LONGITUDINAL ASSOCIATIONS BETWEEN NEIGHBORHOOD ENVIRONMENTAL FACTORS (GASOLINE PRICE AND STREET ATTRIBUTES) AND INDIVIDUAL PHYSICAL ACTIVITY

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ABSTRACT

NINGQI HOU: Longitudinal associations between neighborhood environmental factors (gasoline price and street attributes) and individual physical activity
(Under the direction of Barry Popkin and Penny Gordon-Larsen)

Background: Physical activity (PA) may be influenced by environmental factors. As part of the socioeconomic environment, gasoline price is a key component of the cost of driving and may influence individuals' transportation modes and PA; as part of the built-environment, street attributes such as connectivity are hypothesized to be supportive of PA, particularly street-based PA (SBPA). **Methods:** This research used secondary data from CARDIA study, a prospective cohort of young adults (N=5115 at baseline, 1985-86) followed through 2000-01 with three repeated examinations. Based on a PA history questionnaire administered at each examination, we calculated PA scores in exercise units (EU) by intensity and frequency of 13 PA categories, and characterized SBPA as total frequency of walking, bicycling, and jogging/running. The individual-level CARDIA data were spatially and temporally linked to multiple environmental datasets by participants' time-varying residential locations, using Geographic Information Systems technology. This dissertation follows two aims. Aim 1 consists of analysis examining longitudinal association between inflation-adjusted, county-level gasoline price and PA, using a random-effect longitudinal regression model and two-part marginal effect models. Aim 2 is to investigate longitudinal association between neighborhood street attributes (intersection density, link-node ratio, and characteristics of local roads) and SBPA, using the two-part marginal effect modeling, by urbanicity and gender. **Results:** A $.25 increase in gasoline price was significantly associated with an increase of 11.6EU in total PA score (95% CI: 2.5-20.6). Gasoline price was also positively associated with jogging/running and non-strenuous sports that do not generally involve driving, and inversely associated with bowling and racket sports that generally involve car travel. A 1 standard deviation increase in intersection density (~15/km^2 additional intersections) was associated with a ~5% increase in SBPA in low urbanicity areas, where density of local roads was also positively associated with SBPA, but null or negative in middle/high urbanicity areas. **Conclusions:** Gasoline price was positively associated with overall PA, suggesting some additional PA is done in place of driving. Characteristics of neighborhood streets may influence SBPA of adult residents, particularly in rural areas. This research may inform policy efforts to encourage PA at population level.

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CHAPTER I

INTRODUCTION

I.A. Overview

Physical activity (PA) is inadequate at the population level, which has been a public health issue with high priority. Owing to the minimal impact of behavioral interventions to increase PA[1], recent work has turned to environmental factors as intervention targets[2], with some attention to dimensions of the built environment that support PA, such as walking[3-5]. Environmental factors that have been shown to support walking behaviors include reduced urban sprawl [5] and pedestrian or biking infrastructure (e.g., sidewalks, bike lanes [6] and street connectivity [7, 8]). While there has been some study of the association between street attributes, such as block size and numbers of street intersections, the literature is dominated by cross sectional designs [8-15]or within single metropolitan areas[8, 13, 15], resulting in inconsistent findings across studies. Also, while diet research has begun to address economic factors, such as food prices as they relate to dietary intake and obesity[16, 17], very little research has addressed broader economic factors likely to impact PA, such as gasoline price. Nor has there been much research on how community-level prices of gasoline affect overall PA patterns as well as shifts in types of leisure PA patterns (e.g., running, walking and bicycling) over time.

As part of the socioeconomic environment, gasoline price is a key component of the cost of driving and may influence individuals' transportation modes and PA. As part of the built-environment, street attributes may facilitate PA, particularly street-based PA

(SBPA), including walking, bicycling, and jogging. The purpose of this research project is to investigate how changes in gasoline price and changes in street attributes are associated with changes in overall PA as well as changes in sub-PA, such as walking and other forms of SBPA. Understanding longitudinal environment-PA association is a start by providing evidences, and ultimately, practical implications for neighborhood design that may contribute making policy to modify environment to be friendly to PA and well being.

I.B. Specific Aims

Aim 1: To investigate how changes in county-level gasoline price is associated with changes in overall individual-level PA as well as changes in subcategories of PA (walking, cycling, etc.) that may substitute driving.

Aim 2: To investigate how changes in residential street attributes (street connectivity and local roads) are associated with changes in overall PA and change in street-based PA, and how these associations vary across urban context and by gender

CHAPTER II

CONCEPTUAL FRAMEWORK

II.A. Aim 1 conceptual framework

The overall framework for Aim 1 is shown in Figure 2.1. The price of gasoline is directly related to purchase decisions. A lower price may promote purchasing, while a higher price is likely to discourage it. With driving being more expensive, people may reduce driving and alternatively choose active transportation such as walking, bicycling, or taking buses, which are cheaper than driving. People may also reduce trips that involve driving, and stay at home, in the neighborhood, or go to nearby places for leisure activities. Therefore, their PA pattern may change in responding to a rise in gasoline price. Also, gasoline price should be considered along with income and overall cost of living. For people who are wealthy and living in already expensive areas, increased gasoline price may be less of a concern, compared to those with less money. Other sociodemographics may also relate to purchase behaviors and PA behaviors, and should thus be adjusted for. An ideal way to model the gasoline price-PA relation is to learn how a shift in gas price affects the selection of each trip to work or shopping and so on, and look at the tradeoffs. However, to do this, we would need data on mode of travel to work, shopping and for other activities. In turn we would look at how temporal shifts in transportation modes are associated with overall activity and sub-categories. Ultimately, we would want to measure car use, public transit use, walking, and biking to work or combinations of several of these at each time period.

II.B. Aim 2 conceptual framework

Figure 2.2. shows the overall framework for Aim 2. Street connectivity and local roads are neighborhood-level street attributes. Individual-level walking, cycling, and jogging/running are common forms of PA that are usually conducted in streets. We hypothesized that street attributes are positively associated with PA, and that higher connectivity and availability of local roads may affect overall PA and particularly street-based PA (SBPA: walking, cycling and jogging/running). Characteristics of the built environment also relate to urbanicity, which may reflect different types of urban form or context, such as downtown, suburb, and rural areas, where street patterns may vary greatly. We hypothesized that the level of urbanicity modifies the association between street attributes and SBPA, because changes in street attributes may have different impact on PA depending on the context. Gender is related to PA level and patterns, with men usually being more active than women. We hypothesize gender as another potential effect measure modifier because different aspects of environmental attributes may be differentially important to men vs. women.

Figure 2.1. Conceptual model for Aim 1 (county-level gasoline price and individual-level physical activities)

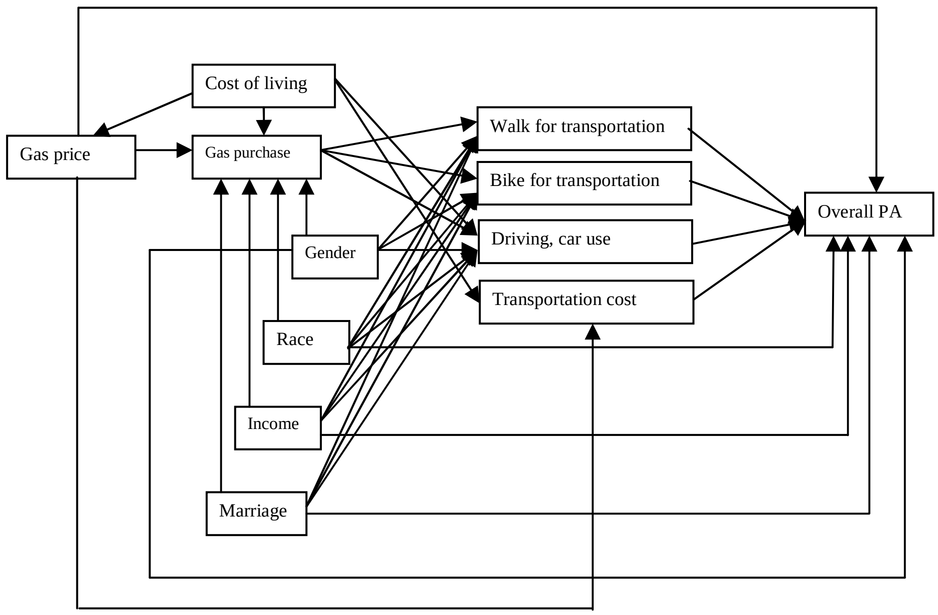
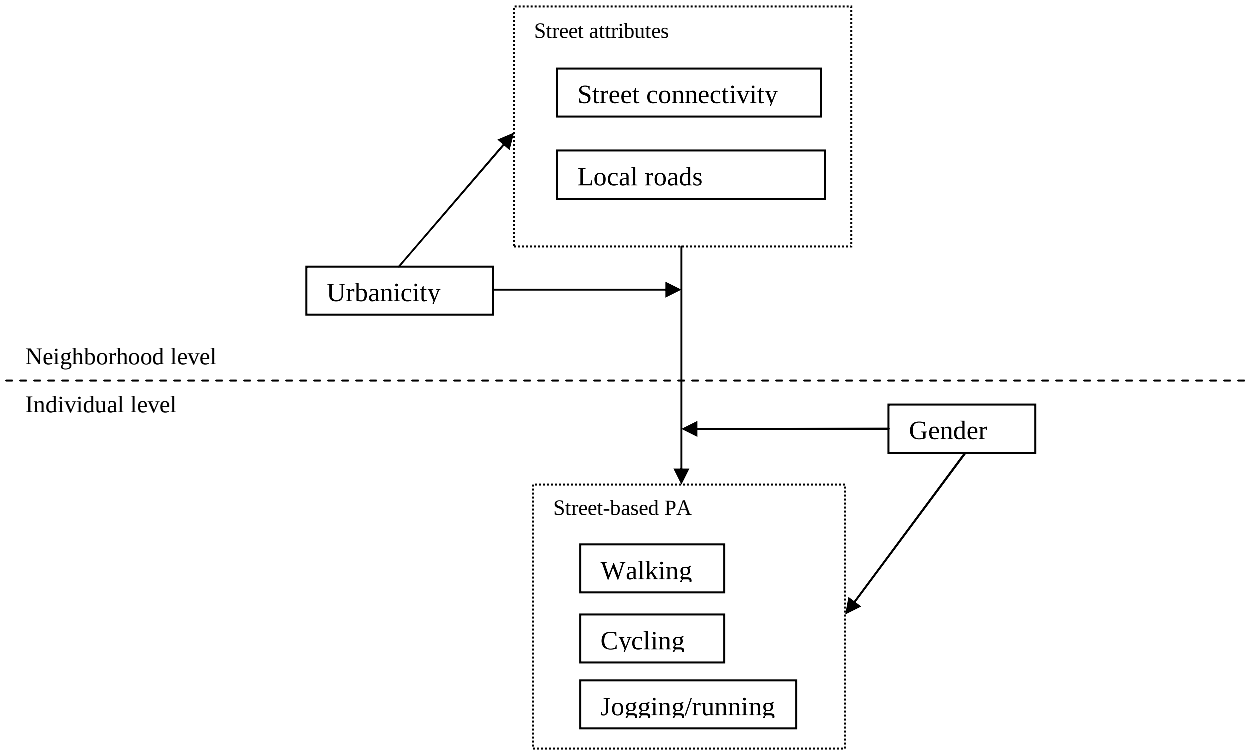


Figure 2.2. Conceptual model for Aim 2 (street attributes and PA)



CHAPTER III

LITERATURE REVIEW

III.A. Physical activity

Problems of sedentary lifestyle and benefits of PA

In the United States, it was estimated that 200,000 deaths annually were related to a sedentary lifestyle [18]. Physical inactivity has become the second leading modifiable risk factor for chronic disease after smoking, and contributes significantly to total mortality in western countries [19]. The estimated annual cost in lives lost ranged from $200,000 to $300,000, and the medical costs due to inactivity and related consequences were estimated to be $76 billion in 2000 [20]. Regular PA reduces the risk of premature death and chronic diseases such as obesity, coronary heart disease, type 2 diabetes, colon cancer, osteoarthritis and osteoporosis [21]. Data from the Framingham Heart Study show that moderate and high, compared to low PA level increase life expectancy for men at age 50 by 1.3 and 3.7 years, and results were similar for women (1.5 and 3.5 years for moderate and high PA compared to low PA)[22].

Low PA at population level

Most Americans have little or no PA in their daily lives. According to data from the Behavioral Risk Factor Surveillance System (BRFSS), in 2001, 26% of American adults were sedentary, and only 45.4% of the U.S. population met the Centers for Disease

Control and Prevention (CDC) recommendations for PA (at least 30 minutes of moderate PA five or more days per week). Women, African-Americans, Hispanics, older people and those with lower incomes are more physically inactive [23]. From 1990 to 2000, recreational activity was relatively stable or slightly increasing, but all other types of physical activities (occupation, transportation, and home) declined. Promotion of PA is a high public health priority. To correct the high prevalence of physical inactivity, many individual- and community-level lifestyle interventions have been carried out to promote PA among a wide range of the population, emphasizing common activities with mild to moderate intensities that contribute to overall PA. Increasing PA in population level has been described as the "best buy" for improving public health [24].

Overall PA

Overall PA is a grand summary of all forms of activities as far as they involve the use of one or more large muscle groups and raises the heart rate. Accurate measurement of total daily energy expenditure is possible using doubly-labeled water technique but this is very expensive and thus not suitable for epidemiology studies that usually recruit large population samples. Alternative approaches to PA measurements are based largely upon questionnaires that estimate PA in metabolic equivalents (METS), physical activity scores, or values obtained from accelerometers or pedometers. In this research we used a PA questionnaire and derived a total PA score. Overall PA is usually measured and included in most PA related research. All sub-categories of PA contribute to overall PA, and accumulating adequate PA overall is the ultimate goal to provide health benefits.

Street-based PA

Street-based PA (SBPA), including walking, jogging/running and cycling, are the most common forms of PA, and are usually performed in neighborhood streets and public open spaces. Public health policy literature has identified walking as the PA behavior of adults that should be the most amendable to influence. Walking has been described as near perfect exercise [25], and even walking at a moderate pace of 5km/hour (3miles/hour) expends sufficient energy to meet the definition of moderate intensity PA [26]. Walking, together with cycling, is a healthy alternative to vehicle driving that contributes to traffic congestion, air pollution and the risk of injury and death to road users. There have been many behavior interventions aimed in promoting population shift from using cars towards walking and cycling, but only resulted in a shift of ~5% of all trips among the motivated subgroups[1]. In other words, interventions targeting individuals haven't shown much effectiveness, and new strategies in promoting walking and cycling are warranted. Jogging and running are commonly performed aerobic exercises, and can be quite vigorous. There has been epidemiological evidence that a lifelong habit of vigorous PA results in a reduction of cardiovascular disease [27]. Recreational running is also linked to better weight control [28].

Other sub-categories of PA

PA questionnaires usually categorize different forms of PA into sub-categories based on their similarity in intensity and type, instead of asking for each of them specifically. For example, varying kinds of sports can be grouped into strenuous sports (such as basketball, football, skating, and skiing), and non-strenuous sports (such as softball, shooting baskets, and ping pong). The categorizations may vary by questionnaire. In this research, we used a PA questionnaire that contains 13 sub-categories of PA, with details discussed in Chapter IV.

III.B. Environment attributes and PA levels

Factors that can be changed to influence PA have been classified within several domains: demographic and biological, psychological, cognitive and emotional, behavioral attributes and skills, social and cultural, built environmental, and PA characteristics (perceived effort and intensity)[7]. Within these domains, built environment attributes is a new topic of research interest and among the least understood of the known influences on PA [7].

Role of economic factors

Time cost and money cost are socioeconomic factors that may play a role in shifting people's activity mode. This dissertation focuses on gasoline price, as it is a key component of the cost of driving with which people are usually concerned. We examine how gasoline price is related to overall PA and PA components. While overall gas prices remained moderately stable over time, there have been large variations spatially and temporally within each area in the U.S. The cost of a gallon of gasoline reflects several different components, including the cost of crude oil, federal/state/local taxes, refining costs and profits, distribution, marketing and station costs and profits. In 2000, prices varied by 15-20 cents per gallon with prices lowest in the Southeast and highest in the West and Midwest, and in general, prices are higher in summer and fall and lower in late winter [29]. On average, the price of a gallon of unleaded regular gasoline has been relatively stable in the 80s and 90s ranging from $1.06-1.25 including tax, however, since the new millennium gasoline price has increased substantially to $3.26 in March 2008 [30].

Figure 3.1. Average price of unleaded gasoline (per gallon), 1990 to 2008; data from U.S. Energy Information Administration.

Price elasticity of gasoline demand measures the sensitivity of changes in gasoline demand quantity with respect to changes in gasoline price. The short-run price elasticity of gasoline demand in the United States during the 1970s and 1980s has been studied extensively, ranging between -0.21 and -0.34 consistently from the literature. For the period from 2001 to 2006 the price elasticity was estimated as -0.034 to -0.077, which is significant though less elastic today than in previous decades [31].

