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Leaking Underground Storage Tanks and Environmental Injustice: Is There a Hidden and Unequal Threat to Public Health in South Carolina?

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Abstract

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There are approximately 590,000 underground storage tanks (USTs) nationwide that store petroleum or hazardous substances. Many of these tanks are leaking, which may increase the risk of exposure to contaminants that promote health problems in host neighborhoods. Within this study, we assessed disparities in the spatial distribution of leaking underground storage tanks (LUSTs) based on socioeconomic status (SES) and race/ethnicity in South Carolina (SC). Chi-square tests were used to evaluate the difference in the proportion of populations who host a LUST compared to those not hosting a LUST for all sociodemographic factors. Linear regression models were applied to examine the association of distance to the nearest LUST with relevant sociodemographic measures. As percent black increased, the distance (both in kilometers and miles) to the nearest LUST decreased. Similar results were observed for percent poverty, unemployment, persons with less than a high school education, blacks in poverty, and whites in poverty. Furthermore, chi-square tests indicated that blacks or non-whites or people with low SES were more likely to live in LUST host areas than in non-host areas. As buffer distance increased, percent black and non-white decreased. SES variables demonstrated a similar inverse relationship. Overall, burden disparities exist in the distribution of LUSTs based on race/ethnicity and SES in SC.

INTRODUCTION

An underground storage tank (UST) refers to a tank and any underground piping connected to a tank that has at least 10% of its combined volume underground.[1] USTs are used to store petroleum and oil at automobile filling stations as well as other hazardous substances. There are approximately 590,000 active USTs located in 212,000 sites throughout the United States.[2] In 1984, Subtitle 1 was added to the Solid Waste Disposal Act (SWDA)[3] which encouraged the closing of more than 1.7 million USTs[2] due to more stringent regulations. Despite guidelines to prevent releases from USTs and innovations in leak detection methods, leaks, spills, and overfills still occur[3] which may lead to environmental contamination. As of March 2010, over 491,000 leaking underground storage tanks (LUSTs) have been confirmed, and of those, 395,000 sites have been cleaned up with 96,000 sites still awaiting clean-up.[2]

In the event of a leak, spill, or overflow, the risk of contamination to soil and groundwater is exceptionally high. According to Nadim et al., some aquifer contamination may be attributable to LUSTs.[4] These LUSTs may impact nearly 50% of the U.S. population and 99% of rural U.S. populations who rely on groundwater as their major source of drinking water.[5] Rural populations primarily rely on private well water which is not regulated under the Safe Drinking Water Act (SDWA) in systems that serve less than 25 individuals.[6] Many of the impurities released from LUSTs include volatile organic compounds (VOCs) and petroleum which readily evaporate into the air and soil. According to the U.S. Environmental Protection Agency (USEPA), specific pollutants of concern include methyl tert-butyl ether (MTBE), benzene, toluene, ethylbenzene, and xylenes (BTEX). Exposure to these contaminants pose a significant public health risk as some of them have been classified as carcinogenic, teratogenic, and/or implicated in the etiology of other systemic symptoms.[7–14]

Health effects associated with LUSTs

Benzene, one of the contaminants released from LUSTs, has been classified by the USEPA[13] and the Department of Health and Human Services (DHHS) as a known human carcinogen that causes acute myelocytic leukemia and bone marrow depression.[10] Furthermore, benzene exposure may cause excessive bleeding and affect the immune system, increasing the probability of infection. Aside from the direct release of benzene into the atmosphere, inhalation of benzene may also occur through a process called vapor intrusion where benzene and other VOCs move through soils and into nearby apartment buildings, thus contaminating indoor air.[10] When inhaled at high levels, benzene may cause confusion, dizziness, rapid or irregular heartbeat, and loss of consciousness.[10]

Toluene, xylene, and other contaminants such as ethylbenzene that are released from LUSTs have yet to be identified as human carcinogens.[10] Many of the toxic effects that ensue from exposure to the aforementioned pollutants include tiredness, confusion, weakness, drunken-type actions, memory loss, nausea, loss of appetite, hearing loss, color vision loss, irritation of the skin, eyes, nose, and throat, difficulty breathing, and problems with the lungs and kidneys.[10] Specifically, the toxic effects of ethylbenzene include eye and throat irritation and the International Agency for Research on Cancer (IARC) has classified the compound as a possible human carcinogen.[12] MTBE is a petroleum byproduct used as an additive in unleaded gasoline.[14] While MTBE dissolves easily in water and does not “cling” to soil very well, it does migrate faster and farther in the ground than other gasoline components, thus making it more likely to contaminate public water systems and private drinking water wells. MTBE is very persistent and may be costly to remove from ground water.[15]

