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Driving reduction after the introduction of light rail transit: Evidence from an experimental-control group evaluation of the Los Angeles Expo Line

Steven Spears
University of Iowa, USA

Marlon G Boarnet
University of Southern California, USA

Douglas Houston
University of California, Irvine, USA

Abstract

There is a pressing need to estimate the magnitude and dynamics of the behavioural effects of transportation investments and policy. This article innovates by applying an experimental-control group research design to the case of new light rail transit service in Los Angeles, California. Only a handful of previous studies use an experimental design to assess impacts of light rail transit, and this is the first to use an experimental design to measure impacts on vehicle miles travelled, a key determinant of greenhouse gas emissions from the transport sector. We administered an annual seven-day travel study to a panel of households in the vicinity of Los Angeles' Expo light rail line before the 2012 start of rail service and twice after the line opened. We find that households living within walking distance (1 km) of the new light rail drove approximately 10 fewer miles per day relative to control households farther away. Rail transit trips among near-station households approximately tripled relative to households beyond walking distance. Such driving reductions among households within walking distance of new rail transit stations suggest that Los Angeles' large rail transit investment, coupled with land use policy, has the potential to help achieve climate change policy goals. More broadly, experimental evaluation can provide insights into causality and patterns of travel behaviour change associated with planning policies.

Keywords

experimental design, panel methods, program evaluation, public transport, travel behaviour

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Corresponding author:
Steven Spears, School of Urban and Regional Planning, University of Iowa, 349 Jessup Hall, Iowa City, IA 52242, USA.
Email: steven-spears@uiowa.edu

Introduction

Urban regions worldwide are moving forward with major investments in public transportation infrastructure. In North America, this investment is often focused on light rail. North American light rail investments totaled US$40 billion in 2015 (Freemark, 2015). The 27 light rail systems in the United States, more than in any other country, were responsible for approximately 1.5 million daily unlinked passenger trips, double the volume for the year 2000 (APTA, 2000, 2015). In many cities, light rail, and particularly transit oriented development (TOD) around rail stations, is seen as a way to help meet environmental goals. The idea is that those who live near new high-quality transit service will drive less and therefore reduce their transport-related greenhouse gas (GHG) emissions.

California provides an excellent example of the ways transit investment and land use planning are being integrated to meet legislative mandates for GHG reduction. The State's Sustainable Communities and Climate Protection Act of 2008 (SB 375) requires that metropolitan planning organisations (MPOs) develop transportation investment plans that, when combined with affordable housing allocation plans and projected growth patterns, comply with state greenhouse gas emission targets for the ground transport sector (Barbour and Deakin, 2012). In response to state requirements, Los Angeles' Regional Transportation Plan and Sustainable Communities Strategy (RTP/SCS) stipulates that over half of new employment growth and housing development will occur within half a mile of a well-serviced rail or bus transit stop. The explicit goal of this policy is to reduce private vehicle use and increase the use of transit, walking and bicycling (Southern California Association of Governments, 2012).

Funding for transportation improvements, including public transportation, is being provided in part through a half-cent sales tax increase approved by Los Angeles County voters in 2008. This initiative, known as Measure R, is projected to generate US$40 billion in transportation funding over 30 years, nearly US$14 billion of which is programmed for new light rail and rapid bus capital projects. The region's main transit agency has committed funds for construction of six new light rail transit (LRT) lines, scheduled for completion by 2019. This is in addition to a longer-term investment in rail transit extending beyond 2020, making this famously auto-oriented city the home to what is likely the most ambitious rail transit construction program in North America.

Yet amidst this sea change in planning approaches and expenditures in Los Angeles and elsewhere, a fundamental question remains unanswered. How do those who live in neighbourhoods affected by transportation investments change their travel, and how do these changes evolve over time? Though a large body of evidence exists on the relationship between transit service and travel behaviour (Ewing and Cervero, 2010), most empirical studies to date have methodological limitations that limit identification of the causal processes behind individual and household travel behaviour change. For example, much of what we know about the influence of nearby transit service on travel is based on analysis of cross-sectional surveys, which are primarily conducted at one point in time, and often at the scale of metropolitan areas, states or the nation (i.e. Bento et al., 2005; Brownstone and Golob, 2009; Taylor et al., 2009). While cross-sectional studies provide insights into the associations between travel patterns, demographics and built environment characteristics, their lack of a temporal dimension limits their ability to provide direct evidence about how individuals or households will alter their behaviour in response to infrastructure changes (Boarnet, 2011; Salon et al., 2012). Though retrospective cross-sectional designs that capture past behaviour have the potential to help address this shortcoming (Wunsch et al., 2010), neither they nor longitudinal study designs, which utilise repeated measures of the same individuals over time, are often used in transportation research (Paaswell, 1997).

