The Effect of E-Cigarette Tax on Health Outcomes

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Abstract

The alarming rise in the use of electronic cigarettes (e-cigarettes) among teens in the US has become a major health concern, driving many states to take action, including Illinois, which implemented a 15% tax on e-cigarettes. This research aims to evaluate the effectiveness of taxation to control e-cigarette use, measured by improvement in health outcomes in Illinois, from before and after the state implemented the 15% tax. Additionally, a comparison was done with neighboring states of Michigan and Missouri. Using difference-in-difference hypothesis testing, a statistically significant decrease in reported rates of asthma, depression, toothache, and bleeding gums, was noted when comparing health outcomes before and after the implementation of the state tax in Illinois as compared to Michigan. A decrease in the reported rate of asthma was noted to be significant in the comparison with Missouri as well.

Introduction

Since electronic cigarettes (e-cigarettes) were introduced in the market in 2007, vaping has been on the rise in the US. It reached "epidemic proportions" in 2018, when the US Surgeon General issued a call to action to address the epidemic of e-cigarette use in adolescents, while asserting the health risks associated with e-cigarette use (*Surgeon General's Advisory on E-Cigarette Use among Youth*, 2018). E-cigarettes or vapes are also called electronic nicotine delivery systems (ENDS) as they insufflate nicotine. The CDC warns that the nicotine present in e-cigarettes is highly addictive. Nicotine can be toxic to developing fetuses, and harmful for teen and adult brain development until the mid-20s (About Electronic Cigarettes (E-Cigarettes), n.d.). Per the CDC, e-cigarettes produce an aerosol by heating a nicotine-containing liquid along with other component chemicals, which users inhale into their lungs as they vape (About Electronic Cigarettes (E-Cigarettes), n.d.).

Initially, e-cigarettes were marketed as a nicotine-cessation device, which led to their popularity, especially with teens and young adults. In mid-2019, the US experienced an e-cigarette product use-associated lung injury (EVALI) outbreak due to lack of long-term data on health risks, coupled with a lack of regulation of e-cigarettes. In 2019, clusters of lung injury were reported with e-cigarette use, especially in Illinois and Wisconsin, with the key symptoms being respiratory, gastrointestinal, and constitutional complaints (*Outbreak of Severe Pulmonary Disease Linked with E-Cigarette Product Use*, 2020).

E-cigarettes have many detrimental effects on public health. The National Academies of Science, Engineering, and Medicine published a report that reviewed over 800 studies in January 2018, which asserted that using e-cigarettes causes health risks (The National Academies of Sciences, Engineering, and Medicine, 2018). The report stated that e-cigarettes contain and emit a number of potentially toxic substances harmful to human health, and youth who use e-cigarettes are at a heightened risk of asthma exacerbations, cough, and wheezing. Also, e-cigarettes produce a number of toxic chemicals such as acetaldehyde, acrolein, and formaldehyde, which can lead to lung and cardiovascular diseases (Ogunwale

et al., 2017). Acrolein, used in e-cigarettes, is a herbicide primarily used to kill weeds, and can cause acute lung injury, chronic obstructive pulmonary disease, asthma, and lung cancer. Two primary ingredients found in e-cigarettes—propylene glycol and vegetable glycerin—have been identified as toxic to cells in a study at the University of North Carolina (Sassano et al., 2018). The U.S. Surgeon General as well as the National Academies of Science, Engineering, and Medicine have warned about the risks of inhaling secondhand e-cigarette emissions, which are released when an e-cigarette user exhales the chemicals created by e-cigarettes as they contain nicotine, volatile organic compounds such as benzene, and chemicals such as diacetyl that are linked to serious lung disease (The National Academies of Sciences, Engineering, and Medicine, 2018).

As e-cigarettes are a major health hazard amongst youth, there is focus both from regulating the supply side as well as controlling the demand. In the US, for decreasing the demand and controlling the use of tobacco, taxation has proved to be an efficient strategy. While regulation concentrates on the supply side of the e-cigarette market, taxation focuses on the demand side, providing a unique advantage of creating public revenue (Mainous et al., 2015).

This study aims to evaluate the effectiveness of taxation of e-cigarette in Illinois by comparing various health risk factors including asthma, headache, depression, and bleeding gums before and after the implementation of the policy. As the e-cigarette tax was implemented in 2019, we compared and analyzed health data from 2017 and 2021 to assess the effectiveness of the policy. Additionally, we compared the Illinois data with neighboring states Michigan and Missouri, as neither Michigan nor Missouri have implemented any tax policies to curb e-cigarette sales. Our hypothesis is that there is a correlation between current e-cigarette usage and taxation, and therefore the health risks would improve after the policy was put into effect. Therefore, we expect rates of asthma, breathing difficulties, headache, depression, toothache, and bleeding gums to decrease in Illinois as compared to Michigan and Missouri between 2017 and 2021.

Literature Review

As vaping has become rampant in the past decade, there has been significant interest in researching the relationship between prevalence of e-cigarettes and the various variables that affect its usage including price and health risks. Several studies have investigated the use of vaping products and its impact on health and safety including Thirión-Romero et al. (2018), Bircan et al. (2021), King et al. (2020), Obisesan et al. (2019), Akinkugbe (2018), and Alhajj et al. (2022). Additionally, papers including Corrigan et al. (2021) and Yao et al. (2020) looked into the price elasticity of demand in an effort to estimate sensitivity to price increase amongst teens, while Jun et al. (2021) evaluated the effect of policy on prevalence of vaping.

Thirión-Romero et al. (2018) conducted an investigation into the respiratory impact of e-cigarettes and found that vape aerosols pose cytotoxic effects on lung tissue, similar to that of a tobacco cigarette, as they contain various respiratory toxins. Known toxins such as formaldehyde, acetaldehyde, metallic nanoparticles, and acrolei have been detected in e-liquid and aerosols, and as a result, e-cigarettes could be linked with an increase in symptoms in individuals with asthma (Thirión-Romero et al., 2018). Bircan et al. (2021) further evaluated the link between e-cigarette use and self-reported diagnosis of asthma, COPD, and ACOS. Using a multinomial logistic regression, the study leveraged a representative sample of over 8000 adults from the Behavioral Risk Factor Surveillance System (BRFSS) from 2016 to 2018 while controlling for marital status and employment along with matching variables. The study found that the e-cigarette smokers had increased likelihood of self-reported ACOS (OR=2.27; 95% CI: 2.23–2.31), asthma (OR=1.26; 95% CI: 1.25–1.27), and COPD (OR=1.44; 95% CI: 1.42–1.46) as compared to

non e-cigarette smokers (Bircan et al., 2021). Both Thirión-Romero et al. (2018) and Bircan et al. (2021) found a positive correlation between e-cigarette use and asthma, revealing asthma is a key risk factor for e-cigarette use.

