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Longitudinal trends in gasoline price and physical activity: The CARDIA study

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Abstract

Objective—To investigate longitudinal associations between community-level gasoline price and physical activity (PA).

Method—In the Coronary Artery Risk Development in Young Adults study, 5,115 black and white participants aged 18–30 at baseline 1985–86 were recruited from four U.S. cities (Birmingham, Chicago, Minneapolis and Oakland) and followed over time. We used data from 3 follow-up exams: 1992–93, 1995–96, and 2000–01, when the participants were located across 48 states. From questionnaire data, a total PA score was summarized in exercise units (EU) based on intensity and frequency of 13 PA categories. Using Geographic Information Systems, participants' residential locations were linked to county-level inflation-adjusted gasoline price data collected by the Council for Community & Economic Research. We used a random-effect longitudinal regression model to examine associations between time-varying gasoline price and time-varying PA, controlling for age, race, gender, baseline study center, and time-varying education, marital status, household income, county cost of living, county bus fare, census block-group poverty, and urbanicity.

Results—Holding all control variables constant, a 25-cent increase in inflation-adjusted gasoline price was significantly associated with an increase of 9.9 EU in total PA (95%CI: 0.8–19.1).

Conclusion—Rising prices of gasoline may be associated with an unintended increase in leisure PA.

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Conflict of interest statement

The authors declare that there are no conflicts of interest.

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Keywords

GIS; economics; longitudinal study; obesity; young adults

Introduction

To address increasing obesity, recent attention on physical activity (PA) related environment-level factors, has focused on activity-friendly modifications, such as reducing urban sprawl (Ewing et al., 2003), increasing pedestrian/bicycle infrastructure (Giles-Corti and Donovan, 2002) and increasing street connectivity (Frank et al., 2004; Humpel et al., 2002). While some economic-related research has addressed food prices (Glanz et al., 1998; Shannon et al., 2002), little research has addressed broader economic factors, such as gasoline price, that might impact PA behaviors.

Gasoline price may influence active commuting such as walking and biking, but may also influence leisure PA that requires driving. Since gasoline consumption is responsive to price changes (Harrington et al., 2008; Hughes et al., 2008; Leigh and Geraghty, 2008), increasing gas price could theoretically reduce driving and possibly increase PA and decrease obesity (Edwards, 2008; Wen and Rissel, 2008; Zheng, 2008). While one European study showed that gasoline price and prevalence of obesity were inversely associated (Rabin et al., 2007), this association is indirect since the most likely pathway would be through PA. To date, one cross-sectional study suggests higher cycling in areas with higher gasoline prices (Rashad, 2009), and a recent surveillance study shows an association between increasing gas prices and walking (Courtemanche, 2010). Yet there has been little study of gas price and leisure PA.

Using longitudinal data on leisure PA and spatially linked neighborhood price data in a large, biracial, adult cohort, we estimate the influence of community-level gasoline price on overall PA as well as specific types of PA (e.g., walking and bicycling). We hypothesize that increased gasoline price would discourage car driving and potentially affect leisure PA choices through substitution of home-based as opposed to travel-based PA.

Methods

Study Sample

The CARDIA study enrolled 5,115 black and white young adults from four U.S. metropolitan areas (Birmingham, AL; Chicago, IL; Minneapolis, MN; and Oakland, CA), at baseline 1985–86 and followed over time 1992–1993 (Year 7), 1995–1996 (Year 10), and 2000–2001 (Year 15). Specific recruitment procedures are described elsewhere (Friedman et al, 1988). CARDIA follows all participants even those who have relocated over time; whereas participants are from 4 cities at baseline, by 2000–01, the participants were located in 48 states, 1 federal district, 529 Counties and 3,805 Census Tracts. Using Geographic Information Systems (GIS), we linked individual participant residential addresses at each time point to externally derived, area-level environmental/economic data. Thus we obtained data from all 48 states, but extracted and used only those data linked or matched to participants' residential locations.

Main Exposure: County-level gasoline price

Gasoline price data come from the Council for Community & Economic Research (C2ER), which are widely used by economists in studies of tobacco pricing and smoking behavior (Chaloupka et al., 2002; Christian, 2009; Grossman and Chaloupka, 1997). C2ER data are reported by city (defined as Metropolitan Statistical Area, MSA) via County Federal Information Processing Standards (FIPS) codes. CARDIA participant residential locations fell within and outside of the MSAs across time. We report community price data at the county level based on within-county MSA or average C2ER values for the county (where there are more than one MSA's within a county). We used county and MSA data for approximately 75–83% of the sample across all time points, and imputed prices using state averages or data from other seasons when there was no direct match for participant by location and/or season of price data as previously published (Raper, 1999; Grossman, 1989; Grossman and Chaloupka, 1997; Chou et al., 2004; Duffey et al., 2010). We used inflation-adjusted gasoline price by Bureau of Labor Statistics Consumer Price Index (CPI) [(actual gasoline price/concurrent CPI) × anchor CPI in 2001 first quarter] for temporal comparisons.

