Is fluoridation of drinking water in the United States an effective preventive health care measure?

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Senior Thesis in Economics
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Spring 2006

This paper examines the effects of fluoridation of drinking water on the incidence of dental caries (decay of bone or tooth). Scientific research has shown that adding fluoride to water has decreased the amount of dental decay in children in the United States; however, other studies demonstrate that states with minimum fluoridation also experienced lower levels of dental caries in children. This paper will explore fluoridation percentages, income, poverty, and bottled water sales, comparing states that fluoridate their water against states that minimally fluoridate, ultimately seeking to answer the question of whether or not fluoridating drinking water is an effective preventive care measure for oral health. This study shows that fluoride is effective in preventing dental caries; however, other effects, such as income, may be a better indicator of lower dental caries prevalence.

INTRODUCTION

Public health initiatives typically must confront the key issues of efficiency and cost. Consequently, economic analysis has often played a large role in assessing public health initiatives. A major branch of public health is dental/oral health. During the 20th century, oral health increased dramatically, and the improvement if often attributed to the fluoridation of drinking water in the United States.

Although improved oral-hygiene, awareness of oral-health measures, better nutrition and dietary practices, and various dental procedures all contribute to the decline in dental caries, or tooth decay, in the United States, fluoride use has been considered the most effective and widely used approach in caries prevention. Studies conducted by the American Dental Association show that fluoridation of community water supplies reduces tooth decay by as much as 40%. Although most scientific research has shown that adding fluoride to water has decreased the amount of dental decay in children in the United States, observation of state data on caries incidence interestingly shows that dental caries is still highly prevalent in states that have maximum fluoridation percentages. Such a finding gives way to the controversy over the actual benefits of community water fluoridation. Fluoride is undisputedly a protector and strengthener of tooth enamel; however, with the influx of fluoride toothpastes into the market, people are better able to get the amount of fluoride they need and expectorate it from their body, rather than ingesting it.

Even though the number of children and teens with cavities declined from 1994 to 2002, dental experts are still concerned about the oral health of the United States youth. The Centers for Disease Control report that two-thirds of all 16- to 19-year-olds have had tooth decay or fillings. Furthermore, bottled water sales have increased dramatically in the last decade, and some health experts believe that the consumption of bottled water may prevent the public from receiving enough fluoride to assist in caries prevention.

This paper examines the effects of fluoridation of drinking water on the incidence of dental caries in children. It begins with an overview of community water fluoridation followed by the hypothesis that is to be tested under multiple-regression analysis. This paper will compare states that fluoridate their drinking water against states that minimally fluoridate, ultimately seeking to shed more light on the question of whether or not fluoridating drinking water is an effective preventive care measure for oral health. We find that fluoride and income are important factors in determining dental caries incidence, while bottled water is not.

LITERATURE REVIEW

Fluoride is a negatively charged ionic compound of the element fluorine, the 13th most abundant element in the earth's crust. Due to its negative charge, fluoride can bind well with positively charged ions, such as calcium (Ca^{2+}), which is found in human teeth and bones. Therefore, fluoride has been widely explored for its health benefits in preventing, inhibiting, and even reversing the progression of dental caries, or tooth decay. Fluoride is especially critical during childhood when teeth are forming. Children are normally exposed to fluoride through the drinking water (if their community has it), toothpaste, and fluoride treatments when they visit the dentist.

The fluoridation of drinking water first began in 1945 in the United States by adding hydrofluorosilicic acid to the water reserves. At this time, health officials assumed that drinking water would be the major source of fluoride for most U.S. residents. In fact, after implementation of the fluoridation program, officials claimed that fluoridated water caused a 60% drop in cavities (Centers for Disease Control and Prevention). This success in preventing and controlling dental caries led to the development of fluoride-containing products, including toothpaste (which now accounts for 95% of total US toothpaste sales as of 1989 (Newbrun 1989), fluoride mouth-rinse, dietary supplements, and professionally applied or prescribed gel or foam. Additionally, processed beverages and food, which are consumed by a large proportion of Americans today, can contain small amounts of fluoride, especially if they are processed with fluoridated water. Thus, U.S. residents have more sources of fluoride available now than 50 years ago (Centers for Disease Control and Prevention).