This gap in the literature is particularly noteworthy given the robust debate among transportation researchers about whether cross-sectional associations between built environment characteristics and travel represent a causal relationship in the presence of residential self-selection based on underlying travel preferences (e.g. Cao et al., 2009; Zhou and Kockelman, 2008).

The current study

In light of the fact that cities have limited resources to address increasingly urgent sustainability problems, accurate evaluation of the impact of policies and infrastructure investments is crucial. Though social scientists have spent almost five decades developing experimental-control group methods to evaluate programs and policies (for examples, see Vedung, 2008), very few travel behaviour studies make use of these methods. This is despite the fact that the spatial nature of transportation improvements, such as new light rail stations, often means that they lend themselves to the use of experimental, longitudinal study methods. In such studies, those in close proximity to a new improvement serve as an experimental group whose behaviour change can be evaluated against comparable control households residing beyond the influence of the improvement.

To our knowledge, only three previous studies have used an experimental design to assess impacts of light rail transit. Brown and Werner (2008) found increases in physical activity and fewer car trips among those who rode transit both before and after a new light rail stop opened in Salt Lake City. Brown et al. (2015) found that new transit riders increased their physical activity and lowered their body mass index (BMI), a key health measure, in a new light rail–complete streets corridor in Salt Lake City. MacDonald et al. (2010) found that those who began commuting to work using a new light rail line in Charlotte significantly reduced their BMI in the 18 months between survey periods.

The current study is the first to use an experimental design to measure impacts of light rail on vehicle miles travelled, a key determinant of transport-based greenhouse gas emissions. We report the results of a three year, before-after, experimental-control group study of travel behaviour change in response to new light rail transit service. Our key finding is that residents in the experimental group, those living within walking distance of new light rail stations, reduced household VMT by approximately 10 miles per day compared with a comparable control group. We draw on available data to suggest underlying patterns associated with this substantial, policy-relevant decline, and identify future research directions that could help more fully understand changes in household trip-making dynamics associated with a new nearby light rail service. Our study demonstrates methods that can be used strategically in future studies to evaluate the success or failure of sustainable planning initiatives, and our findings provide important insights into how light rail transit investment has the potential to help achieve policy goals related to climate change.

Study area selection and research design

The current study was designed to take advantage of the opening of the Expo light rail line, which extends south and west from downtown Los Angeles. Phase 1 of the line (the focus of the current study) runs 8.7 miles from downtown Los Angeles westward to Culver City, near the junction of the 405 and 10 Freeways. Service began on the eastern portion of the Phase 1 section on 28 April 2012, and was extended to Culver City on 20 June 2012.

We used an experimental-control study design to assess the impact of the Expo Line on the travel behaviour of existing residents. We selected neighbourhoods within walking distance of new stations (the 'experimental' group), and comparison neighbourhoods with similar built environment and socio-demographic characteristics located further from the new stations (the 'control' group). The experimental neighbourhoods were chosen from within a 1 km (approximately 5/8 mile) radius of the six westernmost stations. This distance was based on research that indicates that half and three-quarter mile radius circles produce the best fitting models of residence-based transit catchment areas (Guerra et al., 2012) and our own data, which indicate a sharp drop in rail use beyond a 1 km radius of new rail stations. We performed sensitivity tests using both circular (half mile and 1 km) and roadway network (1000 and 1200 metres) buffers, all of which returned results similar to those reported in this article. In all cases, experimental-control differences in vehicle miles travelled before and 18 months after opening were similar in magnitude (10.7 to 11.0 miles/household/day) and significant at the 0.05 level. Details of these sensitivity tests are available from the authors.

The control group neighbourhoods are contiguous to the experimental neighbourhoods and extend to distances from 1 to 5 km (three miles) from a new Expo Line station. Control neighbourhoods were chosen along commercial corridors similar to those of the Expo Line, and are aligned with former rail corridors that are scheduled for future light rail expansion. These include the Expo Line Phase II from Culver City to Santa Monica and the Crenshaw Line from Downtown Los Angeles to the Los Angeles International Airport.