While the health effects associated with LUST contaminants have been extensively researched, no prior studies have performed a statewide assessment on the siting of USTs and LUSTs across South Carolina (SC) and the populations most impacted. Expanding our work from Charleston, SC, where we found burden disparities in the distribution of LUSTs by race/ethnicity and socioeconomic status (SES),[16] to LUSTs across the state will allow us to identify clusters of differentially burdened populations and further inform policy that will drive UST management efforts. The purpose of this study was to assess disparities in the spatial distribution of LUSTs based on sociodemographic and racial/ethnic characteristics in SC.

METHODS

Leaking underground storage tank data

Data on LUSTs were downloaded from SC’s Department of Health and Environmental Control (DHEC) Bureau of Land Waste Management’s (BLWM) data sharing website. LUSTs across the state were geocoded and mapped using geographic information systems (GIS). There were a total of 5,028 LUSTs with Charleston (n = 464) having the highest concentration of sites in the state.

Sociodemographic variables

This study used the 2000 U.S. Census Bureau demographic data derived from summary files 1 and 3. While demographic information is available at various geographic scales (ZIP code tabulation areas [ZCTAs], tracts, block groups, and blocks), we utilized census data at the tract and block level to enumerate the following population characteristics: race/ethnicity (percent white defined as all non-Hispanic whites, percent non-white defined as all other races except non-Hispanic whites, and percent black defined as non-Hispanic blacks) and variables related to SES. The SES variables utilized in our study included education (percent population with less than a high school education), poverty (percent population below poverty level), unemployment (percent population unemployed), homeowners (percent population who own a home), and home built before 1950 (percent population who own a home built before 1950). Other SES-related variables included in the analyses were percent black below poverty level and percent black having less than a high school education. The same summary statistics (percent below poverty and percent having less than a high school education) were also considered for white populations. The variables related specifically to income were per-capita and median household income.

Statistical analysis

We used SAS version 9.2 (SAS Institute Cary, NC) to perform the statistical analyses, graphical tool gnuplot version 4.6 for the association visualization, and R to conduct the buffer analysis. Buffer analysis techniques were used to address burden disparities in the distribution of LUST sites across SC at the census block and tract level. Buffer distances of 0.5, 1.0, and 5.0 miles (mi) as well as 0.5, 1.0, and 5.0 kilometers (km) were created. For example, a buffer of 0.5 km means that the distance between the host and census tract falls under 0.5 km which is similar for the remaining buffers.

The population size, percent black and percent non-white were calculated for each buffer distance. The mean distance of census tracts to the nearest LUST site was calculated for all sociodemographic variables at the 10th, 25th, 50th, 75th, and 90th percentiles. Summary statistics were further calculated for each sociodemographic measure and gnuplot was used to visualize the association between each sociodemographic measure and distance to the nearest LUST.

Chi-square tests were conducted for each buffer distance to evaluate the difference in the proportion of populations in a buffer who host a LUST compared to those in that buffer not hosting a LUST for all sociodemographic factors. Linear regression models were applied to describe the relationship between distance to the nearest LUST (dependent variable) and sociodemographic factors (independent variable). Selection of all significant sociodemographic factors was done using the backward selection model. For the variables related to income (per capita income, median household income), we performed t-tests to determine whether they were significantly different for populations hosting a LUST and those not hosting a LUST. In all analyses, the overall significance level for each type of test was set at 0.05, and the Bonferroni method was used to adjust for multiple testing.

RESULTS

Descriptive statistics for each sociodemographic measure may be found in Table 1. Based on the analysis, 32.42% of the population was black while 64.41% was white. There was 15.78% of the population living below poverty, which was higher than the national average of 11.30% in 2000. Those with less than a high school education comprised 25.13% of the population and the unemployment rate was equivalent to 3.91%. When considering housing characteristics, 69.63% of the population owned their home and 13.61% built their home before 1950. There was 6.05% of the white population living below poverty while 9.01% of the black population was living below poverty.