As a key component of the cost of driving, gasoline price may influence individuals' transportation choices, including active ones such as walking and bicycling, and inactive choices such as driving. As gasoline consumption is responsive to price changes [31-33], any price increase would reduce driving and possibly increase other modes of active commuting. There are studies on how the shift in mode of transport affects incident obesity and weight gain [34-36]. One European study showed significant inverse association between gasoline price and prevalence of obesity [37], which is contributed by reduced PA. There is evidence from urban planning literature suggesting that a combination of urban design, land use patterns and transportation systems that promote walking and bicycling will help create active and healthier communities [38]. However, there is minimal research on how community-level prices of gasoline affect overall PA patterns as well as shifts in types of leisure PA patterns (e.g., running, walking and bicycling) over time. Walking and bicycling are also forms of active transportation that may substitute inactive transportation when driving becomes less affordable.

Role of built environment factors

The built environment encompasses all buildings, spaces and products that are created, or modified, by people. It includes homes, schools, workplaces, parks/recreation areas, greenways, business areas and transportation systems. Beyond the individual and community level approaches, public health advocates have now moved from the traditional domains to include the societal and built environments that have been largely ignored in earlier studies, and environmental characteristics that correlate with improved health have become a public health research priority [2]. Understanding environmental influences on PA is an important and challenging new area of population health research [2]. Environmental determinants are modifiable factors in the physical environment that impose a direct influence on the opportunity to engage PA, providing cues and facilities for activities. Environmental changes that reinforce factors supporting physical activities and reduce the barriers, may serve to promote PA. Environmental interventions, such as the design of more walkable neighborhoods, are appealing because they have the potential for sustained impact on populations rather than short-term impacts on individuals [39].

From a policy making perspective, to provide confidence for the advocacy of making substantial and long-lasting environmental change as an important opportunity making physically active choices easier, research is needed to determine whether the environmental changes indeed increase the likelihood of more active behavioral choices [2]. There has been evidence that supportive attributes of community physical environments can be associated with increased activity level, and the availability of PA equipment is convincingly associated with vigorous PA/sports and connectivity of trails with active commuting. Studies in the 1960s and 1970s showed an inverse relation between recreation participation and the distance between residences and a recreational opportunity (Cicchetti 1969; Lindsay, 1970). The presence of a positive association between objective availability of resources and PA suggests that improving spatial access to resources is an appropriate strategy to increase PA in population level [40].

Both perceived and objectively determined environmental attributes (particularly aesthetics, convenience and access) are associated with an increased likelihood of PA. However, a review article indicated that most studies used cross-sectional designs with limited measures of environments, thus no strong conclusion has been drawn and more research of better quality is needed [19]. It is important to conduct research with clear definitions of environmental attributes and PA within stronger study design, and the predictive capacity of studies could be further enhanced if specific activities were studied within clearly defined environments.

Street attributes and street-based PA

Recent studies developed walkability models combining several built environment characteristics to optimally predict walking [9]. A neighborhood is more walkable if it has higher residential density, more mixed land use, and greater street connectivity. Saelens et al. found that living in a highly walkable neighborhood was associated with participants spending more time walking for errands and on breaks at work or school, compared to those living in a low walkable neighborhood [3]. Frank et al. found walking was consistently higher for all gender/ethnic groups in more walkable neighborhoods [4]. Residential density, connectivity, and land use mix have all been studied as predictors of walking or PA[2, 7, 11, 38, 41-44], but results from these studies have not been consistent [9]. For example, residential density and connectivity are associated with walking or PA in some studies[5, 8, 45], but not in others [13, 46]. Boer et al. found higher levels of business diversity and higher percentages of four-way intersections were associated with more walking, but housing density and block length did not appear to be associated with walking [12]. There are unexpected but significant findings that more walking or PA was observed in neighborhoods with reduced access to shops[47, 48], fewer PA facilities[15, 49], or poor sidewalk conditions[50]. Discordance among studies may be due to differences in populations, disagreement between perceptions and objective measures of the environment, or environmental measurement at aggregate levels that mask relevant small-scale variations[2, 38, 44].

Previous research has either examined walking, jogging/running, and cycling separately, or study the overall PA with all activity categories combined. As out-door non-sport activities, walking, jogging and cycling share similar environmental requirements such as street/sidewalk availability and community safety. Few studies have considered the three popular activities together, which may together be influenced through improving the built environment.

III.C. Objective measurements for environmental factors

There are three main types of measurement methods to identify environmental attributes as independent variables: 1) microlevel ratings of relevant environmental attributes in specific areas by trained observers; 2) self-report measures of attributes such as facilities, activity opportunities and aesthetics; and 3) the use of GIS data to derive spatial measures of particular environmental attributes in local areas [51]. Several cross-sectional studies have measured the built environment objectively using field surveys to obtain measures of sidewalk continuity, street connectivity, ease of street crossing and block length, but these measurements are either subjective or only applicable in small study areas or samplings. There have been studies using perceived environment as the exposure, which was assessed by questions on perception of heavy traffic, lack of crosswalks/sidewalks, as a measurement of one's neighborhood. It was found that perceptions of an attractive, safe, and interesting neighborhood to be associated with walking for recreation[52]. However, the perceived measure is subjective, likely to be biased, and less comparable across studies. As a favorable alternative, some researchers have utilized the GIS to objectively measure the built environment, such as residential density, land use mix, access to attractive public open spaces, trails, linking with publicly available street networks over large study areas.

III.D. Neighborhood definitions

To contextualize activities of interest, the scale of the environment needs to be studied, and a clear definition of 'the neighborhood' is required in terms of subjective and objective measures of the environment. Although neighborhoods and their boundaries may be obvious to local residents, it is more common to find considerable disagreement on the size and contents of a neighborhood [53]. Studies that collect objective area-level data vary enormously in terms of the scale of the environment being measured or the definitions of the neighborhood boundary. Measures include: the quality of streetscapes within the subject's own street; urban form attributes within 400m or 1km of the subject's home or the metropolitan area or county level; spatial access to every facility within a study area with distance weighted by a distance of decay parameter; road network distance to a specific destination; or access to facilities within a buffer distance of the subject's home. In addition to the little agreement about which boundary or scale to use, the boundary to be used may differ for different populations, such as children, adults, and older adults [39], and for type of PA. Existing travel surveys show that most walking trips are well under one mile. Jogging/running may take longer than walking, and trips by bicycling may reach further but usually by less than 5 miles. In this research, 1, 3, 5, and 8km Euclidean buffers (circles with 1, 3, 5, and 8km radiuses surrounding each address) were available. One kilometer buffers were selected because of the relatively small territory typically covered on foot[43, 54]. Also, we studied three types of street-based PAs together (walking, jogging/running, and bicycling), and a smaller buffer reflects street/neighborhood conditions where the trip starts, which is important in making decisions in initiating the trip.

III.E. Summary

PA is inadequate at the population level and has been a public health issue with high priority. Gasoline price is a key factor in cost of driving, thus may play a role in shifting transportation modes, overall PA, and sub-components of PA that usually involve driving. Walking is the most common form of PA, which is known to be an important contributor to health. Along with jogging/running and cycling, the street-based PAs are cheap alternatives for both commuting and leisure PA when driving is more costly, and may be promoted by activity-supportive environment attributes, such as well connected neighborhoods and high density of walkable roads. Moreover, the environment-PA literature has been dominated by cross-sectional studies, and longitudinal research that allows studying changes may provide further evidences and insights.

CHAPTER IV

STUDY SAMPLE

IV.A. Overview

The Coronary Artery Risk Development in Young Adults (CARDIA) Study is a population-based prospective epidemiologic study of the evolution of cardiovascular risk factors among young adults, and data have been collected on a variety of factors believed to be related to heart disease. The CARDIA study has been used to answer a wide range of research questions, leading to more than 100 publications (listed at http://www.cardia.dopm.uab.edu/p_bopm.htm).

At baseline (1985-6), 5,115 eligible participants, aged 18-30 years, were enrolled with balance according to race, gender, education (high school or less and more than high school) and age (18-24 and 25-30) from the populations of Birmingham, AL; Chicago, IL; Minneapolis, MN; and Oakland, CA. Specific recruitment procedures were described elsewhere[55]. Seven repeated examinations were conducted: 1985-86 (Baseline), 1987-88 (Year 2), 1990-91 (Year 5), 1992-1993 (Year 7), 1995-1996 (Year 10), 2000-2001 (Year 15), and 2005-2006 (Year 20), with retention rates of 90%, 86%, 81%, 79%, 74%, and 72%, respectively.

IV.B. Individual-level Physical Activity

At each examination, self-reported PA was ascertained by an interviewer-administered questionnaire designed for CARDIA. Study participants were asked about frequency of participation in 13 different PA categories over the previous 12 months. Vigorous activities included jogging (or running), vigorous racquet sports, bicycling >10 miles/hour or exercising hard on an exercise bike, swimming, vigorous exercise classes or vigorous dancing, vigorous job activities such as lifting, carrying, or digging, home or leisure activities such as snow shoveling, moving heavy objects or weight lifting, strenuous sports such as basketball, football, skating, or skiing. Moderate activities included walking (or hiking), bowling (or playing golf), home exercise (or calisthenics), non-strenuous sports (such as softball, shooting baskets, volleyball, ping pong, or leisure jogging, swimming or biking), and home maintenance (or gardening, including carpentry, painting, raking or mowing). The reliability and validity of the instrument is comparable to other activity questionnaires[56] .

Because the participants were not asked explicitly about the duration of the activity, the amount of each activity performed is based on months of participation and an assumption about the relative duration of the activity for more versus less frequent participation. More frequent participation was assumed to be three times as great as the duration of infrequent participation. For each activity, frequency of participation was calculated as (m_i+3n_i), where i is each of the activity categories (walking, bicycling and jogging/running), m_i is the number of months of less frequent participation, and n_i is the number of months of more frequent participation. The cutoff-point for more vs. less frequent participation varies by activity, e.g., walking ≥4hours/week, and bicycling or jogging/running ≥2hours/week. The calculated frequency for each activity ranged from 0-36 units, with 36 representing more frequent participation of the activity for every month of a year (3×12month). We calculated frequency of SBPA as a summary of frequencies of walking, bicycling and jogging/running $\Sigma(m_i+3n_i)$, reflecting total amount of time spent in those street-based activities.

PA scores were expressed in exercise units (EU), and scores for each activity category were computed by multiplying frequency of participation by intensity of the activity. For each activity, the score was calculated as $b_i \times (m_i+3n_i)$, where b_i is the intensity level, while (m_i+3n_i) reflects frequency of participation, as described earlier . For example, walking scores ranged from 0-144 EU, with 144 EU roughly approximate to regular walking at ≥4hours/week over 12 months at 4 MET; biking scores ranged from 0-216 EU, with 216 EU representing regular, vigorous bicycling at ≥2hours/week over 12 months at 6 MET, whereas moderate bicycling was included in non-strenuous sports and was thus not examined. The calculated scores for all 13 categories of PA were then summarized for a total PA score.

IV.C. Environmental data

Community-level environmental data are available for baseline, exam year 7, 10 and 15. Residential street addresses of CARDIA participants were collected at each exam year and geocoded using a national geocoding service. Thus, we were able to link time-varying residential location of participants using GIS technology with externally derived data on environmental and economic factors, such as gasoline price, census-level sociodemographics, and street attributes. All geocodes were linked to time-varying spatial polygons for U.S. Census Aggregate areas and Counties to derive community-level measures. Specific measures will be discussed in method sessions in later chapters.

IV.D. Relocation over time

There was a substantial percentage of the sample that showed residential movement. We had the following proportions moving to a new state from exam Year 0 to 7 (10%), from Year 7 to 10 (14%) and from Year 10 to 15 (5%), and moving to a new county from year 0 to 7 (19%), from Year 7 to 10 (27%) and from year 10 to 15 (11%). Despite starting at baseline in the four U.S. metropolitan areas, by 2000-01 the CARDIA participants were located in 48 states, 1 federal district, 1 territory, 529 Counties and 3,805 Census Tracts. The spatial variability is great.

CHAPTER V

LONG-TERM PHYSICAL ACTIVITY INCREASES WITH LONGITUDINAL TRENDS IN GASOLINE PRICE: THE CARDIA STUDY

V.A. Abstract

Background: Gasoline price is part of the socioeconomic environment that may influence individuals' PA, yet research on this topic has been scarce. **Objective**: To investigate the long-term association between community-level gasoline price and PA. **Methods**: We used prospective data over 8 years from 3 exams of the Coronary Artery Risk Development in Young Adults (CARDIA) study N=3,968 black and white participants aged 25-37 at 1992-93, followed into 2000-01. From questionnaire data, a total PA score was summarized in exercise units (EU) based on intensity and frequency of 13 categories of PA including vigorous (e.g., running), moderate (e.g., walking), and household activities (e.g., chores). Using Geographic Information Systems, participants' residential locations were linked to county-level gasoline price data (inflation adjusted using BLS Consumer Purchase Index) derived from the Council for Community & Economic Research Cost of Living Index data and further to individual CARDIA data. We used a random-effect longitudinal regression model to examine associations between time-varying gasoline price and time-varying PA score, controlling for time-varying age, race, gender, education, marital status, household income, county cost of living, county

bus fare, census block-group poverty, urbanicity indicator, and baseline study center. **Results**: Holding all controlled variables constant, a quarter (25cent) increase in inflation-adjusted gasoline price was significantly associated with an increase of 11.6EU in total PA score (95%CI: 2.5-20.6). **Conclusion**: Gasoline price was positively associated with overall PA, suggesting some additional PA done in place of driving.

V.B. Introduction

Recent research has focused on environmental-level factors that may support active living, and thus potentially influence obesity. Environmental factors that have been shown to support walking behaviors include reduced urban sprawl [5], pedestrian or biking infrastructure (e.g., sidewalks, bike lanes [6] and street connectivity [7, 8]). While diet research has begun to address economic factors, such as food prices as they relate to dietary intake and obesity[16, 17], very little research has addressed broader economic factors likely to impact travel behaviors, such as gasoline price. Nor has there been much research on how community-level prices of gasoline affect overall PA patterns as well as shifts in types of leisure PA patterns (e.g., running, walking and bicycling) over time.

The price of gasoline is a key component of the cost of driving and thus may influence individuals' transportation choices, including active modes of transit, such as walking and bicycling, versus inactive choices, such as driving. As gasoline consumption is responsive to price changes [31-33], any price increase could theoretically reduce driving and possibly increase modes of active commuting, such as walking and biking. There are studies on the association between mode of transit and obesity [34-36]. One European study showed a significant inverse association between gasoline price and prevalence of obesity[37] . Yet, gasoline price would not be assumed to affect obesity directly. However, research on how price may influence PA is scarce. Up to date, there is only one cross-sectional study on gasoline price and suggested prevalence of cycling is higher in areas with higher gasoline prices[57].

In this chapter, we investigate the longitudinal association between community-level gasoline price and overall leisure PA as well as specific types of PA theoretically most likely influenced by gasoline price (e.g., walking and bicycling). We capitalize upon 8-year time-series data from the CARDIA study, including time-varying PA data as well as time-varying community-level gasoline price data linked to the time-varying residential location of study participants using GIS technology.

V.C. Methods

Main Exposure: Gasoline price

The Council for Community & Economic Research (C2ER, www.c2er.org, was founded in 1961 as the American Chamber of Commerce Research Association, ACCRA) provided the only price data available at the smallest geographic unit in the US, which are widely used by researchers in the field of Economics, particularly in studies of tobacco pricing and smoking behavior [58-60] . Researchers have found high correlation between C2ER data and the Bureau of Labor Statistics consumer price index data, which is collected at much larger aggregate US region[60]. County-level Gasoline Price (USD per gallon) for each participant was part of Cost of Living Index (COLI) data compiled and reported on a quarterly basis by the C2ER. Gasoline price data were linked to each individual participant by their residential county, at each exam year. When gasoline price was collected, the season (1-4 quarter of a year) was also recorded. For those counties that gasoline prices were unavailable, imputation strategies were applied to replace the missing data. A gasoline price dummy indicates whether gasoline price was imputed: 1) Not imputed: gasoline price was as originally collected in county or averaged across the residential Metropolitan Statistical Area (MSA); 2) Imputed: gasoline price was imputed using state averages or data from other seasons (Year 7: 30%; Year 10: 16%; Year15: 15%). We did not use gasoline price data from Year 0 given that at baseline, participants lived in close geographic proximity to the study centers, resulting in very little variation in gasoline price. Therefore, we used data from exam year 7, 10 and 15 only for analysis.

For comparability across time, we inflation adjusted gasoline price data using Bureau of Labor Statistics Consumer Price Index (CPI). CPI estimates changes in the prices paid by urban consumers for a representative basket of goods and services over time. The inflation-adjusted gasoline price was calculated by dividing actual gasoline price by concurrent CPI when the price was collected, then multiplying by the anchor CPI in 2001 first quarter. We used the inflation adjusted gasoline price as our main exposure variable.

Covariates (control variables)

Individual-level covariates included race, gender, age, educational attainment, marital status, household income, and baseline study center.

