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Estimating the effects of light rail transit on health care costs

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Abstract

In recent years, there has been a proliferation of research on the effects of the built environment, including mass transit systems, on health-related outcomes. While there is general agreement that the built environment affects travel choices and physical activity, it remains unclear how much of a public health benefit (in dollars) can be derived from land use policies that support walking, biking, and transit. In the present study, we develop a model to assess the potential cost savings in public health that will be realized from the investment in a new light rail transit system in Charlotte, NC. Relying on estimates of future riders, area obesity rates, and the effects of public transit on physical activity (daily walking to and from the transit stations), we simulated the potential yearly public health cost savings associated with this infrastructure investment. Our results indicate that investing in light rail is associated with a 9-year cumulative public health cost savings of $12.6 million. While these results suggest that there is a sizable public health benefit associated with the adoption of light rail, they also indicate that the effects are relatively small compared to the costs associated with constructing and operating such systems. These findings suggest that planning efforts that focus solely on the health impact of modifications in the built environment are likely to overstate the economic benefits. Public health benefits should be considered along with broader environmental health benefits.

Keywords: Built environment; Mass transit; Public health; Health impacts

Introduction

Physical activity is an important component to maintaining a healthy lifestyle. The increase in obesity in the United States has been accompanied by a steady decline in leading indicators of physical activity (Mokdad et al., 1999). Societal factors that affect levels of physical activity include individual characteristics (demographics, household, and lifestyle characteristics, culture, time allocation, etc.); the built environment (land use patterns, transportation systems, and design features); and the social environment (societal values and preferences, public policies, and economic forces) (Transportation Research Board, 2005). Physical activity levels have declined over the past 30 years due, in large part, to reduced physical demands of work, household

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maintenance, and travel (Fenton, 2005). Technology and leisure time activity trends have also created more sedentary lifestyles. Ultimately, weight gain and obesity result from an energy imbalance: that is, energy consumed in the form of calories is not offset by calories expended through physical exertion.

Obesity in the United States has become a serious public health concern (Mokdad et al., 1999; Cutler et al., 2003). The obesity rate has risen 60% since 1994, to the current high of 59 million people. The rate of obesity for children aged 6–12 has risen from 7% in 1980 to 15.3% in 2000 (American Obesity Association, 2007). The relationship between obesity levels and chronic diseases, including diabetes, heart disease, and cancer, is clear. Current demographic trends suggest that the incidence of obesity-related illnesses will continue to increase. This negative public health trend clearly poses a challenge to the nation's future ability to address both obesity-related problems and other important social needs.

Obesity and obesity-related illnesses exact a heavy social and economic toll on families, communities, and the nation. Obesity increases the risk of morbidity and mortality by increasing the risk of high blood pressure, coronary heart disease, diabetes, insulin resistance, and certain cancers (Allison et al., 1999). Additionally, obesity is associated with a number of negative psychosocial outcomes, including low self-esteem, mood disorders, poor school performance, and lower levels of employment success (Tershakovec et al., 1994; Mokdad et al., 2001; McElroy et al., 2004; Rohrer et al., 2005).

According to one calculation, obesity is associated with approximately $75 billion in direct health-related expenses in the US (Wolf and Colditz, 1998; Finkelstein et al., 2003). The economic costs of obesity (for example, loss of work productivity) may exceed even the direct health costs. The projected costs associated with treating chronic diseases will increase to $1.07 trillion by 2020 (up from $510 billion in 2000) (Adams and Corrigan, 2003). Because 125 million Americans live with chronic diseases and 70% of the nation's medical care costs are expended to treat these conditions, the impetus to craft policies that affect lifestyle changes has gained momentum.

The challenge to reducing obesity-related illness in the US is made more difficult by the sheer amount of money spent on marketing and distributing low-cost, calorie-dense foods, and beverages. Indeed, private marketing funds directed towards increasing the consumption of such foods dwarf the public funds directed towards fostering better nutrition and exercise habits. Educational programs designed to change the lifestyle and eating habits of obese people have shown only modest results (Jeffrey et al., 1995; James et al., 2004). There is, however, growing optimism that modifications in the built environment, including the availability of public transportation systems, can help reverse the obesity trend through increased opportunities for physical activity and reduced reliance on automobiles for basic transportation (Dannenberg et al., 2003; Leslie et al., 2005; Transportation Research Board, 2005).

In this paper, we discuss the potential role of light rail transit (LRT) systems for increasing exercise patterns and reducing obesity rates among Americans. Specifically, we lay out a cost–benefit framework that weighs the economic costs of investing in relatively costly forms of public transportation, like LRT, against the related public health benefits. First, we discuss the literature on the built environment and health, as well as the costs and benefits of light rail transportation. Second, we provide a case study analysis of a new LRT being built in Charlotte, NC, and calculate its development costs in relation to its potential public health benefit. Finally, we discuss how urban planners can use planning models that include health outcomes in their assessments of the costs and benefits of infrastructure design.

The built environment and health

The idea that the built environment can affect public health is not new. Historically, urban planning has often been linked to public health. For example, the Sanitary Reform movement, which began in United Kingdom in the 19th century as a result of that nation's desire to curtail battlefield deaths caused by infection, was adapted by civic leaders in the United States in their development of municipal waste systems (Fishman, 1982). In the early 20th century, overcrowded and unsanitary housing conditions in the United States also led to increased use of zoning regulations. The legal justification for the regulation of land use emanated from the desire to promote the public health, safety, and welfare. Additional connections between health, safety, and urban planning involved utopian or garden-city developments designed to promote open space, clean air, and recreational opportunities (Jacobs, 1961; Fishman, 1982).