King et al. (2020) investigated the negative health symptoms, including headaches, reported by youth e-cigarette users by conducting a national cross-sectional telephone survey of 975 adolescents between ages 13–17. The study looked into six health issues caused by e-cigarettes and examined various factors including demographics and tobacco use. They found that most of the users had experienced at least one health symptom during their e-cigarette use, with cough being the most common symptom and headaches being more common among the past 30-day users as compared to non-users (King et al., 2020). This paper's findings around correlation between e-cigarette usage and headaches in adolescents indicates that headaches can be considered as a health risk factor for e-cigarette use.

Obisesan et al. (2019) examined the association between e-cigarette usage and depression through a cross-sectional study of 892,394 participants in the Behavioral Risk Factor Surveillance System between 2016 and 2017. Their investigation revealed a higher likelihood for e-cigarette users to report a history of clinical diagnosis of depression as compared to others who never used e-cigarettes. They also found that higher frequency of e-cigarette use was linked with higher odds of reporting depression (Obisesan et al., 2019). Moustafa et al. (2021) further examined the association between depression symptoms and adolescent e-cigarette progression by conducting a longitudinal survey of 1822 teenagers from four Philadelphia area public schools. They found that the e-cigarette use trend was significantly affected by baseline depressive symptoms while holding other variables constant ($b = 0.01$, $z = 4.29$, $p < 0.0001$). Their paper provided evidence that greater depressive symptoms during teenage years were associated with a faster rate of e-cigarette escalation (Moustafa et al., 2021). Studies by Obisesan et al. (2019) and Moustafa et al. (2021) highlights the prevalence of depression as an important variable to consider while evaluating effectiveness of e-cigarette policies.

Akinkugbe (2018) investigated the association between use of e-cigarettes and oral health status by studying the data from 13,650 adolescents aged 12 to 17 years from the Population Assessment of Tobacco and Health study of self-reported current use of e-cigarettes, using survey-adjusted logistic regression. The covariate-adjusted associations between current e-cigarette use on dental problems showed a Prevalence Odds Ratio (POR) of 1.11 (95% CI, 0.79 to 1.55), suggesting an increased risk of dental disorders for the adolescents using e-cigarettes currently (Akinkugbe, 2018). Alhajj et al. (2022) explored and found association between e-cigarette usage and worsening oral health, including oral candidiasis, oral mucosal lesions, halitosis, dental caries, and periodontal disease (Alhajj et al., 2022). Studies by Akinkugbe (2018) and Alhajj et al. (2022) highlight the impact on oral health such as bleeding gums being an important consideration for evaluating the effectiveness of e-cigarette policies.

There are two recent studies that examine price elasticity of demand for e-cigarettes. Diaz et al. (2023) studied the sensitivity of US youth to changes in e-cigarette prices and tax using standardized measures of e-cigarette taxes and prices. They analyzed the cross-sectional 2015–2019 Youth Risk Behavior Survey along with standardized inflation-adjusted e-cigarette price and tax data to evaluate whether changes in e-cigarette price and tax were associated with changes in e-cigarette use. They built two-part demand regression models controlling for demographics and e-cigarette restriction policies. They found that a $0.50 and $1.00 tax increase led to a 6.3% and 12.2% decrease, respectively, in past 30-day e-cigarette use, showing correlation between taxation on e-cigarettes and reduced usage in youth (Diaz et al., 2023).

Corrigan et al. (2021) investigated the question of how sensitive teens' demand for one of the most used brands of e-cigarettes, JUUL, with

respect to change in price. They recruited 300 teenagers from the University of South Carolina (N = 188) and Susquehanna University (N = 112) between 2018 and 2019 and conducted an experimental auction where adolescents bid on a JUUL kit. Their analysis of Price Elasticity of Demand (PED) showed that 10% increase in price leads to as much as a 24% reduction in e-cigarette demand among current teen users, and a 45% reduction among teens who have not used e-cigarettes. This paper concluded that teens are sensitive to increase in price and e-cigarette taxes can be an effective measure at reducing the e-cigarette use among teenagers (Corrigan et al., 2021).

With e-cigarettes becoming a public health concern, several studies have investigated the price elasticity of demand for e-cigarettes. Yao et al. (2020) examined the impact of e-cigarette prices on e-cigarette sales in California. They built fixed-effects models to predict the impact of e-cigarette and cigarette prices on e-cigarette sales separately for each type of e-cigarettes controlling for year, quarter, scantrack market, and California SFAL coverage. A two-tailed p-value < 0.05 was considered to be statistically significant. Their analysis found that when there was a 1% increase in prices of disposable e-cigarettes, reusable e-cigarettes, and cigarettes, there was a decrease in per capita sales of the products by 0.37%, 0.20%, and 0.21% respectively. The study found that e-cigarette sales are responsive to price changes, which suggests that raising prices, such as increasing the tobacco excise tax, can help reduce sales of e-cigarettes (Yao et al., 2020).

Jun et al. (2021) investigated the impact of state regulations and policy on e-cigarette prevalence by performing logistic regressions on 2017 Behavioral Risk Factor Surveillance System and the US e-cigarette regulations-50 state review by the Public Health Law Center. Their paper found that there were significant differences in e-cigarette use based on the number of state laws regulating e-cigarettes, concluding that policy efforts to regulate e-cigarettes could have significant impact on e-cigarette prevalence (Jun & Kim, 2021).

The past studies conducted to evaluate the impact of price and health risks on e-cigarette use have provided a compelling story. The current literature provides sound evidence about health risks associated with e-cigarette usage including asthma, respiratory illnesses, headaches, depression, and oral health issues. Teenagers' demand for e-cigarettes seems to be sensitive to price increase, and e-cigarette tax, with evidence highlighting a reduction in usage of e-cigarettes when the price of e-cigarettes was increased with taxation. However, there have not been any studies conducted to measure the impact of a state that imposed e-cigarette tax. Therefore, our research aims to evaluate the effectiveness of e-cigarette taxes in Illinois by comparing health risks before and after the policy implementation to confirm correlation between current e-cigarette usage and taxation. Further, our study compares the health outcomes with a state that has not imposed e-cigarette taxes to further estimate the effectiveness of taxation as a mitigation strategy for worsening health outcomes with e-cigarette use.

