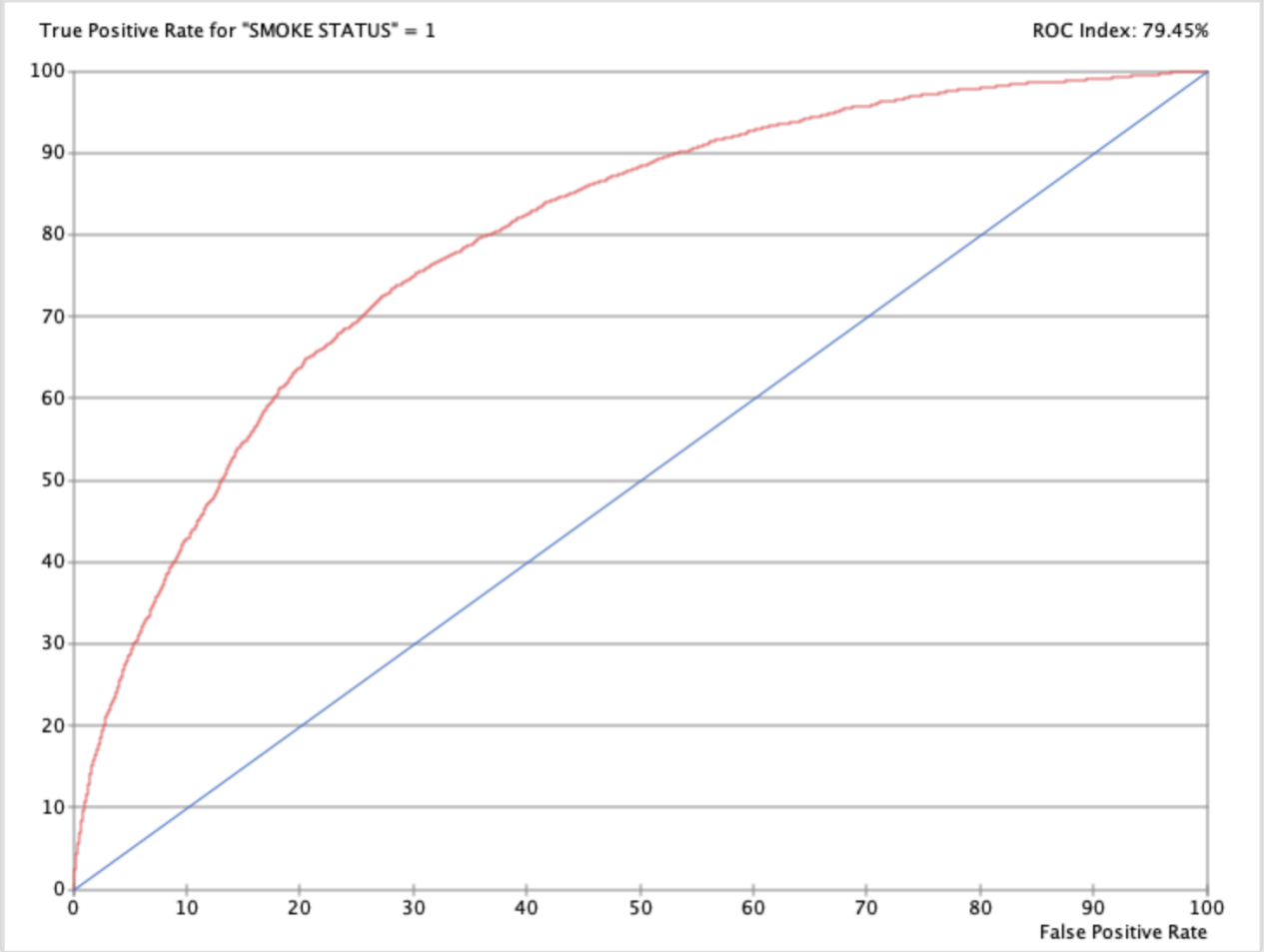
Classification | Posterior Probabilities | Regression | Triage

Statistics

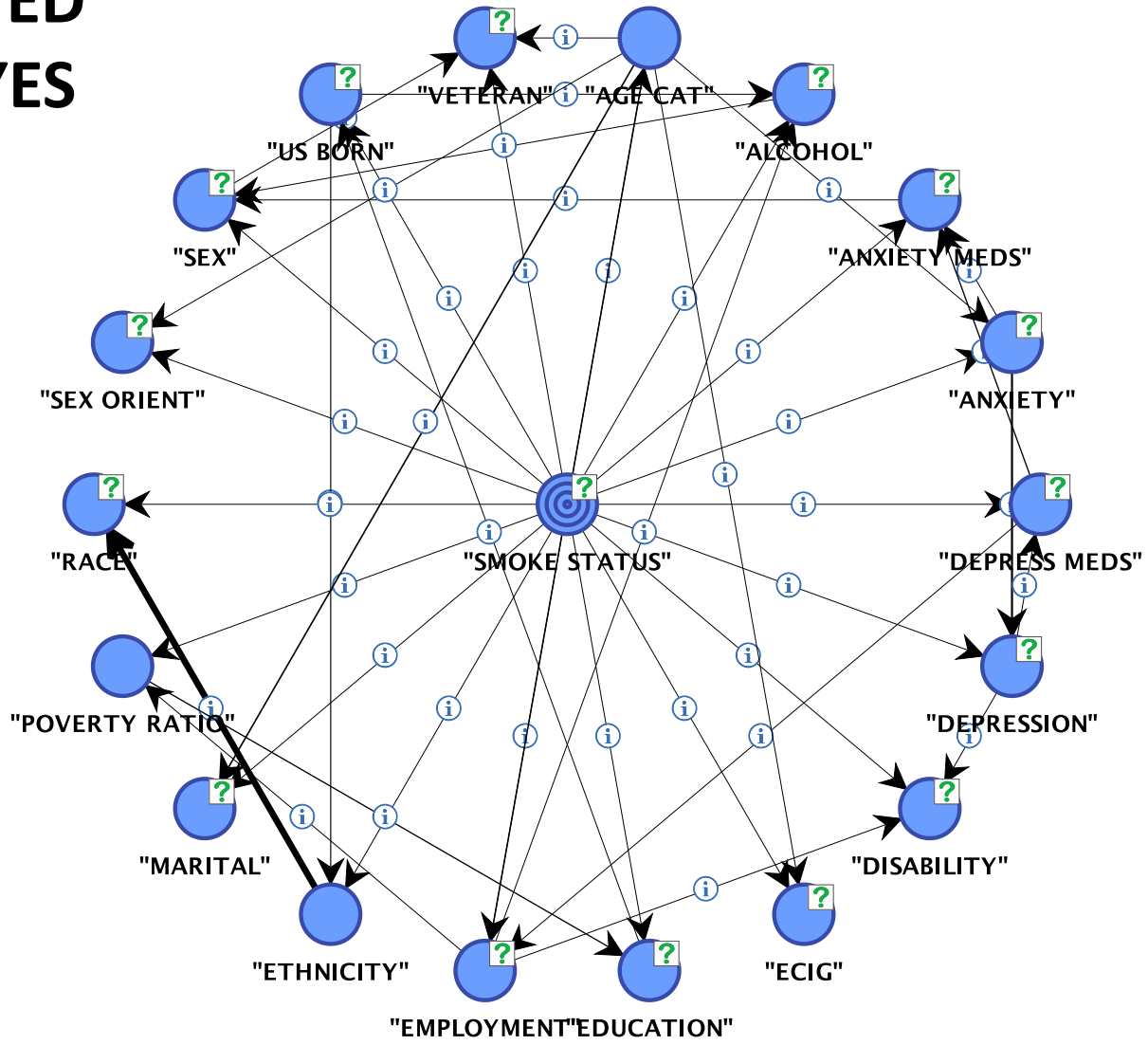
Overall Relative Gini Index: 51.4190%
Mean Relative Gini Index: 51.0472%
Overall Relative Lift Index: 78.3843%
Mean Relative Lift Index: 64.0338%
Overall ROC Index: 75.7095%
Mean ROC Index: 75.5236%

1 | 2 | 3 | 4

Gains Curve | Lift Curve | ROC Curve



AUGMENTED NAIVE BAYES



Augmented Naive learning on "SMOKE STATUS":
Delete All Arcs
Variable Selection: false

Missing values treated with Structural EM
Total Weight: 27,651
Initial MDL score: 745,005.421
Final MDL score: 658,672.252
Total learning time: 18s

Target Evaluation - "SMOKE STATUS"

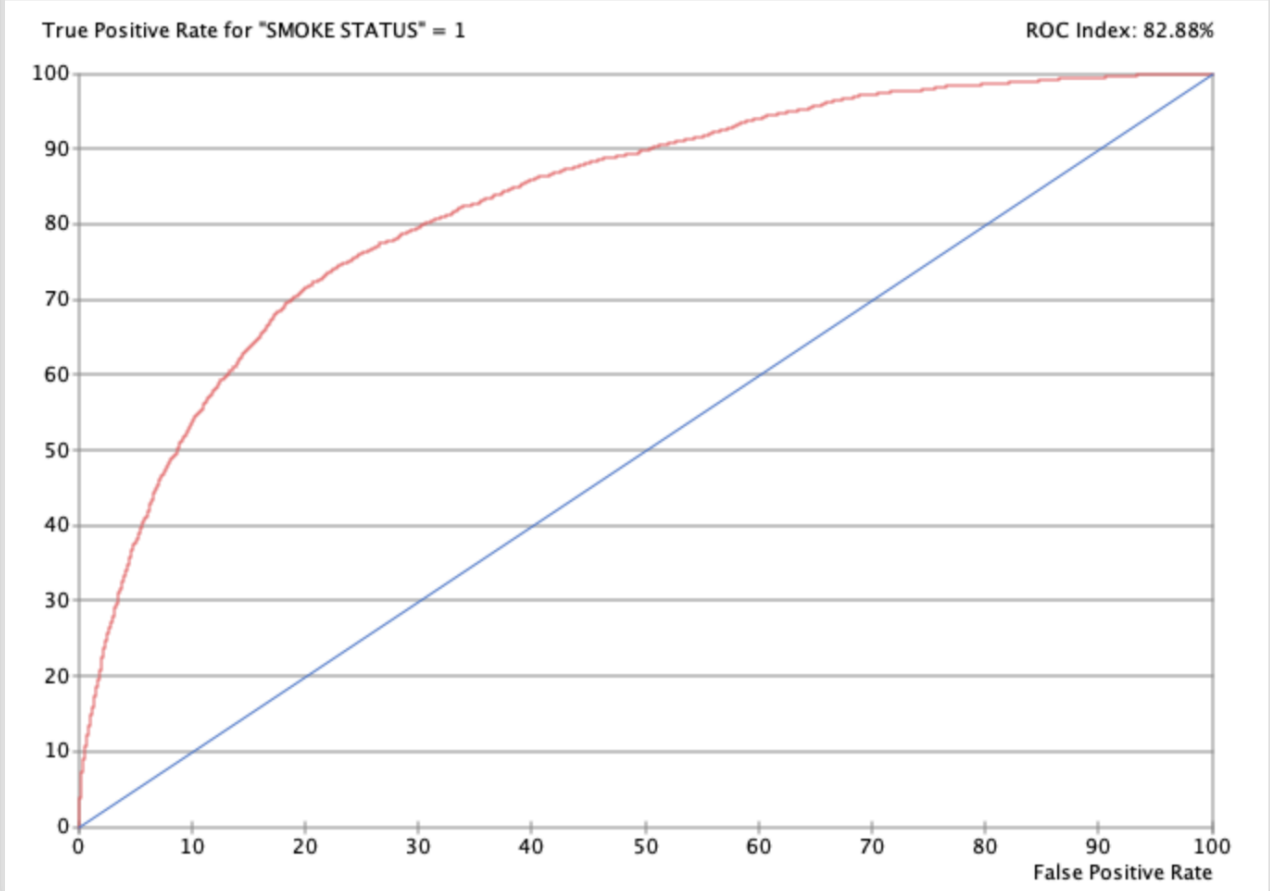
Classification | Posterior Probabilities | Regression | Triage