Current efforts to link the built environment to public health mirror developments in the 19th century, and include neo-traditional planning models that borrow from these historic land use and neighborhood planning efforts (CNU, 1998). The neo-traditional planning model, or new urbanism, is an attempt to re-establish traditional urban layouts that were prevalent before the advent of automobiles and suburban developments in the US (Calthorpe, 1993; CNU, 1998; Duany and Plater-Zyberk, 1992). New urbanism developments are defined by three planning goals: higher residential densities, a mix of residential and commercial land uses, and a return to a grid street pattern that promotes better spatial connectivity (Frank et al., 2004). A wealth of research in the field of urban planning links denser urban environments with shorter and more frequent trips (for example, to a neighborhood grocery store); more transportation options (including mass transit, walking, and biking); and less reliance on automobile travel (Ewing and Cervero, 2001; Frank, 2000; Frank et al., 2004, 2006; Southworth, 1997; Leslie et al., 2005). Mixed-use development also provides more local commercial options that do not require automobile trips. Grid street patterns lessen pedestrian distances and provide a safer walking environment.

The majority of research on the built environment and obesity-related co-morbidities, however, relies on cross-sectional research designs (see Frank et al., 2006) that compare one type of environment with others. As a result, there is a limited amount of evaluation research that documents how a specific change in the built environment actually leads to increased physical activity and reduced obesity-related morbidities and health care costs.[1] This study is intended to contribute towards filling this gap by estimating potential health care costs saved through modifications in the built environment.

Physical activity, health, and the built environment

Thirty percent of US citizens are completely inactive. This has severe implications for obesity and its attendant co-morbidities, including heart disease, diabetes, and some forms of cancer (Farley and Cohen, 2001). These problems are particularly acute among children and racial minorities (Mokdad et al., 1999). Research on the failure to maintain moderate forms of physical activity (Siegel et al., 1995; Lopez-Zetina et al., 2005; Frank, 2004) has found a number of related factors, including age, race, gender, social economic class, modes of transportation, and residential land use patterns (Farley and Cohen, 2001; Frank et al., 2004; Vandergrift and Yoked, 2004). The benefits of moderate physical activity, such as walking (Vuori et al., 1994; Southwarth, 1997; Craig et al., 2002), or biking (Boarnet and Sarmiento, 1998; Schwanen et al., 2004) are well-documented. Walking and other less vigorous forms of physical activity are also easier to sustain over time (Frank, 2004). In contrast, although diet restrictions and vigorous exercise can lead to short-term weight loss and cardiovascular health benefits, these approaches have high failure rates over time (Siegel et al., 1995; Bauman et al., 2002).

Recent research has examined the relationship between the built environment and health. Kelly-Schwartz et al. (2004), for example, using data on residential sprawl (“sprawl” means low-density land use, such as neighborhoods devoted entirely to single-family houses), found a significant correlation between residential sprawl and deleterious public health consequences. Ewing et al. (2003) also found a link between land use variables, activity patterns, and obesity. Craig et al. (2002), using data from Canada, found that neighborhood design characteristics such as pedestrian-friendly sidewalks influenced whether people chose to walk to work. Giles-Corti and Donovan (2003) working with data from Perth, Australia, examined three forms of walking behavior influences: individual, social, environmental and physical environmental. Using a relative accessibility model (distance decay) this research found that the perceived accessibility of the physical environment was associated with walking behaviors. Frank et al. (2004) examined travel survey data from the Atlanta region and found that land use mix was the strongest correlate to body mass index (BMI), which is used to measure obesity. According to their estimates, each additional hour spent in a car per day resulted in a 6% increase in the probability of being obese (Frank et al., 2004). Similarly, an analysis of land use mix and street networks in King County, Washington found that

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[1] In a recent review of the literature, Handy (2004) found 22 studies from the field of urban planning and 28 studies from public health that examined the role of the built environment and physical activity.

neighborhoods with increased walkability were associated with more minutes devoted to walking and biking and lower BMI (Frank et al., 2006). In sum, the empirical research lends credence to the argument that more pedestrian-friendly options in communities can increase physical activity for residents (see Cervero, 1996; Cervero and Duncan, 2003; Cervero and Gorham, 1995; Audirac, 1999; Boarnet and Sarmiento, 1998; Frank, 2000; Frank et al., 2006; Lopez-Zetina et al., 2005; Leslie et al., 2005; Suminski et al., 2005; Litman, 2005).

Transportation modes, land use, and travel behavior

A clear link exists between modes of transportation and land use patterns (Frank, 2004). Zoning and land use ordinances have tended to separate residential and business communities in the US, rendering walking as a mode of travel choice difficult (Schilling and Linton, 2005). Separation of land uses has led to an over-reliance on personal motor vehicles. In less-dense urban environments, trips are more likely to involve a motor vehicle (Cervero and Gorham, 1995; Frumpkin et al., 2004; Boarnet and Crane, 2001; Litman, 2005).