Studies conducted by various economists and public health researchers, including Klein (1985), Shobo (2002), Armfield (2005) and Slade et. al. (1996) have all contributed empirical evidence that fluoridation of community water is an effective public health strategy for preventing dental caries in the populations it serves, and for somewhat reducing the disparity in caries experience among poor and nonpoor children. Kumar, et. al (1998) also found similar findings for a Kingston, New York community, comparing those who lived for 15 years under fluoridated water against those without fluoridated water, and found that there were lower caries levels in those with fluoridated water, regardless of socioeconomic status.

While fluoridation depressed child caries rates for all income groups, caries rates still vary across income groups. Socioeconomic status is a very important indicator of health access and availability of services. Demographic groups who lack dental access include low income groups, members of rural communities, racial or ethnic minorities, non-English speaking individuals, children, elderly, and developmentally challenged individuals (Mertz 2002).

People with incomes below $14,000 visited the dentist an average of 1.3 times in 1989, while people of incomes of $50,000+ were almost 2.5 times as likely, at 3.1 (Mogelonski 47). The probability of seeing a dentist at least once a year also increases with income. Those with an income at $14,000 or below say their last dental visit was within the past year, compared with 76% of those with household incomes of $50,000 or more (Mogelonski 47). In light of other studies on demographics and income distribution, income differentials are used to explain why white Americans have almost twice as many visits per year as their black counterparts (Mogelonski 48).

Studies by economists (such as Schefler, 1996) of the public payments and access to dental care highlight the inability of lower income groups to fulfill their dental needs. A lack of dental services (the supply side) provided by dentists results from disputes about insurance and government reimbursements, or a patient's lack of insurance altogether, causing a large decrease in the supply, and thus availability, of dental services to lower income groups. In fact, 85% of dentists refuse to provide service to Medicaid patients because of reimbursement issues (Roosevelt 2005).

As a result, caries experience is considerably higher among persons in low income brackets than among those in higher socioeconomic strata. Some explanations for this discrepancy are that lower income groups have less knowledge of oral diseases, lack adequate access to dental care, and may be less likely to follow recommended oral hygiene practices. According to McKay (2006), twenty percent of the total children, who are poor, account for 80% of the total cavities, and although they may not have the best oral hygiene, drinking fluoridated water would provide them with some protection everytime they drank. Thus, these persons might receive more benefit from fluoridated community water than persons from a higher socioeconomic status.

Another trend that has dentists concerned is the increased consumption of bottled water in the United States. Many persons prefer drinking bottled water in place of tap water because of taste preferences, or a belief in its "purity" or health benefits. Although some bottled waters marketed in the United States contain an optimal concentration of fluoride (approximately 1.0 ppm), most contain less than 0.3 ppm, a third of the optimal amount (Roosevelt 2005). Thus, a person substituting bottled water containing a low fluoride concentration for fluoridated community tap water will not receive the full benefits of the water fluoridation. This is an increasingly large concern in children, whose teeth are still developing and need the fluoride. While they admit their evidence on the worsening dental health of children and teens' is largely subjective, dentists worry that if the trend of bottled water consumption continues, some of the gains made in dental health since mass fluoridation could be lost (Roosevelt 2005). Now, a growing number of bottled-water producers are adding fluoride to brands and packages aimed at kids (McKay 2006).

Although most scientific research has shown that adding fluoride to water has decreased the amount of dental decay in children in the United States, observation of state data on caries incidence interestingly shows that dental caries is still highly prevalent in states that have maximum fluoridation percentages. Such a finding gives way to the controversy over the actual benefits of community water fluoridation. Fluoride is undisputedly a protector and strengthener of tooth enamel; however, with the influx of fluoride toothpastes into the market, people are better able to get the amount of fluoride they need and expectorate it from their body, getting it in their mouth and on the surface of their teeth without ingesting it (Roosevelt 2005).