Community-level covariates: From C2ER we used county-level COLI and bus fare. COLI was designed to compare cost of living differences among urban areas based on price of consumer goods and services consisting of six major categories including grocery items, housing, utilities, transportation, health care, and miscellaneous goods and services. County-level bus fare (one-way, 10 miles) reflects the cost of public transportation.

From U.S. Census data, which are available for 1990 (contemporaneous to Year 7: 1992-93 and Year 10: 1995-96) and 2000 (contemporaneous to Year 15: 2000-01) for the time frame that CARDIA data were collected, we used aggregate unit Census block group (BG) level poverty (i.e. in participant's residential BG, % households that were >200% poverty level), BG-level means of transportation to work for workers >=16 years of age (i.e. in participant's residential BG, % workers travel to work by walking or cycling), BG-level distance to work (i.e. in participant's residential BG, % workers that take >=30min travel time to work), and BG-level urbanicity indicator of living in MSA or out (urban vs. rural). These variables reflected community characters where the individual participants resided.

Statistical Analysis

All statistical analyses were conducted using Stata (version 10.1, College Station, TX). Descriptive statistics were computed for gasoline price, PA scores, and covariates. We used longitudinal data with repeated measures across individuals, which could theoretically result in correlation of observations due to time invariant unobservable factors. To address this correlation, we used Random-Effect (RE) longitudinal regression models, which cluster on individuals and incorporate both between- and within-individual variation. We controlled for season during which gasoline prices were collected, 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, BG-level inflation-adjusted bus fare, BG-level poverty, urbanicity, and a dummy indicator for imputed gasoline prices). We tested gender, race, and household income for interaction with the main exposure by including the appropriate cross-product terms in the model and employing the likelihood ratio test. We observed no statistically significant effect measure modification.

In addition to modeling overall PA, we modeled walking and bicycling separately given the potential for substitution in transportation modes (from driving to walking or bicycling). Given the considerable (>10%) proportion of participants who reported no walking or bicycling, we used a two-part marginal effect model (MEM). Two-part MEM models are appropriate when examining outcomes that have a large proportion of zero values (i.e., no activity) while the remaining values are positive and continuous [61]. In the two-part MEM, we estimated two separate decisions: 1) the decision to conduct the activity (a probit regression model using maximum likelihood estimation to estimate probability of conducting a given activity); and 2) the amount of activity, conditioning on the decision to conduct said activity (an ordinary least square regression model conditioned on only those who conducted the given activity). We multiplied the two point estimates from each part, resulting in a weighted mean of the association between gasoline price and score of the given activity. The two parts were estimated separately before deriving unconditional estimates and bootstrapped standard errors (using 1000 replications, each clustered on individual). We pooled data across three exam years and used robust standard errors to correct for multiple observations on individuals. We included all individual- and community-level covariates as in the RE models, plus two additional community-level measures (proportion of population walking or bicycling to work, and proportion of population who travel over 30 min to work). In addition to walking and biking, we also ran two-part MEM models for all other 11 PA sub-categories to understand how each of the 11 sub-categories of PA contributed to total PA change.

As a sensitive analysis, we ran all models by including body mass index and smoking (smoker, ex-smoker, vs. non-smoker) as additional control variables, but the estimations have minimal change.

V.D. Results

Descriptive Characteristics

The analysis sample reflects CARDIA sampling to achieve a race (black and white), gender, and education balanced mix of young to mid-aged adults; our sample reflects this **(Table 5.1)**. Over the eight years of follow-up, average household income has significantly increased even after inflation adjustment (average \$44.9±25.6K at year 7, and \$71.6±47.6K at year 15). Individual-level total PA, walking, and bicycling scores remained stable across exam years

Inflation-adjusted gasoline prices decreased from 1992-93 to 1995-96, and then significantly increased at 2000-01 (**Table 5.2**). The majority of the sample was from urban areas (<4% from rural areas), and gasoline prices were significantly higher in urban areas compared to rural areas in year 7 and 15 ($p<0.001$). CARDIA participants lived in areas where almost half of the population reported traveling at least half an hour to work, where approximately 5% of the population walked (and less than 1% bicycled) to work. As is typical of the US, CARDIA participants come from communities where the proportion of the population that walked to work significantly decreased over time ($p<0.001$).

Random-effect Longitudinal Models

Using the random-effect longitudinal regression model predicting total PA as a function of gasoline price, we observed a significant positive association between gasoline price and total PA, after controlling for relevant covariates (**Table 5.3**). A one quarter (25 cents) increase of inflation-adjusted gasoline price was associated with 11.6 EU increase in total PA score ($p=0.01$), which was about 4% of total PA score and can be translated as, for example, an equivalent of additional 20min walking per week.

Two-Part Marginal Effect Modeling

Using walking score as the outcome, the two-part model results suggested a positive association (although not statistically significant) between gasoline price and walking, where one quarter (25 cents) increase of gasoline price was associated with 1.5 EU increase of walking score (95% CI: -0.5, 3.5 EU, $p=0.2$) after controlling for all related covariates (**Figure 5.1**). The 1.5 EU increase of walking score can be translated as an additional 3 min of walking per week. There was no association between bicycling and gasoline price (beta=-0.2, $p=0.8$). Among the other 11 PA sub-categories, four sub-categories were significantly (p-value<0.05) associated with a 25 cent increase in inflation-adjusted gasoline price (jogging/running, vigorous racket sports, non-strenuous sports, and bowling).

Table 5.1. Individual-level characteristics of participants in the CARDIA study, 1992-93 to 2000-01

% 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%	47.1%
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 [a]	36.3(0.3)	41.4(0.4)	71.3(0.8)
Inflation-adjusted Household Income in $K [b]	44.9(0.4)	47.2(0.4)	71.6(0.8)
Physical Activity in EU[c]			
Walking Score[d]	46.9 (0.8)	46.8 (0.8)	48.9 (0.8)
Bicycling Score[e]	29.6 (0.8)	29.0 (0.8)	27.3 (0.8)
Total PA score[f]	338.6 (4.4)	331.5 (4.4)	346.6 (4.7)

[a]Actual household income was the original income collected before any adjust.
[b]Inflation-adjusted household income = actual household income/(CPI/anchor CPI). Anchor CPI = average CPI in 2001 first quarter.
[a,b] Both actual and inflation-adjusted household income have increased significantly across time (T-tests by pair with Bonferroni correction, all p-values<=0.0001).
[c]EU=exercise units, calculated using frequency and intensity of activity
[d]Walking score was not significantly different between any two exam years (T-tests by pair with Bonferroni correction).
[e]Bicycling score was not significantly different between any two exam years (T-tests by pair with Bonferroni correction).
[f]Total PA score was not significantly different between any two exam years (T-tests by pair with Bonferroni correction).

Table 5.2. County-level gasoline price (actual and inflation-adjusted), and community-level covariates in the CARDIA Study, 1992-93 to 2000-01.

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, $/gallon)			
Actual gasoline price[a*]	1.16 (0.0014)	1.20 (0.0.0016)	1.60 (0.0031)
Inflation-adjusted gasoline price[b*]	1.44 (0.0017)	1.37 (0.0018)	1.61 (0.0032)
Urban	1.44 (0.0017)[**]	1.37 (0.0018)	1.61 (0.0032)[**]
Rural	1.39 (0.014)	1.35 (0.012)	1.51 (0.012)
County-level Covariates			
Cost of Living Index	1.12(0.0021)	1.14(0.0039)	1.18(0.0047)
Inflation-adjusted one-way bus fare ($) [c***]	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%)

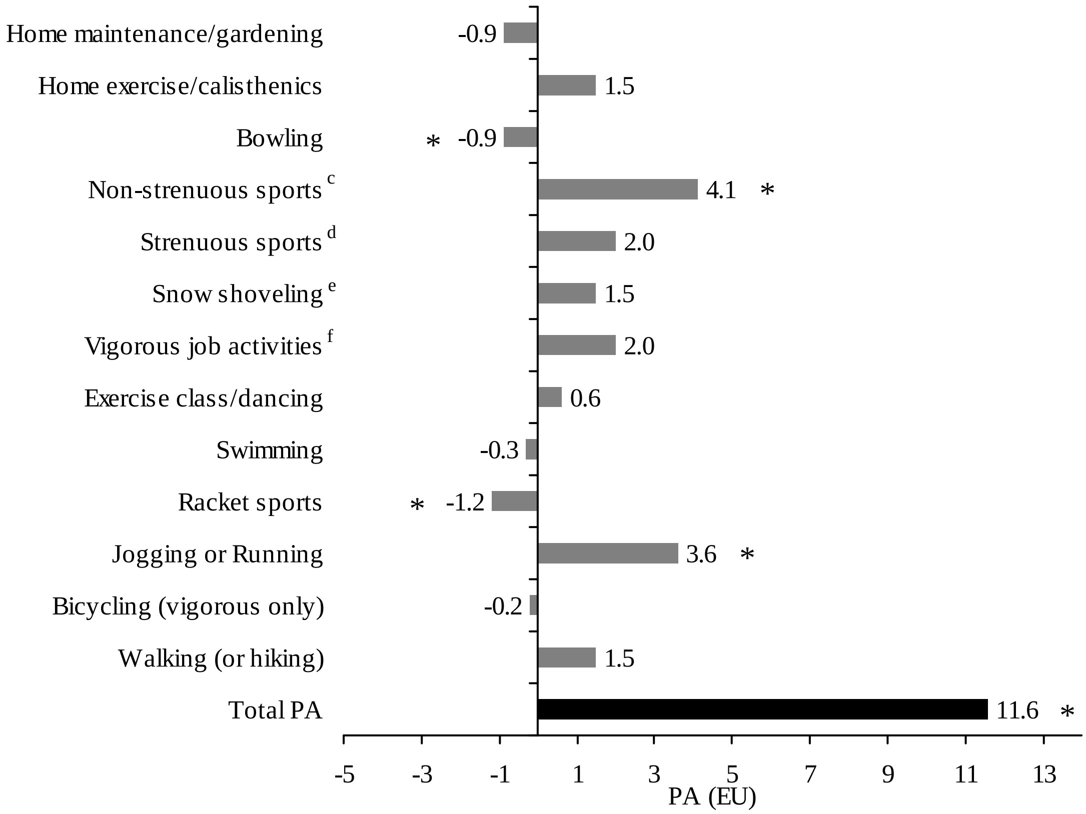
[a]Actual gasoline price is the original before any adjustment.
[b]Inflation adjusted using Consumer Price Index (CPI). Inflation-adjusted gasoline price = actual gasoline price/(CPI/anchor CPI). Anchor CPI = average CPI of year 2001 first quarter.
[c]Inflation-adjusted bus fare = actual bus fare/CPI/anchor CPI. Anchor CPI = average CPI in 2001 first quarter.
[*] Significantly different between any two exam years (p<0.0001; T-tests by pair with Bonferroni correction).
[**] Statistically higher in urban areas than in rural areas (p<0.001) by t-tests.
[***] Significantly different between any two exam years (p<0.001; T-tests by pair with Bonferroni correction)
[****] Significantly decreased from year 7 to year 10 and 15 (p<0.01; T-test by pair with Bonferroni correction).

Table 5.3. Predictors of total physical activity using random-effect longitudinal regression models[1], the CARDIA Study 1992-93 to 2000-01.

	All study centers		
Predictors	***Coeff***	***95% CI***	***P-value***
Inflation-adjusted gasoline price, per 25 cents	**11.6**	**2.5, 20.6**	**0.01**
Age in years	**-2.7**	**-3.8, -1.5**	**<0.001**
Black vs. White	**-17.1**	**-32.3, -1.9**	**0.03**
Female vs. Male	**-162.0**	**-175.7, -148.3**	**<0.001**
High school vs. <High school	**24.5**	**11.2, 37.7**	**<0.001**
>=College vs. <High school	**21.6**	**2.8, 40.5**	**0.03**
Married vs. Unmarried	**-28.7**	**-40.0, -17.5**	**<0.001**
Inflation-adjusted household income in $K	**0.7**	**0.5, 0.8**	**<0.001**
Oakland vs. Birmingham	**49.9**	**23.9, 75.8**	**<0.001**
Chicago vs. Birmingham	**55.2**	**32.9, 77.5**	**<0.001**
Minneapolis vs. Birmingham	**53.2**	**33.1, 73.3**	**<0.001**
Cost of Living Index	-11.7	-45.2, 21.7	0.5
Inflation-adjusted Bus fare, $	3.6	-12.8, 19.9	0.7
% population > 200% poverty level	0.2	-0.08, 0.5	0.2
Rural residence vs. urban	18.7	-19.1, 56.6	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, dummy indicator of urbanicity, and dummy indicator of imputed gasoline prices.

Figure 5.1. Predicted changes of total physical activity [a] and its 13 sub-categories [b], per 25 cents increase of inflation-adjusted gasoline price among participants from the CARDIA Study, using two-part marginal effect modeling with bootstrap.



*p<0.05

[a] By random-effect longitudinal regression model (Table 5.3).

[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 % workers age >=16 travel 30+min to work, BG-level % workers walk to work, BG-level % workers bicycle to work, dummy indicator of urbanicity, and dummy indicator of imputed gasoline prices. Then we performed Bootstrap with 1000 replications to estimate standard error for the derived point estimate.

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

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

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

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

V.E. Discussion

Using a quality time-varying measure of gasoline price and excellent longitudinal PA data, we found a positive long-term association between gasoline price and total PA. Essentially, a one quarter (25 cents) increase of inflation-adjusted gasoline price was associated with 11.6 EU increase in total PA ($p=0.01$), which averaged from 331-347 EU (±274-282 EU) and the average remained stable in this cohort during the examined time period over weight years. As 144EU represent regular walking at four or more hours per week (4×60min=240min walking), 11.6EU is about 1/12 of 144EU that is 240min/12=20min walking. Thus in rough terms, the energy expenditure of 11.6 EU was approximately equivalent to 20 min additional walking per week. On a population-level this increase would have substantial impact.

Gasoline price is a key factor in cost of driving. On average, the price of a gallon unleaded regular gasoline was relatively stable in the 80s and 90s ranging from $1.06-1.25 including tax, and since the new millennium gasoline price has increased substantially[30]. Relative to many other countries/places, gasoline prices are considerably lower in the US, and there is clearly room to change the gasoline price in this country. In addition to the overall trend of gasoline prices over time, there have been large variations spatially and temporally within each area in the US. Gasoline price may influence people's driving and transportation behaviors, as well as PA and its components. Here we studied whether PA changed in relation to local gasoline prices over local times. We hypothesized that increased gasoline price would discourage car driving, and promote active commuting methods like walking and bicycling, which contribute to total PA. According to the two-part MEM model results, the association between gasoline price and walking was weak without statistically significance, and the association for bicycling score appeared null.

While strengths of our study include rich individual-level and community-level data, our study also had several limitations. First, it is important to recognize that while CARDIA has outstanding leisure PA data, no specific information on commuting patterns were collected longitudinally (e.g. the questionnaire questions did not explicit if walking includes those for commuting purposes), thus the measure used in our study might be confined to leisure time walking and bicycling only, which may be influenced by gasoline price to a lesser extent than commuting. Bicycling score captured vigorous bicycling (speed >10 mile/hr, on stationary or other bicycle), thus may omit non-strenuous forms of bicycling that could be used in bicycle commuting. To understand how sub-categories of PA contributed to the increased overall PA, we examined all other PA sub-categories comprising overall PA along with walking and bicycling. Among the 11 PA sub-categories, we found two were positively associated with gasoline price: jogging (or running) and non-strenuous sports, (which do not generally involve driving), while two were inversely associated (racket sports and bowling: generally involve car travel). In addition, the category of non-strenuous sports incorporated multiple activities, including leisure bicycling, which we cannot separate and which may distill results for vigorous bicycling. Another concern is potential errors in self-report PA. Questionnaire respondents may face cognitive difficulties in accurately understanding and reporting PA frequency and intensity, resulting in misreporting [62].

Second, the gasoline price data were missing for considerable proportion of our data. We overcame this limitation by using imputation strategies widely used in the literature [58, 63-65]. Further, price data were only available for larger county-level units. It is possible that within county price variations matter but there is no research on this topic. It is also possible for some degree of county mismatch in individuals who moved residences shortly before measurement. One added complexity was the lack of variation in geographic area for the baseline CARDIA sample, which required exclusion of baseline data. The baseline (1985-86) exam recruited participants living in close geographic proximity to the study centers, so there was little variation in gasoline price after controlling for baseline study center, and we cannot utilize data from the baseline examination.

Generalizability is limited in one sense. The CARDIA participants come from four U.S. cities at baseline. However, over time the participants have moved across the U.S. so that by the latest follow-up the CARDIA participants were located in 48 states, 1 federal district, 1 territory, 529 Counties and 3,805 Census Tracts. On the one hand, this movement across America provided substantial variability. At the same time, the fact that we have considerable residential movement over time, resulting in small numbers of individuals residing in shared geographic units, meant that we were unable to cluster the participants by geographic unit in our statistical models. The bulk of the sample continued to reside in primarily urban areas. Urbanicity could be a potential effect measure modifier as theoretically, people living in less urbanized areas may be likely have to travel further to work and may rely more heavily on driving due to less convenient public transit. Unfortunately given the small number of rural residents (<5%), we were unable to test the potential modification of urbanicity. We don’t yet have data on environmental factors such as specific urbanization level and street network that may be correlated with gasoline price.