Policy Context in Illinois

In 2019, when many states across the US observed an alarming increase in e-cigarette usage amongst their youth, Illinois imposed a statewide 15% tax on e-cigarettes. One of the primary motivations behind Illinois implementing the 15% vapor tax was because Illinois saw an unprecedented surge in the use of e-cigarettes from 18.4% to 26.7% among high school seniors between 2016 to 2018. This growth in usage by the high school seniors was compounded with a 65% increase in usage among high school sophomores and a 15% increase in usage among 8th grade students (*E-Cigarettes and Vapes*, n.d.). Further, the state got a wakeup call in 2019, when three young people were hospitalized for severe breathing problems after vaping, according to their state Department of Public Health (Azad, 2019).

Another major motivation for establishing the policy was the 18th annual "State of Tobacco Control" report published in 2019 by the American Lung Association. This report appealed to Illinois lawmakers to better regulate e-cigarette access and usage to improve community health. This call for action came after a 135% increase in e-cigarette use among highschool students in two years, along with an adjacent three million kid increase in vaping (American Lung Association, 2020).

The state of Illinois was inclined to impose vape tax after observing the City of Chicago and Cook County impose successful taxes on e-cigarettes in 2016. Chicago was the first major city to also impose such a tax. As compared to the 36% of high school students who smoked combustible cigarettes in 1997, only 20.8% of students are reportedly using e-cigarettes in 2018 (The Heartland Institute, 2020). Further, Chicago generated over $1 million in its first fiscal year, which was then used to fund school-based health service programs (The Civic Federation, 2018).

Illinois was one of three states that imposed such a tax on e-cigarettes in 2019. Additionally, Illinois also bans the sale of vapor products to individuals under the age of 21 years old. In 2017, the overall usage of e-cigarettes in Illinois was around 4.4% and after implementing the tax, usage of e-cigarettes reduced to 3.4% in 2020 (America's Health Rankings analysis of CDC, n.d.). Further, after imposing its tax, Illinois has generated approximately $15 million in fiscal 2020 solely from this tax, which was in turn used to fund the state's Medicaid program (Povich, 2019). Governor of Illinois in 2019, J.B. Pritzker, acknowledged the taxation as a means to control the negative health implications of e-cigarette use and stated, "It's about deterrence" (Povich, 2019). With the reduction observed in Illinois in usage of e-cigarettes along with the state's focus on controlling the negative health implications of e-cigarette through implementation of a health policy, this paper focuses on Illinois and compares with two neighboring states, Missouri and Michigan, both of which do not have taxation controlling e-cigarette usage.

Data Presentation

To better evaluate the impacts of a state-wide e-cigarette tax on youth health, data was pulled from the National Survey of Children's Health (NCHS) (US Census Bureau, n.d.). The survey data was collected via mail and web-based surveys conducted by the US Census Bureau for the three states, Illinois, Michigan, and Missouri. The NCHS provides state-specific data around children's physical and mental health, along with their social surroundings, including their family and neighborhood.

For this analysis, a random sample of 440 observations were extracted for Illinois in 2017 and in 2021, in order to understand the effects of the 2019 state tax on e-cigarettes. The years 2017 and 2021 provide data for two years before and after the implementation of this tax, while also working to exclude any skewed health data as a result of the COVID-19 pandemic. Additional analysis was also done to compare the effects of such a policy to two neighboring states that had not implemented any such policy, such as Michigan and Missouri. A random sample of 425 observations were extracted for Michigan and Missouri in 2017 and 2021. Therefore, 2017 is treated as the "Before" period, and 2021 is treated as the "After" period, while Illinois is the "Treatment" state and Michigan and Missouri are the "Control" states. Additionally, averages from 2018 and 2022 were also extracted for understanding the trends.

Since this policy addresses the variability in children's health as a result of e-cigarette use to assess the efficacy of the state tax, the NCHS data set was modified and condensed to only include several key determinants of e-cigarette use—asthma, headaches, depression, toothache, and bleeding gums. Additional control variables include children's age and sex. Since the data was collected via survey through the Census Bureau,

all variables are based on the parent's subjective answers, and any respondents with missing data were excluded. Additionally, the Illinois, Missouri, and Michigan data were condensed to ensure the similar data sample size per state. The variable "Age" is the reported age of the child and for the variable "Sex", 1 indicates male and 0 indicates female. For the variables "Asthma", "Headache", "Depression", "Anxiety", "Toothache", and "Bleeding Gums", the value of 1 indicates that the child has frequent difficulty with or has been diagnosed with the variable, while a 0 indicates that they have not.

Asthma is a critical health outcome that is heavily affected by e-cigarette use by youth. When comparing 2017 Illinois health data to 2021 health data (Tables 1 and 2), the average occurrence of asthma decreased from 0.1065 to 0.0226, indicating that more families responded "No" to the prevalence of asthma in 2021 as compared to 2017. Comparing this to the respective Michigan health data in Tables 3 and 4, the average value for asthma increased in Michigan from 2017 to 2021. This shows that more families in Michigan reported the prevalence of asthma in 2021 as compared to 2017. Comparing Illinois asthma data to Missouri health data in Tables 3 and 4, the average value for asthma increased in Missouri from 2017 to 2021. Additionally difficulty breathing is a common side effect with both asthma as well as e-cigarette use It is noteworthy that while Illinois saw a decrease in the prevalence of both asthma and difficulty breathing after the taxation policy was implemented as seen in Figure 1 and Figure 2.