Fixed transit systems—such as LRT—can have an impact on land use planning outcomes, such as the promotion of transit-oriented developments around such systems. However, the relationship between such developments and public health is a focus of ongoing research. Transit-oriented developments, for example, may impact exercise patterns by encouraging residents to live in areas closer to LRT stations, where they can shop and use the train to commute to work. A recent analysis of the National Household Travel Survey found that people who walk to and from public transit obtain significantly more daily physical activity than those who do not. Moreover, survey respondents who walked at least 30 min daily were significantly more likely to use rail compared to bus transit. Fixed rail transit systems seem to encourage more exercise than bus lines, due to the longer distance between rail stops and residential or work locations. Importantly, minorities and those from lower income groups were significantly more likely than whites to use rail transit, suggesting that the same groups at the greatest risk for obesity also receive more potential public health benefits from public transportation (Besser and Danneberg, 2005).

LRT: costs, benefits, and prospects

In an effort to reduce road congestion and air pollution, a number of cities have recently developed or expanded light rail systems (Light Rail Transit Association, 2004). Planners promote LRT as a means to reduce automobile trips as well as providing additional social benefits. LRT stations are increasingly being planned as transit-oriented developments, with mixed-use zoning, higher-density residential development, and retail and entertainment uses. Thus, some of the costs associated with LRT development can be offset by factors such as: (1) property development activities around planned transit stations; (2) decreased air pollution; and (3) potential health benefits related to increased exercise for residents living in the surrounding communities (Calthorpe, 1993; Belzer and Autler, 2002; Campion et al., 2004), factors that may promote more active lifestyles.

Research on LRT systems, however, points to heavy development costs, and for older systems, declining numbers of riders (Gomez-Ibanez, 1985). Some research indicates that more recent LRT developments provide economic benefits in excess of their costs (Minnesota Department of Transportation, 1999). Alternatively, some analysts in the field of urban planning see LRT as an expensive and inefficient answer to the problem of traffic congestion (Gordon and Richardson, 1997). For example, fare revenue covers only 28.2% of operating costs in St. Louis, 19.4% of costs in Baltimore, and 21.4% of costs in Buffalo. Nationwide, annual LRT operating costs ($778.3 million) far exceed fare revenue ($226.1 million) (Castelazo and Garrett, 2004).

Nevertheless, the economic justifications for LRT developments continue to be debated (Gomez-Ibanez, 1985; Poole, 2004). Indeed, two flourishing cottage industries have sprung up over recent years: those who promote the continued development of LTR and those equally opposed to these systems (Light Rail Transit Association, 2004; O'Toole, 2005; Texas Public Policy Foundation, 2000). The research evidence in support of positive economic effects of light rail is mixed. Cervero and Gorman (1995) questioned whether small "islands" of pedestrian-friendly, transit-linked enclaves, surrounded by sprawling land use patterns, have much of an impact on declining automobile usage. Boarnet and Compin (1999) found that transit-oriented developments around LRT stations in San Diego were not pursued as vigorously as planning documents predicted due to the cyclical nature of real estate markets as well as a general failure of planners to facilitate transit-oriented developments around rail stops. Ryan (2005) also found no significant relationship between LRT access and increases in residential property rents in San Diego (in other words, LRT access did not engender greater demand for residential properties). In contrast, research found a significant increase in land values around LRT station stops in Dallas, TX compared to matched comparison areas (Weinstein and Clower, 2002). Economic analyses of LRT, however, focus almost exclusively on the costs of development versus benefits associated with traffic congestion reduction and real estate values. The planning literature has yet to account for the economic value of health benefits that LRT may produce through its association with denser land use patterns and increased physical activity of the populations it serves (see Frank, 2004).

Pack (1997) provided one of the few examples of a cost–benefit analysis of a heavy rail transit system that involves a more extended accounting of public benefits. Using Philadelphia's regional rail system as an example, Pack (1997) offered a simple cost–benefit analysis that included a wide array of social benefit categories. By extending the possible benefits of rail, Pack was able to offer a more sanguine assessment of the system's positive impacts, even when weighed against expensive operating deficits and capital improvement costs. Included in Pack's model were five areas of social benefits: (1) the decrease in accidents attributable to fewer car trips; (2) decreased car and truck commuting times; (3) decreased congestion and pollution; (4) welfare gains for transit riders (measured by time saved for commuters over other forms of transit); (5) welfare gains for commuter riders (measured as an estimate of the capitalization into housing values of accessibility to the regional rail system; or, the willingness for rail riders to pay a premium for housing in census tracts with commuter rail stations). However, missing from Pack's assessment of the social benefits of the commuter rail system in Philadelphia were benefits related to increased physical activity associated with this form of travel.

The Charlotte case study

LRT's role in Charlotte's Projected Development

In the present study, we use a case study of a new LRT system in Charlotte, NC to develop a model of the costs and projected benefits of this form of public transportation. Our model, building on the work of Frank (2004), offers a framework for estimating the economic health benefits associated with investing in a new LRT system.