Ours is the first study to examine gasoline price and PA longitudinally with great geographical variations using objectively measured, community-level gasoline price data, which were contemporaneously and geographically linked to individual participant's residential locations using GIS technology. The 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 the Consumer Price Index.[60] Further, we had excellent longitudinal data with standardized measures of physical activity from an instrument with known reliability and validity[56], and objectively measured gasoline prices that were linked to individuals by residential location. The association of gasoline price with PA cannot be attributed to long term time and age trends in PA, because, unlike the decrease in PA previously reported for years 0 through 7 [66], mean PA in CARDIA participants 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.

We found a positive association between gasoline price and total PA, where the energy expenditure is roughly equivalent to 20 minutes of additional walking per week (per 25 cents increase in gasoline price). Though active commuting cannot be examined explicitly in this study, our findings provide some evidence for the relationship between gasoline price and PA, suggesting increased gasoline price may promote PA in the long run. As the world's largest consumer of gasoline, the U.S. has lower gasoline prices compared with most other western countries while gasoline price largely reflects national pricing policy (mainly fuel taxes). Policy changes that introduce a significant elevation in gasoline price may positively impact PA at the population level.

CHAPTER VI

LONGITUDINAL ASSOCIATIONS BETWEEN RESIDENTIAL STREET ATTRIBUTES AND PHYSICAL ACTIVITY: THE CARDIA STUDY

VI.A. Abstract

Background: While street attributes, such as interconnected and walkable streets, are hypothesized to be supportive of physical activity, cross-sectional studies in homogeneous environmental settings predominate the literature. **Objective**: To investigate differential association between residential street attributes and street-based physical activity (SBPA) by urbanicity and gender. **Methods**: We used prospective data from 4 repeated exams including 5,115 young adults recruited in 1985-86, followed through 2000-01. Self-report SBPA was a total frequency of walking, bicycling, and jogging/running. Using Geographic Information Systems, we spatially and temporally linked time-varying residential locations to street attribute data (street connectivity and local roads) in a 1 Euclidean km residential buffer. We performed two-part marginal effect modeling to examine longitudinal associations between street attributes and SBPA, by urbanicity and gender, controlling for time-varying individual- and census-level covariates. **Results**: A 1 SD increase in intersection density (~15/km^2 additional intersections) was associated with a ~5% increase in SBPA in low urbanicity areas, where density of local roads was also positively associated with SBPA, but null or negative in middle/high urbanicity areas. **Conclusion**: Characteristics of neighborhood

streets may influence SBPA of adult residents, particularly in rural areas. This research may inform policy efforts to encourage physical activity.

VI.B. Introduction

Owing to minimal impact of behavioral interventions on increasing physical activity (PA)[1] , recent work has turned to environmental factors as intervention targets[2], with some attention to dimensions of the built-environment that support street-based physical activity (SBPA), such as walking[3-5]. The majority of this research has focused on characteristics of residential streets [12, 46, 67], with the idea that better street connectivity, indicated by more intersections, less dead end streets, more streets, and smaller blocks, leads to more SBPA, generally by reducing travel distance and providing a wide range of possible routes [68-72]. While there is a lack of national data on sidewalks, road size and type has been used as an indicator of walkability[69, 73].

We focus on two dimensions of residential streets: connectivity of streets, and density of local roads (generally, designated as roads for local traffic with a single lane of traffic in each direction)[73, 74]. Although there has been some study of the association between SBPA and residential street attributes, such as block size and numbers of street intersections, the literature is dominated by cross sectional designs [8-15], and single metropolitan areas[8, 13, 15], with inconsistent findings across studies. In contrast, there are very few studies that have focused on the relationship between road size and type and physical activity occurring in and around streets[73].

Further, given the lack of national data on this topic as well as studies with diverse geographic range and coverage, there is little understanding of how the relationship between residential street attributes and SBPA varies across diverse environmental contexts. Urban, suburban, and rural areas may have different land use and street patterns, ranging from urban gridded streets to suburban cul-de-sac design, which may differentially impact SBPA. Yet, few studies have the geographic variation necessary to capture differences in SBPA across these different environmental settings[75]. Further, it is likely that such relationships may vary by gender. One cross-sectional study on environment and obesity in later life, suggests that economic and social environment aspects are important for men, whereas built environment factors are more salient for women [76]. A Canadian study suggests that metropolitan sprawl, defined relative to population characteristics, was associated with higher BMI for men only [77]. Yet findings are mixed and all are cross-sectional [4, 8].

We aim to better understand the relationship between residential street attributes and leisure SBPA and how this relationship varies across urbanicity and gender. We capitalize upon 15-year longitudinal data from the Coronary Artery Risk Development in Young Adults (CARDIA) study, including longitudinal PA data as well as longitudinal street attribute data that are spatially and temporally linked to time-varying residential location of study participants using Geographic Information Systems (GIS) technology.

VI.C. Methods

The analysis sample includes only participants with complete and acceptably measured data without significant physical disabilities. Among 20,460 observations across the four exam years, 19.0% (obs=3,900) were excluded from analysis, mostly due to sample attrition during follow-up (obs=3,643), missing outcome data (obs=146), missing environmental data (obs=2) or statistical control variables (obs=109). A substantial percentage of the sample showed residential movement. Percentages moving to a new state were 10% from exam Year 0 to7, 14% from Year 7 to 10 and 5% from Year 10 to 15. Percentages moving to a new county were 19% from year 0-7, 27% from Year 7 to 10 and 11% from year 10 to 15.

Main Exposure: residential street attributes within 1 km Euclidean buffer

We selected a 1 km Euclidean buffer (circle of 1 km radius) for each residential point at each time period for each participant because of the relatively small territory typically covered on foot [43, 54] and the 1 km buffer has been empirically determined to be an easy walking distance [78, 79]. Attributes for street connectivity were extracted from StreetMap 2000 data (for exam years 0, 7, and 10) and from the enhanced product StreetMap Pro 2003 data (for exam year 15) by ESRI, Redlands, CA. Attributes for local roads were extracted from TIGER/line™ files. We describe these measures below and provide examples in **Figure 6.1**.

Street connectivity Higher street connectivity is defined as high number of intersections, few dead end streets, more streets, and smaller blocks. We hypothesized greater SBPA in areas with greater street connectivity. Using the StreetMap data, we identified intersections and based connectivity on the number of unique street connections at each intersection. We measured two dimensions of street connectivity: 1) *intersection density* is calculated as number of intersections with 3 or more unique intersecting streets (true intersections) in buffer divided by buffer area ($3.14 km^2$); and 2) *link-node ratio* is an index of connectivity and equals to the number of links divided by the number of nodes in buffer, where links = street segments (continuous street without interruption of intersection or cul-de-sac); nodes = intersections or cul-de-sacs (**Figure 6.1**). Higher values of intersection density and link-node ratio reflect higher level of street connectivity, largely through the provision of many possible direct routes (links) across the possible intersections (nodes) within the 1 km buffer. We hypothesize that higher street connectivity is positively associated with higher SBPA[68].

Characteristics of local roads: We measured local roads reflect as an indicator of more walkable roads relative to highways and other vehicle-friendly roads. We hypothesized that higher density of local roads and higher proportion of local relative to total roads would be positively associated with higher SBPA. We separated local roads from the total roads that include 7 major categories of road types: 1) road with major category unknown (A00-A08); 2) primary highway with limited access, such as interstate highway (A10-A18); 3) primary road without limited access, such as U.S. and State highway (A20-A28); 4) secondary and connecting road, such as State and county highways (A30-A38); 5) local, neighborhood, and rural roads, designated for local traffic usually with a single lane of traffic in each direction (A40-A48); 6) vehicular trail that is passable only by four-wheel drive vehicles (A50-A53); and 7) road with special characteristics, such as traffic circle and access ramp (A60-A65). Detailed descriptions can be accessed at http://www.census.gov/geo/www/tiger/appendxe.asc.

We focused on the major A4x category 'local, neighborhood, and rural roads', which we refer to as 'local roads' in contrast to the remaining categories, which we refer to as 'non-local' roads. We characterized local roads in two dimensions: 1) *density of local roads*: as total length of local roads within the 1km buffer, and 2) *proportion of* *local relative to total roads*: as the proportion of local road length relative to total road length in the 1km buffer.

We defined non-local roads by summarizing related major road categories (A0x-A3x, A5x, and A6x) and then calculated length and density of non-local roads as well as total roads within the 1km buffer (**Figure 6.1**). In models using density of local roads as main exposure, the density of non-local roads served as a control variable, because both local and non-local roads are related to behavior and non-local roads may confound the association between local roads and PA. This is analogous to what is done in energy partitioning models[80] Density of total roads served as a control variable in models using proportion of local relative to total roads as main exposure, because it is a proportion measure and total roads can be a potential confounder. This is analogous to what is done in nutrient density models [80].

In **Figure 6.1**, we provide examples of each of the connectivity (Panels A & B) and road type (Panels C & D) measures. For illustrative purposes, a low connectivity area would have <15 3 or more-way intersections per km^2 and <1.5 link-node ratio, which would be typical of a rural isolated area, whereas, a high connectivity area would have >50 3 or more-way intersections per km^2 and ~2.0 link-node ratio, typical of a dense city with a system of gridded streets (for illustrative purposes we include a small number of 3 or more-way intersections so as to not clutter space). A typical rural area might have less than 15 km of local roads within a 1km buffer and local roads might account for 60-100% of total roads. A typical urban area might have more than 30 km of local roads within a 1km buffer and local roads might account for 70-90% of total roads.

Effect Measure Modifiers

Given our primary hypothesis that association between street attributes and SBPA varies by level of **urbanicity**, we tested effect measure modification by urbanicity, which we defined using a combination of urban boundary data and population density.
Urban boundary was defined using Census-tract level indicator of living in vs. out of Metropolitan Statistical Areas (MSA). We derived population density from proportion of Census geography population and area within the 1 km buffer for each participant. Each exam year was contemporaneously matched with US Census and GIS data (exam year 0: 1980 county/Census tract; exam year 7 and 10: 1990 Census block-group; exam year 15: 2000 Census block-group). County/Census tract and block group populations were adjusted proportional to the percent of the county/Census tract/block group area that fell within the participant buffer. These proportional calculations were summed to produce total buffer population and area calculations.

As CARDIA participants were originally recruited from four U.S. major cities, most of them resided in an MSA, with only ~5% from rural areas. To refine our measure of urbanicity, we categorized Census tract-level population density in tertiles among participants living in an MSA, representing low (including rural), middle, and high urbanicity. The average population density in low urbanicity areas was 1,087/km^2, similar to density in low population-dense states such as South Dakota or New Mexico. In middle urbanicity areas, the average density was 2,893/km^2, similar to Staten Island, New York City's most suburban borough. In high urbanicity areas, the averaged population density of 7,348/km^2 is close to that in Queens, part of the most populous area in NYC [81].

Our secondary hypothesis is that residential street attributes and SBPA vary by **gender** across level of urbanicity. We hypothesized that men and women may respond differently to the street attributes, perhaps for safety or other reasons, Investigation of differences in street attributes in predicting physical activity across urbanicity has not been well addressed in the literature. While we included urbanicity and gender as effect modifiers, we did not consider effect modification by race for conceptual reasons. Our rationale was that in terms of potential policy efforts targeting environmental changes in street attributes, our findings would inform whether such changes would be relatively more or less important in rural versus urban settings, for example, and such efforts would target the full population in those areas, regardless of race. Nonetheless, we tested race for effect measure modification, purely for empirical purposes.

Covariates (control variables)

Individual-level covariates included age, gender, race, educational attainment, marital status, and baseline study center

Census-tract level covariates: Using U.S. Census data (1980, 1990, and 2000) contemporaneous to CARDIA exam years, we linked tract level variables that reflected neighborhood characteristics where the individual participants resided: 1) proportion of residents in the tract who walk to work, i.e. in participant's residential tract, % workers (≥16 years of age) travel to work by walking. This variable should indicate if neighborhoods have a sufficient mix of residential and employment land uses to make walking feasible and attractive[14], and it was reported to be inversely associated with BMI and risks of overweight/obesity[82]; 2) Median age of houses in the residential tract.

Residents of older neighborhoods generally report more walking[83]. 3) Proportion of white residents in the residential tract, reflecting racial composition in neighborhood. 4) Median household income in the residential tract, as a proxy of neighborhood socioeconomic status and was inflation-adjusted using Bureau of Labor Statistics Consumer Price Index, for comparability across time.

Statistical Analysis

We conducted all statistical analyses using Stata (version 10.1, College Station, TX). We computed descriptive statistics for the four street attribute main exposure (intersection density, link-node ratio, density of local roads, and proportion of local relate to total roads), the outcome measure of SBPA frequency, and all covariates. We performed separate models for each of the four street attribute main exposures to estimate the association between each type of street attribute and SBPA frequency.

A considerable proportion of participants reported no SBPA, resulting in positively skewed distributions on the outcome variable (12.4% zero values, the remainder positive and continuous). The type of outcome distribution is common in health economics literature (e.g. medical costs) and the prevailing strategy in such contexts is to use the two-part MEM to properly analyze these data [84-86]. Using the two-part MEM, a zero value of outcome is interpreted as a meaningful zero characterized by lack of participation in a given activity. The two-part model allows flexibility of separate decisions (in contrast to a traditional one-step longitudinal regression model), and is a more realistic approximation to the way people behave relative to our central hypothesis: street attributes that support PA will increase the likelihood for individuals to engage in

SBPA. This type of model is recommended in cases where the proportion of zero outcomes is ≥ 5%, and has been recently used in the public health literature [61, 87-90].

In the two-part MEM, we made separate estimations for two separate decisions: first, the decision to conduct SBPA, and second, the conditional frequency, thus resulting in estimates conditioned on whether or not SBPA was conducted. Programming of the two-part MEM model includes (1) a probit model using maximum likelihood estimation as the first part to estimate probability of conducting SBPA, and (2) an ordinary least square regression model conditioned on only those who conducted SBPA as the second part, to predict frequency of participation conditioning on any SBPA. The two parts have the same specifications and the equations are demonstrated below:

(1) $Pr(ConductSBPA_{it}) = \gamma_0 + \gamma_1 StreetAttribute_{it} + \gamma_2 StreetAttribute \times Urbanicity_{it} + \gamma_3 Urbanicity_{it} + \Sigma\gamma_x Covar_{it} + \mu_i + \nu_{it}$

(2) $SBPAfreq_{it}|ConductSBPA = \theta_0 + \theta_1 StreetAttribute_{it} + \theta_2 StreetAttribute \times Urbanicity_{it} + \theta_3 Urbanicity_{it} + \theta_x Covar_{it} + \mu_i + \nu_{it}$

Where the subscript *i* denotes an individual and *t* denotes time.

We pooled data across four exam years and robust standard errors were used to correct for multiple observations on individuals. The two parts were estimated separately during programming before deriving unconditional estimates (a weighted mean by multiplying estimates from the two parts) and bootstrapped standard errors (using 1000 replications, each clustered on individual). We controlled for individual- and Census tract-level covariates for both parts of the model. We included density of non-local roads as an additional control when density of local roads served as main exposure, and we included density of total roads as an additional control when proportion of local relative to total roads served as main exposure. We tested gender and urbanicity separately for effect measure modification by including appropriate cross-product terms (e.g., urbanicity by intersection density) and likelihood ratio testing at $p<0.05$. Both were statistically significant modifiers. Therefore we stratified all regression models by gender, and in each gender group we entered a product term of urbanicity with each main exposure variable. In addition, we tested effect modification by race by including a cross-product term of race by each main exposure, within each gender strata with urbanicity interactions, and followed by a likelihood ratio test. Race did not modify the association between street attributes and SBPA in men ($p>0.05$), but did in women ($p<0.001$). However, results from the race-stratified models in women were remarkably similar in effect and direction, albeit with reduced power. Given our conceptual rationale described earlier as well as statistical power concerns, we present non-race- stratified results for females. We also conducted a sensitivity analysis to assess our measure of street-based physical activity. We re-ran our models with frequency of additional (non-street-based) forms of PA as an additional control variable.

As the four main exposures have very different values and distributions, a1 unit change in value can vary greatly across measures. Thus, we present model estimations associated with a 1 SD change in each main exposure. For example, in low urbanicity areas, a 1 SD change in intersection density was 14.7 intersections per km^2; a 1 SD change in link-node ratio was 0.2; a 1 SD change in local road density was 8.3 km local roads in the 1 km buffer; and a 1 SD change in proportion of local relative to total roads was 11.0%.

VI.D. Results

Descriptive Characteristics

The analysis sample reflects CARDIA sampling to achieve a race (black and white), gender, and education balanced mix of young to mid-aged adults as shown in **Table 6.1**. SBPA frequency was significantly higher at baseline, while remaining relatively stable across years 7, 10, and 15. There was also temporal variation across the environment exposures, street connectivity and road density. Neither street connectivity nor road density differed significantly by gender for any exam year.