Furthermore, fluoride-toothpaste use combined with the greater use of plastic sealants by dentists has caused dental caries levels in children to fall even in regions where there is little or no fluoride in the water. A study conducted by the CDC in 2001 showed that by age 12, children living in fluoridated communities averaged only 1.4 fewer cavities than those in nonfluoridated areas (Roosevelt 2005). Furthermore, in Western Europe, the decline in dental caries mirrored that of the US; however, 17 of 21 European countries have either refused or discontinued community water fluoridation, contending that fluoride toothpastes offer adequate protection (Roosevelt 2005).

DATA and METHODS

This literature suggests a series of causal variables to explain the variation in dental caries across states. Following the discussion above we examine data on state fluoridation percentages, income of the population, percent of the population below poverty, and bottled water sales by state to determine whether or not fluoride in drinking water is an effective measure for caries prevention and whether the benefits are diminished by increased consumption of bottled water.

Data on the percentage of the population receiving optimally fluoridated water through public water systems by state was obtained from the Centers for Disease Control and Prevention’s Morbidity and Mortality Weekly Report. It reflects two years of data, 1992 and 2000, on all 50 states and the District of Columbia. The percentage of the drinking water that is fluoridated is highest in Minnesota (98.2%), North Dakota (95.4%), Indiana (95.3%), Kansas (96.1%), Tennessee (94.5%), plus the District of Columbia (100%), and lowest in Utah (2%), Hawaii (9%), New Jersey (15.5%), Oregon (22.7%), Montana (22.2%), California (28.7%) and Wyoming (30.0%).

Data on the demographic variables was gathered from the US Census Bureau archives for the 1990 and 2000 Census (median income of the population and percentage of the population below the federal poverty line) for all 50 states. Bottled water sales were not available for all 50 states, but were available for 20 states for the years 1994 and 1999, including Arizona, Arkansas, Colorado, California, Connecticut, Delaware, Florida, Illinois, Louisiana, Kansas, Massachusetts, Michigan, Nevada, New Jersey, New York, Ohio, Pennsylvania, South Dakota, Texas, and Washington, plus the District of Columbia. This data was found in the International Bottled Water Association's 2001 Marketing Report findings. State level data was unavailable for both confectionery industry sales and soda sales; however, national trends in these industries, obtained from the US Census Bureau's 1990 and 2000 Census of Manufacturers Industry Series of Sugar and Confectionery Products, could help to explain certain findings and trends in the model.

The research suggests the following hypothesis for the determinants of dental caries in children:

$$CARIES = f\ (FL, INC, POV, WATER)$$

Where FL = percentage of fluoridated drinking water by state

INC = median income for each state

POV = percent of population below federal poverty line for each state

WATER = bottled water sales by state

The expected signs of the variables stem from the research and knowledge about dental caries. The expected sign of FL is negative, reflecting the likely negative impact that fluoridation would have on dental caries. INC is expected to be negative because more income denotes better access to dental care or better oral hygiene. The sign of POV will be positive because poorer populations are expected to have greater levels of caries incidence. Finally, WATER is expected to be positive because states with the most bottled water sales supposedly ingest less fluoride, therefore, have a greater chance of increased caries.

Table 1 reports the summaries of each variable, including number of observations, standard deviations, ranges, coefficients of variation, and definitions for the dependent and independent variables.

We estimated the relationships through the traditional OLS method with robust standard errors. We used robust standard errors because tests indicated a modest amount of heteroskedasticity. Two equations were set up to serve as base models for the two separate years 1990 and 2000; however, because of the small sample size, the data was pooled to increase the degrees of freedom. Each state was counted twice, once for 1990 and again for 2000. The dummy variable YEAR1 was created, which signified 0 for year 1990 and 1 for year 2000.

A closer look at the variables suggests that there may be a collinearity problem between the INC and POV variables. Also, one can expect possible causality between INC and WATER: higher rates of income may increase the purchases of bottled water.