The overall mean distance of all SC census tracts combined to the nearest LUST was 0.02 mi. The mean distance between the nearest LUST and census tracts where the non-white population was greater than 50% was 0.017 mi and the mean distance between the nearest LUST and census tracts where whites accounted for more than 50% was 0.021 mi. Moreover, among census tracts where population sizes of blacks were in the first quartile (25th percentile), the mean distance was 0.025 mi from the nearest LUST to these census tracts. The distance decreased to 0.02 mi among census tracts in the third quartile (75th percentile).

Furthermore, as percent black increased, the distance (both in km and mi) to the nearest LUST decreased. We observed similar results for SES variables (percent poverty, percent unemployment, percent with less than a high school education, percent poverty who are black, percent poverty who are white, percent black with less than a high school education, and percent white with less than a high school education). In addition, the plots (Figure 1) of distance by sociodemographic factors illustrate that in general as the distance to the nearest

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LUST increased, percent black, non-white, and SES (percent poverty, percent unemployment) decreased, while percent white increased. We did not observe a clear pattern for percent of homes built before 1950. As a result, populations that are black, non-white, poor, or have less than a high school education may have a greater risk of being exposed to contaminants released from LUSTs in the state of SC.

Our chi-square tests (Table 2) indicate that blacks or non-whites or people with low SES more likely lived in LUST host areas than in non-host areas. For instance, among people living in the host area, 29.86% were black and 14.36% were living in poverty, which was higher than the percentages among people living in the non-host areas (23.87% and 10.44%, respectively). All of the results were significant at the multiple-testing adjusted significance level 0.0038 except for blacks with less than a high school education and income variables ($p = 0.016$, 0.65, and 0.16, respectively).

We further evaluated the distribution patterns of race/ethnicity and SES factors across different buffers (in mi only). It was found that all ratios of host versus non-host were significantly different from 1, except in the black population having less than a high school education, per-capita income, and median household income (Table 3).

Linear regression models were used to examine the association of distance to the nearest LUST (dependent variable) with relevant sociodemographic variables (independent variables). After adjusting for socio-demographic factors noted earlier, the percent black population with less than a high school education was statistically significant with a p-value of 0.0082 before adjusting for multiple testing. The significance disappeared after we adjusted for multiple testing. We performed model selection of variables based on backward selection and found three variables that were statistically significant. The statistically significant variables included percent poverty (Beta = 0.0016, $p = 0.006$), percent white population with less than a high school education (Beta = 0.0032, $p = 0.0029$), and percent black population with less than a high school education (Beta = 0.0034, $p = 0.0031$).

Figure 2 is a choropleth map that was constructed in ArcGIS 10.0 that depicts the distribution of LUSTs in relation to percent non-white across SC. There were large clusters of LUSTs located in densely populated areas in the northwest, northeast, central, and coastal regions of the state. Specifically, these clusters appear to be concentrated in high-density counties such as Greenville, Spartanburg, Richland, Charleston, Florence, York, Beaufort, and Horry. While the northeast region has multiple LUST clusters, this part of the state has the highest percentage of whites and lowest number of LUSTs. Despite the geographical illustration of an association, the relationship between the number of LUSTs and percent white alone was not significant in previous results unless the population included whites with less than a high school education and whites living in poverty. Other regions of the state have LUST clusters in areas that are more consistent with our findings of racial disparities such as Charleston and Richland County. These counties are located in a quartile with the highest percent of non-whites as well as the highest number of LUST sites.

DISCUSSION

After merging the 2000 census data with LUST site coordinates in the ArcGIS platform, we found evidence of racial/ethnic and SES disparities in the spatial distribution of LUSTs. Results from chi-square and linear regression analyses demonstrate a statistically significant difference in the sociodemographic composition of populations living near LUSTs which were predominately non-white and low-income groups. As percent non-white increased, the mean distance to the nearest LUSTs decreased substantially. Similar results were found for percent black, percent black (and white) below poverty, unemployed, and percent black (and white) with less than a high school education. Furthermore, as the buffer distance increased, the percent black and non-white populations decreased. This finding suggests that non-whites are disproportionately burdened by the distribution of LUSTs within their respective communities.

