Longitudinal Analysis on the Effect of E-cigarette Use on Cigarette Smoking Using the PATH Adult Study

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Abstract

This analysis examined adult data from the Population Assessment of Tobacco and Health (**PATH**) study (Waves 1 through 4) to measure cigarette smoking cessation among baseline exclusive cigarette smokers compared to baseline dual users of cigarettes and e-cigarettes.

METHODS: Analyses applied a Markov multi-state chain model to project 1-year transition probabilities for up to 5 years, with a focus on cigarette abstinence in a subsequent wave. A linear mixed effects model estimating the effect of e-cigarette adoption on cigarette consumption was also executed.

RESULTS: Analyses included 5,573 baseline exclusive cigarettes smokers and 462 baseline dual users. Results from the Markov multi-state chain model showed that cessation rates remained consistently higher among dual users than among exclusive cigarette smokers throughout the projected years.

After 1 year, *a higher percentage of baseline dual users reported no cigarette smoking* compared to baseline exclusive cigarette smokers (12.2% versus 8.6%, respectively). *After 2 years, 17.8% of baseline dual users reported no cigarette smoking, compared to 14.1% of baseline exclusive cigarette smokers*. After 3 years, 20.5% of baseline dual users and 17.7% of baseline exclusive cigarette smokers reported no cigarette smoking. After 4 years, 21.9% of baseline dual users and 19.9% of baseline exclusive cigarette smokers reported no cigarette smoking.

These findings suggest that e-cigarette use among current cigarette smokers contributes to subsequent cigarette smoking cessation.

Introduction

- E-cigarettes have gained popularity among US adults while changing the landscape of tobacco products and patterns of use in recent years.
- Studies suggest that ***cigarette smokers who use e-cigarettes report reduced cigarette consumption***, and for some, **complete smoking cessation**.

However, findings from these studies remain confounded by the definition of cigarette smoking or e-cigarettes use, and most studies fail to consider the order of product initiation.

OBJECTIVES: This analysis investigated:

Research Question 1: To what extent are cigarette smoking cessation rates among baseline exclusive cigarette smokers comparable to cigarette smoking cessation rates among baseline dual cigarette and e-cigarette users (Markov Multi-state Chain Model).

Research Question 2: To what extent does subsequent e-cigarette adoption affect cigarette consumption among baseline exclusive cigarette smokers (Linear Effects Mixed Model).

Methods

DATA SOURCE

- The PATH study is a nationally representative longitudinal study that was launched in 2013 to inform FDA's regulatory activities under the Family Smoking Prevention and Tobacco Control Act.
  - These data allow for the assessment of patterns of tobacco use behaviors, including initiation, cessation, relapse, transition between products, and factors associated with use patterns *over time*.

STUDY POPULATION

- ✓ **The PATH adult sample (Waves 1 [2013] thru 4 [2018]):** U.S. Adults (18+ years of age)
- ✓ **Analytic sample:** Current established cigarette smokers at baseline (Wave 1) who completed the subsequent three waves.

ANALYSIS

- ✓ The first analysis assessed the extent to which cigarette smoking cessation rates differed between baseline cigarette exclusive smokers and baseline dual cigarette and e-cigarette users.
- ✓ In subsequent waves, the analysis defined six possible transition paths from baseline tobacco use status: 1) exclusive cigarette smoker, 2) dual cigarette smoker and e-cigarette user, 3) exclusive e-cigarette user, 4) no current use, 5) cigarette smokers who also use other tobacco products (but not e-cigarettes), or 6) users of tobacco products other than cigarettes.

Results

STUDY POPULATION

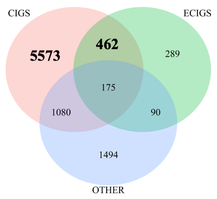
Current Established Cigarette Smokers

(Exclusive Cigarette Smokers or Dual Users of Cigarettes and E-cigarettes)

- At baseline, 82.5% of respondents were adults between the ages of 25 and 64 years old.
- 7.5% were respondents 65 years of age or older.
- The gender distribution was generally comparable (males: 47.4%; females: 52.6%).
- Most of the study population (72.7%) reported high school graduation or more.
- 68.9% of the study population were non-Hispanic White.
- 63.2% of baseline dual users of cigarettes and e-cigarettes were younger than 45 years old, compared to 52.1% of exclusive cigarette smokers for the same age group.
- About 16.0% of baseline dual users had a bachelor's degree or more, compared to 11.5% of exclusive cigarette smokers.
- Nearly 81.0% of baseline dual users were non-Hispanic Whites, compared to 68.0% of exclusive cigarette smokers.