ECONOMETRIC RESULTS

This section discusses the results from the regression on caries incidence, which are reported in Table 2. The results of the first two regressions are found in columns 1 and 2, which report the estimated coefficients and t-values of each variable. All of the variables had the expected coefficient signs, but almost none of the results were statistically significant, which is most likely due to the small sample size. The F values were significant, but the R squared values were low at 0.369 and 0.400.

To increase degrees of freedom, the data was pooled, which in turn doubled the number of observations from 21 to 42. In the pooled data model (regression 3), all of the variables were statistically significant, with INC and YEAR1 at 1%, POV at 5%, and FL at 10%. The results indicate that an increase in income by one thousand dollars would decrease caries incidence by 0.00057 percentage points, and a one percentage point increase in poverty would increase caries incidence by 1.09 percentage points. Additionally, a one percentage point increase in the percentage of total state water that is fluoridated will decrease caries by 5.75 percentage points. Lastly, the positive YEAR1 coefficient indicates an increase in caries incidence by 8.93 percentage points over the 10 year span. The pooled regression accounts for approximately 38% of the variation in the data, and the F statistic is significant at a 1% level, thus rendering the model reliable. The next step requires running a regression including the additional variables to be analyzed, which in this case is WATER.

Table 3 provides the regression results from the addition of the WATER variable into the model. Comparing regressions (3) and (4), the F statistic is still significant at the 1% level, and all variables have the expected coefficient signs, except POV, which becomes negative. POV also loses significance in regression (4). This reflects on the possibility that INC and

POV are highly correlated, which would lead to skewed results. If included together, INC and POV could turn out to be insignificant, despite the importance of some measure of income or poverty alone, so it is best to run them separately, which results in regressions (5) and (6). Regression (5) regresses all of the variables except POV, and regression (6) excludes INC.

When POV and INC are run separately, the F and R squared statistics are both better for INC than for POV. The F value is significant at the 1% level in regressions (5) and (6), but R squared for regression (5) is higher than regression (6) at 0.643 versus 0.304. This difference may not be important, but it may suggest empirical evidence that INC is capturing more of the underlying relationships in the model. Income can capture a large spectrum of characteristics of the population, such as consumption and disposable income, while poverty is a highly specific measure. Therefore, it is best to run the model with just INC because it is more statistically significant, making regression (5) the best illustration of the model. For regression (5), INC and YEAR1 are significant at the 1% level and FL at 5%.

Results for regression (5) indicate that an increase in the amount of total fluoridated state water by one percentage point will result in a 9.492 percentage point reduction in dental caries incidence. Also, an increase in income by one thousand dollars will yield a decrease in caries by 0.0011 percentage points. In regression (6), a one percent increase in poverty would lead to a 2.387 percentage point increase in dental caries incidence. In all of the cases, WATER was statistically insignificant, but it had the expected coefficient sign. WATER was speculated to be highly correlated with INC because people with more disposable income are more inclined to purchase bottled water; however, tests showed that there was no correlation.

Another interesting finding is that the YEAR1 dummy variable was statistically significant at the 1% level in all four regressions. This significance, along with its positive coefficient, indicates that caries incidences have increased over 10 years. This increase could be explained by the increase in confectionery goods and soda sales over the years 1990 to 2000; thus, increased sugar consumption negates the preventive efforts of fluoridated drinking water against dental caries.

CONCLUSION

This study shows that fluoride and income are important factors in determining dental caries incidence, while bottled water is not. This suggests that fluoride's role as a fortifier against tooth decay fluoridation is helpful, but limited, because when combined with other factors (such as income, sugar consumption, and inadequate oral hygiene) its benefits could be lost.