Based on data from the 2010 US Census, the experimental and control neighbourhoods are similar in terms of population density, housing density, age and income distribution. Racial and ethnic makeup of the areas differ somewhat. In the experimental areas, Hispanics of any race comprise 52 percent of the population and African Americans 28 percent. Control neighbourhoods have a lower Hispanic population (33%) and a higher proportion of African Americans (46%). Housing in both areas is a mix of single family detached homes and multi-family apartment complexes.

The current study began after construction of the Expo Line was substantially complete, but before the service opened to the public. Test trains began operating on the line in April 2011, approximately five months before our initial survey period, and continued until the line opened for service in late April 2012. Our study area was largely free of major transportation-related construction in each of the three survey periods, reducing the possibility that construction impacts on surrounding streets or sidewalks affected travel behaviour.

Participant recruitment and data collection

Before opening data collection

Households were originally recruited for the study from September to November of 2011. We purchased addresses of 27,275 households in the study area from InfoUSA, and mailed each household a letter in both English and Spanish inviting them to take part in the study. To avoid potentially influencing their behaviour, participants were not notified that the study was focused on the Expo Line. Rather, our outreach materials stated that the purpose was to examine the effects of local employment, shopping, transportation and neighbourhood design on the distance people travel and the types of transportation they use. A total of 651 households indicated interest in the study and were provided information and materials required to participate in the full study.

All participants completed a seven-day travel log for each household member 12 years old or older and a seven-day odometer log for each household vehicle, in addition to detailed baseline surveys about household demographics and transportation-related attitudes. The estimated baseline survey completion time was about 20 minutes, with an additional five minutes per day per household member for the odometer and travel logs. Our VMT data are derived from the odometer log, which included odometer mileage readings for each household vehicle on each of the seven survey days. The trip logs for each household member also included trip counts by travel mode and minutes spent walking and bicycling.

The first phase of data collection was completed in February 2012, before Expo service began in April 2012. A total of 285 households provided complete and usable responses: 114 (40.0%) in control neighbourhoods and 171 (60.0%) in experimental neighbourhoods. Each household that completed the survey materials received an incentive for participation in the form of a US$15 or US$30 supermarket gift card.

Our response rate from households that indicated initial interest was 43.8 percent (285/651). If the response rate is calculated as the number of complete seven-day surveys from among all households contacted, it is approximately 1 percent (285/27,275). Though the overall response rate is low, it is not atypical for travel surveys. Our response rate is comparable to the 0.4% response rate of the 2010–2012 California Household Travel Survey (California Department of Transportation, 2013: 83) and the 0.4% response rate for the 2012 Neighborhood Travel and Activity Study of residents of rail transit corridors in Los Angeles (Houston et al., 2015), both of which collected travel diary survey data using a similar mail-only recruitment approach.

Comparison of the characteristics of responding households to non-responding households in the study area is limited to the InfoUSA marketing information obtained from our purchased mailing lists. The full InfoUSA list contained all households in the study area neighbourhoods, and included basic demographic information. Compared to all households contacted, the study sample includes a slightly lower percentage of households headed by a male (36% vs. 42%), households headed by a younger adult aged 18–39 (21% vs. 27%) and households with an annual income below US$30,000 (33% vs. 38%), but these differences are not statistically significant. This suggests the final sample was representative of the study area population based on observable characteristics.

After opening data collection

In September 2012, approximately five months after the opening of the Expo Line, we re-contacted households that participated in the before opening survey. In order to maximise participant retention, respondent compensation was increased to US$50 or US$75 gift cards. This phase of data collection was completed by the end of November 2012, and a total of 208 households out of the 285 households (73%) from the before opening survey returned a usable set of study materials.