While there were relatively small changes in the percentage of black and non-white populations located in each buffer zone, these populations were consistently concentrated closer to a LUST than at distances further away from a LUST. In addition, there was a statistical difference found between LUST host and non-host tracts for blacks with less than a high school education and blacks living below the poverty level (Table 2), which indicated that there were still disparities found in the proportion of the population living within a host tract. More specifically, black and non-white populations, black (and white) populations living below poverty the level, and black (and white) populations with less than a high school education were more likely to live in LUST host tracts.

Incorporating GIS and other spatial analyses techniques into environmental justice (EJ) research has become an important tool in gathering preliminary data to illustrate disparities in the distribution of environmental hazards.[17] Much of this work was based on the 1987 landmark publication *Toxic Waste and Race in America*[18] and the recent 2007 Toxic Waste and Race at Twenty[19] report which both documented how non-white populations are differentially targeted by the siting of hazardous waste facilities. With the increase in sound techniques to assess spatial disparities exemplified by Maantay,[20] Chakraborty and Armstrong,[21] and other studies;[22–25] determining which communities are differentially burdened by hazardous waste sites and related health risks has become less of a challenge. Wilson et al. used similar spatial methods to assess the distribution of LUSTs in Charleston, SC and found that there was a higher prevalence of blacks and non-whites in census tracts and blocks that host LUSTs versus those not hosting LUSTs which supports the findings in this particular study.[16]

We believe that this approach is generalizable to other contexts to assess whether disadvantaged communities throughout a state are differentially burdened by environmental hazards such as LUSTs, which may contribute to poor health outcomes and limit the effectiveness of revitalization efforts. Moreover, this work contributes to general EJ science as a case study for state agencies to model in order to assess racial/ethnic and SES disparities in UST placement and potentially utilize results in future planning and development. While these results are beneficial to understanding exposure and health risks across the state, there are limitations in this study and future work should address variations in exposure media to ascertain cumulative risk. Moreover, we plan to perform plume modeling to obtain better estimates of plume movement from LUSTs as well as use the cumulative risk assessment approach to calculate risk estimates that may be used in GIS to develop a more accurate risk profile for populations across the state. In addition to incorporating plume patterns, soil and water samples should be collected near LUSTs to determine which media may be of concern to local residents.

CONCLUSION

This study has shown that there are visible burden disparities of LUSTs in SC at the block and census tract levels across varying levels of demographic composition, particularly for race/ethnicity and SES. While there were some limitations in the methodology, the study found significant differences in the proportion of populations living within a LUST host and non-host census tract for black and non-white populations, populations below poverty level, and other sociodemographic groups. We are confident that the BLWM will be able to use the results of this study to help impact environmental decision making throughout the state,

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particularly in communities that are disproportionately burdened by a number of LUSTs. We believe that many USTs and LUSTs are part of convenience store complexes that provide gasoline but also provide cheap food products. The high concentration of these facilities in poor and underserved communities of color may be a factor in creating obesogenic conditions as well. This has implications for how planning and zoning can be used to not only reduce LUST disparities, but also improve food access and reduce negative diet-related health outcomes (e.g., diabetes). This issue will be explored in future built and food environment research.

We believe that preventing LUSTs is less expensive, invasive, and hazardous to the environment than similar environmental mitigation processes. Specifically, proper management of petroleum products, equipping USTs with self-regulating technologies such as leak detectors, implementing mandatory reporting of leaks, and ultimately creating a local environmental hazard surveillance system may significantly reduce the prevalence of LUSTs. Future studies will incorporate human exposure data such as biomarkers to provide a more comprehensive assessment of burden and exposure disparities as well as cumulative impacts. In addition to acquiring human exposure data, we further plan to obtain data on community water systems and privately maintained wells in order to more accurately evaluate exposure disparities.