Another interesting discovery is that states like Nevada, who have a relatively high median income level but lower fluoridation percentage, still have a higher caries incidence rate than Kansas (67.1% versus 58.6%), a state that, unlike Nevada, has a significantly lower income level and a 96.1% rate of fluoridation. Interestingly, Utah also has a higher income level and virtually no fluoridation (2%), but still has a very high rate of dental caries prevalence at 61%. This finding may lead to the conclusion that although fluoride itself is effective in preventing dental caries, its addition to drinking water may be unnecessary since caries incidence is still highly prevalent with or without it. In fact, these findings suggest that income, and therefore access to dental care, is more important that mass fluoridation. Furthermore, even though bottled water consumption is on the rise, it does not affect caries levels, since those who consume bottled water also tend to have better dental care and hygiene due to the their socioeconomic status.

This paper illustrates the difficulties in quantifying the benefits of instituting nationwide public health initiatives. Fluoridation of a community's drinking water was considered a foolproof way to give all socioeconomic classes some basic form of preventive dental care; however, the negative effects of overconsumption of fluoride, including cancer and fluorosis, could outweigh the good intentions of public health officials.

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APPENDIX

TABLE 1: Summary of variables

Variable	Obs	Mean	S.D.	Min	Max	Coeff. of Var
CARIES	42	57.919	8.719	42	72.2	0.151
FL	102	0.668	0.266	.02	1	0.398
POV	102	10.493	3.353	4.3	18.6	0.319
INC	102	38570.19	6361.901	27415	55146	0.165
WATER	40	18.563	12.659	3.75	60.8	0.682

CARIES = incidence of caries in children in the US

FL = percentage of total drinking water that is fluoridated by state

POV = percent of population below federal poverty line for each state

INC = median income for each state

WATER = bottled water sales (gallons per capita) by state

TABLE 2: Regression results for Base Models with robust standard errors

Regression	**1**	**2**	**3**
Variable	**CARIES1990**	**CARIES2000**	**CARIES1**
INC1990	-.000713 -2.20**		
POV1990	1.075 1.38		
FL1990	-.064 -1.11		
INC2000		-.00043 -1.38	
POV2000		1.235 1.55	
FL2000		-.039 -0.84	
INC			-.00057 -2.80***
POV			1.09 2.18**
FL			-5.75 -1.65*
YEAR1			8.93 3.75***
n	21	21	42
F	9.59***	8.46***	15.13***
R^2	0.3687	0.400	0.379

Dependent variables: CARIES1990,2000: caries incidence for state x in year t
Independent variables: INC1990,2000: median income for state x in year t
POV1990,2000: percent of population below poverty line for state x in year t
FL1990,2000: percent of fluoridated drinking water in state x for year t
YEAR1: dummy variable

*** = significant at 1% level, ** = significant at 5% level, * = significant at 10% level.

Table 3: Regression results for the addition of the WATER variable

Regression	3	4	5	6
Variable	**CARIES1**	**CARIES2**	**CARIES3**	**CARIES4**
INC	-.00057 -2.80***	-.0011 -3.64***	-.0011 -7.22***	
POV	1.09 2.18**	-.0060 -0.01		2.387 3.29**
FL	-5.75 -1.65*	-9.504 -1.69*	-9.492 -2.00**	-3.473 -0.04
WATER		0.0128 0.14	0.0129 0.15	0.0098 0.08
YEAR1	8.93 3.75***	8.439 4.02***	8.454 3.94***	10.647 2.81***
n	42	26	26	26
F	15.13***	33.53***	16.34***	4.29***
R^2	0.379	0.643	0.643	0.304

Dependent variables: CARIES1 = caries incidence for all explanatory variables excluding water
CARIES2 = caries incidence for all explanatory variables including water
CARIES3 = caries incidence for all explanatory variables including water, but excluding POV
CARIES4 = caries incidence for all explanatory variables including water, but excluding INC
Independent variables: INC: median income for state x in year t
POV1990,2000: percent of population below poverty line for state x in year t
FL1990,2000: percent of fluoridated drinking water in state x for year t
WATER: bottled water sales (gallons per capita) in state x for year t
YEAR1: dummy variable
*** = significant at 1% level, ** = significant at 5% level, * = significant at 10% level.