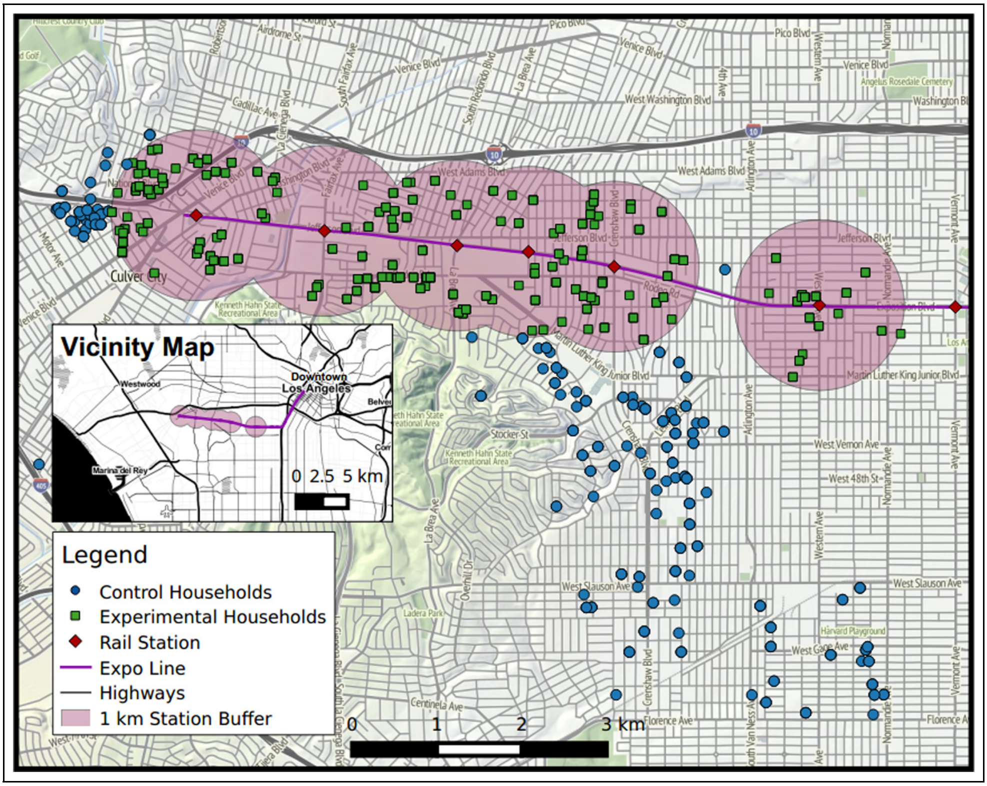

Figure 1. Expo Line sample household approximate locations.

The second after opening survey began in September 2013, approximately 18 months after the opening of the Expo Line, and was completed in early December 2013. A total of 173 households returned a usable set of study materials from the 2013 survey. This represents 85% of households who completed the first after opening survey, and 61% of the households who completed the before opening survey. Figure 1 shows the approximate location of households that participated in the study and the 1 km boundary around new light rail stations. All three survey periods began after the start of the school year and were not conducted during holiday periods, in order to capture normal travel patterns. The survey instrument, questions and protocol were the same in all phases of data collection.

Because of the potential for bias due to drop outs in any longitudinal study, we attempted to investigate the possibility that systematic differences exist between those who dropped out of the study and those who remained. Results could be biased if households that participated in all three waves differ in terms of their propensity to use light rail or reduce their car use compared to those who dropped out. For example, households with positive attitudes towards transit could possibly have been more willing to continue their participation while others were not. The opposite could be true for those with higher levels of personal safety fear on transit. Spears et al. (2013) found both of these factors to be significant predictors of transit use among residents in Los Angeles. To test whether differences in attitudes and perceptions exist between our final panel and dropouts, we conducted an exploratory factor analysis (EFA) on the wave 1 responses to 40 attitudinal questions that were completed by the main respondent in each household. EFA is a statistical technique designed to identify a smaller set of underlying factors based on correlations between responses to a larger set of survey items. This analysis yielded six distinct factors: transit attitude, environmental attitude, personal safety fear on transit, car attachment, perceived neighbourhood amenities and perceived comfort with transit/car use. No significant difference exists in the scores on any of these factors between panel households and those who left the study, indicating a lack of systematic drop out patterns on these indicators of propensity to use transit.

Analytical approach. The first stage of analysis is comprised of descriptive statistics and Chi-square and t-tests analysis of differences in the demographic and socioeconomic characteristics of experimental and control groups. The second stage includes between-group differences for travel in the experimental and control households six months before and six and 18 months after the opening of the Expo Line. The third stage is a difference-in-differences (DID) regression analysis of all travel outcome variables. In this analysis we use a panel where only households that provide valid responses in at least waves 1 and 2 (before-after opening) are included in the model for each travel outcome.