Statistics

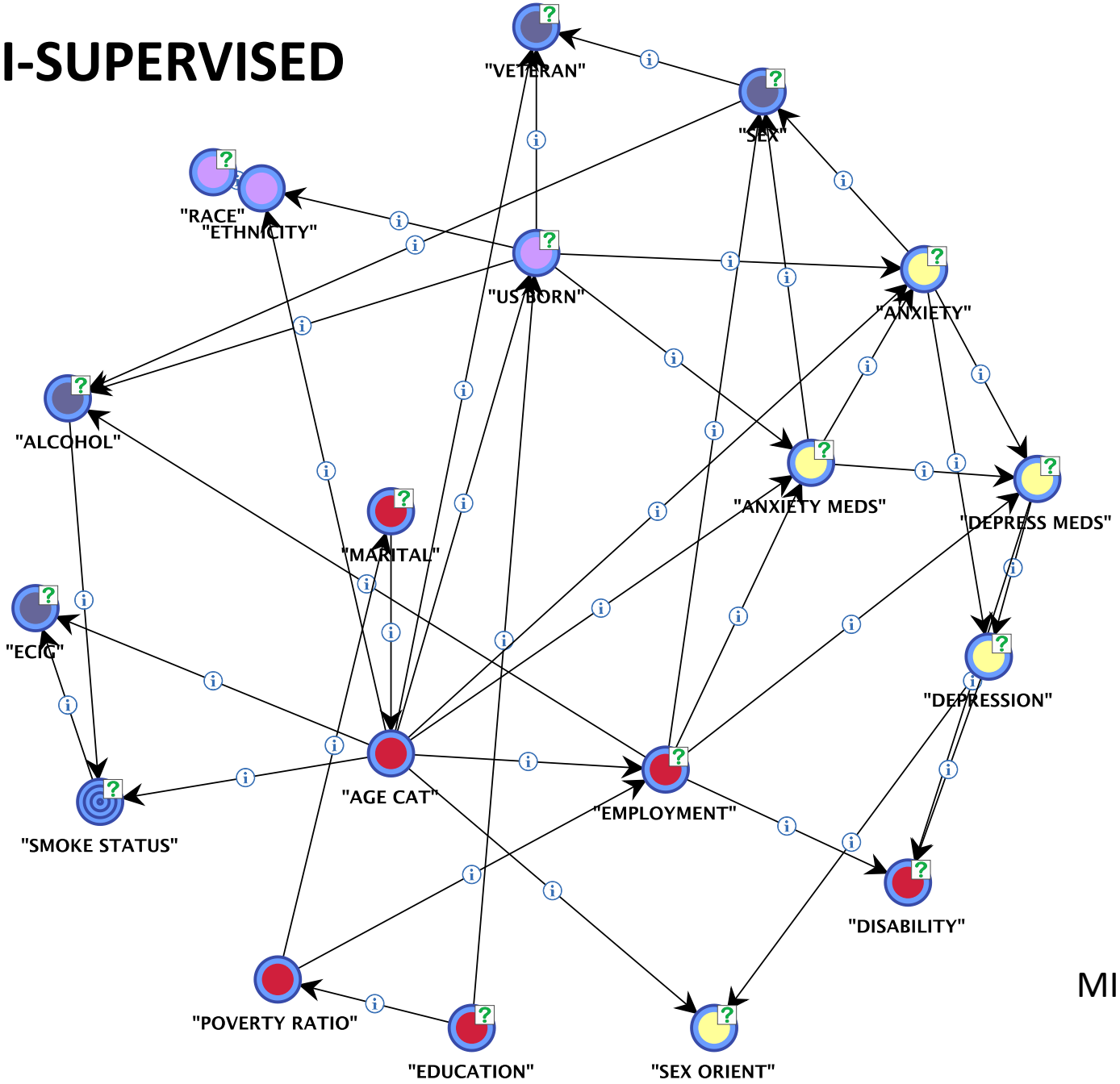
Overall Relative Gini Index: 58.2847%
Mean Relative Gini Index: 59.5630%
Overall Relative Lift Index: 81.4949%
Mean Relative Lift Index: 69.2538%
Overall ROC Index: 79.1423%
Mean ROC Index: 79.7815%

1 | 2 | 3 | 4

Gains Curve | Lift Curve | ROC Curve



SEMI-SUPERVISED



Semi-Supervised learning on "SMOKE STATUS":
Variable Selection: false
Radius: 8 Algorithm: Taboo

Missing values treated with Structural EM
Total Weight: 27,651
Initial MDL score: 745,005.421
Final MDL score: 651,939.97
Total learning time: 12s

MI distance mapping; Variable clustering

Target Evaluation - "SMOKE STATUS"

Classification | Posterior Probabilities | Regression | Triage

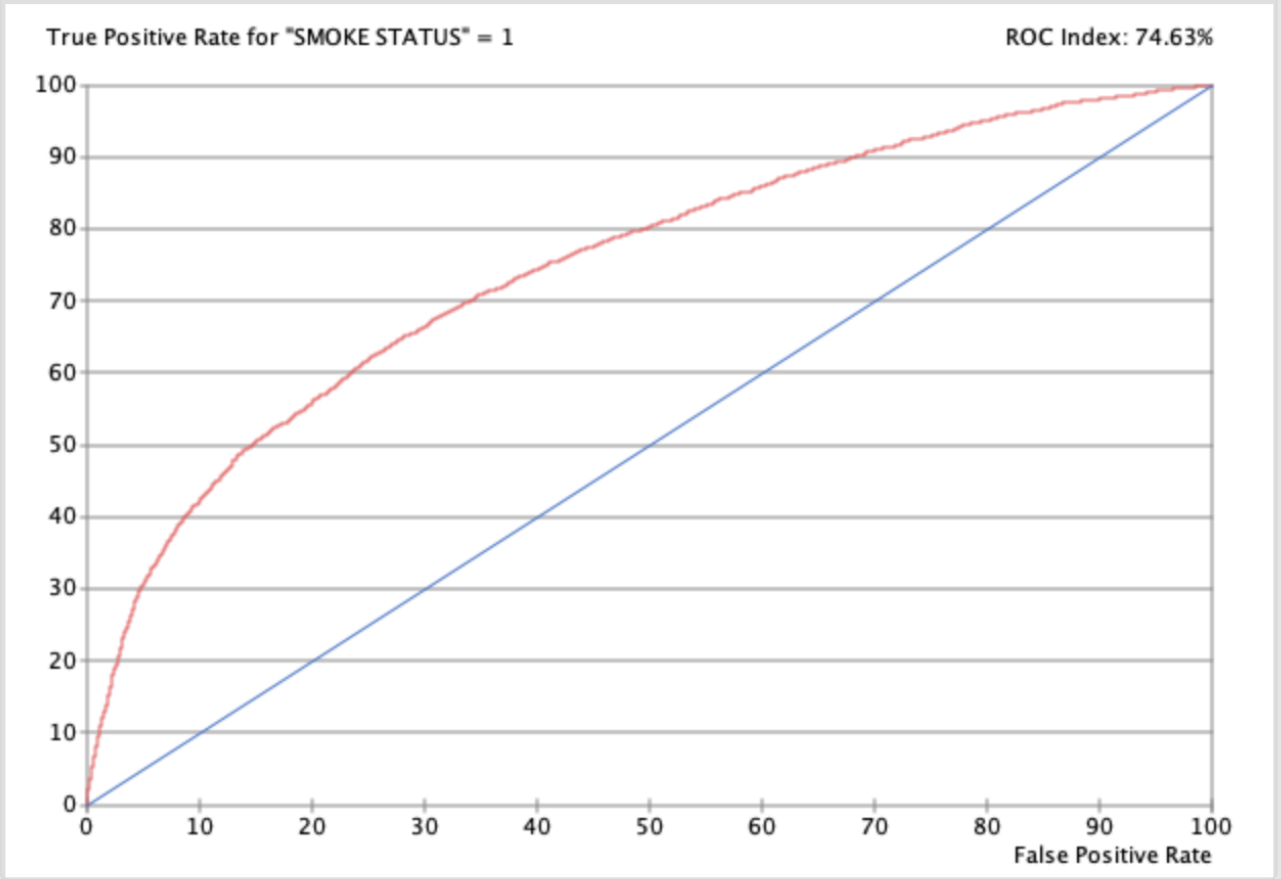
Statistics

Overall Relative Gini Index: 50.6622%
Overall Relative Lift Index: 78.1393%
Overall ROC Index: 75.3311%