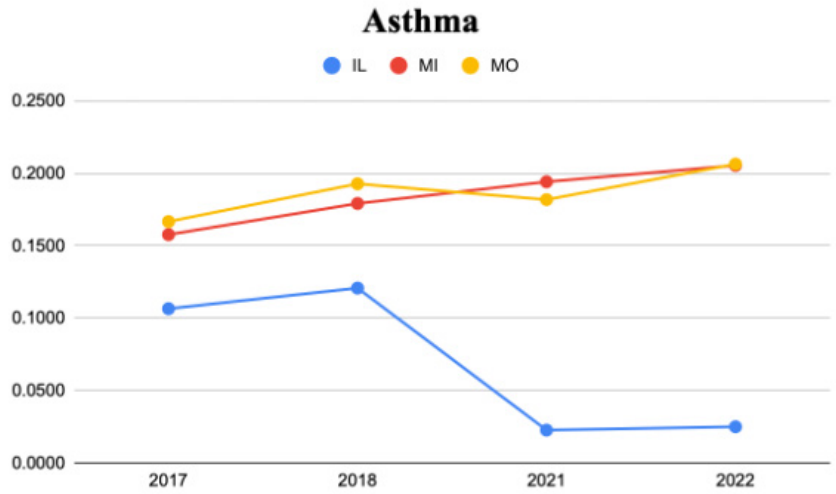

Figure 1: Average prevalence of Asthma for Illinois, Michigan, and Missouri (2017, 2018, 2021, 2022)

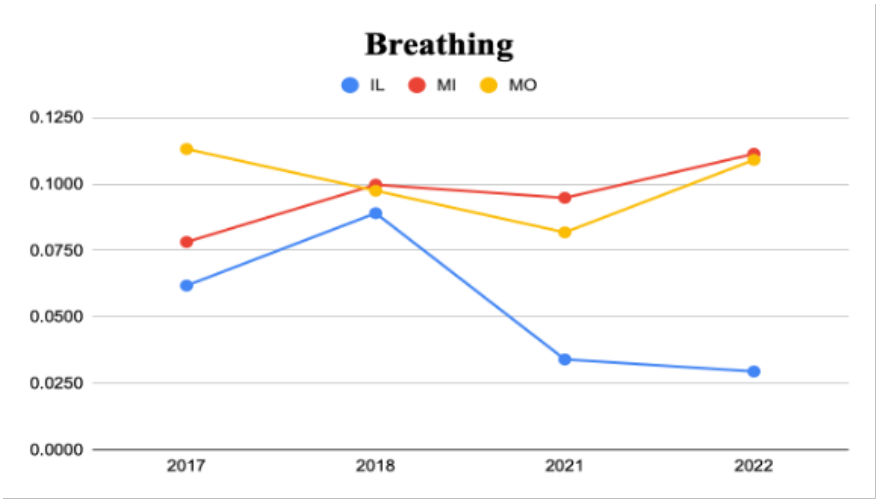

Figure 2: Average prevalence of Breathing problems for Illinois, Michigan, and Missouri (2017, 2018, 2021, 2022)

Table 1: Descriptive Statistics for Illinois in 2017

IL 2017 Data	Average	Std.Dev.	95% CI
Asthma	0.1065	0.3088	0.0100
Breathing	0.0618	0.2851	0.0092
Headache	0.0228	0.1494	0.0048
Gumbleed	0.0185	0.1348	0.0044
Toothache	0.0228	0.1495	0.0048
Depression	0.0477	0.2134	0.0069
Age	9.3832	5.4565	0.1753
Sex	0.5306	0.4996	0.0160

Table 2: Descriptive Statistics for Illinois in 2021

IL 2021 Data	Average	Std.Dev.	95% CI
Asthma	0.0226	0.1489	0.0048
Breathing	0.0340	0.1815	0.0058
Headache	0.0407	0.1979	0.0063
Gumbleed	0.0045	0.0672	0.0022
Toothache	0.0273	0.1631	0.0052
Depression	0.0611	0.2398	0.0077
Age	8.3258	5.4467	0.1747
Sex	0.5271	0.4998	0.0160

Table 3: Descriptive Statistics for Michigan in 2017

MI 2017 Data	Average	Std.Dev.	95% CI
Asthma	0.1576	0.3648	0.0119
Breathing	0.0782	0.2688	0.0088
Headache	0.0468	0.2115	0.0069
Gumbleed	0.0071	0.0842	0.0028
Toothache	0.0260	0.1593	0.0052
Depression	0.0468	0.2115	0.0069
Age	9.4486	5.0764	0.1655
Sex	0.4813	0.5002	0.0163

Table 4: Descriptive Statistics for Michigan in 2021

MI 2021 Data	Average	Std.Dev.	95% CI
Asthma	0.1941	0.3960	0.0127
Breathing	0.0948	0.2933	0.0094
Headache	0.0724	0.2594	0.0083
Gumbleed	0.0183	0.1341	0.0043
Toothache	0.0724	0.2594	0.0083
Depression	0.1400	0.3473	0.0111
Age	9.2045	5.0311	0.1609
Sex	0.5281	0.4998	0.0160

Table 5: Descriptive Statistics for Missouri in 2017

MO 2017 Data	Average	Std.Dev.	95% CI
Asthma	0.1667	0.3731	0.0123
Breathing	0.1132	0.3172	0.0104
Headache	0.0401	0.1964	0.0064
Gumbleed	0.0118	0.1082	0.0035
Toothache	0.0354	0.1849	0.0061
Depression	0.0472	0.2123	0.0070
Age	9.3271	5.3345	0.1745
Sex	0.5176	0.5003	0.0164

Table 6: Descriptive Statistics for Missouri in 2021

MO 2021 Data	Average	Std.Dev.	95% CI
Asthma	0.1818	0.3861	0.0124
Breathing	0.0818	0.2744	0.0088
Headache	0.0250	0.1563	0.0050
Gumbleed	0.0182	0.1339	0.0043
Toothache	0.0455	0.2085	0.0067
Depression	0.0481	0.2141	0.0069
Age	8.2426	5.1210	0.1645
Sex	0.5533	0.4977	0.0160

Headaches are a common side effect of e-cigarette usage in youth. When comparing 2017 Illinois health data to 2021 health data (Tables 1 and 2), the average prevalence of headaches rose from 0.0228 to 0.0407, indicating that more families responded "Yes" to the prevalence of headaches in 2021 as compared to 2017. However, when reviewing the trend in Figure 3, it can be observed that headaches in Illinois rose between 2017 and 2018 and then trended down in 2021 after the policy implementation. Comparing this to the respective Michigan health data in Tables 3 and 4, the average value for headaches increased from 2017 to 2021. Missouri saw an interesting trend of a decrease in 2021 but a spike in 2022. It is noteworthy that Illinois saw a decreasing trend since 2018 and a lower average value for headaches in 2022 as seen in Figure 3.