Charlotte provides an ideal case study of public health outcomes associated with LRT implementation, and the impact of transit mode options on public health outcomes. As a region Charlotte is both sprawling and has high risk factors for obesity and its related health complications. Charlotte ranked 40th out of the 41 metropolitan areas (with 1,000,000 + pop. in 2000) in the lowest percentage of residents living in a core urbanized area (39.2%). As a comparison, in the US as a whole, about 74.6% of a metropolitan area's population live in the metropolitan core (US Census, 2003). Charlotte also has a low percentage of residents who report getting at least a moderate amount of exercise; with only 41.7% of the region reporting to have got 30 min of moderate exercise 5 times a week or 20 min of vigorous exercise 3 times a week. This compares to a national average of 49% (Centers for Disease Control and Prevention, 2007).

Charlotte's City Council has proposed a comprehensive plan that seeks to shepherd future growth into established centers and corridors. Traffic congestion and related economic, environmental, and social impacts are also major concerns for the Charlotte area. While the region is served by a number of urban interstate highways, these highways are becoming more congested. For example, the average commuting time in Charlotte rose 20% from 1990 to 2003, and is currently at approximately 25 min per average trip to work. This rivals the growth of commuting time in the US with an average of 24.3 min in 2003 (US Census, 2005). Charlotte was ranked 19th in annual road delays (in hours) per traveler in 2003. Travel delays in the Charlotte region have risen from 10 h per traveler in 1982, to 43 annual hours per traveler in 2003 (Shrank and Lomax, 2005). Additionally, only 1.8% of Charlotte's metro area residents regularly use public transit, compared to a national average of 5% (Bureau of Transportation Statistics, 2005). Close to 80% of Charlotte workers commute to work alone in an automobile. In 1998, Charlotte voters, responding to concerns about traffic congestion, approved a half percent sales tax to be dedicated to developing public transit.

The Charlotte Area Transit System, in conjunction with the city of Charlotte, is building the South

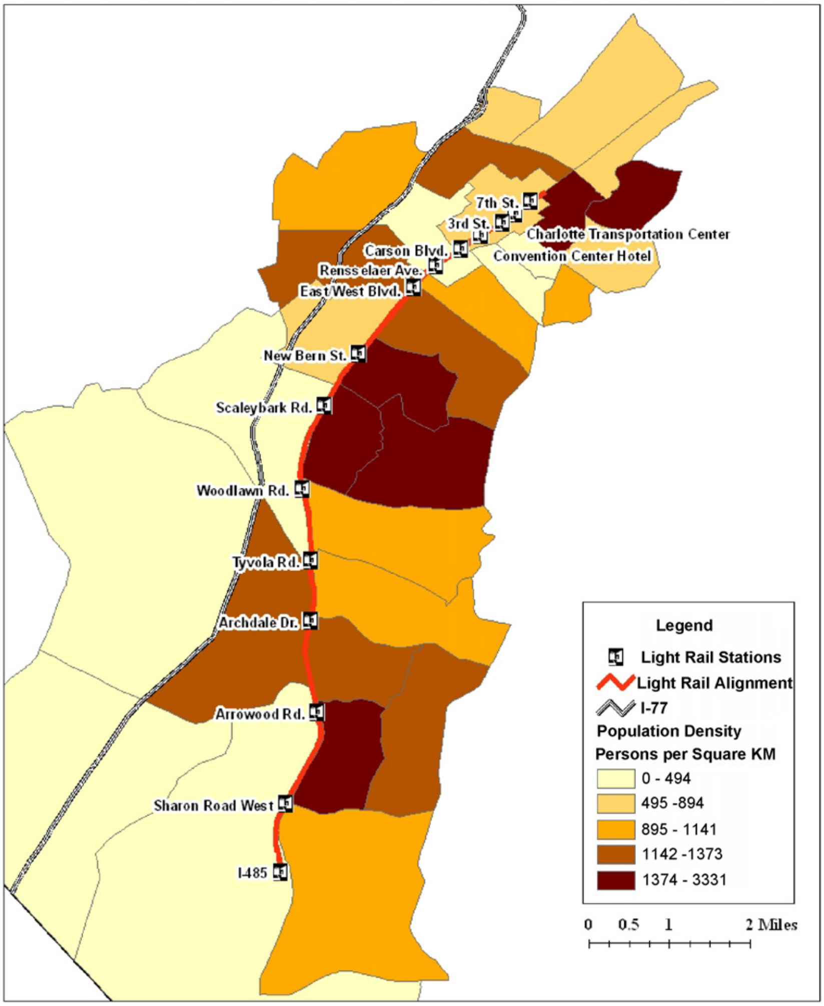

Fig. 1. South corridor alignment map.

Corridor LRT, a 9.6-mile, 15-station system that originates in uptown Charlotte and extends southward to Interstate 485. The South Corridor LRT parallels Interstate 77 and South Boulevard, the most heavily traveled roads used by commuters living to the city's south region and working in downtown Charlotte (see Fig. 1). Therefore, this LRT system offers a viable alternative to commuters in southern Charlotte neighborhoods. The city has also planned to zone for and provide necessary infrastructure relating to transit-oriented developments along the new LRT line. Thus, the new transit system is providing both a new choice for commuters and a mechanism to create denser land use patters around rail stops. Because it originates in the city's downtown, this line also has the potential to bolster economic redevelopment efforts in the center city related to downtown recreation (sports, entertainment, retail and cultural facilities) (Clark, 2003).