ANALYTIC SAMPLE

Figure 1: Tobacco Product Categories at Baseline (Wave 1)

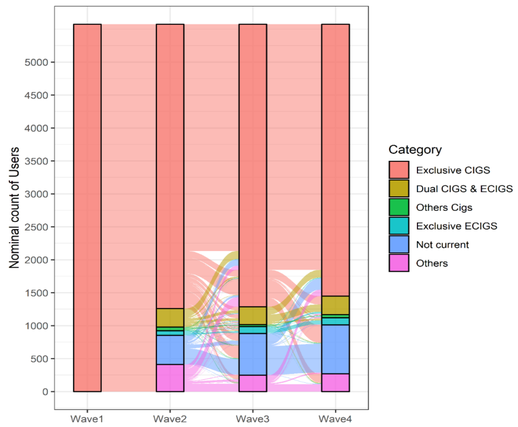


A total of 21,285 adults completed all four waves.

The final sample consisted of 6,035 baseline current established cigarette smokers among whom, 5,573 (92.5%) were exclusive smokers, and 462 were dual cigarette and e-cigarettes users (7.5%) (Figure 1).

- Baseline current established users of products other than cigarettes and exclusive e-cigarette users were excluded from the final sample.

Figure 3: Transition Patterns Among Baseline Exclusive Cigarette Smokers



- Exclusive cigarette smoking steadily declined over time (Figure 3).
  - Wave 2: 80.2%; Wave 3: 76.9%; Wave 4: 74.0%.
- Among exclusive cigarette smokers at Wave 1, e-cigarette use increased over time (exclusive or dual use with cigarette smoking).
- The majority (82.3%) of Wave 2 exclusive cigarette smokers remained exclusive cigarette smokers at Wave 4.
- Over half (51.6%) of baseline exclusive cigarette smokers who reported e-cigarette use at Wave 2 were not exclusive cigarette smokers at Wave 4.

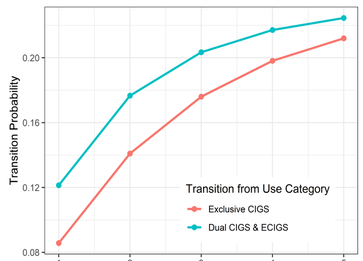
DEMOGRAPHICS & BASELINE CHARACTERISTICS

Characteristic	Exclusive cigarette smokers (n=5,549*)	Dual users of cigarettes and e-cigarettes (n=462)	P-value
Age group n (%)			<0.05
18 – 24	877 (9.9)	83 (11.8)	
25 – 34	1,215 (22.6)	125 (30.1)	
35 – 44	1,055 (19.6)	99 (21.3)	
45 – 54	1,178 (22.7)	80 (17.4)	
55 – 64	865 (17.5)	59 (15.0)	
65+	359 (7.7)	16 (4.4)	
Sex, n (%) Male / Female	2,468 (47.8) / 3,081 (52.2)	185 (41.4) / 277 (58.6)	0.05
Race-Ethnicity, n (%)			<0.001
Non-Hispanic White	3614 (68)	355 (80.6)	
Non-Hispanic Black	844 (15.1)	29 (6.7)	
Hispanic	630 (10.1)	33 (5.2)	
Others	461 (6.9)	45 (7.5)	
Education, n (%)			<0.001
Less than High School	1,006 (17.4)	52 (10.2)	
GED	598 (10.5)	45 (9.8)	
High School Graduate	1,376 (27.7)	108 (25.4)	
Some College or Associate	1,955 (33.0)	190 (38.7)	
Bachelor's degree	457 (9.0)	50 (13.0)	
Advance degree	157 (2.5)	17 (3.0)	

* Note: *A total of 24 respondents were excluded from this table because they lacked valid data on at least one sociodemographic characteristic. Unweighted n and weighted percent are presented. P-value from Pearson chi-square.*

MARKOV MULTI-STATE CHAIN MODEL

Figure 2: One-wave (Approximately 1 Year) Transition Probability Between Tobacco Use States Estimated From Four Waves Transition Probabilities



At each year, ***baseline dual cigarettes and e-cigarette users had the highest probabilities of reaching cigarette cessation***, compared to exclusive cigarette smokers (Figure 2).