Mean values for intersection density, link-node ratio, and density of local roads were significantly higher with higher urbanicity, while the proportion of local relative to total roads was significantly lower with higher urbanicity (**Table 6.2**). For the Census tract-level covariates, the proportion of tract residents who walk to work and median age of housing were higher with higher urbanicity , while low urbanicity areas had a higher percentage of white residents (p-values=0.0001).

Statistical modeling results

We examined the association between street attributes and SBPA using two-part marginal effect models, stratified by gender, with interactions between urbanicity and each main exposure (**Table 6.3**).

In low urbanicity areas, intersection density was positively associated with SBPA, for both men and women. A 1 SD increase in 3 or more-way intersection density was associated with a 1.0-1.3 unit increase in SBPA frequency. This translates to approximately 15 additional 3 or more-way intersections per 1 km^2 with an approximate 5% increase in SBPA. Similarly, density of local roads was positively associated with SBPA, though only in men: a 1 SD increase in local road density was associated with a 1.0 unit increase in SBPA frequency. This translates to approximately 8 km additional local roads per 1 km buffer with an approximate 5% increase in SBPA. **In middle urbanicity areas,** we observed no significant association between street attributes and SBPA. **In high urbanicity areas**, we observed inverse associations between local roads and SBPA in women. A 1 SD increase in local road density (approximately 6 km additional local roads per 1 km buffer) was associated with a 1.3 unit lower SBPA frequency, or approximately 5-6% of mean SBPA or approximately 6 minutes per week of SBPA. A 1 SD increase in proportion of local relative to total roads was associated with a 1.4 unit decrease in SBPA frequency (~6% of average SBPA).

Table 6.1. Individual- and neighborhood-level characteristics in the CARDIA study, 1985-86 to 2000-01

% or mean ± SD	***Year 0 1985-86 (N=5,015)***	***Year 7 1992-93 (N=4,001)***	***Year 10 1995-96 (N=3,898)***	***Year 15 2000-01 (N=3,646)***
Sociodemographics				
Black %	52.0%	48.1%	48.5%	47.1%
Female %	54.5%	54.8%	55.3%	55.8%
Age in years	24.8 ±3.7	32.0 ±3.6	35.0 ±3.7	40.2 ±3.6
Married %	22.1%	44.2%	49.3%	60.3%
Education %				
<=High School	40.0%	28.9%	29.4%	23.0%
>High School; <=College	50.4%	53.0%	51.2%	56.3%
>College	9.6%	18.2%	19.4%	20.7%
Street-based Physical Activity (SBPA)				
SBPA frequency [a]	25.9 ±21.4*	21.5±19.9	21.2±20.4	22.1±20.8
1 km radius buffer level variables				
Street Connectivity				
Intersection density/km^2	52.2±14.4	46.8 ±18.5*	41.5 ±20.0*	44.7 ±21.7*
Link-node ratio	1.8 ±0.2*	1.7 ±0.2*	1.7 ±0.3	1.6 ±0.2
Local roads				
Local road density (km in 1 km buffer)	36.5 ±7.6*	33.2 ±9.7*	30.6 ±10.9	30.2 ±10.5
Proportion of local relative to total roads (%)	78.4% ±8.7%	78.7% ±9.8%	79.9% ± 10.7%*	77.7% ±11.8%**
Census Tract-level variables*				
Population density per km^2	4,555±3,450*	4,092 ±3,814*	2,802 ±3,011	2,760 ±3,161
Proportion of residents walk to work (%)	7.7% ±9.5%*	5.4% ± 8.1%*	4.0% ±6.4%*	3.1% ±5.6%*
Median age of houses in years	43.4 ±11.3*	41.7 ±14.6	41.3 ±15.9	41.8 ±17.0
Proportion of residents of white race (%)	54.3% ±33.8%*	58.7% ±34.7%	65.8% ±33.2%*	59.6% ±32.1%
Inflation-adjusted median household income	23,467 ±10,151*	38,158 ±17,156	38,557 ±18,383	50,278 ± 23,974*

[a]SBPA frequency = walking frequency + bicycling frequency + jogging/running frequency

Kruskal-Wallis rank tests with Bonferroni correction ($p<0.5/6=0.0083$)

*Significantly different from any other exam years

** Significantly different between year7&15

Table 6.2. Neighborhood-level exposures and related covariates in the CARDIA Study by neighborhood level of urbanicity, at baseline 1985-86.

	Urbanicity		
Mean ±SD	***Low***	***Middle***	***High***
Main Exposures: 1 km radius buffer level			
Street Connectivity			
Intersection density, 3+ intersections/km^2	37.6 ±14.7*	53.7 ±11.2*	57.2 ±12.3*
Link-node ratio	1.6 ±0.2*	1.8 ±0.2*	1.9 ±0.1*
Local roads			
Local road density (km in 1 km buffer)	28.6 ±8.3*	37.7 ±5.8*	38.9 ±6.3*
Proportion of local relative to total roads (%)	80.3% ±11.0%*	78.2% ±8.7%*	77.7% ±7.4%*
Covariates: Census Tract-level			
Population density (per km^2)	1,087 ±405*	2,893 ±671*	7,348 ±3,320*
Proportion of residents walk to work (%)	5.4% ±9.5%*	6.3% ±7.5%*	9.8% ±10.4%*
Median age of houses in years	32.7 ±10.4*	44.3 ±11.0*	47.2 ±8.7*
Proportion of residents of white race (%)	64.9% ±36.1%*	51.1% ±31.8%	52.6%±33.6%
Inflation-adjusted median household income	23,800 ±14,023**	23,082 ±9,870	23,641 ±8,278

Kruskal-Wallis rank tests with Bonferroni correction ($p<0.5/6=0.0083$)

*Significantly different from any other two columns

**Significantly different between low and high urbanicity.

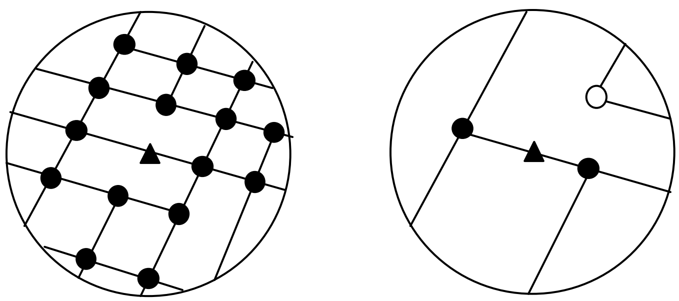
Table 6.3. Associations between residential street attributes and street-based physical activity frequency using two-part marginal effect models[a], the CARDIA Study 1985-86 to 2000-01.

	Urbanicity								
	Low			***Middle***			***High***		
Main Exposures (per 1 SD increase)	***β***	***95% CI***	***P-value***	***β***	***95% CI***	***P-value***	***β***	***95% CI***	***P-value***
	Street-Based Physical Activity(SBPA) frequency								
Men									
Street connectivity									
Model A: Intersection density, 3+ intersections /km^2	**1.0**	**0.04,1.9**	**0.04**	-0.6	-1.5,0.2	0.2	-0.2	-1.1,0.6	0.6
Model B: Link-node ratio	-0.4	-1.2,0.5	0.4	0.6	-0.7,1.8	0.4	-0.1	-0.9,0.7	0.8
Local roads									
Model C: Local road density (km in 1 km buffer)	**1.0**	**0.1,2.0**	**0.03**	-0.4	-1.3,0.6	0.4	-0.7	-1.7,0.4	0.2
Model D: Proportion of local relative to total roads (%)	0.6	-0.2,1.4	0.2	-0.1	-1.0,0.7	0.7	-0.1	-1.0,0.8	0.8
Women									
Street connectivity									
Model A': Intersection density, 3+ intersections /km^2	**1.3**	**0.6,2.0**	**0.001**	-0.3	-1.0,0.4	0.4	-0.6	-1.3,0.1	0.1
Model B': Link-node ratio	-0.1	-0.8,0.6	0.8	0.1	-0.8,1.0	0.8	0.2	-0.5,0.9	0.6
Local roads									
Model C': Local road density (km in 1 km buffer)	0.7	-0.06,1.4	0.07	-0.7	-1.5,0.04	0.06	**-1.3**	**-2.2,-0.3**	**0.007**
Model D': Proportion of local relative to total roads (%)	-0.2	-0.8,0.4	0.5	-0.07	-0.9,0.7	0.9	**-1.4**	**-2.3,-0.6**	**0.001**

[a] The two-part MEM model includes a probit model using maximum likelihood estimation as the first step to estimate probability of conducting SBPA. The second part is an ordinary least square regression model conditioned on only those who conducted SBPA. The coefficients are the marginal effect (weighted average) from the point estimates from both parts of the equation. Models control for individual-level age, race, education level, marital status, baseline study center, Census tract-level % white residents, inflation-adjusted median household income, % residents walk to work, and median age of houses.

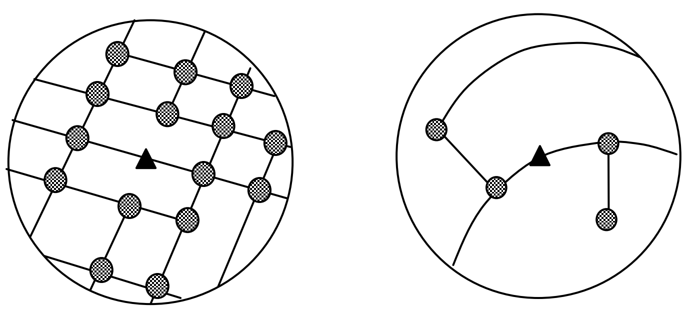
Figure 6.1, Panels A-D. Illustrative examples of each of the four street attribute measures: (A) intersection density, (B) link-node ratio, (C) density of local roads, and (D) proportion of local relative to total roads, within 1 km Euclidean buffer from residential location. Hypothetical examples for relatively high versus relatively low values are presented for each of the four street attribute measures, with high values hypothesized to be positively associated with SBPA. These hypothetical illustrations do not reflect real values of street attributes.

Panel A: Intersection Density (density of 3 or more-way intersections)



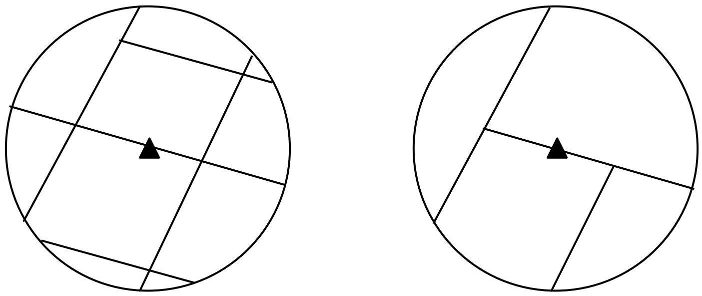
High	Low
Number of ≥3-way intersections = 15	Number of ≥3-way intersections = 2
Intersection density = 15÷ 3.14 km^2 =4.8/km^2	Intersection density = 2 ÷ 3.14 km^2 = 0.6/km^2

Panel B: Link-node Ratio [ratio of streets (links) to intersections (nodes)]



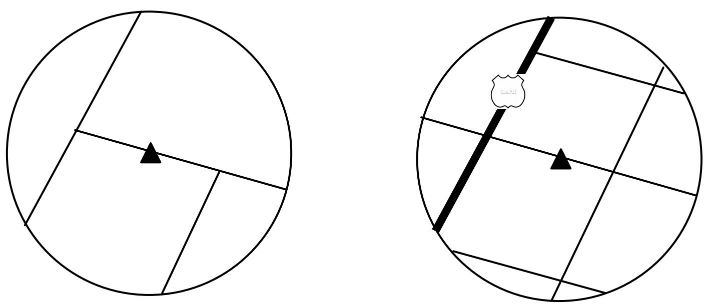
High	Low
Number of links = 32	Number of links = 6
Number of nodes = 15	Number of nodes = 4
Link-node ratio = 32÷15 = 2.1	Link-node ratio = 6÷4 =1.5

Panel C: Density of Local Roads (roads with a single lane of traffic in each direction) based on total length of local roads



High	Low
Density of local roads = ~ 8 km in 1 km buffer	Density of local roads = ~ 4 km in 1 km buffer

Panel D: Proportion of local roads (roads with two or more lanes of traffic in each direction) to total roads



High	Low
100% local roads in buffer	~80% local roads in buffer

▲ Residential location
● True intersection (≥3-way intersection)
○ Two-way intersection
◍ Node (any intersection, including cul-de-sac)
— Link (continuous street segment without interruption by intersection or cul-de-sac)
— Local road, generally with a single lane of traffic in each direction [(TIGER/Line™ Files, 1992, Census Feature Class Codes (A4x category 'local, neighborhood, and rural roads')]
Indicates non-local roads, such as state and county highways, generally with two or more lanes of traffic in each direction [(TIGER/Line™ Files, 1992, Census Feature Class Codes (major road categories (A0x-A3x, A5x, and A6x)]
NOTE: all examples feature local roads except Panel D (low example)

VI. E. Discussion

Using unique time-varying, GIS-derived environment data, we observed variation in the association between residential street attributes and street-based physical activity across varying environmental contexts and by gender. In low, but not in middle and high urban areas, higher density of intersections and local roads were associated with higher SBPA frequency in males, whereas higher intersection density was associated with SBPA in females. In contrast, in high urbanicity areas we observed negative associations for local road density and proportion of local roads in women. Thus overall, residential street attributes were positively associated with SBPA in low urbanicity areas, but in middle and high urbanicity areas, these positive associations became null (in men) or even inverse (in women).

Street attributes differ across environmental contexts. Generally higher urbanicity areas have higher intersection density and link-node ratio, which reflect greater street connectivity, largely through the provision of many possible direct routes across space. Modern suburban neighborhoods, characterized by segregated land uses and cul-de-sacs are hypothesized to constrain SBPA, thus SBPA level in residents of less urban areas tend to be lower than in neighborhoods that are more compact with higher population density and traditional gridded streets [5, 91-93]. While cross-sectional findings suggest that urbanization is a significant effect modifier in the association between obesity and perceived neighborhood barriers for PA[94], there is little research in this area. In contrast, in our study, we characterized urbanicity using a combination of living outside versus inside an MSA and population density, which we then categorized into tertiles roughly representing low, middle, and high urbanicity areas. We observed differential associations between street attributes with SBPA in low urban areas, while in high urban areas, these associations became null or negative.

The magnitude of the observed associations is small, compared to cross-sectional studies. For example, one study reported odds ratios for walking for transport ranging from 1.3 (top quartile, 95% CI: 0.95-1.7) and 1.6 (2nd quartile, 95% CI: 1.2-2.0) of street connectivity [95]. However, considering the contrasts across environmental settings (e.g., low urbanicity areas with rapid population growth and development), the associations we observed in our study have potential magnitude. For example, with a 1 SD increase in intersections (about 15 additional 3 or more-way intersections per km^2, a ~40% increase) in low urbanicity areas, we observed a 1.0-1.3 unit increase in SBPA frequency in men and women, which was about 5% of the averaged SBPA frequency. As an estimate (using 4 MET for walking, as an example), the increase in 1.0-1.3 unit SBPA frequency has the equivalent energy expenditure of an additional 5-9 minutes of walking per week. Also, the 1.0-1.3 unit increase in SBPA could be an additional 3-7 minutes of bicycling or jogging/running per week. At the population level, these increases could translate to meaningful PA over time. The fact that we observed associations in lower urbanicity areas could reflect the importance of interconnected streets and local roads in areas devoid of other environmental supports for physical activity.

Gender has also been reported to modify the relationship between environmental factors with obesity and PA. In our study, we found that gender modified the association between street attributes and SBPA. Though street connectivity was positively associated with SBPA in men and women in low urbanicity areas, our findings suggest inverse associations between local roads and SBPA among women living in high urbanicity areas. This inverse association was in contrast to our hypothesis. It is possible that high urbanicity areas, such as urban cores, may feature more local roads but also have greater barriers to PA, such as poorer aesthetics and higher crime rates. In such areas, women may prefer to engage in SBPA in areas with major thoroughfares (i.e., more than two lanes in the opposite direction). Crime and aesthetics may be particularly salient for women. Though aesthetics and crime data were unavailable for this study, we found density of local roads and tract-level median household income were negatively correlated particularly in high urbanicity areas (r=-0.28), suggesting poorer neighborhoods with less aesthetic surroundings and higher crime rate may have more local roads.

The observed decrease in intersection and local road density over time parallels the shifts in CARDIA study population over time. CARDIA participants were recruited from four major metropolitan areas at baseline, but over time a considerable proportion of the sample moved to new residential locations so by the most recent follow-up the CARDIA participants have widely spread across the country with great geographic variation. Many participants moved from the four major metropolitan areas to more suburban areas as they moved from early to mid-adulthood. These residential relocations over time provide considerable environmental variation, which is an advantage of our study.