The transit utility goal of the LRT project is to generate 4200 h of travel time benefits during weekdays by 2025. The Charlotte Area Transit System estimates that the new light rail line will carry 9100 weekday riders in its first year of operation in 2007 (Charlotte Area Transit System, 2002). The cost of the project's 9.6 miles of track is \$427 million.[2] It is estimated that 45% of operating

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[2] This equates to \$45 million per mile of track. This cost per mile is similar to projects in Dallas, TX, Houston, TX, and Denver CO. The average cost per mile of LTR in the US is approximately \$50 million per mile of track, with costly outliers in New York City (JFK Light rail \$230 million per mile) and San

and maintenance costs will be covered by the Charlotte Area Transit System sales and use taxes. Additional capital and operating expenses of the proposed transit system would be financed through operating revenues, Federal Transit Administration and North Carolina Department of Transportation grants, and other, including private, sources of income (Charlotte Area Transit System, 2002). The capital costs of this system are partially offset by the use of the existing railroad right-of-way paralleling South Boulevard.

The establishment of LRT is part of the Charlotte region's comprehensive land use and development plan. The plan calls for future regional development and redevelopment to take place along five major transportation corridors (North Corridor, Northeast, South Corridor, Southeast, and West). This plan includes as its linchpin the development of a regional rapid transit system to serve the dual purposes of improving regional mobility while encouraging more compact development. The Charlotte Area Transit System also performed a transportation investment analysis to determine proper transit improvements in each corridor to bolster the goals of the comprehensive land use plan.

The Charlotte City Council adopted a set of transit station area development principles to support the LRT and focus future development into an area that is within a half-mile walking distance from the station stops (Charlotte Area Transit System, 2002). Planners in Charlotte have come to realize that creating better facilities for walking and bicycle travel is an important component of transit planning, and have therefore developed a bicycle plan. They also have dedicated capital monies to constructing more pedestrian-friendly street design and sidewalk projects along the LTR line. The city has also created a new zoning approach—a pedestrian overlay district—to facilitate a safer, more accessible pedestrian and bike travel option (Charlotte Area Transit System, 2003). Overall, the city of Charlotte has developed a set of ambitious planning goals tied to the new LRT. Our focus in the remainder of this paper is to provide an analysis of the costs and potential public health benefits associated with this major infrastructure program.

Quantifying the health care benefits of LRT in Charlotte

We recognize that there are many potential mechanisms for undertaking costs and benefit analyses of public transportation systems (Litman, 2003; Frank, 2004). For the purposes of this case study, we offer a cost–benefit model that specifically focuses on estimated public health benefits (savings) of LRT.[3] In this model, we estimate how much the yearly operation of the new LRT system produces in potential public health benefits by increasing the amount of walking to and from the LRT stations. This is done by estimating the net new walking patterns enabled by a new LRT system, followed by an assessment of how these estimates of increased exercise might reduce the prevalence of obesity for transit riders. We then estimate the public health savings of these impacts by modeling a specific example: public health savings associated with LTR in Charlotte.

Estimating the incremental improvements in public health associated with transit use is difficult because of the lack of refined data. Without directly measuring transit users' walking patterns via an accelerometer (e.g., Frank et al., 2006), we must use estimates generated from previous research on other rail users. Estimates from the National Household Travel Survey, for example, indicate that rail transit riders walked an average of 24 min a day related to transit trips, while 29% of riders met the minimum required exercise recommendation of 30 min a day merely walking to and from their transit stops (Besser and Danneberg, 2005). The use of rail transit increases the odds of walking at least 30 min a day by 67% (Besser and Danneberg, 2005). Research has also found that every additional 30 min spent in a car increases the risk of being obese by 3%; while each additional kilometer walked each day is associated with a 4.8% reduction in the odds of being obese (Frank et al., 2004).

Projected weekly riders: We used estimates of the number of weekly riders provided by the Charlotte Area Transit System for the first 9 years of operation (2007–2015) (Charlotte Area Transit System, 2003). The Charlotte Area Transit System

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(*footnote continued*)
Francisco ($105 mil per mile for the 3rd Street extension) (Light Rail Transit Association, 2005).

[3] One of the problems with traditional cost–benefit analysis of transportation infrastructure is that road construction in outlying areas is cheaper because land is less expensive. Thus, even controlling for the political pressures to invest transportation infrastructure dollars in outlying (low-density) areas, transportation infrastructure investments in urban areas often fail a simple cost–benefit comparison (Frank, 2004).

estimates 9100 weekly riders in 2007 and 15,609 weekly riders by 2015. We assume that this estimate may vary by +/−5%.

Prevalence of obesity: We used estimates from the Behavioral Risk Factor Surveillance System for North Carolina to estimate that 23% of potential transit riders have a BMI over 30 (and are therefore considered obese).

Direct and indirect costs of health care: Obesity is associated with a number of negative health outcomes, including coronary heart disease, diabetes, high blood pressure, reduced bone density, and cancer (Visscher and Seidel, 2001). Importantly, the economic consequences of obesity are clear. Studies indicate that obesity is associated with an average increases of 30–37% in an individual's yearly medical-related costs (Sturm, 2002; Andreyeva et al., 2004; Finkelstein et al., 2003). Based on this range, we estimate that obesity is associated with an average yearly increase of $458 in direct medical costs, and $429 in indirect medical costs (Sturm, 2002; Finkelstein et al., 2003).