DID is an econometric technique commonly used with quasi-experimental panel data to evaluate the effect of a treatment over time. DID analysis assumes that the differences that arise in the control and experimental groups are due only to the treatment – in this case, the opening of the new light rail line. Defining μ_{it} as the mean of the outcome for group i at time t, the DID estimator is $(\mu_{11} - \mu_{01}) - (\mu_{10} - \mu_{00})$, where 'i' = 1 for experimental households and 'i' = 0 for control households. This can be estimated using the following regression model:

$$Y_{it} = \beta_0 + \beta_1 X_i + \beta_2 T_t + \beta_3 X_i * T_t + \varepsilon_{it} \quad (1)$$

where Y_{it} is the outcome for household i at time t, X_i is a dummy variable with values 0 for the control group and 1 for the experimental group and T_t is a dummy variable that takes the value 0 in the before opening period and 1 for the after opening period. The coefficient β_3 on the interaction term between X_i and T_t represents the DID estimator. Note that X_i*T_t takes a value of 1 only for experimental households in the after opening time period. The coefficient β_3 is therefore the effect of the treatment (the Expo Line in this case) on the treated households (those within 1 km of new Expo stations). See, e.g., Card and Krueger (1994) for a detailed discussion of difference-in-differences analysis.

In the current study, we add household size, income and number of personal vehicles as control variables to account for the independent effect that changes in these variables can have on travel outcomes. Omitting the 'i' and 't' subscripts, the full DID model used to examine the impact of the Expo line is then:

$$\begin{aligned} Y = \beta_0 &+ \beta_1 X_{grp} + \beta_2 X_{t2} + \beta_3 X_{t3} \\ &+ \beta_4 X_{grp} * X_{t2} + \beta_5 X_{grp} * X_{t3} \\ &+ \beta_6 X_{hs} + \beta_7 X_{veh} + \beta_8 X_{inc2} \\ &+ \beta_9 X_{inc3} + \varepsilon \end{aligned} \quad (2)$$

where:

- Y is the travel outcome of interest,
- X_{grp} is an experimental/control dummy variable, coded 1 for experimental households and 0 for control households,
- X_{t2} and X_{t3} are dummy variables = 1 for, respectively, each of the two after opening time periods,

- X_{hs} is a control variable for the number of people in the household,
- X_{veh} is a control variable for the number of vehicles available to the household,
- X_{inc2} and X_{inc3} are dummy control variables for the middle (US$35k to US$75k/year) and highest (more than US$75k/year) of our three household income categories.

As is the case for the basic model, the parameter estimates of interest are those for the two interaction terms (β_4 and β_5), which represent the treatment effect of the Expo Line at six and 18 months after opening, respectively.

The fourth stage of analysis includes exploratory analysis which draws on available data to suggest underlying household dynamics associated with the substantial household VMT decline we identified using DID analysis. We examine household trip and VMT patterns in the before and after opening periods to propose a hypothesis that a combination of mode substitution and changes in car use may be responsible for the VMT drop in experimental households. Unfortunately, available data are not sufficient to fully explore this hypothesis or to identify alternative explanations. This exploratory analysis provides insights into future research directions that could help more fully understand trip-making changes prompted by a new nearby light rail service.

In each wave of the study, a small number of responses included very high daily mileages that likely reflect out of region travel. In order to prevent the influence of these very long trips from affecting our results, we conducted a systematic analysis to assess the impact of extreme outliers. We focused on VMT, because that is possibly the most important policy-relevant variable in our study. After inspecting the data, we developed five outlier removal criteria: (1) remove individual days where a household vehicle travelled 500 or more miles and compute VMT based on remaining valid days, (2) remove households with a vehicle that travelled more than 500 miles in any day, (3) remove households with average household VMT over 200 miles per day, (4) remove households with average VMT per adult over 150 miles per day and (5) remove observations that contribute overly strongly to the DID regression results, using the Cook's distance criterion. Cook's distance is a measure of the influence of each data point on the parameter estimates obtained from a regression model. Large values of Cook's distance may indicate the need to check the validity of a given observation. The VMT results are very similar both in magnitude and significance using each of these outlier removal criteria. Criterion 1 (days over 500 miles removed) was used for all non-regression based analyses, while Criterion 5 (Cook's distance) was used for the difference-in-differences regression analysis. The 500 miles per day criterion resulted in the exclusion of five of 3885 days (0.13 percent), while the Cook's distance criterion removed three of 173 households (1.7 percent) from the DID analysis. The VMT results from the analyses that follow all show a smaller Expo Line treatment effect than the same analyses without outlier removal, indicating that the presented results are more conservative than they would be if outliers were not removed.

Results

Sample characteristics

Table 1 shows descriptive demographic statistics obtained from our survey responses, for households that participated in the study, divided into experimental and control groups. As expected based on our evaluation of the experimental and control neighbourhoods using Census data, both groups are very similar on key demographic and vehicle ownership characteristics in each of the three

Table 1. Before and after opening sample characteristics.