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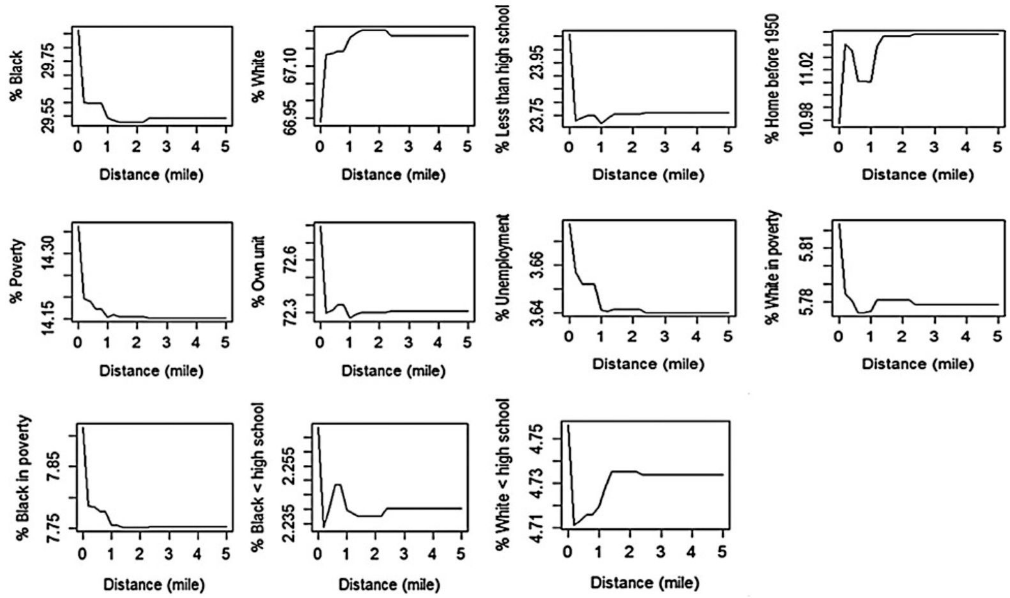

FIG. 1.

The association between sociodemographic composition and distance to the nearest leaking underground storage tank (LUST) in South Carolina.

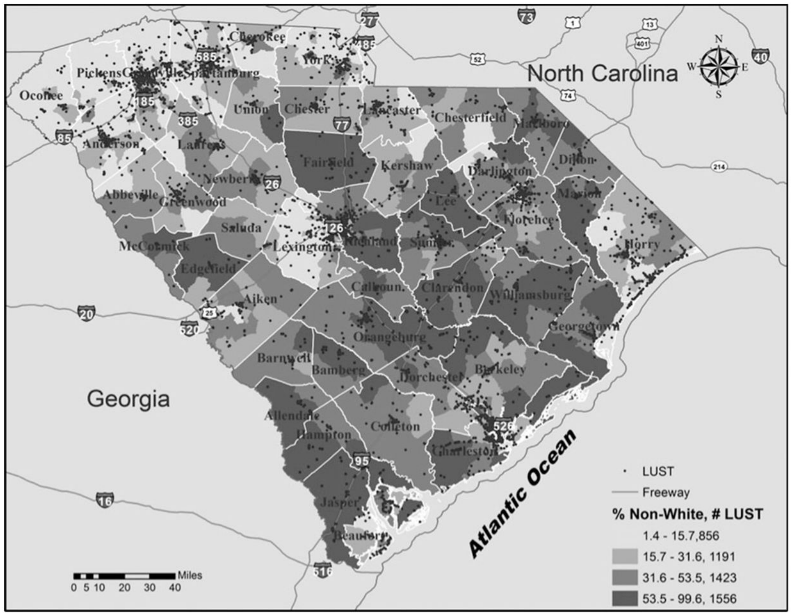

FIG. 2.

Map of leaking underground storage tanks (LUSTs) by percent non-white in South Carolina.

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Table 1

Summary Statistics for Sociodemographic Factors in South Carolina

Sociodemographics	Minimum	Lower Quartile	Mean	Upper Quartile	Maximum	Median
% Black	0.04	11.16	32.42	49.69	98.83	26.05
% Non-White	0.74	14.50	35.59	52.48	99.57	30.23
% White	0.43	47.51	64.41	85.50	99.26	69.76
% Poverty	0.00	8.20	15.78	20.60	100.00	13.60
% Homeowner	0.00	61.40	69.63	84.40	100.00	75.50
% Less than HS Education	0.00	14.60	25.13	33.90	63.10	26.90
% Homes Built Pre-1950	0.00	4.20	13.61	18.70	100.00	9.50
% Unemployment	0.00	2.25	3.91	4.70	53.93	3.30
% Poverty and White	0.00	3.26	6.05	7.67	60.91	5.26
% Poverty and Black	0.00	1.63	9.01	13.67	63.47	5.75
% Less than HS Education and White	0.00	1.47	4.53	6.52	23.94	3.56
% Less than HS Education and Black	0.00	0.10	2.86	4.01	30.38	0.87

HS = High school.