Willingness to pay: Research indicates that obese persons are willing to pay a substantial amount of money for effective weight loss treatment. For instance, the median weekly cost of food for the 10 most popular weight loss programs is 50% higher than the average single American spends on food (Forbes Magazine, 2005). Narbo and Sjostrom's (2000) research found that obese individuals are willing to pay an average of twice their monthly salary for effective weight loss treatment. Clinically tested commercial weight loss programs, however, vary greatly in their costs for the standard 3-month treatment (e.g., $26–2100) (Tsai and Wadden, 2005). Research using a discrete choice experiment (DCE) with a sample of overweight persons found that respondents were willing to pay an average of $787 for the typical 3-month community-based weight loss program (Roux et al., 2004). The advantage of the DCE estimate is that it is a more conservative estimate of "willingness to pay" because it is standardized to a variety of weight loss programs and adjusted for age, race, income, and other demographic factors. We, therefore, rely on this more conservative willingness to pay value of $787 per year for an effective weight loss regimen.

Cost–benefit analysis and results

To estimate the effects of LRT on public health care costs, we used a simulation model with inputs derived from previous studies to estimate the average effect of LRT use on obese persons who will now walk at least 30 min each workday and the health care benefits directly attributable to this added exercise. Taking a conservative approach, we assume that the benefit of walking at least 30 min a day translates into yearly reductions in public health costs for obese individuals only. If we adjust this assumption and distribute the public health benefits to all new riders, our benefit estimates would be considerably larger.[4]

The potential reduction in obesity costs due to light rail can be expressed by the following:

$$\begin{aligned}&\text{Number of riders} \times \text{percentage obese}\\&\quad\times \text{percentage of riders that sufficiently}\\&\quad\text{exercise to reduce obesity} \times \text{cost of being obese.}\end{aligned} \tag{1}$$

While there is information available on each of these inputs, there is a fair amount of uncertainty. Rather than simply plugging in the best available estimates for each of these numbers, we will repeatedly sample values from distributions that characterize the available information and evaluate (1) for each collection of sampled parameters.

While we estimate that obese individuals annually incur direct medical costs of $458, indirect medical costs of $429, and willingness to pay of $787, the uncertainty associated with these numbers could be as large as 47% of the costs. To calculate the expected benefits of LTR, we need to have an estimate of the probability that an LTR user would exercise more than 30 min. We can write this as

$$P(E|R) = P(E|R, W)P(W|R) + P(E|R, \bar{W})P(\bar{W}|R), \tag{2}$$

where E represents exercising more than 30 min per day, R indicates rail usage and W represents walking to transit as part of one's commute. Based on the National Household Travel Survey, Besser and Danneberg (2005) estimate that $P\,(E|R,\,W)$ to be 0.281 with a standard error 0.0169. We have no estimates of the probability of 30 min of exercise for those that used the LRT system but did not walk to the station. We set this probability to 0 so that our forecasts of the probability of exercise will be

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[4] Our model assumes a net benefit on health care costs for all obese persons who achieve an extra 30 min of walking a day and does not assume any additional caloric intake associated with increased walking. Nor does it include the potential benefits associated with preventing obesity in those who might otherwise become obese.

conservative. To estimate $P(W|R)$, the probability of walking given rail use, we utilize Bayes' Theorem

$$P(W|R) = \frac{P(R|W)P(W)}{P(R)}. \tag{3}$$

According to the National Household Travel Survey, an estimated 40.2% of transit walkers use rail, $P(R|W)$ (Besser and Danneberg, 2005). We infer the standard error estimates from their reported confidence interval to be 0.014. They also report $P(R) = 0.398$ (SE = 0.013). However, this estimate is correlated with the estimate of $P(R|W)$. The correlation between a mean compute on N cases with a mean compute on $M < N$ of the same cases is $\sqrt{M/N}$. While estimates from the National Household Travel Survey report only the raw sample sizes rather than the effective sample size due to the use of survey weights, the reported confidence intervals are only slightly wider than what would be expected from an unweighted analysis, indicating little variance in the weights (see Besser and Danneberg, 2005). The slight reduction in effective size will likely affect M and N equally and that effect will cancel in the correlation. We estimate the correlation between the estimated $P(R)$ and $P(R|W)$ to be $\sqrt{1153/1249} = 0.96$, so the covariance will be $0.96 \times 0.013^2 \times 0.014^2 = 0.000178^2$. $P(W)$, the probability of walking, is not reported directly in estimates from the National Household Travel Survey (Besser and Danneberg, 2005), but we can use the reported sample sizes to directly estimate this probability. Again noting that the variance in the survey weights was not sufficient to enlarge the confidence intervals, $P(W) = 1153/(1153 + 1249) = 0.480$ (SE = 0.010).

We can substitute all these values into (3), which then substitute into (2) to produce an estimate of the probability of exercise given rail usage. Table 1 displays the values for the model parameter estimates used in our simulation.

We simulated parameter values from the distributions (see Table 1) 10,000 times for each public health cost category (direct, indirect, and willingness to pay). Fig. 2 displays the results from these simulations for the first 9 years of Charlotte area projected riders (2007–2015). The dark horizontal lines in the middle of the boxes indicate the median forecasted costs over the 10,000 replicates of the simulation for each year. The shaded area reflects the 95% confidence interval.