Depression is a serious health concern among youth and can be further exacerbated by e-cigarette usage. When comparing 2017 Illinois health data to 2021 health data (Tables 1 and 2), the average value for depression increased from 0.0477 to 0.0611, indicating that more families responded "Yes" to the prevalence of depression in 2021 as compared to 2017. Comparing this to the respective Michigan health data (Tables 3 and 4), the average value for depression saw a larger increase, from 0.0468 to 0.14 from 2017 to 2021. Missouri health data in comparison (Tables 5 and 6) only shows a mild increase from 0.0472 to 0.0481. With all three states experiencing an increase, this might be due to the physical, mental, and social effects of the pandemic.

Declining oral health, including bleeding gums and toothache are known to result from repeated e-cigarette usage. When comparing 2017 Illinois health data to 2021 health data (Tables 1 and 2), the average value for bleeding gums decreased from 0.0185 to 0.0045, indicating that more families responded "No" to the prevalence of bleeding gums in 2021 as compared to 2017. Conversely, the average value for bleeding gums increased per the Michigan health data (Tables 3 and 4), from 0.0071 to 0.0183 from 2017 to 2021. Also, per the Missouri health data (Tables 5 and 6), Missouri also saw an increase

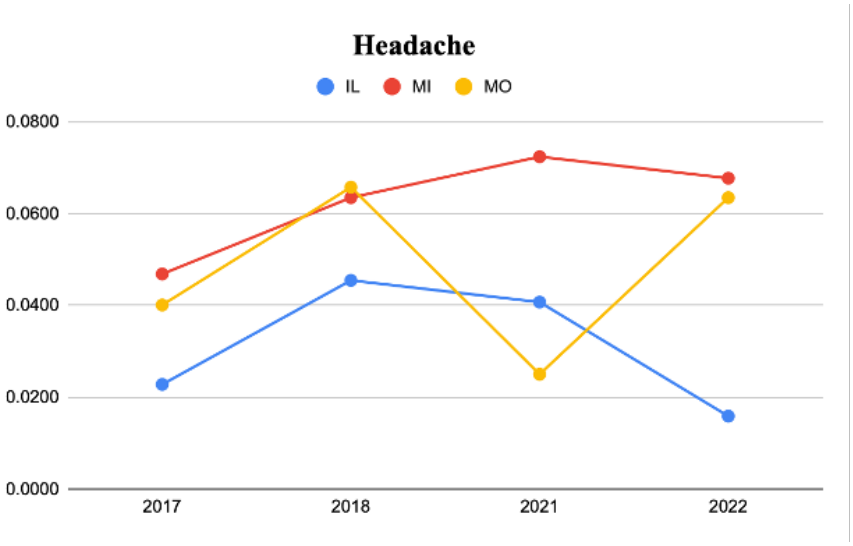

Figure 3: Average prevalence of Headache for Illinois, Michigan, and Missouri (2017, 2018, 2021, 2022)

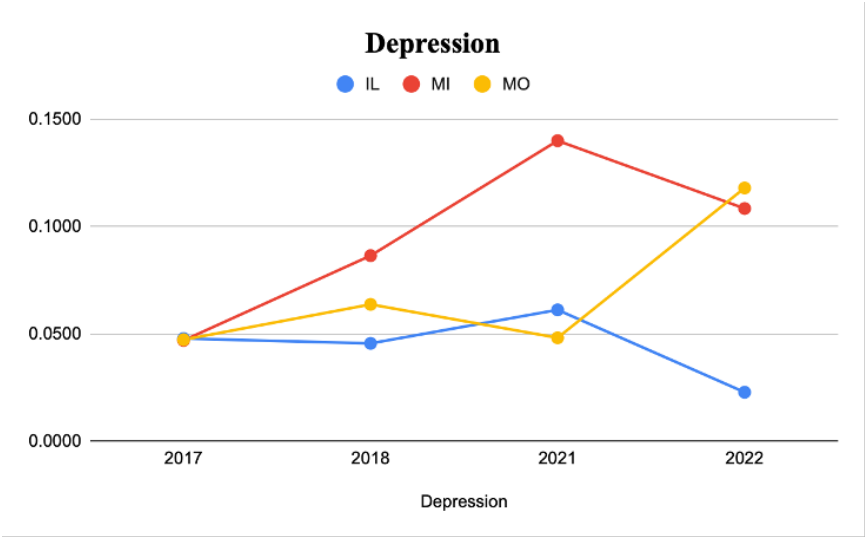

Figure 4: Average prevalence of Depression for Illinois, Michigan, and Missouri (2017, 2018, 2021, 2022)

in the gum bleeds rising from 0.0118 in 2017 to 0.0182 in 2021. This shows that families in Michigan and Missouri reported an increase in prevalence of bleeding gums while Illinois saw a decline in average bleeding gum prevalence after the implementation of the e-cigarette tax, which can also be noted in Figure 5. Reviewing toothache data, Illinois saw a minor increase in toothaches, from 0.0228 to 0.0273, however, Missouri and Michigan saw larger increases in toothache prevalence between 2017 and 2021. Reviewing Figure 6, it is remarkable that Illinois had the lowest occurrence of toothaches in 2022 amongst the three states.

After preliminary analysis of the Illinois, Michigan, and Missouri health data in 2017 and 2021, and reviewing the trend in average occurrence across 2017, 2018, 2021, and 2022, it can be observed that Illinois has experienced an increase in positive health outcomes, specifically asthma, breathing, and bleeding gums. On the other hand, the Michigan health data indicates a decrease in positive health outcomes across all health categories. Missouri health data indicates that they experienced positive health outcomes in 2021 in breathing, headache, and depression, however, those health outcomes became worse in 2022. Thus, the above tables and figures indicate that the e-cigarette taxation did positively affect youth health outcomes in Illinois as compared to its neighboring states. To confirm this hypothesis, further empirical analysis is required.