There are several other strengths of this study. In addition to rich, longitudinal individual-level data, we obtained objectively measured neighborhood environmental data for each participant with three follow-up measures, providing a study time frame of fifteen years and a unique opportunity to research time-varying associations between environmental factors and individual-level behavioral outcomes. We used multiple measures to capture residential street attributes, including street segments (links), the number of intersections (nodes), and street lengths. Further, our modeling strategy of using two-part marginal effect modeling is useful in eliminating bias by properly handling the outcome that have large proportions of zero values with remaining of the values being positive and continuous. In addition, our analysis stratification by urbanicity and gender are unique to the study of neighborhood effects. We relied upon a sophisticated measure of urbanicity, incorporating MSA definitions in combination with population density.

Our study also has limitations. First, it is important to recognize that while CARDIA has outstanding PA data, we only have temporal data on leisure PA, so were unable to model SBPA for commuting purposes. Second, though using radial buffer-defined neighborhoods has the advantage of assessing urban form around each household, the radial buffer can be arbitrary without taking into account other types of neighborhood definitions such as route-based boundaries and does not exclude water, natural or agricultural surfaces from the buffer. We chose a 1 km Euclidean radius buffer to describe residential street attributes in the immediate residential neighborhood to capture pedestrian activity [43, 54]. Third, one disadvantage of using GIS across large geographic range is the lack of detailed information on factors such as sidewalks and walking paths [38, 96]. Thus, although we observed modest associations between street attributes and SBPA, we were unable to fully characterize environment-level pedestrian supports, such as sidewalks, cross-walks, and pedestrian signage. Further, using GIS, CARDIA participants' residential addresses were shifted randomly within a 100 meter buffer to maximize identity protection and eliminate possibility that a single residence could be identified, which may introduce noise to the analysis. Fourth, , link-node ratio does not reflect the length of the links, and the measure may be less intuitive and thus less attractive as a policy tool[68]. A recent instrument, space syntax[97], which incorporates urban design parameters with topological factors, may be an appropriate alternative measure, but was not feasible for our national study. We used a broad category of "walkable" roads from the TIGER/line™ files and the local road type (category A40-A48). A road in the local road category is typically used for local traffic, with a single lane of traffic in each direction. The local roads have varying types, from neighborhood roads in urban areas to short distance roads connecting the smallest towns in rural areas, and even other types such as scenic park roads. Fifth, the benefits of built environments may be offset by social characteristics, such as aesthetics and safety [98, 99], which were not incorporated into the present analysis. While it is possible that the observed inverse association between local roads and SBPA in high urbanicity areas in women is due to exercise occurring outside of the residential neighborhood, we included other forms of exercise as a control variable in our statistical models in an additional sensitivity analysis, finding a similar pattern and magnitude of associations (results not shown). Finally, the two-part MEM does not have a fixed-effect option that can be a useful strategy to reduce self-selection bias, though comparing to which the trade-off of better approximating PA behavior was relatively more important in this case.

In summary, we found positive associations between intersection density and density of local roads with SBPA in low urbanicity areas but not in middle or high urbanicity areas, and local roads were negatively associated with SBPA among urban-living women, suggesting additional research relating street attributes and SBPA by strata of urbanicity and gender. While both factors modified the association between street attributes and SBPA, with some indication of favorable influence of street attributes on PA in low urbanicity areas, the overall pattern of modification was mixed. Moreover, the size of the observed associations was modest. Future research with additional information such as neighborhood safety and aesthetics, more specific categories of road types and greater detail regarding the attributes of streets that are most supportive of SBPA are needed. Our results suggest that a rather dramatic change in 3 or more-way street intersections (plus ~15 per km^2 in exurban areas) would be associated with ~5% increase in SBPA. At a population level this could translate to substantial magnitude, yet the observed associations were less dramatic than suggested by cross-sectional studies.

CHAPTER VII

SYNTHESIS

VII. A. Introduction

In this chapter, data regarding the environmental exposures addressed, gasoline price and street attributes, and outcomes that include overall PA, street-based PA, and other sub-categories of PA that have been presented in the previous chapters are synthesized.

VII.B. Context and contribution

Adequate PA is essential in maintaining healthy weight and well-being, but the majority of Americans do not get enough PA to meet health recommendations outlined by the Surgeon General's report on Physical Activity and Health. With PA level low in population level and the short sustainability of behavioral interventions, promoting PA at environmental and policy level is attractive and numerous authoritative reports have identified environmental and policy interventions as the most promising strategies for creating population-wide improvements in not only PA, but also diet and obesity[100], including reports by the U.S. Surgeon General[101], World Health Organization[102], Institution of Medicine[103], Center for disease control and prevention[104], and International Obesity Task Force[105]. Though evidence is growing rapidly that the attributes of built environments such as neighborhood design are associated with PA, the literature is dominated by cross-sectional studies and findings are inconsistent. In addition to built environment attributes, economic factors may also influence obesity-related behaviors, such as diet and PA. There has been price research suggesting price elasticity of demand for food, e.g., higher levels of fruit and vegetable consumption were associated with lower fruit and venerable prices[106]. However, research on how price may influence PA is scarce, and to date, there is only one cross-sectional study on gasoline price suggesting prevalence of cycling is higher in areas with higher gasoline prices[57]. Prospective studies and economic studies were recommended to fill the research gap and advance the field, which is also the primary motivation for this dissertation work.

VII. C. Overview of findings

The overall objective of this research is to investigate longitudinal associations between two aspects of environment (gasoline price and street attributes) and PA in overall as well as sub-types, using data from a prospective cohort with 15 years of follow-up and objectively measured environmental data. We took advantage of this rich, high quality, time-varying database on detailed individual-level data, GIS-derived neighborhood price and street attributes data, as well as Census data that provide much information on neighborhood characteristics.

The first aim focused on the gasoline price exposure and PA. We inflation-adjusted all related price and income measures including community-level gasoline price, bus fare, and household income, to make them comparable across time. Using time-varying PA as the outcome, we examined overall PA and each of its 13 sub-categories such as walking, bicycling, running, home exercise, and so on, in relation to time-varying gasoline price, using a random-effect longitudinal model (for overall PA) and two-part marginal effect models (for sub-categories of PA that contain large proportion of zero scores, which may introduce bias using regular RE model).

The second aim focused on street attributes and PA, and studied how urbanicity and gender may modify this association. Two main aspects of street attributes, street connectivity and local roads that are hypothesized to facilitate street-based PA (walking, bicycling, and jogging/running) as well as overall PA, were examined separately across degree of urbanicity by gender. While the measures of neighborhood street connectivity have been researched previously, environmental research that examined neighborhood local roads, which reflect street connectivity from another aspect that complement the connectivity measures, is rare. In this work, we were able to obtain measures of local roads, which were categorized based on TIGER/Line™ files from six other major categories that are vehicle friendly roads such as different levels of highways. We used a two-part marginal effect model for the associations between street attributes and street-based PA (walking, bicycling, and jogging/running) to properly handle sub-PA outcomes that include considerable fraction of zeros that can introduce bias by regular longitudinal models. For each model, we interacted the main exposure with urbanicity tertile, with gender stratification.

1. Long-term physical activity increases with longitudinal trends in gasoline price

Hypothesizing that higher gasoline price may discourage driving and promote alternative transportation, thus influencing PA levels, we used prospective data over eight years from three exams of the CARDIA study, with a total of 8,451 observations of black and white young adults. Excellent gasoline price data were obtained from C2ER that provided price data at the county, the smallest available geographic unit in which we have comparable data across the U.S., and were linked to each CARDIA participant by their residential county at each exam year. We inflation adjusted price using Bureau of Labor Statistics CPI Index that estimates changes in the prices for a representative basket of goods and services over time. Overall PA score was summarized from thirteen sub-scores that were calculated for the thirteen PA sub-categories, based on self-report frequency of participation and intensity of each activity. We used a random-effect longitudinal model for the association between gasoline price and overall PA, and a two-part MEM model for the associations between gasoline price and each sub-category of PA to properly handle the considerable proportion of zero scores in those sub-categories with the remaining scores being positive and continuous. As presented in Chapter five, we found a positive association between gasoline price and overall PA, where the energy expenditure is roughly equivalent to 20 minutes of additional walking per week (per 25 cents increase in gasoline price). Gasoline price was also positively associated with jogging/running and non-strenuous sports that do not generally involve driving, and inversely associated with bowling and racket sports that generally involve car travel. Though active commuting cannot be examined explicitly due to data limitation, these findings provide some evidence for the relation between gasoline price and PA, suggesting increased gasoline price may promote PA in the long run. The U.S. consumes large amounts of gasoline, which has been promoted in a degree by the low, affordable prices. The gasoline price largely reflects national pricing policies such as fuel taxes, and policy changes that significantly elevate the gasoline price may reduce vehicle driving and promote PA at population level.

2. Longitudinal associations between neighborhood street attributes (connectivity and local roads) and physical activity

To fill the gap in literature that is lacking longitudinal evidence for the relation between street attributes and PA, we took advantage of CARDIA data that are linked to contemporaneous environmental data derived from a series of public and commercially available databases such as TIGER/Line™ Files and ESRI. We hypothesized that street attributes, including street connectivity and local roads that are relatively walking-friendly compared to other road types such as highways, are positively associated with overall PA and street-based PA (walking, bicycling, and jogging/running). We defined neighborhood as a 1 km Euclidean radial buffer from the residential location, which is typically covered by foot. Street connectivity was measured by density of multi-way intersections as well as link-node ratio, a relative measure that is calculated by the number of streets segments (like a block that contains no intersection) divided by the number of intersections in a unit area. Local roads contain a major category of local, neighborhood and rural roads, which was separated from other vehicle friendly roads (highways) based on TIGER/Line™ Files. We calculated density of local roads in the neighborhood, which means length of local roads within a 1 km buffer, and also calculated the proportion of local roads among all types of roads in the neighborhood to reflect its relative availability.

Most studies on street attributes and PA neglected urban context, which can be reflected by urbanicity level or population density. Urban, suburban, and rural contexts are likely to have different land use and street patterns, ranging from urban gridded network streets to suburban cul-de-sac design with separated work, living, and shopping areas. Changes in street attributes may impact PA differently in different urban contexts, which are part of a macro-environment that reflects large-area characteristics, while street attributes are in the micro-environment level. Limited research used simple, binary measure of urbanicity, and to refine this measure, we created a more sophisticated measure of urbanicity by incorporating the indicator of urban vs. rural in combination with population density. We also hypothesize differential relations by gender, because street attributes may have different importance in men vs. women. Related findings in literature are mainly cross-sectional and inconsistent.

We calculated frequency of SBPA as a summary of frequencies of walking, bicycling and jogging/running, which were derived from the corresponding categories in the physical activity questionnaire. Thus, the SBPA measure reflects the amount of time in physical activities that usually take place in streets. As a considerable proportion of participants (12.4%) reported no SBPA, resulting in a positively skewed distribution on the outcome variable with a mass point of zeroes, we used a two-part MEM model that allows flexibility of separate decisions (decision to conduct SBPA, and decision to conduct amount of SBPA) to have a more realistic approximation of the way people behave. Models included interaction term between each street attribute and urbanicity, and were stratified by gender.

We found the level of urbanicity and gender did modify the association between street attributes and SBPA, with positive associations observed between intersection density and SBPA in low but not in middle and high urbanicity areas, and local roads were unfavorably related to SBPA particularly in urban-living women. Size of the associations is modest. However, if environmental changes occurred at a higher level, which may happen in exurban areas where population growth and development has often occurred at a rapid pace, our observed findings could become meaningful. For example, a rather dramatic change in street intersections (plus 10 per km^2 in low urbanicity areas) would be associated with the equivalent of 5-9 minutes of added walking in a week at population level.

VII.D. Strengths and limitations

The CARDIA participants were recruited from four U.S. metropolitan areas at baseline (1985-86), thus generalizability is limited in one sense. However, over time the participants have moved across the U.S. so that by the latest follow-up the CARDIA participants were located in 48 states, 1 federal district, 1 territory, 529 Counties and 3,805 Census Tracts. This movement across America provided substantial variability, in another hand. Considering that the majority of environment-PA studies were conducted using cross-sectional data from a single or multiple metropolitan areas without follow-up, we consider our geographically diverse sample across over a decade of time a major strength of this study. However, this research does have several other important limitations that need to be mentioned.

Limitations

Ideally, clustering by shared neighborhood may improve accuracy of estimations by performing multi-level modeling that can specify neighborhood effect. However, the CARDIA study was not designed to have a hierarchical structure, i.e., participants were not sampled to have a shared neighborhood. Also, the fact that we have considerable residential movement over time, resulting in even smaller numbers of individuals residing in shared geographic units, meant that we were unable to cluster the participants by geographic unit in our statistical models.

While CARDIA has outstanding leisure PA data, no specific information on commuting patterns were collected longitudinally (e.g., the questionnaire questions did not specify whether walking includes those for commuting purposes, but more of a general frequency of participation), thus the walking and bicycling measures used in our study might be confined to leisure time walking and bicycling only, which may be influenced by gasoline price and street attributes to a lesser extent than commuting. Moreover, bicycling score captured vigorous bicycling (speed >10 mile/hour, on stationary or other bicycle), thus may omit non-strenuous forms of bicycling that could be used in bicycle commuting. Also, during the administration of the PA questionnaire, the participants may face cognitive difficulties in accurately understanding and reporting PA frequency and intensity, resulting in misreporting.

Specifically for aim 1, the gasoline price data were missing for considerable proportion of participants. This limitation was addressed by using imputation strategies. A gasoline price dummy indicates whether gasoline price was imputed: 1) Not imputed: gasoline price was as originally collected in county or averaged across the residential Metropolitan Statistical Area (MSA); 2) Imputed: gasoline price was imputed using state averages or data from other seasons (Year 7: 30%; Year 10: 16%; Year 15: 15%). We controlled the dummy in our regression models. Street attributes data almost have no missing data, thus have no such problem.

Further, price data were only available for larger county-level units. It is possible that within county price variations matter but county was already the smallest geographic unit available for gasoline price data. The neighborhood defined for street attributes is much smaller, where the neighborhood area within a 1 km buffer is likely to be typically covered by foot that is very relevant to street-based PA. In that sense, the county-level gasoline price may not be a real limitation, because with a car people can travel much farther from home to get gasoline, and the averaged gasoline price within a county may well reflect the actual average gasoline price that the participants were exposed to, with the mobility of having a car.

Also, for the gasoline price study, one added complexity was the lack of variation in geographic area for the baseline CARDIA sample, which required exclusion of baseline data. The baseline (1985-86) exam recruited participants living in close geographic proximity to the study centers, so there was little variation in county-level gasoline price after controlling for the baseline study center, and we cannot utilize data from the baseline examination. However for the street attributes study, this is not a problem because neighborhood was defined as a much smaller area (1 km radial buffer) thus the variation of street attributes was large enough at baseline.

Specifically for the street attributes study, although using radial buffer-defined neighborhoods has the advantage of assessing urban form around each household, the radial buffer can be arbitrary and does not take into account other types of neighborhood definitions such as route-based boundaries. We chose a 1 km Euclidean radius buffer to describe street attributes in the immediate residential neighborhood to capture pedestrian activity. In addition, one disadvantage of using GIS derived environmental data is the lack of detailed information on factors such as sidewalks and walking paths[96 38]. Furthermore, we used the broad category of “walkable” roads through our use of the TIGER/Line™ Files and the major category of local roads. A road in this major category is used for local traffic: in urban area, it is a neighborhood road, and in a rural area, it is a short distance road connecting the smallest towns. The major category also includes scenic park roads, unimproved or unpaved roads, and industrial roads. Lastly, the benefits of built environments may be offset by social characteristics, such as aesthetics and safety[98], which were not incorporated into the present analysis. Although being less direct, the gasoline price study may share this limitation, because a decent and safe neighborhood may facilitate one switching to active transportation or leisure PA in neighborhood.

Strengths

This research used rich, longitudinal data with objectively measured environmental data contemporaneously and geographically linked to individual-level CARDIA data, through advanced GIS technologies. It is not common for environment-PA research to have a longitudinal design, especially with a large sample size across national geographical range (N>5000) that retains a good retention rate during the follow-up over a decade, with multiple repeated measures, providing a unique opportunity to research time-varying associations between environmental factors and individual-level behavioral outcomes. We had excellent longitudinal data with standardized measures of PA from an instrument with known reliability and validity, and the quality of the environmental data is outstanding. The gasoline price data derived from the C2ER data are the most detailed time-varying price data available and have been found to be closely correlated with the Consumer Price Index by Bureau of Labor Statistics. Multiple measures were employed to capture street attributes, including varying aspects of street design (intersection density, link-node ratio, density of local roads, and percentage of local roads).

We used powerful longitudinal models, utilizing all time-varying exposures, outcomes, and covariates, and clustered on participant as repeated measures are correlated. We selected different modeling strategies conceptually and practically, based on specific situations. The cost of a gallon of gasoline reflects several different components, including the cost of crude oil, federal/state/local taxes, refining costs and profits, distribution, marketing and station costs and profits. Thus the exposure of gasoline price is theoretically independent from the controlled individual- and neighborhood-level covariates without endogeneity as an issue, and a random-effect longitudinal regression model is appropriate and efficient. In addition, we selected modeling strategy by also considering the outcome variables. The sub-categories of PA have scores that contain considerable fraction of zeros with the remaining values being positive and continuous. A regular one-step longitudinal regression model won't be appropriate in this case. Instead, we used a two-part MEM model strategy. Separate estimations were made for two separate decisions: 1) the decision to conduct the activity and 2) the conditional decision of amount of activity, thus resulting in estimates conditioned on conducting activity or not. Robust standard errors were used to correct for multiple observations on individuals. The two-part MEM model includes a probit model using maximum likely hood estimation as the first step to estimate probability of conducting a given activity. The second part was an Ordinary Least Square regression model on only the subsample of those who conducted that activity. The two point estimates were then multiplied and the resulting estimate is a weight mean of the effect of changes in exposure on changes in that activity for the full sample (the marginal effect). The two parts were estimated separately before deriving unconditional estimate and their bootstrapped standard errors (using 1,000 replications).