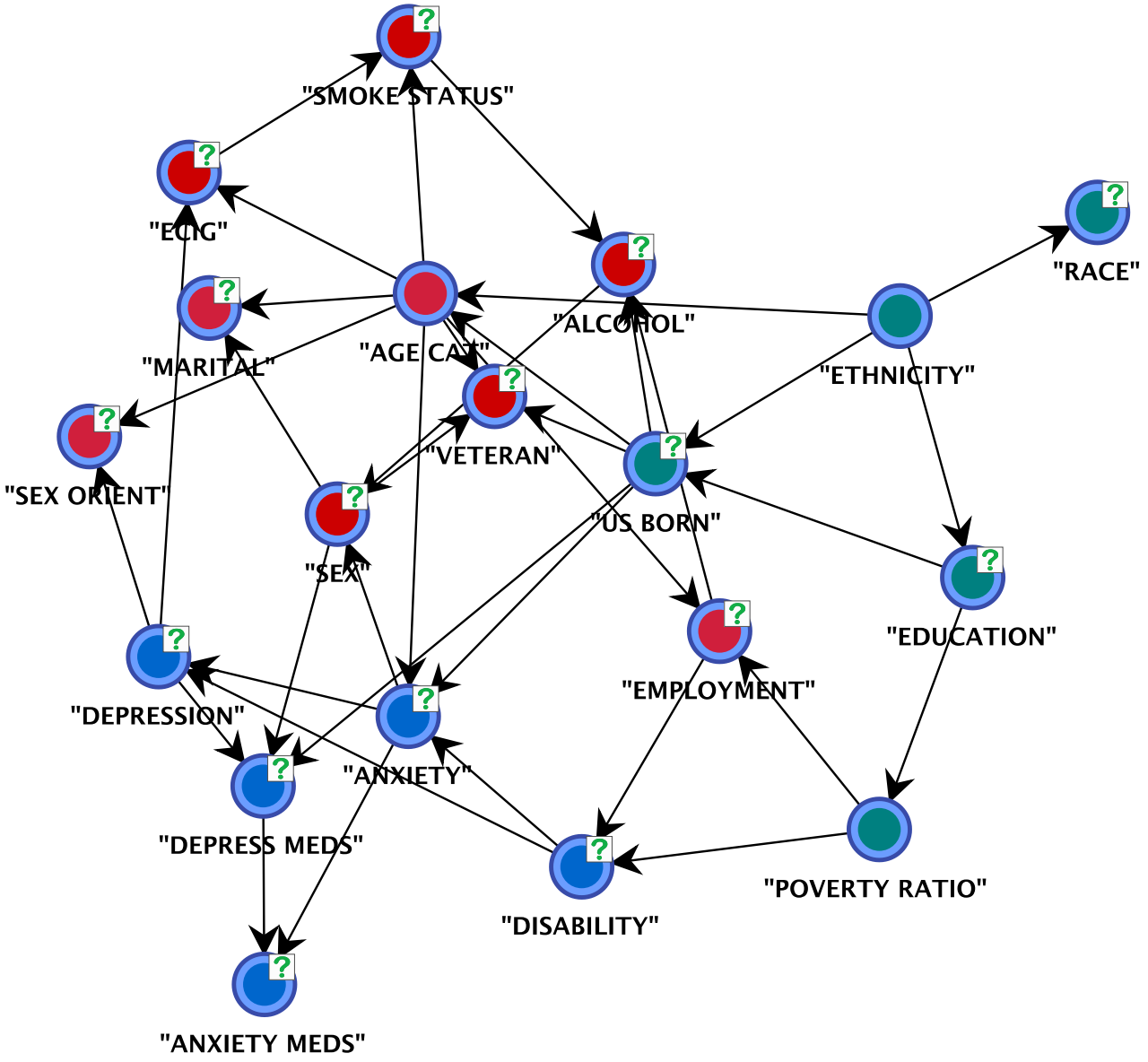
Mean Relative Gini Index: 47.3910%
Mean Relative Lift Index: 62.6500%
Mean ROC Index: 73.6955%

1 | 2 | 3 | 4

Gains Curve | Lift Curve | ROC Curve



MAXIMUM SPANNING TREE



Maximum Spanning Tree learning:
Delete All Arcs
Post-Processed with Taboo (78)
Score Type: MDL

Missing values treated with Structural EM
Total Weight: 27,651
Initial MDL score: 745,005.421
Final MDL score: 652,020.374
Total learning time: 9s

Tobacco Harm Reduction

Tobacco Harm Reduction depends on changing behaviors, or switching states of behavior, from more to less harmful.

Cigarette -> E-cigarette (or some other reduced risk tobacco/nicotine product)

DO E-CIGS HELP SMOKERS QUIT SMOKING?

2023

Cochrane Library

Cochrane Database of Systematic Reviews

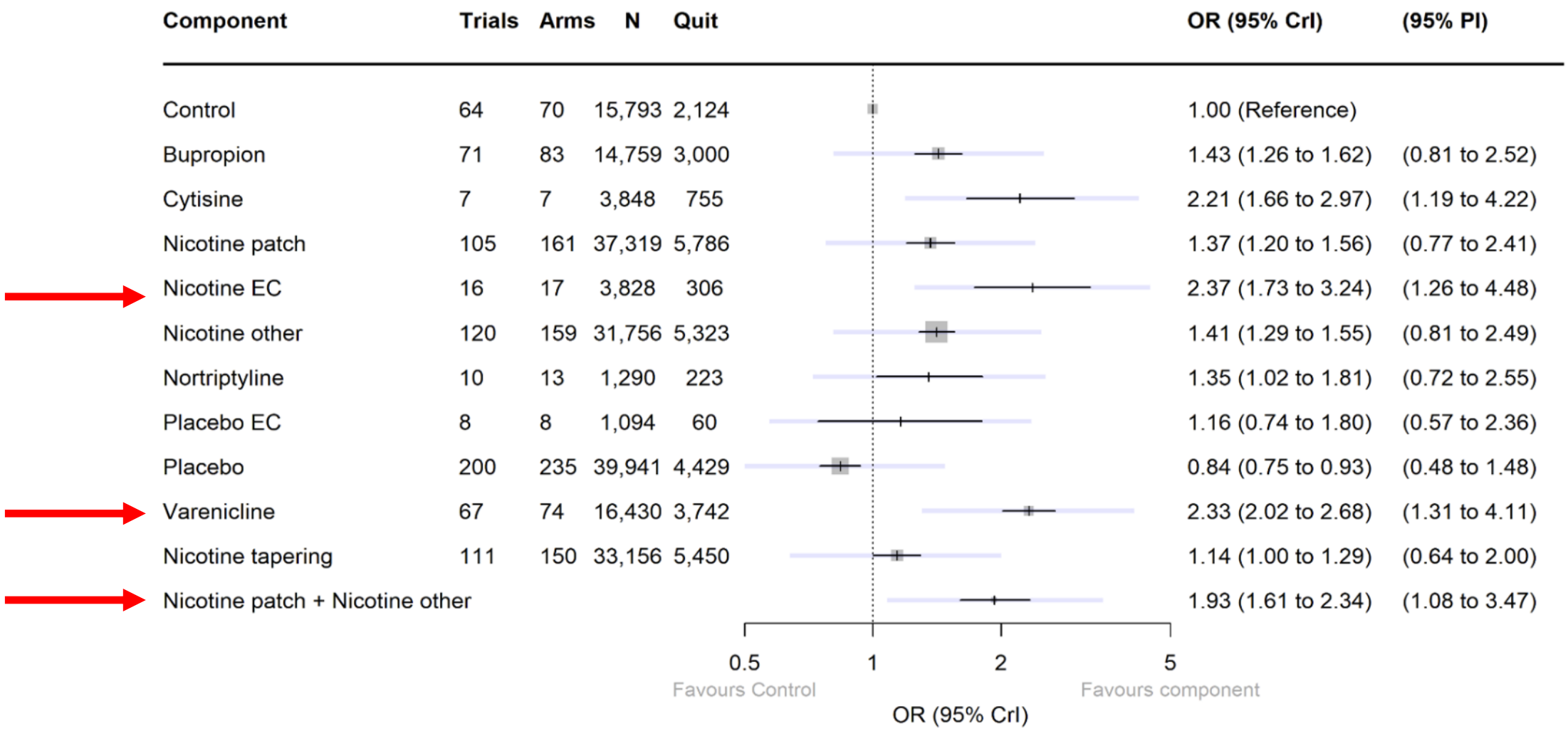
RCTs

Pharmacological and electronic cigarette interventions for smoking cessation in adults: component network meta-analyses (Review)

Lindson N, Theodoulou A, Ordóñez-Mena JM, Fanshawe TR, Sutton AJ, Livingstone-Banks J, Hajizadeh A, Zhu S, Aveyard P, Freeman SC, Agrawal S, Hartmann-Boyce J

DO E-CIGS HELP SMOKERS QUIT SMOKING? - YES

Figure 3. Forest plot illustrating final model for abstinence (efficacy) outcome. Note, darker intervals represent CrI and lighter intervals represent PI. Control: no pharmacological or EC intervention. *Abbreviations* CrI: credibility interval; EC: e-cigarette; N: number of participants; OR: odds ratio; PI: prediction interval



BUT WAIT, NOT SO FAST! WHAT ABOUT THE “REAL WORLD?”

OBSERVATIONAL STUDIES TO THE RESCUE?

Stop-smoking methods used by adults who stopped smoking completely from 2020–2022, US National Health Interview Survey

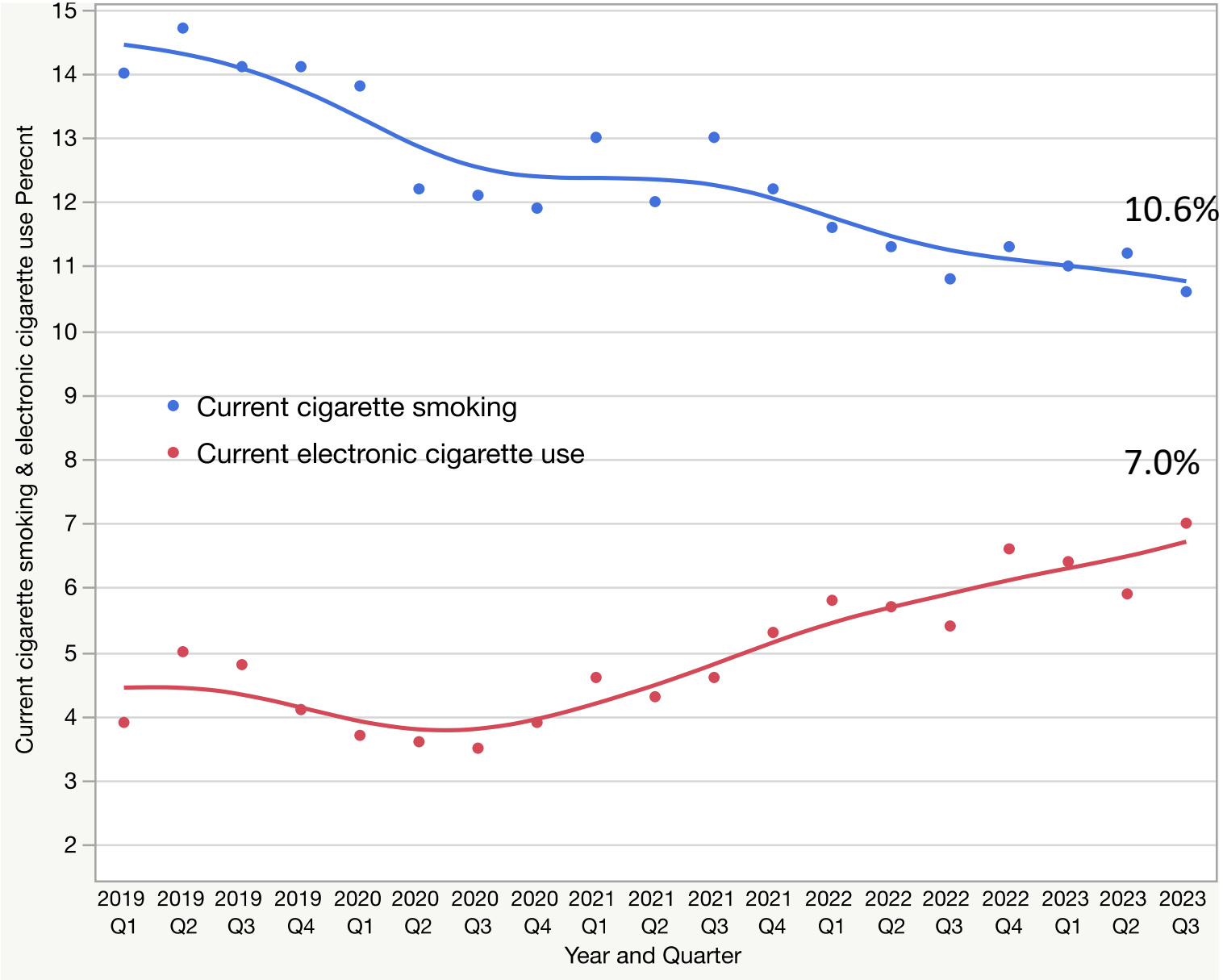
	Weighted Percent (95% CI*; Weighted N)
Any method (Unweighted n=756)	100 (7.5 million)
Nicotine-containing methods	
E-cigarettes	42.5 (38.3–46.8; 3.2 million)
Exclusively	27.2 (23.4–31.2; 2.0 million)
Nicotine gum/lozenge	17.1 (14.0–20.6; 1.3 million)
Exclusively	2.5 (1.5–3.8; 0.2 million)
Nicotine patch	14.8 (12.0–18.1; 1.1 million)
Exclusively	4.7 (3.1–6.7; 0.4 million)
Nicotine nasal spray/inhaler	†
Exclusively	†
One or more of above	54.6 (50.6–58.7; 4.1 million)