Outcome: Physical activity

At each examination, frequency of participation in 13 categories of moderate and vigorous recreational sports, exercise, leisure, and occupational PA over the previous 12 months was ascertained by an interviewer-administered questionnaire designed for CARDIA. As described elsewhere (Jacobs, et al. 1989), PA scores were calculated in exercise units (EU) based on frequency and intensity of participation for each of the 13 PA categories. Of specific interest, the walking score ranged from zero to 144 EU (regular walking ≥4 hour/week at 4 MET); biking score ranged from zero to 216 EU (regular, vigorous bicycling at ≥2 hour/week at 6 MET). The calculated scores for all 13 categories were then summarized for a total PA score. Reliability and validity of the instrument are comparable to other activity questionnaires (Jacobs et al., 1989).

Community-level Covariates

We used Cost of Living Index (COLI) from C2ER as a proxy control for time-varying region effects in our models, and county-level bus fare from C2ER (one-way, 10 miles) reflecting the cost of public transportation. We contemporaneously matched census BG-level data from 1990 (CARDIA Year 7 and Year 10) and 2000 (CARDIA Year 15), for poverty (% households >150% poverty level), employment status (% population unemployed), active commuting (% workers walk/bike to work), distance to work (proportion of workers traveling ≥30min to work), and residence inside (urban) or outside (rural) an MSA.

We used time-varying street connectivity within 1 km of each participant's residence as an indicator of physical support for walking and bicycling (Cervero and Kockelman, 1997) obtained via StreetMap data, including intersection density [number of intersections in buffer divided by buffer area ($3.14 km^2$)], and population density [census-level population in the proportion of census geography population and area within the 1km residential buffer for each participant] as an indicator of urban form (Frank et al., 2004; Rundle et al., 2007).

Statistical Analysis

All statistical analyses were conducted using Stata (version 10.1, College Station, TX). We used a Random-Effect (RE) longitudinal regression model (outcome: PA), which clusters on individuals and incorporates both between- and within-individual variation. We controlled for season of gasoline price collection, individual-level variables (age, gender, race, education level, marital status, inflation-adjusted household income, and baseline study center), as well as community-level variables (county-level COLI, county-level inflation-adjusted bus fare, BG-level poverty, BG-level employment status, living in vs. out an MSA, 1-km buffer level street connectivity, and a dummy indicator for imputed gasoline prices).

We tested gender, race, and household income for interactions with gasoline price by including appropriate cross-product terms followed by likelihood ratio test, and observed no effect measure modification.

We modeled walking and bicycling separately given the potential for substitution in transportation modes (from driving to walking or bicycling). A considerable proportion of participants reported no walking (26.6%) or no bicycling (60.4%), resulting in positively skewed distributions with a bulk of zero scores (≥ 5%), necessitating the prevailing strategy of using a two-part marginal effect model (MEM) (Duan, 1983; Liu et al., 2010; Madden, 2008), commonly used in the public health literature (Haines et al., 1988; Hu et al., 2009; Ng et al., 2008; Pendergast et al., 2010; Walls et al., 2009). In the two-part MEM, we estimated two separate decisions: 1) to engage in any specific activity (a probit regression model to estimate probability of conducting a given activity); and 2) the amount of activity, if conducted (an ordinary least square regression model conditioned on only those who conducted the given activity). We pooled data across three exam years, used robust standard errors to correct for multiple observations on individuals and included two additional community-level covariates (% population walk/bike to work, and % population who travel ≥30 min to work). The two parts were estimated separately and a weighted mean (unconditional estimates) calculated. Bootstrapped standard errors were then obtained using 1000 replications, each clustered at the individual level. Finally, we applied the two-part MEM model for all other 11 PA sub-categories to understand how each PA sub-category contributed to total PA change.

Results

Descriptive Characteristics

The analysis sample reflects the race, gender, and education balanced mix of young to mid-aged adults in CARDIA (Table 1). Over the eight years of follow-up, average total PA, walking, and bicycling scores remained generally stable.