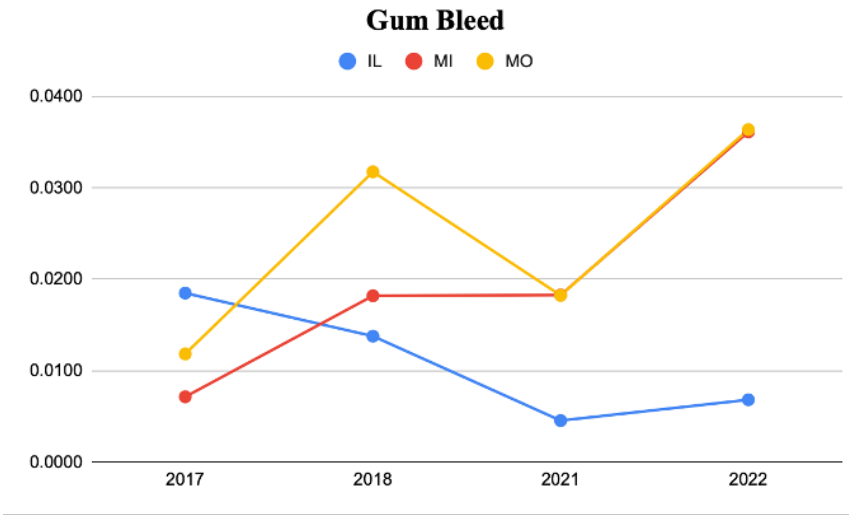

Figure 5: Average prevalence of Gum Bleed for Illinois, Michigan, and Missouri (2017, 2018, 2021, 2022)

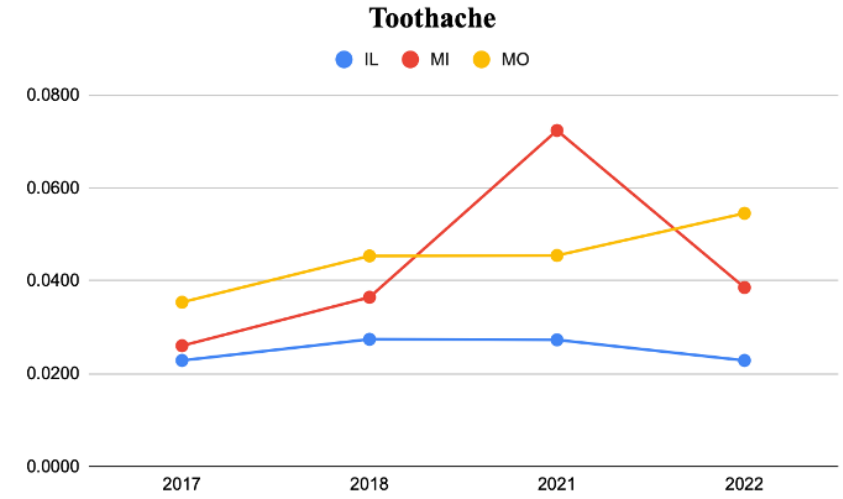

Figure 6: Average prevalence of Toothache for Illinois, Michigan, and Missouri (2017, 2018, 2021, 2022)

Empirical Estimates

To begin the data analysis in order to understand the effects of an e-cigarette tax on health, several hypothesis tests were run. Firstly, two Difference-in-Means hypothesis tests were run in order to understand the changes in the six variables—asthma, breathing, headache, depression, toothache, and gumbleed—in 2017 and again in 2021. The Difference-in-Means tests allows for the analysis of whether or not there was a statistically significant change in the average rates of asthma, headache, depression, and gumbleed between 2017 and 2021. The t-scores were analyzed at the 5% and 10% significance level, and the following conclusions were made, respectively. The null hypothesis indicates no change in the means, while the alternative hypothesis suggests there was a change between 2017 and 2021. The results of the first two hypothesis tests can be seen in the tables below.

Table 7: Hypothesis Testing for Difference in Means in Illinois in 2017 and 2021

Variable	H_0	H_A	t_{actual}	5% Significance Level $t_{critical}$ 1.96	10% Significance Level $t_{critical}$ 1.65
Asthma	$(\mu_{21}-\mu_{17})=0$	$(\mu_{21}-\mu_{17})\neq 0$	5.131	Reject H_0	Reject H_0
Breathing	$(\mu_{21}-\mu_{17})=0$	$(\mu_{21}-\mu_{17})\neq 0$	1.724	Fail to reject H_0	Reject H_0
Headache	$(\mu_{21}-\mu_{17})=0$	$(\mu_{21}-\mu_{17})\neq 0$	1.518	Fail to reject H_0	Fail to reject H_0
Depression	$(\mu_{21}-\mu_{17})=0$	$(\mu_{21}-\mu_{17})\neq 0$	0.873	Fail to reject H_0	Fail to reject H_0
Toothache	$(\mu_{21}-\mu_{17})=0$	$(\mu_{21}-\mu_{17})\neq 0$	0.421	Fail to reject H_0	Fail to reject H_0
Gumbleed	$(\mu_{21}-\mu_{17})=0$	$(\mu_{21}-\mu_{17})\neq 0$	1.943	Fail to reject H_0	Reject H_0

From the above table, it can be noted that in Illinois, there was a statistical difference in rates of asthma at the 5% significance level, and a statistically significant difference in rates of difficulty breathing and gum bleeds at the 10% significance level, between 2017 and 2021. This difference may be attributed to the beneficial effects of the e-cigarette tax. However, there was no statistical difference in rates of headache, depression, and toothache in Illinois between 2017 and 2021, which may be due to the COVID-19 pandemic.

Table 8: Hypothesis Testing for Difference of Means in Michigan in 2017 and 2021

Variable	H_0	H_A	t_{actual}	5% Significance Level $t_{critical}$ 1.96	10% Significance Level $t_{critical}$ 1.65
Asthma	$(\mu_{21}-\mu_{17})=0$	$(\mu_{21}-\mu_{17})\neq 0$	1.397	Reject H_0	Reject H_0
Breathing	$(\mu_{21}-\mu_{17})=0$	$(\mu_{21}-\mu_{17})\neq 0$	0.861	Reject H_0	Reject H_0
Headache	$(\mu_{21}-\mu_{17})=0$	$(\mu_{21}-\mu_{17})\neq 0$	1.574	Reject H_0	Reject H_0
Depression	$(\mu_{21}-\mu_{17})=0$	$(\mu_{21}-\mu_{17})\neq 0$	4.720	Fail to reject H_0	Fail to reject H_0
Toothache	$(\mu_{21}-\mu_{17})=0$	$(\mu_{21}-\mu_{17})\neq 0$	3.141	Fail to reject H_0	Fail to reject H_0
Gumbleed	$(\mu_{21}-\mu_{17})=0$	$(\mu_{21}-\mu_{17})\neq 0$	1.450	Reject H_0	Reject H_0

In reference to the above table, it can be noted that in Michigan, there was a statistical difference only in rates of depression and toothache at both a 5% and 10% significance level between 2017 and 2021. However, between 2017 and 2021, there was no statistical difference in rates of asthma, difficulty breathing, headaches, or gumbleeds in Michigan, a state where no taxation policy exists for e-cigarettes.