E-cigarette and nicotine replacement are the most popular methods

Stop-smoking methods used by adults who stopped smoking completely from 2020–2022

Prescription drug methods	
Chantix/Varenicline	6.4 (4.6–8.5; 0.5 million)
Exclusively	2.4 (1.4–3.7; 0.2 million)
Zyban/Bupropion/Wellbutrin	4.5 (3.1–6.3; 0.3 million)
Exclusively	†
One or more of above	9.6 (7.4–12.2; 0.7 million)
Non-nicotine, non-prescription drug methods	
Quit line	2.5 (1.5–3.9; 0.2 million)
Exclusively	†

Current cigarette smoking & electronic cigarette use % vs. Year and Quarter- US National Health Interview Survey



Are they connected?

Population Assessment of Tobacco and Health (PATH) Study

- The PATH Study is a collaboration between the National Institute on Drug Abuse (NIDA), National Institutes of Health (NIH), and the Center for Tobacco Products (CTP), Food and Drug Administration (FDA).[14]
- It was launched in 2011 to inform FDA's regulatory activities under the Family Smoking Prevention and Tobacco Control Act.[14]
- The PATH Study is an ongoing longitudinal cohort study on tobacco use behavior, attitudes, beliefs, and tobacco-related health outcomes.[14]

PATH Data Collection and Sample Sizes

Wave 1 Sep. 2013–Dec. 2014	Wave 2 Oct. 2014–Oct. 2015	Wave 3 Oct. 2015–Oct. 2016	Wave 4 Dec. 2016–Jan. 2018	Wave 4.5 Special Collection: Youth Only Dec. 2017–Nov. 2018
Adult: **32,320**	Adult: **28,362**	Adult: **28,148**	Adult: **33,822**	
Youth: **13,651**	Youth: **12,172**	Youth: **11,814**	Youth: **14,798**	Youth: **13,131**

Wave 5 Dec. 2018–Nov. 2019	Wave 5.5 & PATH-ATS Special Collection: Adult & Youth Wave 5.5: Jul.–Dec. 2020 PATH-ATS: Sep.–Dec. 2020	Wave 6 Mar.–Nov. 2021	Wave 7 Jan. 2022 – Apr. 2023 Data not yet available
Adult: **34,309**	Adult (PATH-ATS): **8,874**	Adult: **30,516**	Adult: **xx,xxx**
Youth: **12,098**	Young Adult (W5.5): **3,628**	Youth: **5,652**	Youth: **xx,xxx**
	Youth (W5.5): **7,129**		

The overall weighted response rate for adults was 74% in Wave 1 and 65.1% in Wave 5.[15]

Source: NIDA.NIH.gov

Analyses: Wave 1 – 6 adults with complete longitudinal data

Basic sociodemographic info: Age, sex, education, race, region, poverty, depression

Exposure: E-cigarette use frequency (days used in past month); Past month use – yes/no

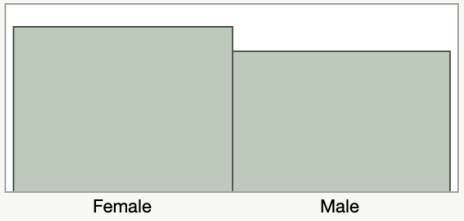
Outcomes: Cigarette use frequency (days used in past month); Past month use – yes/no

Covariates: Other tobacco product use, depression

PATH Study Wave 1 Sociodemographic characteristics

Distributions

male_w1

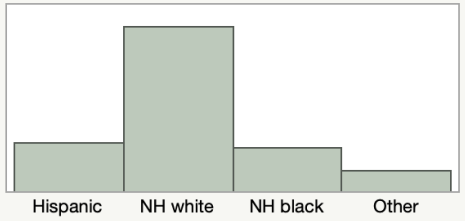


Frequencies

Level	Count	Prob
Female	8056	0.53966
Male	6872	0.46034
Total	14928	1.00000

N Missing 0
2 Levels

Race_w1

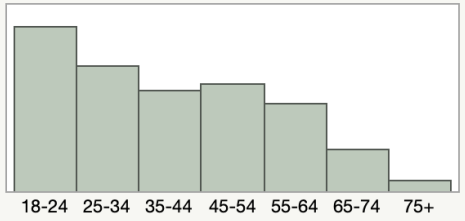


Frequencies

Level	Count	Prob
Hispanic	2573	0.17236
NH white	8972	0.60102
NH black	2314	0.15501
Other	1069	0.07161
Total	14928	1.00000

N Missing 0
4 Levels

age_w1a

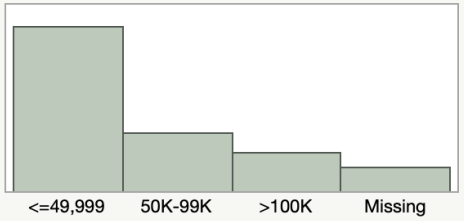


Frequencies

Level	Count	Prob
18-24	3873	0.25948
25-34	2942	0.19711
35-44	2373	0.15898
45-54	2500	0.16749
55-64	2047	0.13714
65-74	957	0.06412
75+	234	0.01568
Total	14926	1.00000

N Missing 2
7 Levels

POVERTY3_w1a



Frequencies

Level	Count	Prob
<=49,999	8704	0.58307
50K-99K	3046	0.20405
>100K	1965	0.13163
Missing	1213	0.08126
Total	14928	1.00000

N Missing 0
4 Levels

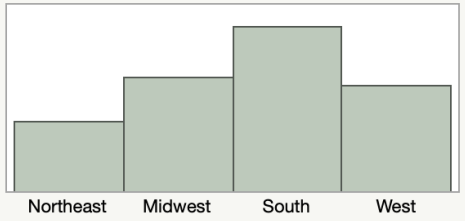
education_w1a

Frequencies

Level	Count	Prob
< High School	1758	0.11823
GED	908	0.06107
HS	3210	0.21589
Some college	5280	0.35510
Bachelors >	3713	0.24971
Total	14869	1.00000

N Missing 59
5 Levels

REGION

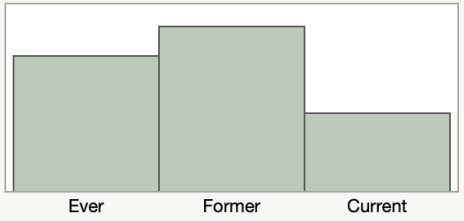


Frequencies

Level	Count	Prob
Northeast	2264	0.15166
Midwest	3763	0.25208
South	5417	0.36288
West	3484	0.23339
Total	14928	1.00000

N Missing 0
4 Levels

Othertobacco_w1a

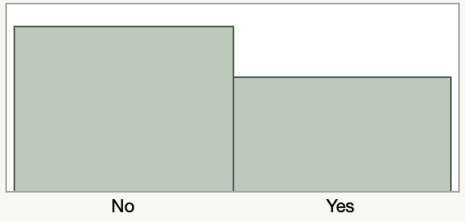


Frequencies

Level	Count	Prob
Ever	5370	0.35977
Former	6514	0.43642
Current	3042	0.20381
Total	14926	1.00000