Inflation-adjusted gasoline prices slightly decreased from 1992–93 to 1995–96, and then significantly increased in 2000–01 (Table 2). The majority (>95%) of the sample was from urban areas, with significantly higher gasoline prices than rural areas (p<0.001, year 7 & 15). Approximately 50% of the block group population reported traveling ≥30min to work, with a small proportion walking (~5%) or biking (~1%) to work, similar to national data (U.S. Census Bureau). Further, the CARDIA participants come from communities where the proportion of the population walking to work significantly declined over time (p<0.001).

Modeling results

Using random-effect longitudinal models, we observed a significant positive association between gasoline price and total PA, after controlling for relevant covariates (Table 3). A 25-cent increase in inflation-adjusted gasoline price was associated with a 9.9 EU increase in total PA (p=0.01), which was about 3% of total PA.

After controlling for all covariates, a 25-cent increase in gasoline price was associated with 1.3 EU increase in walking score (p=0.2), which can be translated to an additional 3-min walking per week (Figure 1). Three out of 11 PA sub-categories were significantly associated with gasoline price (positive association: non-strenuous sports; inverse associations: vigorous racket sports and bowling).

Discussion

We observed a positive longitudinal association between gasoline price and total PA. Essentially, a 25-cent increase in inflation-adjusted gasoline price was associated with 9.9 EU increase in total PA (p=0.03). For example, since 144 EU represents regular walking at ≥4 hr/wk (≥240 min/wk), 9.9 EU translates to about 7% of 144 EU or 240min×7%=17min walking per week, a substantial population-level impact. We also observed some evidence of substitution of home-based physical activity (e.g., jogging, walking, and non-strenuous sports) as opposed to physical activities that require driving to a particular location (e.g., bowling and racket sports).

On average, gasoline price was relatively stable in the 1980s and 1990s ranging from $1.06–1.25 including tax, with substantial spatial variation across the US. Since the new millennium, the price has increased significantly (U.S. Energy Information Administration, 2006). However, relative to many other countries, gasoline prices are considerably low in the US.

Study limitations and strengths

CARDIA included measures of leisure PA only, thus our findings relate to leisure rather than commuting behavior. Our results suggest a relatively weak association between gasoline price and walking and a null association for bicycling. As in all physical activity questionnaires, individuals may misreport PA frequency and intensity (Altschuler et al., 2009).

Further, gasoline price was missing for approximately 20% of the sample, which were imputed via a well-published strategy. We performed a sensitivity analysis (models with and without imputed values) and found the estimations are essentially the same. While county is the smallest geographic unit with price data available, it is possible that gas prices vary minimally within-county. It is also possible for some degree of county mismatch in individuals who moved residences shortly before measurement. In addition, there is the possibility of unobserved heterogeneity and residential selectivity bias related to movement of health conscious individuals to health conscious states that tend to have higher gas taxes. Whereas our random effects modeling did not account for unobservable individual-specific characteristics, with three observations per individual, we had low power for fixed-effect modeling. There is a great need for the collection of community price data coupled with high quality behavioral data in large samples followed over time.

While we did not have actual public transit use measures, we used county-level bus fare (transportation cost) as a control measure. According to Census data, at the national level, only 4.7% of commuters used public transit to travel to work in 2005, an increase of about 0.1% over 2000 levels (U.S. Census Bureau).

In terms of generalizability, the CARDIA sampling frame used census tract information to insure desired population balance at baseline, and thus the sample can be considered representative of the baseline city populations. By 2000–01, participants were located across 48 states, mostly in urban areas. Thus, results are more relevant for urban vs. rural populations that have less access to PA facilities and less walking/bicycling supportive environments. As CARDIA has implemented an extremely rigorous system to protect the data and the identities of participants, the contextual database includes information about the communities in which the participants reside, without identifying the communities. Thus, full comparative analysis of generalizability is not possible.

Despite the limitations, the CARDIA data boasts objectively measured, community-level price data, which were contemporaneously and geographically linked to individual participant's residential locations using GIS. Thus, our study is one of the first longitudinal studies to examine gasoline price and PA. The objectively measured gasoline price data available with the C2ER data are the most detailed time-varying data available and have been found to be closely correlated with CPI (Christian, 2009). Further, we used rich longitudinal data with standardized measures of PA from an instrument with known reliability and validity. The association of gasoline price with PA cannot be attributed to long term time and age trends in PA — unlike the decrease in PA previously reported for years 0 through 7 (Anderssen et al., 1996); mean PA has been stable between years 7 and 15. We used powerful longitudinal models, including a two-step model to examine gasoline price in relation to walking, bicycling, as well as other sub-categories of overall PA.