Table 9: Hypothesis Testing for Difference of Means in Missouri in 2017 and 2021

Variable	H_0	H_A	t_{actual}	5% Significance Level $t_{critical}$ 1.96	10% Significance Level $t_{critical}$ 1.65
Asthma	$(\mu_{21}-\mu_{17})=0$	$(\mu_{21}-\mu_{17})\neq 0$	0.582	Fail to reject H_0	Fail to reject H_0
Breathing	$(\mu_{21}-\mu_{17})=0$	$(\mu_{21}-\mu_{17})\neq 0$	1.543	Fail to reject H_0	Fail to reject H_0
Headache	$(\mu_{21}-\mu_{17})=0$	$(\mu_{21}-\mu_{17})\neq 0$	1.240	Fail to reject H_0	Fail to reject H_0
Depression	$(\mu_{21}-\mu_{17})=0$	$(\mu_{21}-\mu_{17})\neq 0$	0.061	Fail to reject H_0	Fail to reject H_0
Toothache	$(\mu_{21}-\mu_{17})=0$	$(\mu_{21}-\mu_{17})\neq 0$	0.745	Fail to reject H_0	Fail to reject H_0
Gumbleed	$(\mu_{21}-\mu_{17})=0$	$(\mu_{21}-\mu_{17})\neq 0$	0.767	Fail to reject H_0	Fail to reject H_0

As noted in the above table, in Missouri, there was no statistical significance with the changes in the rates of asthma, difficulty breathing, headache, depression, toothache, or bleeding gums, between 2017 and 2021.

After the analysis of the Difference-of-Means hypothesis tests, a Difference-in-Difference hypothesis test was performed to understand if the change in average values of asthma, difficulty breathing, headache, depression, toothache, and gumbleeds in Illinois was significant as compared to the change in average values of the same in Michigan and Missouri between 2017 and 2021.

Table 10: Hypothesis Testing for Difference in Difference Between Illinois and Michigan in 2017 and 2021

Variable	H_0	H_A	t_{actual}	5% Significance Level $t_{critical}$ 1.96	10% Significance Level $t_{critical}$ 1.65
Asthma	$(\mu_{TA}-\mu_{TB})-(\mu_{CA}-\mu_{CBl})=0$	$(\mu_{TA}-\mu_{TB})-(\mu_{CA}-\mu_{CB})\neq 0$	3.906	Reject H_0	Reject H_0
Breathing	$(\mu_{TA}-\mu_{TB})-(\mu_{CA}-\mu_{CBl})=0$	$(\mu_{TA}-\mu_{TB})-(\mu_{CA}-\mu_{CB})\neq 0$	1.765	Fail to reject H_0	Reject H_0
Headache	$(\mu_{TA}-\mu_{TB})-(\mu_{CA}-\mu_{CBl})=0$	$(\mu_{TA}-\mu_{TB})-(\mu_{CA}-\mu_{CB})\neq 0$	0.379	Fail to reject H_0	Fail to reject H_0
Depression	$(\mu_{TA}-\mu_{TB})-(\mu_{CA}-\mu_{CBl})=0$	$(\mu_{TA}-\mu_{TB})-(\mu_{CA}-\mu_{CB})\neq 0$	3.195	Reject H_0	Reject H_0
Toothache	$(\mu_{TA}-\mu_{TB})-(\mu_{CA}-\mu_{CBl})=0$	$(\mu_{TA}-\mu_{TB})-(\mu_{CA}-\mu_{CB})\neq 0$	2.312	Reject H_0	Reject H_0
Gumbleed	$(\mu_{TA}-\mu_{TB})-(\mu_{CA}-\mu_{CBl})=0$	$(\mu_{TA}-\mu_{TB})-(\mu_{CA}-\mu_{CB})\neq 0$	2.386	Reject H_0	Reject H_0

Table 11: Hypothesis Testing for Difference in Difference Between Illinois and Missouri in 2017 and 2021

Variable	H_0	H_A	t_{actual}	5% Significance Level $t_{critical}$ 1.96	10% Significance Level $t_{critical}$ 1.65
Asthma	$(\mu_{TA}-\mu_{TB})-(\mu_{CA}-\mu_{CBl})=0$	$(\mu_{TA}-\mu_{TB})-(\mu_{CA}-\mu_{CB})\neq 0$	3.220	Reject H_0	Reject H_0
Breathing	$(\mu_{TA}-\mu_{TB})-(\mu_{CA}-\mu_{CBl})=0$	$(\mu_{TA}-\mu_{TB})-(\mu_{CA}-\mu_{CB})\neq 0$	0.139	Fail to reject H_0	Fail to reject H_0
Headache	$(\mu_{TA}-\mu_{TB})-(\mu_{CA}-\mu_{CBl})=0$	$(\mu_{TA}-\mu_{TB})-(\mu_{CA}-\mu_{CB})\neq 0$	1.947	Fail to reject H_0	Reject H_0
Depression	$(\mu_{TA}-\mu_{TB})-(\mu_{CA}-\mu_{CBl})=0$	$(\mu_{TA}-\mu_{TB})-(\mu_{CA}-\mu_{CB})\neq 0$	0.589	Fail to reject H_0	Fail to reject H_0
Toothache	$(\mu_{TA}-\mu_{TB})-(\mu_{CA}-\mu_{CBl})=0$	$(\mu_{TA}-\mu_{TB})-(\mu_{CA}-\mu_{CB})\neq 0$	0.329	Fail to reject H_0	Fail to reject H_0
Gumbleed	$(\mu_{TA}-\mu_{TB})-(\mu_{CA}-\mu_{CBl})=0$	$(\mu_{TA}-\mu_{TB})-(\mu_{CA}-\mu_{CB})\neq 0$	1.848	Fail to reject H_0	Reject H_0

As observed in Table 10, the difference-in-difference hypothesis test indicates that for asthma, depression, toothache, and bleeding gums, there is a statistical significance between Illinois and Michigan at the 5% significance level, and in addition, the difference between rates of difficulty breathing is significant at the 10% significance level. However, there was no statistical significance noted in the change in rates of headache.