Table 2 reports the median predicted values of annual health care expenditures saved by using the LRT, according to our simulations for projected riders in years 2007–2015. We estimate that the light rail system could reduce total public health costs by \$903,000 for the anticipated 9100 light rail users for the first year (2007) of operation alone. The 95%

Table 1
Summary of model parameters

Parameter	Distribution	Source
Number riders		CAT
2007	$N\ (9100, 228^2)$	
2008	$N\ (12\,069, 302^2)$	
2009	$N\ (14\,483, 362^2)$	
2010	$N\ (14\,805, 370^2)$	
2011	$N\ (14\,966, 374^2)$	
2012	$N\ (15\,126, 378^2)$	
2013	$N\ (15\,287, 382^2)$	
2014	$N\ (15\,448, 386^2)$	
2015	$N\ (15\,609, 390^2)$	
P(obese)	$N\ (0.23, 0.012^2)$	BSFF
$P(E\|R, W)$	$N\ (0.281, 0.0169^2)$	Besser and Danneberg, 2005, Table 2
$P(R)$, $P(R\|W)$	$MVN\left(\begin{pmatrix}0.398\\0.402\end{pmatrix},\begin{pmatrix}0.013^2 & 0.000178^2\\0.000178^2 & 0.014^2\end{pmatrix}\right)$	Besser and Danneberg, 2005, Table 1
$P(W)$	$N\ (0.480, 0.010^2)$	Besser and Danneberg, 2005, Table 1
Direct costs	$N\ (458, (\frac{1}{2} \times 0.47 \times 458)^2)$	Sturm, 2002; Finkelstein et al., 2003
Indirect costs	$N\ (429, (\frac{1}{2} \times 0.47 \times 429)^2)$	Sturm, 2002; Finkelstein et al., 2003
Willing to pay	$N\ (787, (\frac{1}{2} \times 0.47 \times 787)^2)$	Roux et al., 2004

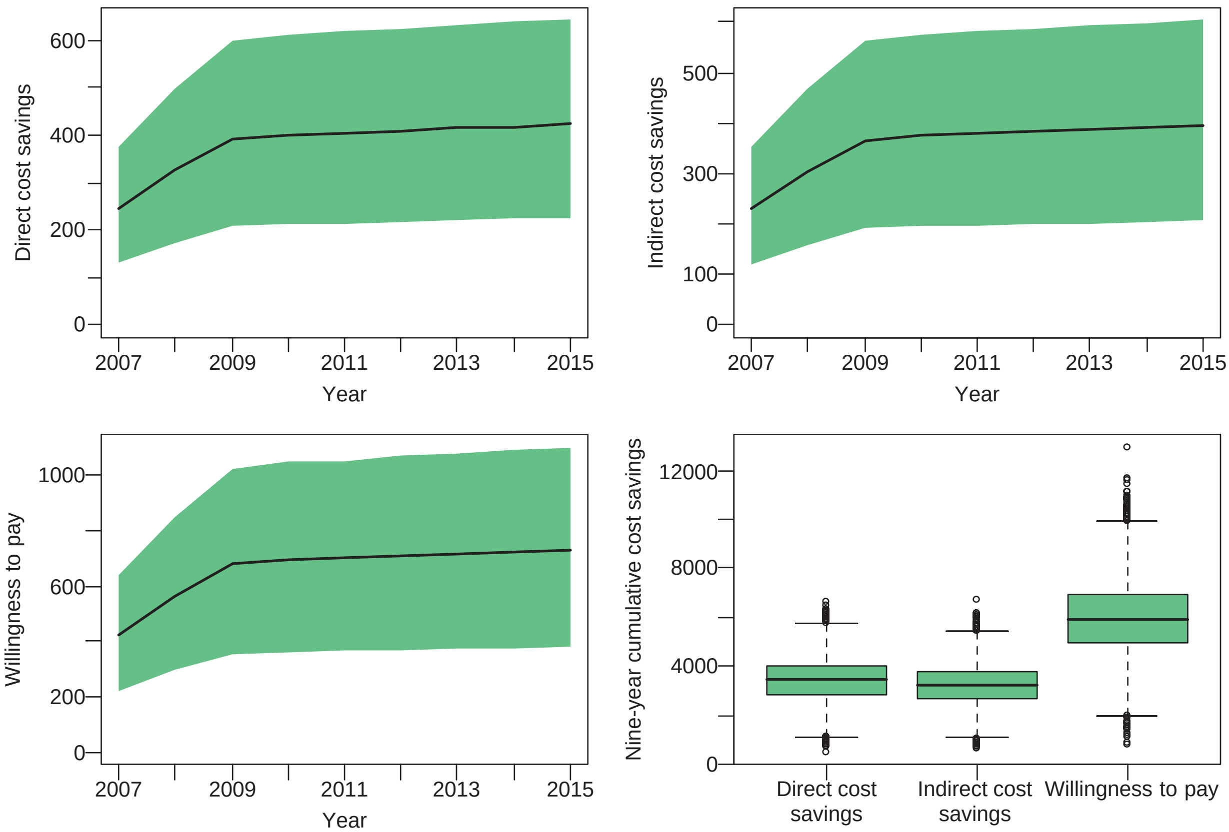

Fig. 2. Annual cost savings (in thousands of dollars) in public health generated by light rail.