N Missing 2
3 Levels

depress2_w1a

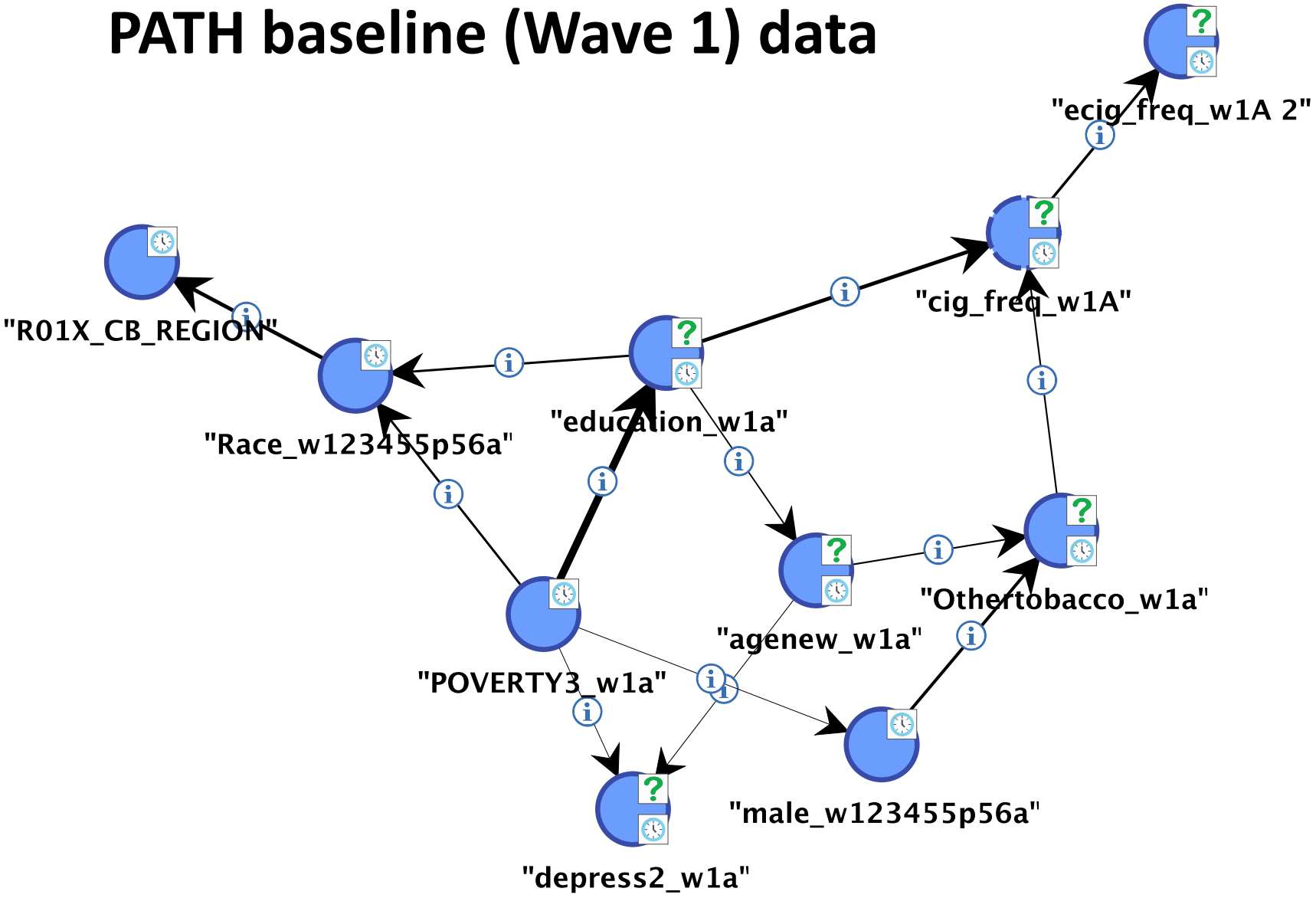


Frequencies

Level	Count	Prob
No	8797	0.59044
Yes	6102	0.40956
Total	14899	1.00000

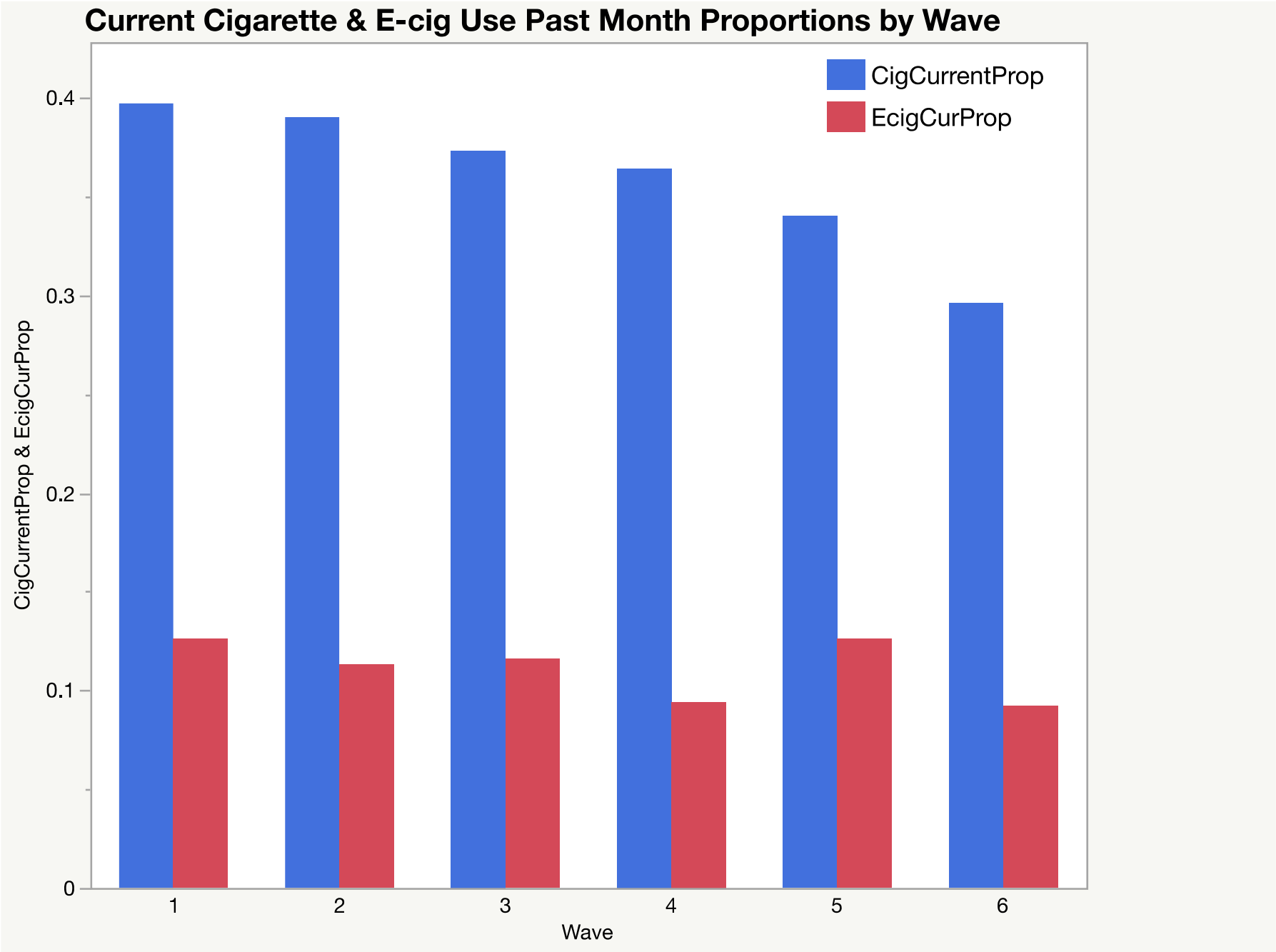
N Missing 29
2 Levels

PATH baseline (Wave 1) data

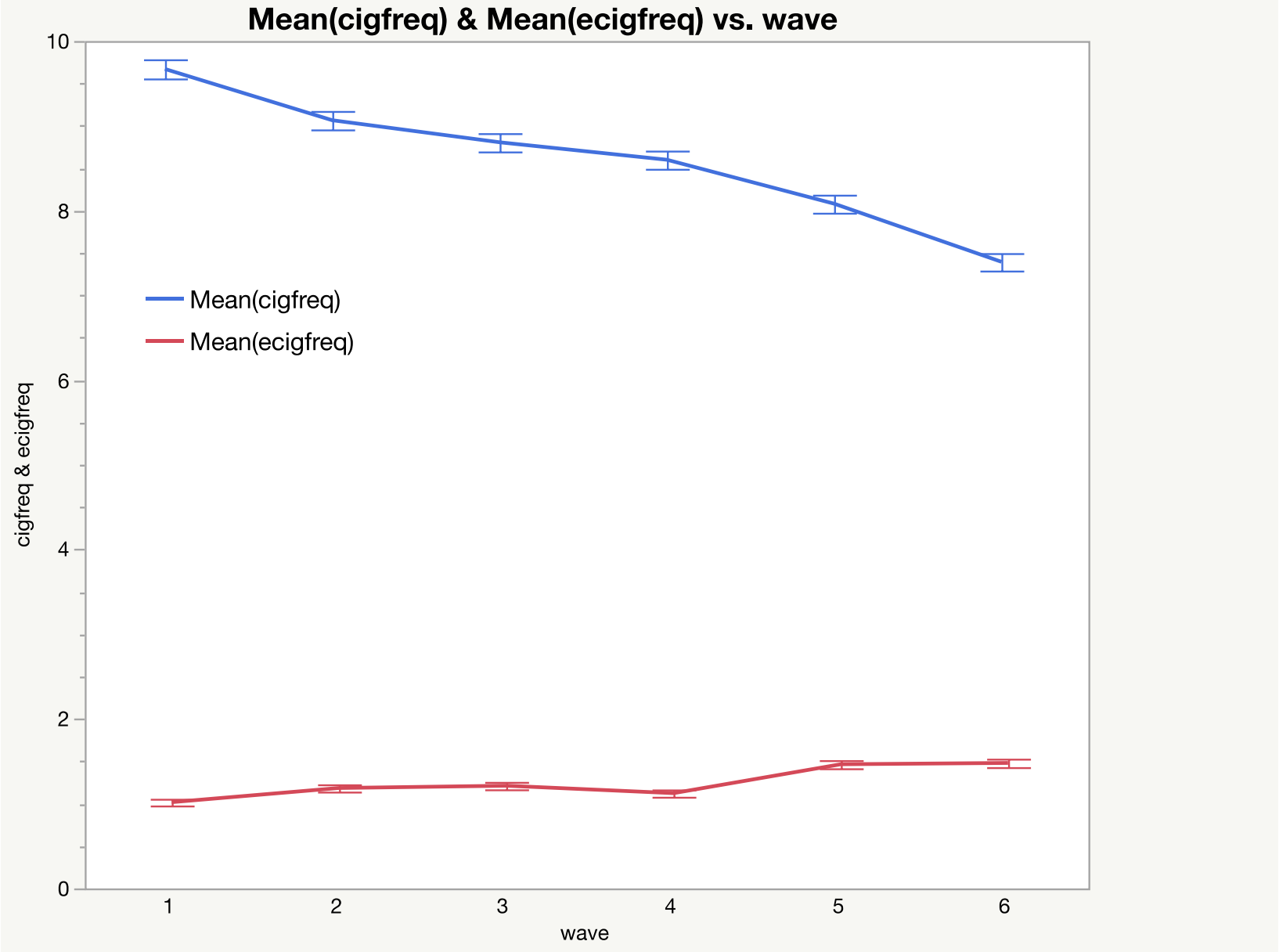


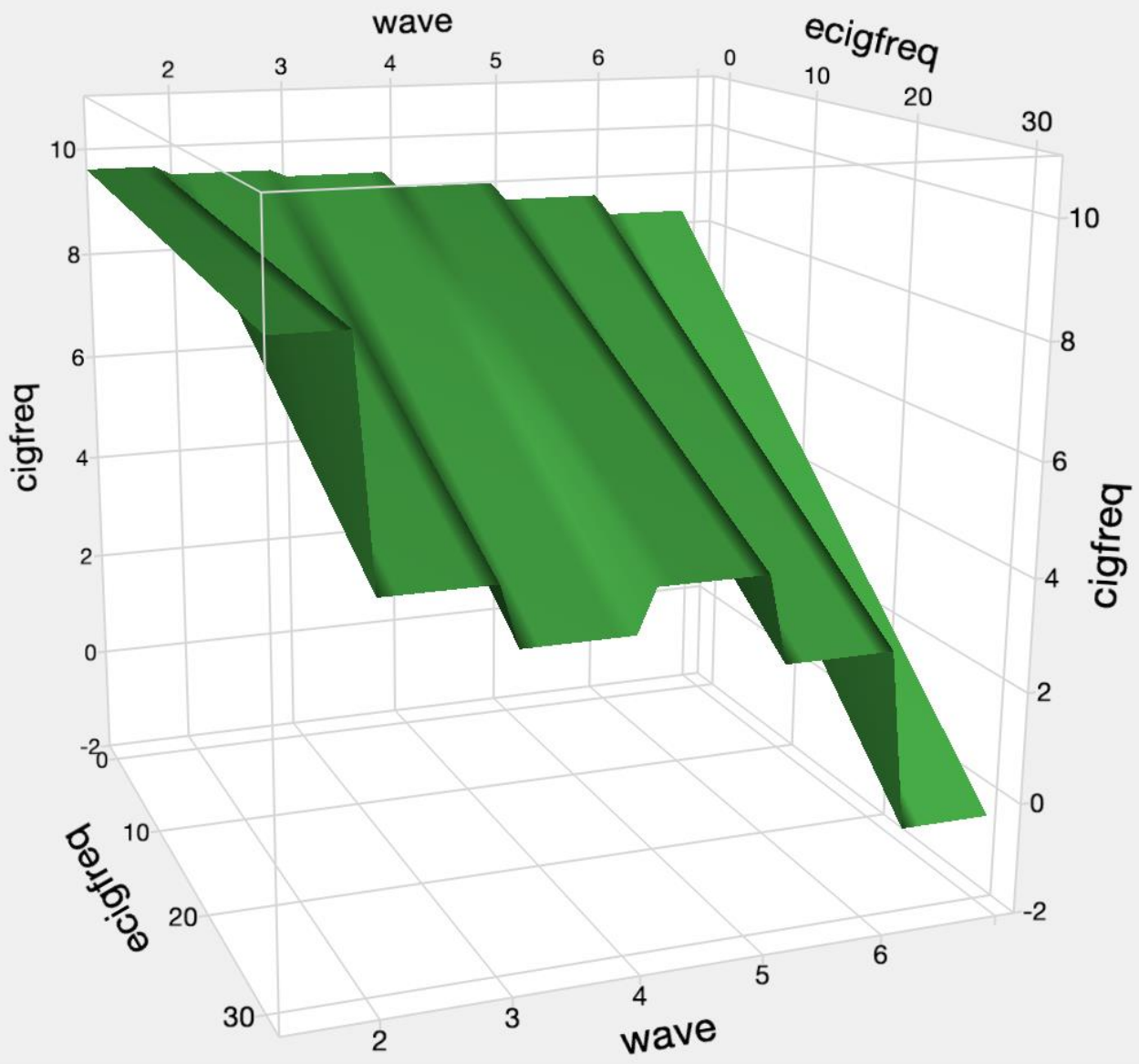
Taboo learning:
Delete All Arcs
Taboo List Size: 36