In addition, for the street attributes study, our analysis interaction/stratification by urbanicity and gender are unique to the study of neighborhood effects. We relied upon a sophisticated measure of urbanicity, incorporating the commonly used simple indicator of rural vs. urban in combination with population density.

VII.E. Public health significance

1. Our findings indicate that changes in environmental factors are associated with changes in street-based PA, and policy makers may use these evidences in developing relevant policies that may promote PA at population level in a sustainable way.

Results from Aim 1 suggested a positive association between gasoline price and overall PA, where the energy expenditure is roughly equivalent to 20 minutes of additional walking per week (per 25 cents increase in gasoline price). Gasoline price was also positively associated with jogging/running and non-strenuous sports that do not generally involve driving, and inversely associated with bowling and racket sports that generally involve car travel. These findings suggest that increased gasoline price may promote PA in the long run. As the world's largest consumer of gasoline, the U.S. has lower gasoline prices compared with most other western countries while gasoline price largely reflects national pricing policy (mainly fuel taxes). There is plenty of space to raise gasoline price, and additional taxes collected on gasoline can be used to subsidize designing and developing PA-friendly neighborhoods with enhanced street connectivity. It occurred that when gasoline price significantly increased during 2006-2008, the total miles traveled by vehicle reduced by around 5%. In short, policy changes that introduce a significant elevation in gasoline price may positively impact society in terms of people's PA level.

Results from Aim 2 suggested positive associations between street connectivity and density of local roads with street-based PA in low population-dense areas, though not in more urbanized areas. Though size of the associations seems small, if environmental changes occurred at a higher level, which may happen in exurban areas where population growth and development has often occurred at a rapid pace, our observed findings could become meaningful. For example, with a 40% increase in intersections (about 15 additional intersections per km^2) in low population-dense areas, we observed a 5% increase in street-based PA for men and women, an equivalent energy expenditure of approximately 5-9 minutes of additional walking per week. Some may argue that the built-environment is fixed and will be difficult to modify, which is true for those already highly developed and populous areas such as cities. However, in rural areas or areas with low population density, such as emerging suburbs and commuting towns, a great deal can be done by urban planners in designing PA-promoting communities to prevent poorly-connected or isolated neighborhoods. Our findings also support that increasing intersection density is related to higher PA in rural or low population areas, but not in high population areas.

2. This research contributed to literature with longitudinal evidences on environment-PA relation, with methodological advances.

There has been a large emerging literature especially since 2000 that focused on potential environmental influences on PA, diet, and obesity. There were many studies on street attributes, such as block size and numbers of street intersections, however, the literature is dominated by cross sectional designs or within metropolitan areas with a lack of larger geographical variation, and results from the previous studies weren't consistent. Also, while diet research has begun to address economic factors, such as food prices as they relate to dietary intake and obesity, very little research has addressed broader economic factors likely to impact PA, such as gasoline price. Nor has there been much research on how community-level prices of gasoline affect overall PA patterns as well as shifts in types of leisure PA patterns over time. Few existing studies are like CARDIA, which contains rich, longitudinal individual, price, and spatial data, that provides a study time frame of fifteen years and a unique opportunity to research how changes in environmental factors are associated with changes in individual-level behavioral outcomes.

Methodologically, many studies largely ignored the urban context in studying the street attributes and PA relation. Urban, suburban, and rural settings are likely to have different land use and street patterns, ranging from urban gridded network streets to suburban cul-de-sac design with separated work, living, and shopping areas. Street attributes may impact PA differently in different urban contexts, for example, increasing the same amount of multi-way intersections would produce different results across urbanicity level: in urban areas, the proportion of increase would be relatively small considering pre-existing intersection density is already decent; in suburban areas, increasing intersections does contribute a higher relative proportion of intersections in neighborhood, but the overall layout of cul-de-sac design and pre-existing separation between work, school, and shopping may reduce efficiency of the increased intersection density on PA; however, in rural or less population dense areas, the same amount of intersection increase can be a significant addition to street connectivity and facilitate street-based PA. To approximate urban context, limited research used simple, binary measures of urbanicity. We refined this measure, by incorporating the simple indicator of urban vs. rural with a continuous measure of population density, and then categorized urbanicity into rural/low, mid, and high levels. The average population density in rural or low population-dense areas was 1,087/km^2, similar to density in low population-dense states such as South Dakota or New Mexico. In medium population-dense areas, the average density was 2,893/km^2, similar to Staten Island, New York City's most suburban borough. While in high population dense area, the averaged population density of 7,348/km^2 is close to that in Queens, part of the most populous area in NYC.

VII.F. Directions for future research

Several possible extensions to this work could enhance understanding of the longitudinal environment-PA associations.

1) Though the CARDIA participants were originally recruited from four U.S. metropolitan areas, the geographical variation became great during the follow-up period when considerable proportion of participants moved to new residential locations. Future research may further expand the geographical coverage by recruiting diverse study populations from varying geographical locations, or even by obtaining national representative samples, if possible.
2) There are many ways to define neighborhood boundaries. However, boundary selection can be limited due to nature of available data and study design. As an individually perceived neighborhood and a neighborhood defined by radical buffer may be different, a more sophisticated boundary definition that is likely to reduce this difference, would add great merit to this research.

3) To examine the environment-PA relation, an ideal measure of PA would have specific, detailed information on commuting PA, along with leisure and occupational PA. Also, self-report PA can be improved by conducting cognitive interviews during questionnaire administration, to help respondents accurately understand questionnaire questions and minimize misreport. Additional measures of car use and public transit use would be a plus.
4) Pedestrian networks may be different from street networks, and pedestrians may use sidewalks and walking paths that may not be captured by GIS-captured street networks. Measuring environment from a pedestrian's perspective may help refine and complete the environmental exposures that are relevant to street-based PA.
5) There are limited randomly controlled trials (RCT) that intervene on environmental or policy factors, because it is largely impossible to control environmental or policy factors in most situations. In this case, using the longitudinal design is a great advance to the dominating cross-sectional studies for guiding policy change. Also, quasi-experimental evaluations of natural experiments, i.e., environment or policy changes not to be controlled by the investigator, would advance this field. In addition, using existing measures to conduct surveillance of the environment could advance both research and public health practice.
6) In addition to gasoline price and street attributes, there are many other environmental factors that are related to PA, and there is also a lack of longitudinal research that studies changes. Environment may be less modifiable but with small changes accumulated from many attributes, the combined influence could be considerable.

In summary, this dissertation has provided insight into longitudinal associations between economic and neighborhood street attributes with PA. This research sets the stage for the continuation of this work in several other arenas, such as other environmental attributes that may contribute to influencing the behavior of physical activity. While this research has provided a glimpse into how gasoline price and street attributes may be longitudinally associated with PA, more research is needed. Recruiting more diverse study populations from varying geographical locations, using better neighborhood definitions, improving PA and environmental measurements, and utilizing longitudinal design and incorporating other aspects of environmental or individual determinants will help provide more causal and informative evidences for policy making**.**

APPENDIX A

PHYSICAL ACTIVITY HISTORY QUESTIONNAIRE

F18EXDAT

___ / ___ / ______

exam date

1. SHOW PARTICIPANT CARD 1.

Compared to other people your age and sex, what number would you choose for rating your physical activity during the past year? CHECK ONE NUMBER.

F18PSTYR

1 2 3 4 5

Physically Moderately Very Inactive Active Active

2. SHOW PARTICIPANT CARD 2.

Please look at this card. I'll be asking you whether you do the activities listed. Only include the time spent actually doing the activity. For example, sitting by the pool does not count as time swimming; sitting in a chair lift does not count for skiing. First, I'll ask you about vigorous activities. Vigorous activities increase your heart rate, or make you sweat doing them, or make you breathe hard or raise your body temperature. If you do an activity but not vigorously, please include it later when I ask you about other non-strenuous sports.

A1. Did you jog or run in the past 12 months for at least one hour total time in any month? For instance, you might have done three 20-minute sessions in the month.

F18A1RUN

1 No GO TO QUESTION B1

2 Yes

A2. How many months did you do this activity?

_____ months ***F18A2MO***

A3. How many of these months did you do this activity for at least 2 hours per week?

_____ months ***F18A3PWK***

B1. Did you do vigorous racket sports in the past 12 months for at least one hour total time in any month? ***F18B1RAC***

1 No GO TO QUESTION C1

2 Yes

B2. How many months did you do this activity?

_____ months ***F18B2MO***

B3. How many of these months did you do these activities for at least 3 hours per week?

_____ months ***F18B3PWK***

C1. Did you bicycle faster than 10 miles/hour or exercise hard on an exercise bicycle in the past 12 months for at least one hour total time in any month? ***F18C1BKE***

1 No GO TO QUESTION D1

2 Yes

C2. How many months did you do these activities?

______ months ***F18C2MO***

C3. How many of these months did you do this activity for at least 2 hours per week?

_____ months ***F18C3PWK***
D1. Did you swim in the past 12 months for at least one hour total time in any month?
1 No GO TO QUESTION E1 ***F18D1SWM***
2 Yes
D2. How many months did you do this activity?
_____ months ***F18D2MO***
D3. How many of these months did you do this activity for at least 2 hours per week?
_____ months ***F18D3PWK***
E1. Did you do a vigorous exercise class or vigorous dancing in the past 12 months for at least one hour total time in any month? ***F18E1DNC***
1 No GO TO QUESTION F1
2 Yes
E2. How many months did you do this activity?
_____ months ***F18E2MO***
E3. How many of these months did you do this activity for at least 3 hours per week?
_____ months ***F18E3PWK***
F1. Did you do any vigorous job activities such as lifting, carrying, or digging in the past 12 months for at least one hour total time in any month? ***F18F1LFT***
1 No GO TO QUESTION G1
2 Yes
F2. How many months did you do any of these activities?
_____ months ***F18F2MO***

F3. How many of these months were for at least 5 hours per week?
_____ months ***F18F3PWK***
G1. Did you do any home or leisure activities such as snow shoveling, moving heavy objects, or weight lifting in the past 12 months for at least one hour total time in any month?
1 No GO TO QUESTION H1 ***F18G1SHV***
2 Yes
G2. How many months did you do any of these activities?
_____ months ***F18G2MO***
G3. How many of these months were for at least 3 hours per week?
_____ months ***F18G3PWK***
H1. Did you do other strenuous sports such as basketball, football, skating, or skiing in the past 12 months for at least one hour total time in any month? ***F18H1HSP***
1 No GO TO QUESTION I1
2 Yes
H2. How many months did you do any of these activities?
_____ months ***F18H2MO***
H3. How many of these months were for at least 3 hours per week?
_____ months ***F18H3PWK***

Now, I'd like to ask you about more leisurely activities.

I1. Do you do non-strenuous sports such as softball, shooting baskets, volleyball, ping pong, or leisurely jogging, swimming or biking which we haven't included above in the past 12 months for at least one hour total time in any month? ***F18I1LSP***
1 No GO TO QUESTION J1
2 Yes
I2. How many months did you do any of these activities?
_____ months ***F18I2MO***
I3. How many of these months were for at least 3 hours per week?
_____ months ***F18I3PWK***

J1. Did you take walks or hikes or walk to work in the past 12 months for at least one hour total time in any month? ***F18J1WLK***
1 No GO TO QUESTION K1
2 Yes
J2. How many months did you do this activity?
_____ months ***F18J2MO***
J3. How many of these months were for at least 4 hours per week?
_____ months ***F18J3PWK***
K1. Did you bowl or play golf in the past 12 months for at least one hour total time in any month? ***F18K1BWL***
1 No GO TO QUESTION L1
2 Yes
K2. How many months did you do either of these activities?
_____ months ***F18K2MO***
K3. How many of these months were for at least 3 hours per week?
_____ months ***F18K3PWK***
L1. Did you do home exercise or calisthenics in the past 12 months for at least one hour total time in any month? ***F18L1HMX***
1 No GO TO QUESTION M1
2 Yes
L2. How many months did you do this activity?
_____ months ***F18L2MO***
L3. How many of these months did you do this activity for at least 3 hours per week?
_____ months ***F18L3PWK***
M1. Did you do home maintenance or gardening, including carpentry, painting, raking, or mowing in the past 12 months for at least one hour total time in any month?
1 No GO TO QUESTION N1 ***F18M1MNT***
2 Yes

M2. How many months did you do any of these activities?
_____ months ***F18M2MO***
M3. How many of these months were for at least 5 hours per week?
_____ months ***F18M3PWK***

APPENDIX B

TIGER/LINE™ FILES

Source: http://www.census.gov/geo/www/tiger/appendxe.asc

TIGER/Line™ Files, 1992

Appendix E
Census Feature Class Codes (CFCC)

Definition

A CFCC is used to identify the most noticeable characteristic of a feature. The CFCC is applied only once to a chain or landmark with preference given to classifications that cover features that are visible to an observer and are part of the ground transportation network. Thus a road that is also the boundary of a town would have a CFCC describing its road characteristics not its boundary characteristics. The CFCC, as used in the TIGER/Line™ files, is a three-character code; the first character is a letter describing the feature class; the second character is a number describing the major category; and the third character is a number describing the minor category.

Feature Classes

Feature Class A, Road

Definitions Applicable to Road

The definition of a divided highway has been the source of considerable discussion. Earlier specifications have defined a "divided" road as having "... opposing traffic lanes that are physically separated by a median strip no less than 70 feet wide in former GBF/DIME areas or no less than 200 feet wide in non-GBF/DIME areas." This definition caused confusion in the proper coding of interstates having narrow medians. To clarify the situation, the Census Bureau now uses the term "divided" to refer to a road with opposing traffic lanes separated by any size median, and "separated" to refer to lanes that are represented in the Census TIGER data base as two distinct complete chains. Earlier operations may have depicted widely separated lanes as a single line in the data base or created separate lines when the median was small, depending on the available source used during the update.

The term "rail line in center" indicates that a rail line shares the road right-of-way. The rail line may follow the center of the road or be directly next to the road, representation is dependent upon the available source used during the update. The rail line can represent a railroad, a street car line, or other carline.

Road With Major Category Unknown:

Source materials do not allow determination of the major road category. These codes should not, under most circumstances, be used since the source materials usually provide enough information to determine the major category.

CFCC	Description
A00	Road, major and minor categories unknown
A01	Road, unseparated
A02	Road, unseparated, in tunnel
A03	Road, unseparated, underpassing
A04	Road, unseparated, with rail line in center
A05	Road, separated
A06	Road, separated, in tunnel
A07	Road, separated, underpassing
A08	Road, separated, with rail line in center

Primary Highway with Limited Access:

This road is distinguished by the presence of interchanges, access to the highway is by way of ramps, and there are multiple lanes of traffic. A road in this category has the opposing traffic lanes "divided" by a median strip. Interstate highways and some toll highways are in this major category. The TIGER/Line™ files may depict the opposing lanes of a road in this category as two distinct lines; in this case the road is called "separated."

CFCC	Description
A10	Primary road with limited access or interstate highway, major category used alone when the minor category could not be determined
A11	Primary road with limited access or interstate highway, unseparated
A12	Primary road with limited access or interstate highway, unseparated, in tunnel
A13	Primary road with limited access or interstate highway, unseparated, underpassing
A14	Primary road with limited access or interstate highway, unseparated, with rail line in center
A15	Primary road with limited access or interstate highway, separated
A16	Primary road with limited access or interstate highway, separated, in tunnel
A17	Primary road with limited access or interstate highway, separated, underpassing
A18	Primary road with limited access or interstate highway, separated, with rail line in center

Primary Road without Limited Access:

A road in this major category must be hard surface, that is, concrete or asphalt, and may be divided or undivided and have multi-lane or single lane characteristics. This road has intersections with other roads, usually controlled with traffic lights. This major category includes nationally and regionally important highways that do not have limited access as required by major category A1. Thus, major category A2 includes most U.S. and State highways and some county highways that connect cities and larger towns.

CFCC	Description
A20	Primary road without limited access, U.S. and State highway, major category used alone when the minor category could not be determined
A21	Primary road without limited access, U.S. and State highways, unseparated
A22	Primary road without limited access, U.S. and State highways, unseparated, in tunnel
A23	Primary road without limited access, U.S. and State highways, unseparated, underpassing
A24	Primary road without limited access, U.S. and State highways, unseparated, with rail line in center
A25	Primary road without limited access, U.S. and State highways, separated
A26	Primary road without limited access, U.S. and State highways, separated, in tunnel
A27	Primary road without limited access, U.S. and State highways, separated, underpassing
A28	Primary road without limited access, U.S. and State highways, separated, with rail line in center

Secondary and Connecting Road:

A road in this major category must be hard surface, that is, concrete or asphalt, usually undivided with single lane characteristics. This road has intersections with other roads, controlled with traffic lights and stop signs. This major category includes State and county highways that connect smaller towns, subdivisions, and neighborhoods, thus the road is smaller than a road in major category A2. This road, usually with a local name along with a route number, intersects with many other roads and driveways.