Conclusion

We observed a positive association between gasoline price and total PA, where the energy expenditure is roughly equivalent to 17 minutes of additional walking per week with a 25 cent increase in gasoline price. Our findings provide some evidence for association between gasoline price and leisure PA. Future research using multi-panel prospective data is necessary to fully understand the direct effect of gasoline price on PA.

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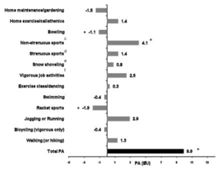

Figure 1.
Predicted changes in total physical activity a and its 13 sub-categories b, per 25 cent increase in inflation-adjusted gasoline price using two-part marginal effect modeling with bootstrap, among black and white American adults from the CARDIA Study c, U.S.A., 1992–2001.

[*] $p<0.05$

[a] By random-effect longitudinal regression model (Table 3).

[b] By two-part models controlled for season that gasoline prices were collected, individual-level variables including age, gender, race, education level, marriage status, inflation-adjusted household income, baseline study center; and community-level variables including, county-level cost of living index, county-level inflation-adjusted bus fare, BG-level poverty, BG-level employment status, BG-level % workers age ≥16 travel 30+ min to work, BG-level % workers walk to work, BG-level % workers bicycle to work, dummy indicator of urbanicity, 1km-buffer level street connectivity and population density, and dummy indicator of imputed gasoline prices. Then we performed Bootstrap with 1000 replications to estimate standard error for the derived point estimate.

[c] Coronary Artery Risk Development in Young Adults Study (U.S., 1992–93 to 2000–01), with black and white young adults recruited from four U.S. cities at baseline

[d] Non-strenuous sports such as softball, shooting baskets, volleyball, ping pong, or leisure jogging, swimming or biking (moderate intensity)

[e] Strenuous sports such as basketball, football, skating, or skiing

[f] Snow shoveling or moving heavy objects or weight lifting at home

[g] Vigorous job activities such as lifting, carrying, or digging

Table 1

Individual-level characteristics of black and white American adults from the CARDIA Study[a] U.S.A., 1992–2001

% or mean(SE)	Year 7 1992–93 (n=3,968)	Year 10 1995–96 (n=3,866)	Year 15 2000–01 (n=3,617)
Sociodemographics			
Black % (vs. White)	48.1	48.5	47.
Female % (vs. Male)	54.8	55.3	55.7
Age in years	32.0(0.06)	35.0(0.06)	40.2(0.06)
Education %			
<=High School	28.8	29.4	23.1
>High School; <=College	53.1	51.2	56.4
>College	18.1	19.4	20.6
Married % (vs. unmarried)	44.3	49.4	60.2
Household Income			
Actual Household Income in $K[b]	36.3(0.3)	41.4(0.4)	71.3(0.8)
Inflation-adjusted Household Income in $K[c]	44.9(0.4)	47.2(0.4)	71.6(0.8)
Physical Activity in EU[d]			
Walking Score[e]	46.9 (0.8)	46.8 (0.8)	48.9 (0.8)
Bicycling Score[f]	29.6 (0.8)	29.0 (0.8)	27.3 (0.8)
Total PA score[g]	338.6 (4.4)	331.5 (4.4)	346.6 (4.7)

[a]Coronary Artery Risk Development in Young Adults Study (U.S., 1992–93 to 2000–01), with black and white young adults recruited from four U.S. cities at baseline

[b]Actual household income was the original income collected before any adjust.

[c]Inflation-adjusted household income = actual household income/(CPI/anchor CPI). Anchor CPI = average CPI in 2001 first quarter.

[b,c]Both actual and inflation-adjusted household income have increased significantly across time (T-tests by pair with Bonferroni correction, all p-values<=0.0001).

[d]EU=exercise units, calculated using frequency and intensity of activity

[e]Walking score was not significantly different between any two exam years (T-tests by pair with Bonferroni correction).

[f]Bicycling score was not significantly different between any two exam years (T-tests by pair with Bonferroni correction).

[g]Total PA score was not significantly different between any two exam years (T-tests by pair with Bonferroni correction).