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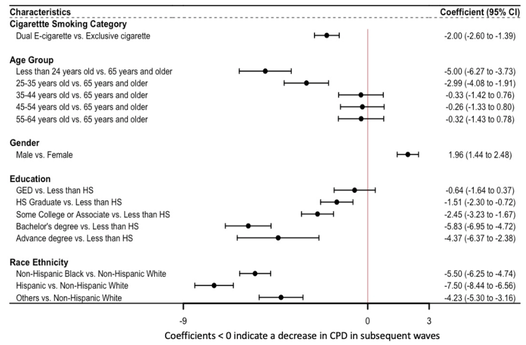
Figure 4: Results From the Linear Mixed Effect Model Estimating the Effect of E-cigarette Adoption on Cigarette Consumption (Wave 1 - Wave 4)



- Results from the fully adjusted linear mixed effect model showed that ***compared to those who remained exclusive cigarette smokers or adopted other tobacco use behaviors in subsequent waves, those who adopted e-cigarettes reported fewer cigarettes per day*** (CPD; coef.: -2.0; 95% C.I.: -2.6, -1.4) (Figure 4).

Methods Cont'd

TOBACCO USE CATEGORIES

Category	Definition
Waves 1, 2, 3, and 4	
Exclusive cigarette smoker	Has smoked 100+ cigarettes in lifetime AND is currently smoking cigarettes every day or some days AND has never been established on other tobacco products
Dual cigarette smoker and e-cigarette user	Has smoked 100+ cigarettes in lifetime AND is currently smoking cigarettes everyday or some days AND has used e-cigarettes 100+ times in lifetime and is currently using e-cigarette everyday or some days AND has never been established on other tobacco products
Waves 2, 3, and 4	
Exclusive e-cigarettes user	Has used e-cigarettes 100+ in lifetime and is currently using e-cigarettes everyday or some days AND is not currently an established user of another tobacco product
No current use	Is not currently using any given tobacco products every day or some days
Cigarettes and other tobacco product use	Has smoked 100+ cigarettes in lifetime AND is currently smoking cigarettes every day or some days AND has used at least one tobacco product other than e-cigarettes 100+ in their lifetime and is currently using that product every day or some days
Others (Non-cigarette products)	Has not smoked 100+ cigarettes in lifetime AND has used other tobacco products 100+ in lifetime AND is currently using the products everyday or some days

- An unadjusted Markov multi-state transition framework was used to estimate 1-year transition probabilities for cigarette smoking cessation rates (i.e., no cigarette smoking in subsequent waves).
  - A Markov multi-state chain model was applied to describe the stochastic process in which an individual moves through a series of tobacco use states over a continuous time period.
- Transition analyses were executed in R version 3.6.3 which supports the msm package and allows a general multi-state model to be fitted to longitudinal data (Jackson & Jackson, 2021).

SPECIFICATION OF THE LINEAR MIXED EFFECT MODEL

- Transition patterns from the first analysis informed the investigation into the second analysis related to the second research question, which assessed *the extent to which subsequent e-cigarette adoption affected the cigarette consumption among baseline exclusive cigarette smokers.*
- To address the second research question (i.e., to what extent subsequent adoption of e-cigarette affects cigarette consumption), analyses focused specifically on baseline exclusive cigarette smokers who adopted e-cigarettes in subsequent waves (i.e., either exclusively or in dual use with cigarettes).
- The analysis estimated the effect of the transition to e-cigarette use on reported cigarette consumption using a linear mixed effect model.
  - This model is well suited to account for both between- and within- individual variations, given the longitudinal nature of the data.
- Descriptive, and linear mixed effect model were completed in SAS Enterprise Guide 7.1 and weighted according to the PATH study user guide (National Institute on Drug Abuse & Products, 2019).

Conclusions

- ***Projections from the multi-state transition model suggest that over time, the relative rates of cigarette smoking cessation (i.e., no current cigarette smoking) are higher among Wave 1 dual cigarette and e-cigarette users compared to Wave 1 exclusive cigarette smokers.***
- The projection trends were consistent through the Year 5 projections, with a higher probability of cessation among Wave 1 baseline dual cigarette and e-cigarette users compared to Wave 1 baseline exclusive cigarette smokers.
- ***Baseline dual users are more likely to report smoking cessation than baseline exclusive cigarette smokers.***
- The linear mixed effect model results suggest that ***baseline exclusive cigarette smokers who adopted e-cigarettes in the interim reported smoking fewer cigarettes than those who remained exclusive cigarette smokers throughout the four waves.***
- These findings suggest that e-cigarette use among current cigarette smokers contributes to a subsequent reduction in cigarette consumption and cigarette smoking cessation.