Missing values treated with Structural EM
Total Weight: 14,928
Initial MDL score: 227,476.42
Final MDL score: 219,343.079
Total learning time: 0s


Current Cigarette & E-cig Use Past Month Proportions by Wave
CigCurrentProp
EcigCurProp
CigCurrentProp & EcigCurProp
0.4
0.3
0.2
0.1
0
1
2
3
4
5
6
Wave

Mean days per last month smoking cigarettes, using e-cigarettes





Fixed Effects Tests

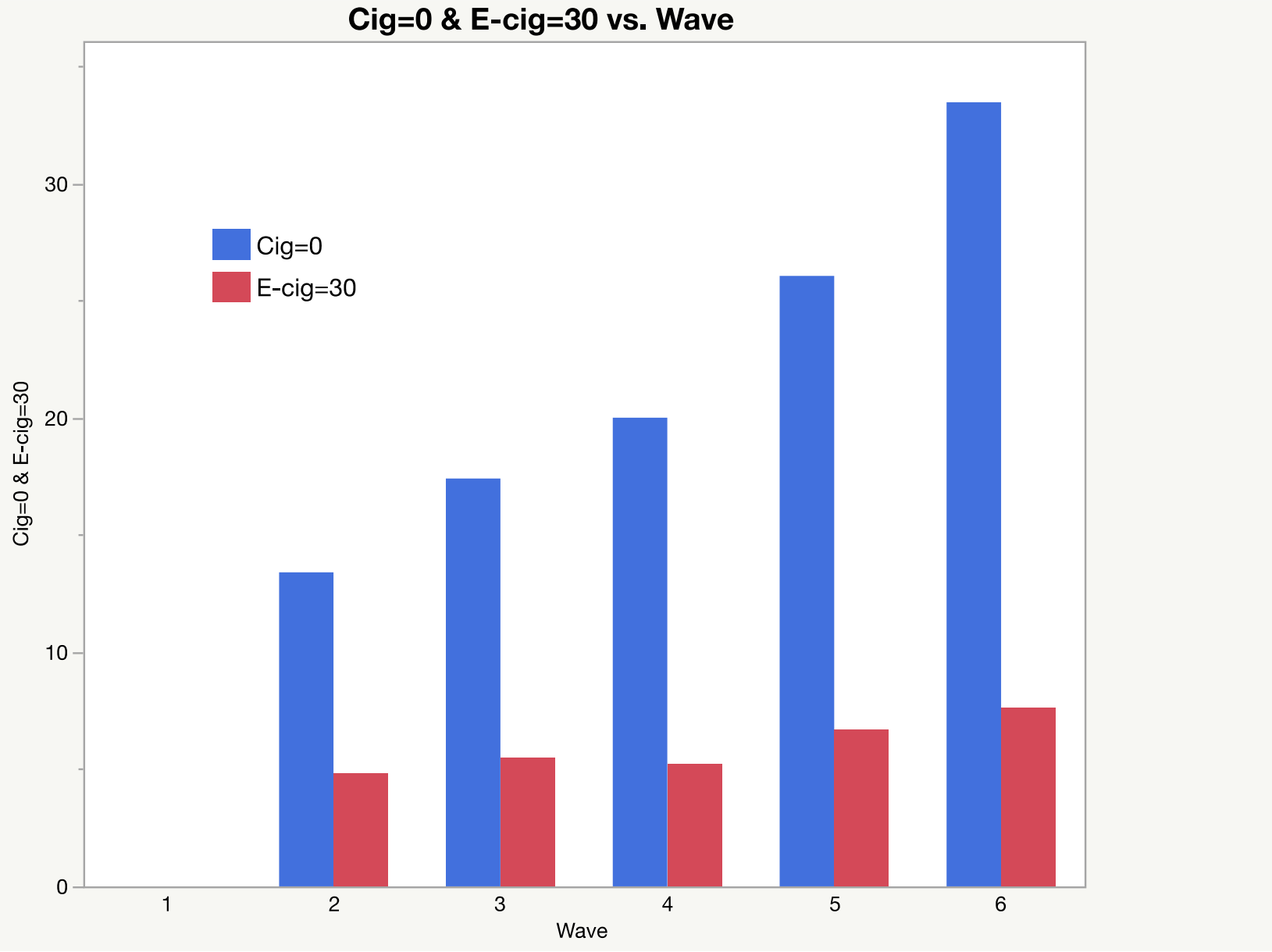
Source	Nparm	DFNum	DFDen	F Ratio	Prob > F
wave	5	5	14460	144.69765	<.0001*
ecigfreq	1	1	15124	2.7563292	0.0969
wave*ecigfreq	5	5	27034	54.125811	<.0001*

Random effects model: Time (wave), e-cigarette frequency (days per month) and interaction effect (time x frequency)

Outcome: Cigarette frequency (days per month)

Selection:

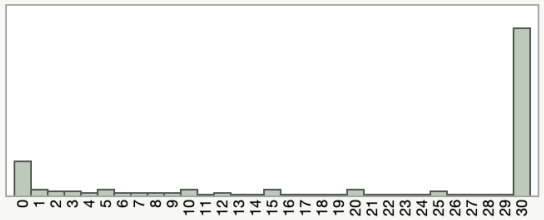
Smokers only selected at Wave 1



Skewed distributions

Distributions

cig_freq_w2A

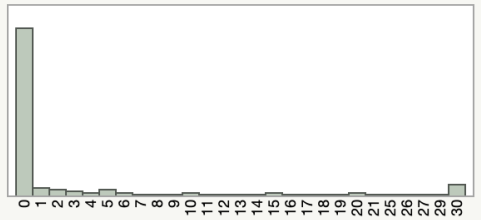


Frequencies

Level	Count	Prob
0	795	0.13434
1	137	0.02315
2	98	0.01656
3	81	0.01369
4	54	0.00912
5	116	0.01960
6	54	0.00912
7	28	0.00473
8	40	0.00676
9	24	0.00406
10	106	0.01791
11	4	0.00068
12	25	0.00422
13	5	0.00084
14	8	0.00135
15	111	0.01876
16	5	0.00084
17	2	0.00034
18	12	0.00203
19	8	0.00135
20	133	0.02247
21	5	0.00084
22	11	0.00186
23	6	0.00101
24	7	0.00118
25	71	0.01200
26	10	0.00169
27	8	0.00135
28	19	0.00321
29	4	0.00068
30	3931	0.66424
Total	5918	1.00000