Table 2

County-level gasoline price (actual and inflation-adjusted), and community-level covariates, in residential counties of black and white American adults from the CARDIA study, U.S.A., 1992–2001[a]

Mean (SE)	Year 7 1992–93 (n=3,968)	Year 10 1995–96 (n=3,866)	Year 15 2000–01 (n=3,617)
Gasoline price (Unleaded, $/gallon)			
Actual gasoline price[b*]	1.16 (0.0014)	1.20 (0.0.0016)	1.60 (0.0031)
Inflation-adjusted gasoline price[c*]	1.44 (0.0017)	1.37 (0.0018)	1.61 (0.0032)
Urban	1.44 (0.0017)[**]	1.37 (0.0018)	1.61 (0.0032)[**]
Rural	1.39 (0.014)	1.35 (0.012)	1.51 (0.012)
County-level covariates			
Cost of Living Index	1.12(0.0021)	1.14(0.0039)	1.18(0.0047)
Inflation-adjusted one-way bus fare ($)[d, *]	1.33(0.0028)	1.37 (0.0060)	1.31 (0.0060)
Census BG-level covariates			
Rural residence % (vs. urban)	1.64	1.64	3.35
% Poverty level >200%[*]	66.3 (0.35)	70.6 (0.35)	72.4 (0.34)
% population distance to work >=30min	45.5 (0.20)	45.0 (0.20)	47.3 (0.20)
% population walk to work[*]	5.33 (0.14)	4.04 (0.12)	3.04 (0.10)
% population bicycle to work[***]	0.77 (0.033)	0.66 (0.029)	0.64 (0.028)
1 km radius buffer level covariates			
Intersection density /km^2,[*]	47.5 (0.25)	42.0 (0.28)	45.9 (0.31)
Population density /km^2,[***]	4,110 (52)	2,901 (42)	2,894 (44)

[a]Coronary Artery Risk Development in Young Adults Study (U.S., 1992–93 to 2000–01), with black and white young adults recruited from four U.S. cities at baseline

[b]Actual gasoline price is the original before any adjustment.

[c]Inflation adjusted using Consumer Price Index (CPI). Inflation-adjusted gasoline price = actual gasoline price/(CPI/anchor CPI). Anchor CPI = average CPI of year 2001 first quarter.

[d]Inflation-adjusted bus fare = actual bus fare/CPI/anchor CPI. Anchor CPI = average CPI in 2001 first quarter.

[*]Significantly different between any two exam years (p<0.001; T-tests by pair with Bonferroni correction).

[**]Statistically higher in urban areas than in rural areas (p<0.001) by t-tests.

[***]Significantly decreased from year 7 to year 10 and 15 (p<0.01; T-test by pair with Bonferroni correction).

Table 3

Predictors of total physical activity using random-effect longitudinal regression models[a], among black and white American adults from the CARDIA study, U.S.A., 1992–2001[b]

	All study centers		
Predictors	**Coeff[c]**	**95% CI**	**P-value**
Inflation-adjusted gasoline price, per 25 cents	**9.9**	**0.8, 19.1**	**0.03**
Age in years	**−3.1**	**−4.3, −1.9**	**<0.001**
Black vs. White	**−16.0**	**−31.1, −0.8**	**0.04**
Female vs. Male	**−161.0**	**−174.7, −147.3**	**<0.001**
High school vs. <High school	**22.7**	**9.4, 35.9**	**<0.001**
>=College vs. <High school	**19.2**	**0.4, 38.1**	**0.046**
Married vs. Unmarried	**−28.4**	**−39.6, −17.2**	**<0.001**
Inflation-adjusted household income in $K	**0.7**	**0.5, 0.8**	**<0.001**
Oakland vs. Birmingham	**47.8**	**21.7, 73.4**	**<0.001**
Chicago vs. Birmingham	**54.3**	**31.8, 77.7**	**<0.001**
Minneapolis vs. Birmingham	**52.6**	**32.4, 72.9**	**<0.001**
% population > 150% poverty level	**0.3**	**0.03, 0.7**	**0.03**
% population unemployed	**−26.5**	**−40.9, −12.1**	**<0.001**
Cost of Living Index	−11.2	−45.5, 23.0	0.5
Inflation-adjusted Bus fare, $	3.0	−13.3, 19.3	0.7
Intersection density in 1km radius buffer	0.2	−0.2, 0.5	0.3
Population density in 1km radius buffer	0.09	−1.8,2.0	0.9
Rural residence vs. urban	22.3	−16.2, 60.8	0.3

[a]Controlling for season that gasoline prices were collected, individual-level variables including age, gender, race, education level, marital status, inflation-adjusted household income, baseline study center; and community-level variables including, county-level cost of living index, BG-level inflation-adjusted bus fare, BG-level poverty, BG-level unemployment, 1 km buffer level street connectivity and population density, dummy indicator of urbanicity, and dummy indicator of imputed gasoline prices.

[a]Coronary Artery Risk Development in Young Adults Study (U.S., 1992–93 to 2000–01), with black and white young adults recruited from four U.S. cities at baseline

[c]Coefficients can be interpreted as changes in total PA score associated with per unit change in each exposure variable.