The difference-in-difference hypothesis test shown in the above table highlights that for asthma, there is a statistical significance between Illinois and Missouri at the 5% significance level, and in addition, the difference between rates of headache and bleeding gums is significant at the 10% significance level. However, there was no statistical significance noted in the change in rates of difficulty breathing, depression, or toothache.

Discussion

Per our findings, there has been a statistically significant decrease in the reported rates of asthma, depression, toothache, and bleeding gums from before and after the implementation of the state tax in Illinois as compared to Michigan at 5% significance level. Additionally, there has been a statistically significant decrease in the reported rates of asthma from before and after the implementation of the state tax in Illinois as compared to Missouri at a 5% significance level. It can be further noted that the vaping tax has had a positive effect on the Illinois population, with a decrease in reported rates of difficulty breathing and gum bleeds at the 10% significance level from 2017 to 2021 alongside a decreasing trend in headaches and depression from 2017 to 2022. This supports our initial hypothesis that the vaping tax will help curb the increasing e-cigarette use, thus improving health outcomes for the community. This study also allows for a deeper understanding of the correlation between these variables and other external variables, while acknowledging limitations and the potential for future research.

This study's findings agree with past literature regarding the negative effects e-cigarettes have on health outcomes, including physical health, mental health, and oral health—all of which can affect the community and pose new challenges. Asthma and trouble breathing are the most common ill-effects of e-cigarette use (Hickman, Jaspers, 2020). This study found asthma to be a significant outcome in Illinois as compared to Missouri and Michigan, thus supporting the hypothesis. Additionally, trouble with breathing was also significant at 10% in comparison with Michigan. As noted in Bircan et al. (2021), studies have found a positive correlation between e-cigarette use and self-reported diagnosis of asthma among other respiratory diseases. Also, Thirión-Romero et al. (2018) highlighted the negative effects of formaldehyde on the increased symptoms of asthma. asthma is one of the most common symptoms of e-cigarette use.

Both Obisesan et al. (2019) and Moustafa et al. (2021) highlight the negative effects of e-cigarette use on depression, as Obisesan et al. (2019) noted a higher frequency of reporting depression among e-cigarette users, and Moustafa et al. (2021) indicated that greater depressive symptoms result in increased use of e-cigarettes. The increasing reported rates of depression correlated with e-cigarette use are a result of short-lived bursts of dopamine that leave the user feeling more depressed than before use. Given both of these studies, it can be understood that a rise in e-cigarette use will be followed by a rise in rates of reported depression, resulting in a worsening state of mental health for the population which has larger socioeconomic and health risks.

Akinkugbe (2018), Yang et al. (2020), and Alhajj et al. (2022) highlight the negative consequences of e-cigarette smoking on oral health. E-cigarette use exposes the mouth to more bacteria and can result in dryness, thus resulting in the saliva not being able to protect the gums and teeth, and the aforementioned studies indicate that bleeding gums and toothache are key precursors to other oral diseases and worse health implications (Alhajj et al., 2022) (Akinkugbe, 2018) (Yang et al., 2020). The improvement in health outcomes in Illinois as compared to

Michigan, seen in our findings, also aligns with the price elasticity of demand for e-cigarettes among teens as highlighted by researchers including Yao et al. (2020) and Corrigan et al. (2021).

One notable outcome from the study was that the policy had no significant effect on headaches at 5% significance level in the sample analyzed. However, headaches were significant in the Illinois to Missouri comparison at 10% significance level. As previously stated, King et al. (2020) found headaches to be the most common symptom of e-cigarette use among past 30-day users who were adolescents, ages 13-17. The negative symptoms of headaches can create larger issues for users, as an increase in headaches can directly result in an increase in stress and anxiety.

Though the results of the study mostly support the proposed hypothesis, the underlying effects of bias and the limitations of this study must be scrutinized. One major limitation to this study is the presence of confounding bias, as seen by the COVID-19 pandemic. As the policy in Illinois was only implemented in 2019, following the recognition of the exponential rise in e-cigarette use in 2018, the study analyzed data two years before and after the policy, hoping to minimize the negative effects of the pandemic on the observed health outcomes. However, as seen by the presented data surrounding asthma, the effects of the COVID-19 pandemic are long-lasting and as such have influenced the reporting of health outcomes in Illinois, Michigan, and Missouri. COVID-19 serves as a confounding variable in this study and to address this issue in the future, it would be beneficial to obtain and analyze data in future years, thus mitigating the effects of the pandemic.

Another limitation of this study is the presence of nonresponse bias in our data. As the National Survey of Children's Health is a mail-in and online survey, not every individual is compelled to answer or will leave questions unanswered, adding a layer of bias to the data. To circumvent this, the hypothesis testing was ensured to only use variables with a valid response value, thus excluding any blanks or unanswered questions. This issue could also be addressed by sampling a larger population, across more states, in order to gather more data such that the effects of the nonresponse bias are nearly negligible.

Looking to the future, hypothesis testing can again be used to analyze the effects of e-cigarette usage on other health outcomes, such as physical activity and cardiopulmonary health. Understanding the effects of e-cigarette use on various health outcomes can showcase the true harmful nature of e-cigarettes and the need for policies such as taxes. Additionally, the same conclusions drawn here regarding health outcomes can be extrapolated into economic gains and losses, as a result of various health outcomes and illnesses. Further research can also be conducted to narrow down the most notable negative health outcomes of e-cigarette use by gender and race to better understand health inequities. Such research can inform educational groups to champion for better health at the community and local level.

Conclusion

To summarize, the results of the study validate the initial hypothesis that the implementation of Illinois' e-cigarette tax had a positive correlation on health outcomes, as the reported rates of asthma, depression, toothache, and bleeding gums decreased. However, the change in rates of headaches between Illinois and Michigan was only significant at 10% and insignificant between Illinois and Missouri, possibly due to confounding effects of the COVID-19 pandemic. Using the National Children's Health Survey, a series of difference-in-difference hypothesis tests were run to compare the difference between the change in health outcomes in Illinois, which imposed a state-wide tax, and Michigan, which presents no such tax or bill. The prevalence of both nonresponse bias and confounding variables pave the way for future research to confirm these findings. This research can also be extrapolated to analyze other health outcomes in the context of e-cigarette usage and the economic values of the health outcomes. This study

can serve as a framework that the other states can leverage to implement similar policies. With more states regulating the use of e-cigarettes with such policies, further testing with wider state-to-state comparisons can be performed to examine the outcomes and trends.

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