N Missing 9
31 Levels

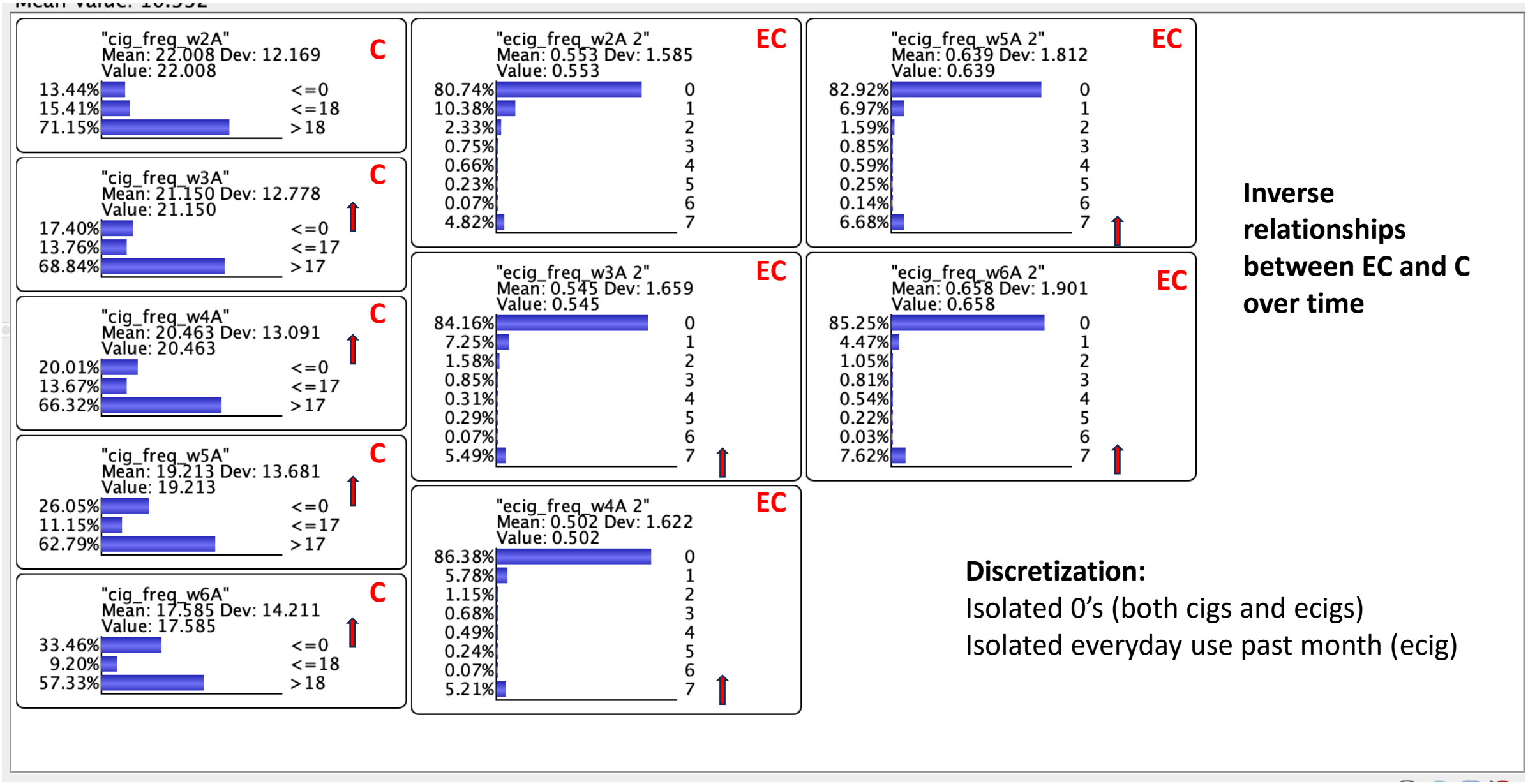
ecig_freq_w2A



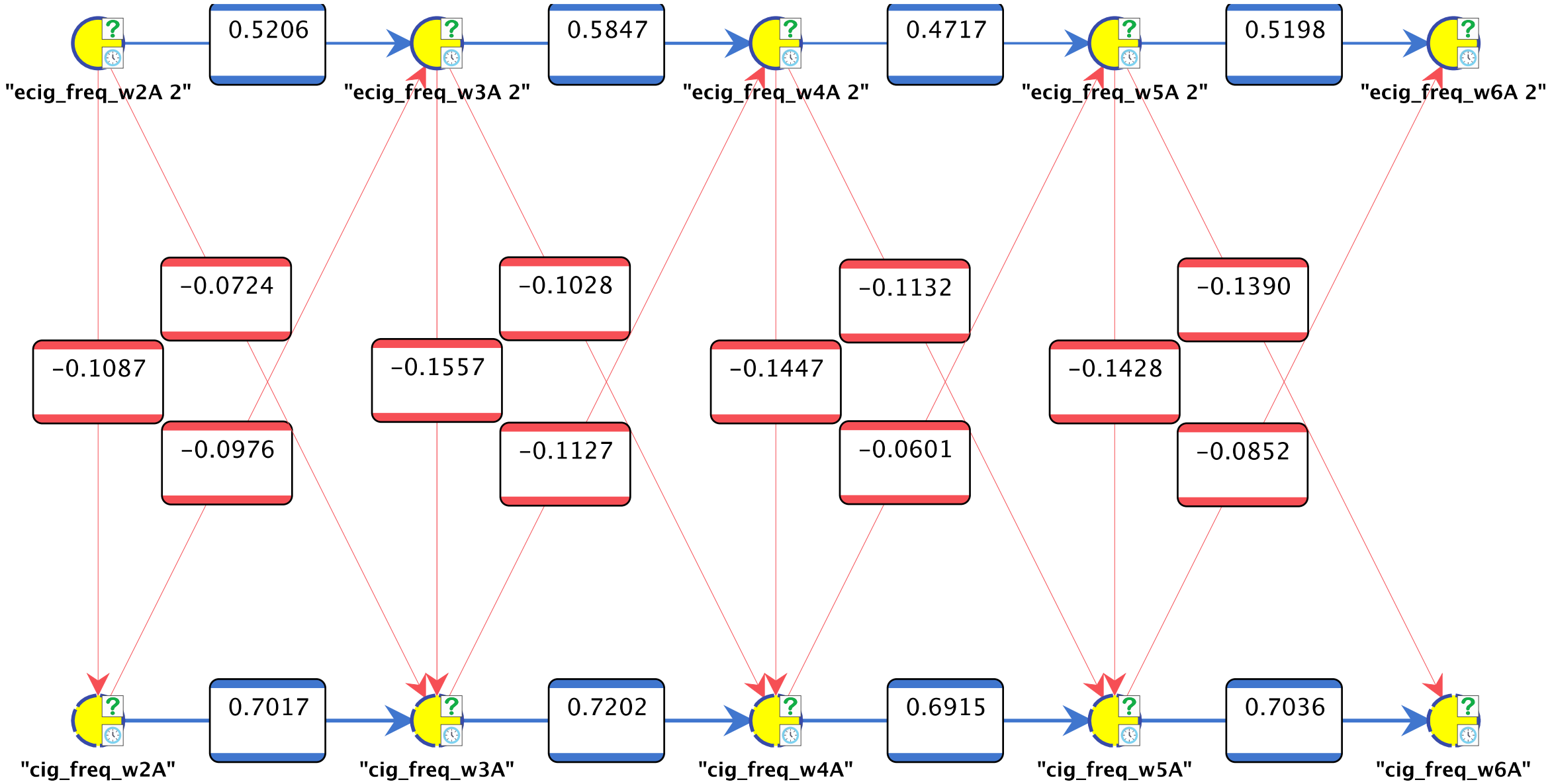
Frequencies

Level	Count	Prob
0	4509	0.80676
1	182	0.03256
2	157	0.02809
3	69	0.01235
4	33	0.00590
5	137	0.02451
6	25	0.00447
7	14	0.00250
8	14	0.00250
9	14	0.00250
10	63	0.01127
11	1	0.00018
12	5	0.00089
13	4	0.00072
14	3	0.00054
15	29	0.00519
16	1	0.00018
17	1	0.00018
18	5	0.00089
19	1	0.00018
20	29	0.00519
21	1	0.00018
25	12	0.00215
26	1	0.00018
27	2	0.00036
29	1	0.00018
30	276	0.04938
Total	5589	1.00000

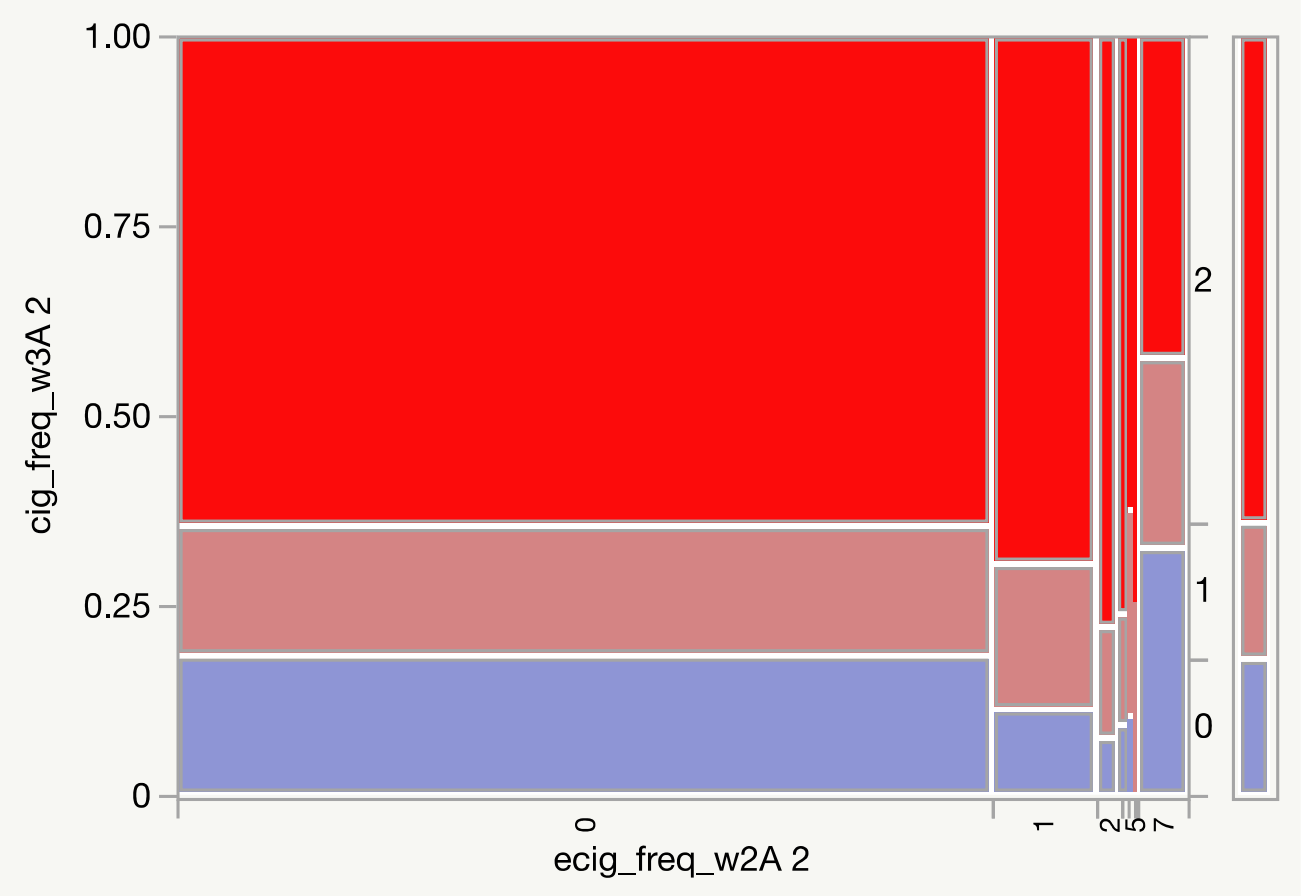
N Missing 338
27 Levels


"cig_freq_w2A"
Mean: 22.008 Dev: 12.169
Value: 22.008
13.44% <=0
15.41% <=18
71.15% >18
C
"cig_freq_w3A"
Mean: 21.150 Dev: 12.778
Value: 21.150
17.40% <=0
13.76% <=17
68.84% >17
C
"cig_freq_w4A"
Mean: 20.463 Dev: 13.091
Value: 20.463
20.01% <=0
13.67% <=17
66.32% >17
C
"cig_freq_w5A"
Mean: 19.213 Dev: 13.681
Value: 19.213
26.05% <=0
11.15% <=17
62.79% >17
C
"cig_freq_w6A"
Mean: 17.585 Dev: 14.211
Value: 17.585
33.46% <=0
9.20% <=18
57.33% >18
C
"ecig_freq_w2A 2"
Mean: 0.553 Dev: 1.585
Value: 0.553
80.74% 0
10.38% 1
2.33% 2
0.75% 3
0.66% 4
0.23% 5
0.07% 6
4.82% 7
EC
"ecig_freq_w3A 2"
Mean: 0.545 Dev: 1.659
Value: 0.545
84.16% 0
7.25% 1
1.58% 2
0.85% 3
0.31% 4
0.29% 5
0.07% 6
5.49% 7
EC
"ecig_freq_w4A 2"
Mean: 0.502 Dev: 1.622
Value: 0.502
86.38% 0
5.78% 1
1.15% 2
0.68% 3
0.49% 4
0.24% 5
0.07% 6
5.21% 7
EC
"ecig_freq_w5A 2"
Mean: 0.639 Dev: 1.812
Value: 0.639
82.92% 0
6.97% 1
1.59% 2
0.85% 3
0.59% 4
0.25% 5
0.14% 6
6.68% 7
EC
"ecig_freq_w6A 2"
Mean: 0.658 Dev: 1.901
Value: 0.658
85.25% 0
4.47% 1
1.05% 2
0.81% 3
0.54% 4
0.22% 5
0.03% 6
7.62% 7
EC
Inverse relationships between EC and C over time
Discretization:
Isolated 0's (both cigs and ecigs)
Isolated everyday use past month (ecig)