Table 2
Yearly comparison of the median public health costs saved for people who use light rail transit

Year	Riders (*n* =)	Direct ($)	95% CI ($)	Indirect ($)	95% CI ($)	Willingness ($)	95% CI ($)	Total savings ($)
2007	9100	246,000	132,000–376,000	231,000	125,000–350,000	426,000	224,000–641,000	903,000
2008	12,069	326,000	175,000–498,000	306,000	165,000–464,000	565,000	299,000–850,000	1,197,000
2009	14,483	392,000	209,000–598,000	368,000	198,000–557,000	679,000	357,000–1,019,000	1,439,000
2010	14,805	400,000	214,000–612,000	375,000	203,000–570,000	692,000	365,000–1,050,000	1,467,000
2011	14,966	405,000	216,000–616,000	380,000	204,000–575,000	701,000	366,000–1,051,000	1,486,000
2012	15,126	410,000	218,000–622,000	383,000	208,000–580,000	708,000	371,000–1,069,000	1,501,000
2013	15,287	414,000	221,000–628,000	388,000	210,000–587,000	715,000	376,000–1,080,000	1,517,000
2014	15,448	418,000	224,000–636,000	392,000	211,000–593,000	723,000	378,000–1,089,000	1,533,000
2015	15,609	423,000	227,000–642,000	396,000	214,000–598,000	732,000	385,000–1,101,000	1,551,000

Note: CI—confidence interval.

confidence interval for the value of the estimates ranges from a low of $125,000 for indirect medical costs to a high of $641,000 for willingness to pay. Overall, the results from our analysis indicate that light rail usage will provide Charlotte, NC with consequential benefits in public health care costs. According to our model, the total cumulative health care costs saved would be approximately $12.6 million dollars over 9 years (2007–2015). While these benefits do not recoup the construction costs of this form of public transportation ($427 million)—even when the constraints on our model are varied by factors of plus or minus 2 standard deviations—they do indicate a significant projected health savings resulting from investing in this form of public transportation.

This cost analysis has a number of important limitations. We did not calculate potential benefits of urban redevelopment efforts associated with the light rail system, such as improved conditions for pedestrians and bicyclists, increasing transportation-oriented developments, lower pollution, and other benefits of urban development. Our analysis also assumes that obese persons who achieve at least 30 min a day of walking will receive the full public health benefit. This assumption, however, is very optimistic given the number of studies indicating that weight loss is difficult and that more than exercise is necessary to generate significant long-term reductions in body weight. Finally, increased exercise is associated with benefits beyond weight loss. In fact, studies indicate that routine physical activity reduces the risk of hypertension, diabetes, and various forms of cancer (see Warburton et al., 2006). Additionally, our analysis does not generate any potential public health savings associated with the overall increase in physical activity that can occur for non-obese individuals walking to and from public transportation. Thus, we present an optimistic benefit estimate for the effect on obese individuals, but a conservative benefit estimate for the overall effect on public health.

Our model estimates the initial public health benefit that will be generated by adding an LRT system to Charlotte's built environment. As the number of weekly riders increase and the share of the public walking increases, the potential public health savings generated will increase accordingly.

Discussion

There is a fast-growing body of research linking land use patterns and negative public health outcomes (Ewing et al., 2003). Most of this research has made efforts to link sprawling land use patterns to the growing public health problem of obesity in the United States. Along with other developments in the US relating to lifestyle changes and demographic factors, there has been a growing sense among researchers and policy makers that an effective set of interventions is needed to turn back these public health trends. There is also increasing optimism that modifying the built environment, including the institution of new public transportation systems, could help reverse obesity trends through increased opportunities for physical activity and reduced reliance on automobiles for basic transportation (Litman, 2003; Frank, 2004).

One such transportation intervention, LRT, has been offered as more than a mere transit mode. LRT can simultaneously facilitate land use changes such as pedestrian-friendly street planning, and denser development around stations. Thus, LTR is seen by some as a linchpin to a planning model, transit-oriented development, designed to reduce reliance on the personal vehicle (Frank, 2004). The development of LTR systems around the US has been hotly debated among planners, researchers and interest groups due to its high per rider development cost. Some transit planners favor alternative modes, such as fixed bus lines that use existing roadway stocks. Supporters of LTR systems have pointed to the non-transit-related benefits of LTR. These benefits include development rights around rail stations and rights of way; increased land values around stations; a reduction in vehicle accident costs; decreased roadway congestion; and, as quantified in this study, public health benefits related to increased exercise.

While the estimated public health benefits modeled here appear to be modest relative to the large-scale infrastructure investment in LRT, they do suggest that LRT can yield a significant public health benefit. Clearly, intertwined lifestyle, social, and demographic trends play key roles in the growth of obesity in the US. While there are increased benefits related to walking as part of one's commute, LTR lines with relatively low ridership may have limited public health benefits. However, investments in LRT, along with larger regional land use and transportation plans, could yield additional public health benefits including some incremental reduction in air pollution. The relative success of this LTR line in affording citizens a more healthy transit choice needs to be coupled with linked developments around increased densities—which would encourage more exercise—as well as the development of pedestrian-friendly streets. Indeed, other LTR systems around the country have not maximized their potential broader social and public health benefits. Thus, the broad-based commitment to planning successful and healthy communities requires large-scale transformations of both transportation modes and urban land use patterns.

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