Table 2

Comparing Sociodemographic Disparity between Host and Non-Host Census Tracts for Leaking Underground Storage Tanks (LUSTs) Based on Chi-Square Tests in South Carolina

Sociodemographics	Host	Non-Host	Ratio of Host and Non-host	P-value
Percent (%)				
Black	29.86	23.87	1.25	< 0.0001
Non-White	33.06	28.40	1.16	< 0.0001
White	66.94	71.60	0.94	< 0.0001
Poverty	14.36	10.44	1.38	< 0.0001
Homeowner	72.80	63.64	1.14	< 0.0001
Less than HS Education	24.06	18.50	1.30	< 0.0001
Homes Built Pre-1950	10.98	12.31	0.89	< 0.0001
Unemployment	3.68	2.98	1.24	< 0.0001
Poverty and Black	26.50	20.48	1.29	< 0.0001
Poverty and White	8.70	6.96	1.25	< 0.0001
Less than HS Education and Black	7.60	7.31	1.04	0.0165
Less than HS Education and White	7.11	6.06	1.17	< 0.0001
Mean (SD)				
Per capita income	18,496.40 (7,183.70)	19,064.70 (9,792.70)	0.97	0.6533
Median HH income	36,489.60 (13,872.70)	39,783.20 (18,089.10)	0.92	0.1622

Note: The percentages were calculated with respect to the host or non-host population sizes. HS = High school; HH = Household.

Table 3

Leaking Underground Storage Tank (LUST) Host versus Non-Host Ratios for Sociodemographic Variables in Different Buffers in South Carolina

Sociodemographics	Host Percentage (%)[a]	0.5 Mile Ratio (p-value)[b]	1.0 Mile Ratio (p-value)[b]	5.0 Miles Ratio (p-value)[b]
% Black	29.86	1.22 (< 0.0001)	1.27 (< 0.0001)	1.25 (< 0.0001)
% Non-White	33.06	1.14 (< 0.0001)	1.17 (< 0.0001)	1.16 (< 0.0001)
% White	66.94	0.94 (< 0.0001)	0.93 (< 0.0001)	0.94 (< 0.0001)
% Poverty	14.36	1.38 (< 0.0001)	1.41 (< 0.0001)	1.38 (< 0.0001)
% Owned home	72.80	1.17 (< 0.0001)	1.17 (< 0.0001)	1.14 (< 0.0001)
% Less than HS Education	24.06	1.37 (< 0.0001)	1.39 (< 0.0001)	1.30 (< 0.0001)
% Homes Built Pre-1950	10.98	0.91 (< 0.0001)	0.94 (< 0.0001)	0.89 (< 0.0001)
% Unemployed	3.68	1.19 (< 0.0001)	1.25 (< 0.0001)	1.24 (< 0.0001)
% Poverty and Black	26.50	1.29 (< 0.0001)	1.31 (< 0.0001)	1.29 (< 0.0001)
% Poverty and White	8.70	1.29 (< 0.0001)	1.29 (< 0.0001)	1.25 (< 0.0001)
% Less than HS Education and Black	7.60	0.98 (0.35)	1.05 (0.0048)	1.04 (0.017)
% Less than HS Education and White	7.11	1.29 (< 0.0001)	1.27 (< 0.0001)	1.17 (< 0.0001)
Mean (SD)				
Per Capita Income	18,496.40	0.94 (0.43)	0.95 (0.50)	0.97 (0.65)
Median HH Income	36,489.60	0.90 (0.16)	0.90 (0.11)	0.92 (0.16)

HS = High school; HH = Household.

[a]Note: The percentages are with respect to the count 4,012,012.

[b]Note: The p-values were from two sample proportion tests.