CFCC	Description
A30	Secondary and connecting road, State and county highways, major category used alone when the minor category could not be determined
A31	Secondary and connecting road, State and county highways, unseparated
A32	Secondary and connecting road, State and county highways, unseparated, in tunnel
A33	Secondary and connecting road, State and county highways, unseparated, underpassing
A34	Secondary and connecting road, State and county highways, unseparated, with rail line in center
A35	Secondary and connecting road, State and county highways, separated
A36	Secondary and connecting road, State and county highways, separated, in tunnel
A37	Secondary and connecting road, State and county highways, separated, underpassing
A38	Secondary and connecting road, State and county highway,

separated, with rail line in center

Local, Neighborhood, and Rural Road:

A road in this major category is used for local traffic, usually with a single lane of traffic in each direction. In an urban area, this is a neighborhood road and street that is not a thoroughfare belonging in categories A2 or A3. In a rural area, this is a short distance road connecting the smallest towns; the road may or may not have a State or county route number. In addition, this major category includes scenic park roads, unimproved or unpaved roads, and industrial roads. Most roads in the Nation are classified in this major category.

CFCC	Description
A40	Local, neighborhood, and rural road, city street, major category used alone when the minor category could not be determined
A41	Local, neighborhood, and rural road, city street, unseparated
A42	Local, neighborhood, and rural road, city street, unseparated, in tunnel
A43	Local, neighborhood, and rural road, city street, unseparated, underpassing
A44	Local, neighborhood, and rural road, city street, unseparated, with rail line in center
A45	Local, neighborhood, and rural road, city street, separated
A46	Local, neighborhood, and rural road, city street, separated, in tunnel
A47	Local, neighborhood, and rural road, city street, separated, underpassing
A48	Local, neighborhood, and rural road, city street, separated, with rail line in center

Vehicular Trail:

A road in this major category is usable only by four-wheel drive vehicles and is usually a one lane, dirt trail. The road is found almost exclusively in a very rural area, sometimes the road is called a fire road or logging road and may include an abandoned railroad grade where the tracks have been removed. Minor, unpaved roads usable by ordinary cars and trucks belong in major category
A4.

CFCC	Description
A50	Vehicular trail, road passable only by four-wheel drive (4WD) vehicle, major category used alone when the minor category could not be determined
A51	Vehicular trail, road passable only by 4WD vehicle, unseparated
A52	Vehicular trail, road passable only by 4WD vehicle, unseparated, in tunnel
A53	Vehicular trail, road passable only by 4WD vehicle, unseparated, underpassing

Road with Special Characteristics:

A road, portion of a road, intersection of a road, or the ends of a road that are parts of the vehicular highway system that have separately identifiable characteristics.

CFCC	Description
A60	Road with characteristic unspecified, major category used alone when the minor category could not be determined
A61	Cul-de-sac, the closed end of a road that forms a loop or turn around (the node symbol that appears on some census maps is not included in the TIGER/Line™ files)
A62	Traffic circle, the portion of a road or intersection of roads that form a roundabout (the node symbol that appears on some census maps is not included in the TIGER/Line™ files)
A63	Access ramp, the portion of a road that forms a cloverleaf or limited access interchange (the node symbol that appears on some census maps is not included in the TIGER/Line™ files)
A64	Service drive, the road or portion of a road that provides access to businesses, facilities, and rest areas along a limited access highway, this frontage road may intersect other roads and be named
A65	Ferry crossing, the portion of a road over water that consists of ships, carrying automobiles, connecting roads on opposite shores

Road as Other Thoroughfare:

A road that is not part of the vehicular highway system. This road is used by bicyclists or pedestrians and is typically inaccessible to mainstream motor traffic except by service vehicles. A stair and walkway may follow a road right-of-way and be named as if it were a road. This major category includes foot and hiking trails located on park and forest land.

CFCC	Description
A70	Other thoroughfare, major category used alone when the minor category could not be determined
A71	Walkway, nearly level road for pedestrians, usually unnamed
A72	Stairway, stepped road for pedestrians, usually unnamed
A73	Alley, road for service vehicles, usually unnamed, located at the rear of buildings and property

Feature Class B, Railroad

Railroad With Major Category Unknown:

Source materials do not allow determination of the major railroad category. These codes should not, under most circumstances, be used since the source materials usually provide enough information to determine the major category.

CFCC	Description
B00	Railroad, major and minor categories unknown
B01	Railroad track, not in tunnel or underpassing, major category used alone when the minor category could not be determined
B02	Railroad track, in tunnel
B03	Railroad track, underpassing

Railroad Main Line:

A railroad in this major category is the primary track that provides service between destinations. A main line track often carries the name of the owning and operating railroad company.

CFCC	Description
B10	Railroad main track, major category used alone when the minor category could not be determined
B11	Railroad main track, not in tunnel or underpassing
B12	Railroad main track, in tunnel
B13	Railroad main track, underpassing

Railroad Spur:

A railroad in this major category is the track that leaves the main track, ending in an industrial park, factory, or warehouse area or forming a siding along the main track.

CFCC	Description
B20	Railroad spur track, major category used alone when the minor category could not be determined
B21	Railroad spur track, not in tunnel or underpassing
B22	Railroad spur track, in tunnel
B23	Railroad spur track, underpassing

Railroad Yard:

A railroad yard track has parallel tracks that form a working area for the railroad company. Train cars and engines are repaired, switched, and dispatched from a yard.

CFCC	Description
B30	Railroad yard track, major category used alone when the minor category could not be determined
B31	Railroad yard track, not in tunnel or underpassing
B32	Railroad yard track, in tunnel
B33	Railroad yard track, underpassing

Railroad with Special Characteristics:

A railroad or portions of a railroad track that are parts of the railroad system and have separately identifiable characteristics.

CFCC	Description
B40	Railroad ferry crossing, the portion of a railroad over water that consists of ships, carrying train cars to connecting railroads on opposite shores. These are primarily located on the Great Lakes.

Railroad as Other Thoroughfare:

A railroad that is not part of the railroad system. This major category is for a specialized rail line or railway that is typically inaccessible to mainstream railroad traffic.

CFCC	Description
B50	Other rail line, major category used alone when the minor category could not be determined
B51	Carline, a track for street cars, trolleys, and other mass transit rail systems, used when the carline is not part of the road right-of-way
B52	Cog railroad, incline railway, or logging tram

Feature Class C, Miscellaneous Ground Transportation

Miscellaneous Ground Transportation With Category Unknown:

Source materials do not allow determination of the miscellaneous ground transportation category. This code should not, under most circumstances, be used since the source materials usually provide enough information to determine the major category.

CFCC	Description
C00	Miscellaneous ground transportation, not road or railroad, major and minor categories unknown

Pipeline:

Enclosed pipe, carrying fluid or slurry, situated above ground or, in special conditions, below ground when marked by a cleared right-of-way and signage.

CFCC	Description
C10	Pipeline, major category used alone

Power Transmission Line:

High voltage electrical line, on towers, situated on cleared right-of-way.

CFCC	Description
C20	Power transmission line, major category used alone

Miscellaneous Ground Transportation with Special

Characteristics:

A portion of a ground transportation system that has separately identifiable characteristics. This major category is for specialized transportation, usually confined to a local area, that is separate from other ground transportation.

CFCC	Description
C30	Other ground transportation that is not a pipeline or a power transmission line. The major category is used alone when the minor category could not be determined.
C31	Aerial tramway, monorail, or ski lift

Feature Class D, Landmark

Definition Applicable to Landmark

Landmark is the general name given to a cartographic or locational landmark, a land use area, and a key geographic location. A cartographic landmark is identified for use by an enumerator while working in the field. A land use area is identified in order to minimize enumeration efforts from where people are restricted or nonexistent. A key geographic location is identified in order to more accurately geocode and enumerate a place of work or place of residence. TIGER/Line™ files contain only cartographic landmarks or land use areas, if identified within the county area, but not key geographic locations.

Landmark With Category Unknown:

Source materials do not allow determination of the landmark category. This code should not, under most circumstances, be used since the source materials usually provide enough information to determine the major category.

CFCC	Description
D00	Landmark, major and minor categories unknown

Military Installation:

Base, yard, or depot used by any of the armed forces or the Coast Guard

CFCC	Description
D10	Military installation or reservation, major category used alone

Multihousehold or Transient Quarters:

CFCC	Description
D20	Multihousehold or transient quarters, major category used alone when the minor category could not be determined
D21	Apartment building or complex
D22	Rooming or boarding house

D23	Trailer court or mobile home park
D24	Marina
D25	Crew of vessel
D26	Housing facility for workers
D27	Hotel, motel, resort, spa, YMCA, or YWCA
D28	Campground
D29	Shelter or mission

Custodial Facility:

This major category is for an institution that maintains guards, nurses, caretakers, and so forth to preserve the welfare of those individuals resident in the facility.

CFCC	Description
D30	Custodial facility, major category used alone when the minor category could not be determined
D31	Hospital
D32	Halfway house
D33	Nursing home, retirement home, or home for the aged
D34	County home or poor farm
D35	Orphanage
D36	Jail or detention center
D37	Federal penitentiary, State prison, or prison farm

Educational or Religious Institution:

CFCC	Description
D40	Educational or religious institution, major category used alone when the minor category could not be determined
D41	Sorority or fraternity
D42	Convent or monastery
D43	Educational institution, including academy, school, college, and university
D44	Religious institution, including church, synagogue, seminary, temple, and mosque

Transportation Terminal:

The facility where transportation equipment is stored, the destination for travel on the transportation system, or the intermodal connection facility between transportation systems.

CFCC	Description
D50	Transportation terminal, major category used alone when the minor category could not be determined
D51	Airport or airfield
D52	Train station
D53	Bus terminal
D54	Marine terminal
D55	Seaplane anchorage

Employment Center:

This major category is for a location with high density employment.

CFCC	Description
D60	Employment center, major category used alone when the minor category could not be determined
D61	Shopping center or major retail center
D62	Industrial building or industrial park
D63	Office building or office park
D64	Amusement center
D65	Government center
D66	Other employment center

Tower:

CFCC	Description
D70	Tower, major category used alone when the minor category could not be determined
D71	Lookout tower

Open Space:

This major category contains areas of open space with no inhabitants or with inhabitants restricted to known sites within the area.

CFCC	Description
D80	Open space, major category used alone when the minor category could not be determined
D81	Golf course
D82	Cemetery
D83	National park or forest
D84	Other Federal land
D85	State or local park or forest

Special Purpose Landmark:

Use this category for landmarks not otherwise classified.

CFCC	Description
D90	Special purpose landmark, major category used alone when the minor category could not be determined
D91	Post office box ZIP Code(R)

Feature Class E, Physical Feature

Physical Feature With Category Unknown:

Source materials do not allow determination of the physical feature category. This code should not, under most circumstances, be used since the source materials usually provide enough information to determine the major category.

CFCC Description

E00 Physical feature, tangible but not transportation or hydrographic. The major and minor categories are unknown.

Fence:

This major category describes a fence that separates property. For example, a fence around a military reservation or prison separates the reservation from civilian land, thus, a fence line is a property line marked by a fence.

CFCC	Description
E10	Fence line locating a visible and permanent fence between separately identified property

Topographic Feature:

This category refers to topographical features that may be used as boundaries or as a reference for an area. The Census TIGER data base contains topographic features used to define the limits of statistical entities in locations where no other visible feature could be identified.

CFCC	Description
E20	Topographic feature, major category used when the minor category could not be determined
E21	Ridge line, the line of highest elevation of a linear mountain
E22	Mountain peak, the point of highest elevation of a mountain

Feature Class F, Nonvisible Features

Definition Applicable to Nonvisible Features

Nonvisible features are used to delimit tabulation entities, property areas, and legal and administrative entities. The Census Bureau separately identifies nonvisible boundaries only when they do not follow a visible feature such as a road, stream, or ridge line.

Nonvisible Boundary With Classification Unknown or Not Elsewhere Classified:

CFCC	Description
F00	Nonvisible boundary, major and minor categories unknown

Nonvisible Legal or Administrative Boundary:

This major category refers to nonvisible boundaries of legal or administrative areas.

CFCC	Description
F10	Nonvisible jurisdictional boundary of a legal or

administrative entity, major category used when the minor category could not be determined

F11	Offset boundary of a legal or administrative entity
F12	Corridor boundary of a legal or administrative entity
F13	Interpolated boundary of a legal or administrative entity used for closure through hydrological areas
F14	Superseded legal or administrative boundary
F15	Superseded legal or administrative boundary, corrected through post census process

Nonvisible Features for Data Base Topology:

This category contains various types of nonvisible lines used to maintain the topology in the Census TIGER data base.

CFCC	Description
F20	Nonvisible feature for data base topology, major category used when the minor category could not be determined
F21	Automated feature extension to lengthen existing physical feature
F22	Irregular feature extension, determined manually, to lengthen existing physical feature
F23	Closure extension to complete data base topological closure between extremely close features (used to close small gaps between complete chains and create polygons to improve block labeling on cartographic products)

CFCC	Description
F24	Nonvisible separation line used with offset and corridor boundaries
F25	Nonvisible centerline of area enclosed by corridor boundary

Point-to-Point Line:

CFCC	Description
F30	Point-to-point line, follows a line of sight and should not cross any visible feature, for example, from the end of a road to a mountain peak.

Property Line:

CFCC	Description
F40	Property line, nonvisible boundary of either public or private lands, e.g., a park boundary

ZIP Code(R) Boundary:

CFCC	Description
F50	ZIP Code(R) boundary, reserved for future use in delineating ZIP Code(R) Tabulation Areas

Map Edge:

CFCC	Description
F60	Map edge, now removed, used during data base creation

Nonvisible Statistical Boundary:

CFCC	Description
F70	Statistical boundary, major category used when the minor category could not be determined
F71	1980 statistical boundary
F72	1990 statistical boundary, used to hold collection and tabulation census block boundaries not represented by existing physical features
F73	1990 statistical boundary and extent of land use, it is not classifiable as a physical feature
F74	1990 statistical boundary, used to hold a tabulation census block boundary not represented by an existing physical feature

Nonvisible Other Tabulation Boundary:

CFCC	Description
F80	Nonvisible other tabulation boundary, major category used when the minor category could not be determined
F81	School district tabulation boundary
F82	Special census tabulation boundary

Feature Class H, Hydrography

Basic Hydrography:

This category includes shorelines of all water regardless of the classification of the water itself.

CFCC	Description
H00	Water feature, classification unknown or not elsewhere classified
H01	Shoreline of perennial water feature
H02	Shoreline of intermittent water feature

Naturally Flowing Water features:

CFCC	Description
H10	Stream, major category used when the minor category could not be determined
H11	Perennial stream or river
H12	Intermittent stream, river, or wash
H13	Braided stream or river

Man-Made Channel to Transport Water:

These features are used for purposes such as transportation, irrigation, or navigation.

CFCC	Description
H20	Canal, ditch, or aqueduct, major category used when the minor category could not be determined
H21	Perennial canal, ditch, or aqueduct
H22	Intermittent canal, ditch, or aqueduct

Inland Body of Water:

CFCC	Description
H30	Lake or pond, major category used when the minor category could not be determined
H31	Perennial lake or pond
H32	Intermittent lake or pond

Man-Made Body of Water:

CFCC	Description
H40	Reservoir, major category used when the minor category could not be determined
H41	Perennial reservoir
H42	Intermittent reservoir

Seaward Body of Water:

CFCC	Description
H50	Bay, estuary, gulf, sound, sea, or ocean, major category used when the minor category could not be determined
H51	Bay, estuary, gulf, or sound
H53	Sea or ocean

Body of Water in a Man-Made Excavation:

CFCC	Description
H60	Gravel pit or quarry filled with water

Nonvisible Definition Between Water Bodies:

The Census Bureau digitizes nonvisible definition boundaries to separate named water areas, for instance, an artificial boundary is drawn to separate a named river from the connecting bay.

CFCC	Description
H70	Nonvisible water area definition boundary, used to separate named water areas and as the major category when the minor category could not be determined
H71	USGS closure line, used as maritime shoreline
H72	Census water center line, computed to use as median

CFCC	Description
	positional boundary
H73	Census water boundary, international in waterways or at 12-mile limit, used as area measurement line
H74	Census water boundary, separates inland from coastal or Great Lakes, used as area measurement line
H75	Census water boundary, separates coastal from territorial at 3-mile limit, used as area measurement line

Special Water Feature:

Includes area covered by glaciers or snow fields.

CFCC	Description
H80	Special water feature, major category used when the minor category could not be determined
H81	Glacier

Feature Class X, Not Yet Classified

Classification Unknown or Not Elsewhere Classified:

CFCC	Description
X00	Feature not yet classified

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