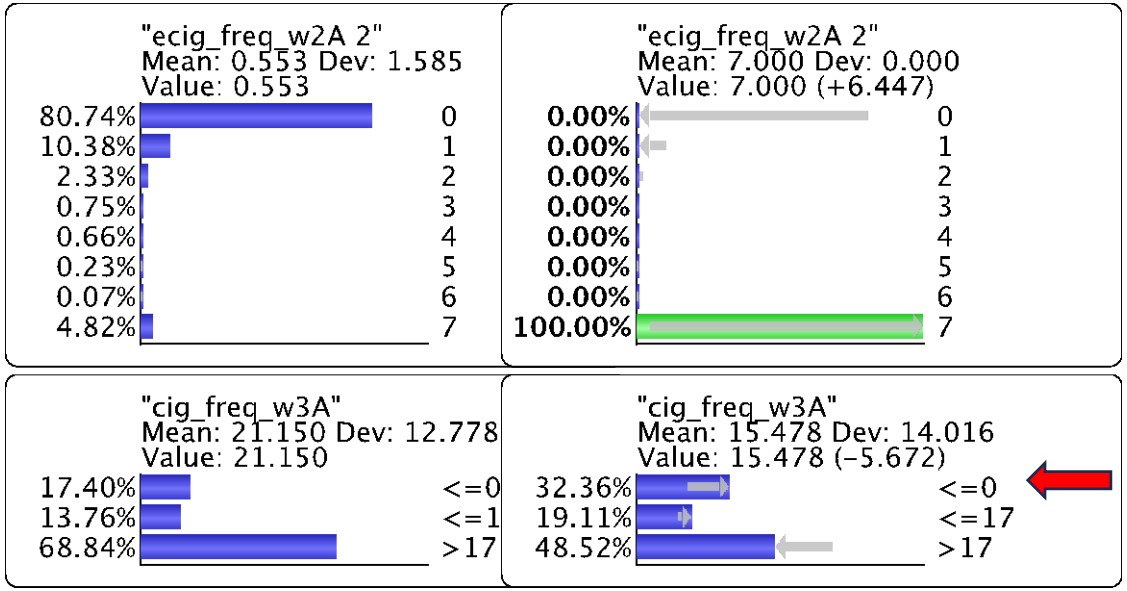
Cross-lagged Panel Model



Wave 2-3 lagged relationship



Setting evidence: 100% of smokers switch to daily e-cig use

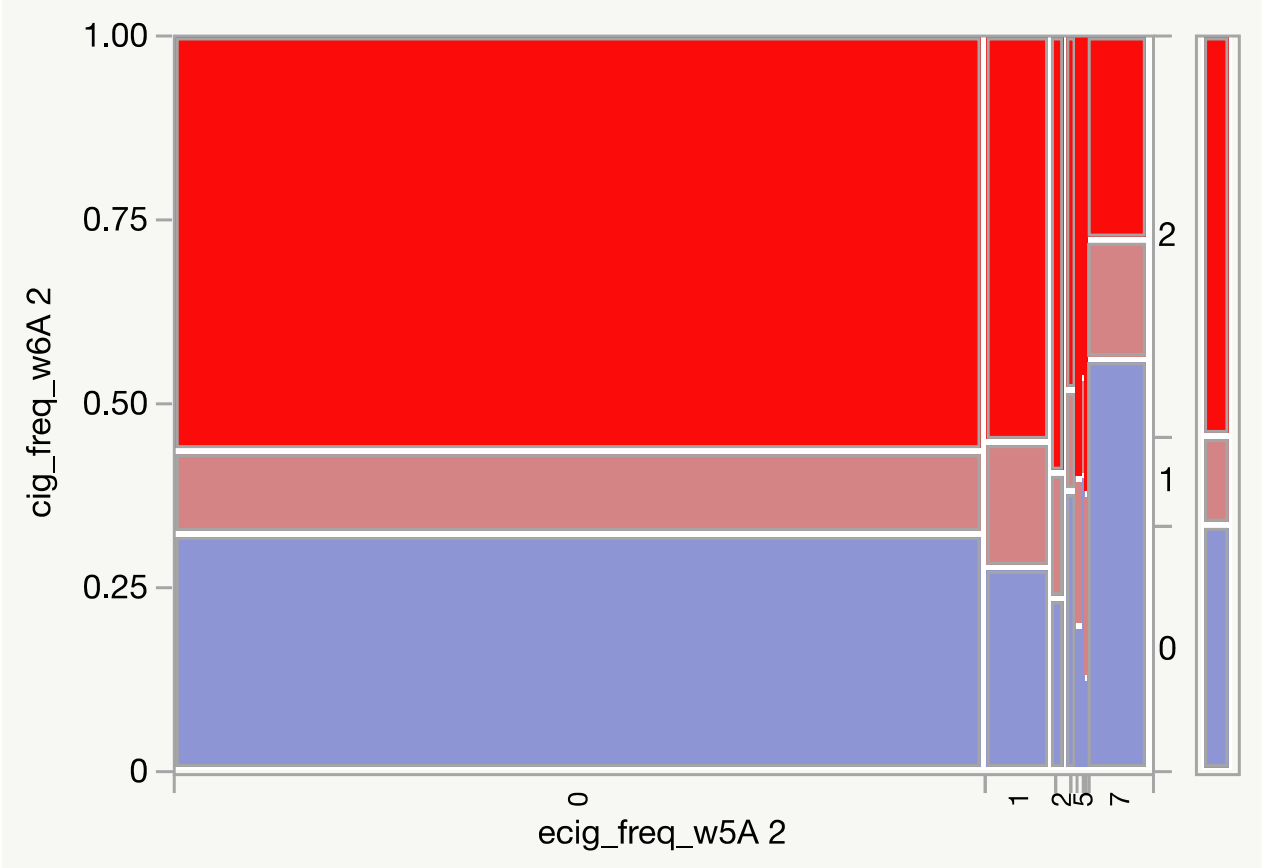


N	DF	-LogLike	RSquare (U)
5581	14	49.975158	0.0099

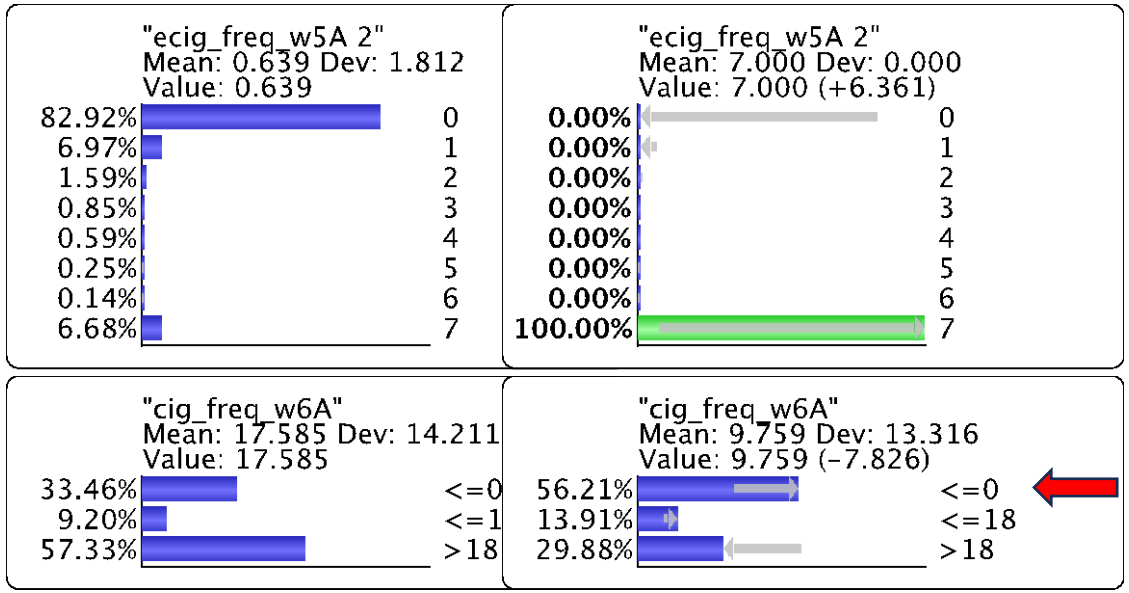
Test	ChiSquare	Prob>ChiSq
Likelihood Ratio	99.950	<.0001*
Pearson	99.672	<.0001*

Daily use of e-cigs show the strongest association

Wave 5-6 lagged relationship



Setting evidence: 100% of smokers switch to daily e-cig use



N	DF	-LogLike	RSquare (U)
5904	14	77.658503	0.0138

Test	ChiSquare	Prob>ChiSq
Likelihood Ratio	155.317	<.0001*
Pearson	155.205	<.0001*

Daily use of e-cigs show the strongest association

Accidental Quitting

by Jemma Wolfe Sep 20, 2022

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December 29, 2021

Study Finds What Vapers Knew: Accidental Quitting Is Real

Jim McDonald

ANOTHER LOOK AT PATH STUDY DATA: SMOKERS NOT PLANNING TO QUIT

JAMA Network | Open™

Original Investigation | Public Health

Association of e-Cigarette Use With Discontinuation of Cigarette Smoking Among Adult Smokers Who Were Initially Never Planning to Quit

Karin A. Kasza, PhD; Kathryn C. Edwards, PhD; Heather L. Kimmel, PhD; Andrew Anesetti-Rothermel, PhD, MPH; K. Michael Cummings, PhD; Raymond S. Niaura, PhD; Akshika Sharma, MDS; Erin M. Ellis, PhD; Rebecca Jackson, MPH; Carlos Blanco, MD, PhD; Marushka L. Silveira, PhD; Dorothy K. Hatsukami, PhD; Andrew Hyland, PhD

JAMA Network Open. 2021;4(12):e2140880. doi:10.1001/jamanetworkopen.2021.40880

Table 2. Cigarette Discontinuation and Discontinuing Daily Cigarette Smoking at Follow-up Wave, Among Daily Cigarette Smokers Who Had No Plans to Ever Quit for Good and Who Were Not Using e-Cigarettes at Baseline Wave, as a Function of e-Cigarette Use at Follow-up Wave[a]

e-Cigarette use at follow-up	Cigarette discontinuation at follow-up wave (ie, no cigarette smoking)		Discontinuing daily cigarette smoking at follow-up wave (ie, no daily cigarette smoking)	
	No. of observations (%) [95% CI]	aOR (95% CI)[b]	No.of observations (%) [95% CI]	aOR (95% CI)[b]
Overall (n = 2489)	158 (6.2) [5.0-7.5]	NA	271 (10.7) [9.1-12.5]	NA
No e-cigarette use (n = 2273)	138 (5.8) [4.7-7.2]	1 [Reference]	228 (9.9) [8.2-11.8]	1 [Reference]
Nondaily e-cigarette use (n = 156)	3 (3.1) [0.8-11.1][c]	0.53 (0.08-3.35)	16 (10.2) [5.8-17.3]	0.96 (0.44-2.09)
Daily e-cigarette use (n = 60)	17 (28.0) [15.2-45.9]	8.11 (3.14-20.97)	27 (45.5) [27.4-64.9]	9.67 (4.02-23.25)

Yes, BUT...

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SYNDICATION
DUDE... THOSE THINGS
WILL KILL YOU!
VAPING

CONCLUSIONS

- **Who are the (U.S.) smokers? National data can point us to important inequalities, but we need more to reach the majority of smokers with effective cessation tools.**

- **What works to help smokers quit?**
  - **E-cigarettes are a popular method. They are consumer not therapeutic products. They may have greater reach and availability and they may benefit smokers who are not even trying to quit, but they must be used daily for complete switching.**

THANK
YOU!