	Before Opening				Six Months After Opening				18 Months After Opening			
	Experimental		Control		Experimental		Control		Experimental		Control	
	N	percent	N	percent	N	percent	N	Percent	N	percent	N	percent
Household Income												
Less than $15k	26	16.4%	20	18.3%	22	17.3%	11	13.9%	20	19.4%	9	13.4%
$15k to $35k	31	19.5%	28	25.7%	22	17.3%	21	26.6%	19	18.4%	22	32.8%
$35k to $55k	32	20.1%	18	16.5%	29	22.8%	16	20.3%	17	16.5%	14	20.9%
$55k to $75k	23	14.5%	20	18.3%	15	11.8%	15	19.0%	21	20.4%	9	13.4%
$75k to $100k	24	15.1%	14	12.8%	20	15.7%	7	8.9%	13	12.6%	7	10.4%
More than $100k	23	14.5%	9	8.3%	19	15.0%	9	11.4%	13	12.6%	6	9.0%
Total	159	100.0%	109	100.0%	127	100.0%	79	100.0%	103	100.0%	67	100.0%
Home Ownership												
Rent	86	52.4%	60	56.6%	70	56.0%	43	55.8%	52	51.0%	36	52.9%
Own	78	47.6%	46	43.4%	55	44.0%	34	44.2%	50	49.0%	32	47.1%
Total	164	100.0%	106	100.0%	125	100.0%	77	100.0%	102	100.0%	68	100.0%
Housing Tenure												
Less than 1 year	12	7.6%	6	5.7%	7	5.9%	3	3.8%	3	2.9%	4	5.8%
1 to 5 years	53	33.8%	27	25.7%	43	36.4%	24	30.8%	22	21.6%	14	20.3%
5 to 10 years	29	18.5%	19	18.1%	24	20.3%	10	12.8%	24	23.5%	11	15.9%
More than 10 years	63	40.1%	53	50.5%	44	37.3%	41	52.6%	53	52.0%	40	58.0%
Total	157	100.0%	105	100.0%	118	100.0%	78	100.0%	102	100.0%	69	100.0%
	mean	S.D.	mean	S.D.	Mean	S.D.	mean	S.D.	mean	S.D.	mean	S.D.
Household Size	2.05	1.22	2.18	2.04	1.85	1.15	1.94	1.22	1.97	1.24	2.17	1.22
Number of Vehicles	**1.28**	**0.81**	**1.48**	**0.95**	1.27	0.79	1.35	0.81	1.31	0.83	1.36	1.03
Number of Driving Licences	1.60	0.84	1.68	0.76	**1.44**	**0.62**	**1.64**	**0.80**	1.43	0.77	1.54	0.90
Household Age Composition (average in each age group)												
Under 12 years' old	0.26	0.65	0.19	0.48	0.23	0.59	0.24	0.53	0.26	0.67	0.20	0.50
12 to 17 years' old	0.14	0.49	0.17	0.38	0.12	0.45	0.06	0.24	0.11	0.39	0.19	0.46
18 years and older	**1.65**	**0.74**	**1.82**	**0.89**	1.51	0.70	1.66	0.88	1.63	0.82	1.80	0.93

Note: Figures in bold indicate differences significant at the 0.10 level.

waves of the study. Chi-square and t-tests between the experimental and control samples in each wave do not reveal any statistically significant differences at the 0.05 level.

Impacts on travel outcomes

Between-groups differences – experimental/control households

Table 2 shows the between-group differences for travel in the experimental and control households six months before and six and 18 months after the opening of the Expo Line. Differences in the number of observations between waves are the result of missing data in one or more of the travel outcome variables. Values are daily means, computed from vehicle odometer logs in the case of VMT and trip logs for all other outcomes. Because our research design compares experimental and control group households, one threat to validity is whether households in the experimental and control groups selected into the study in ways that are associated with travel preferences. We have no reason to believe that any such differential selection into the study occurred because (1) there is virtually no difference in the travel patterns of the two groups during the before opening period (Table 2), and (2) as discussed earlier, the pattern of attrition out of the study showed no relationship to survey respondent attitudes about travel, car attachment, safety, neighbourhood amenities or the environment.

Six months after the opening of the line however, differences in travel outcomes appear. Experimental households, within 1 km of a new station, made more than seven times as many rail transit trips (0.29 versus 0.04 per day), and more walking trips. The increase in walking is notable since the experimental households are located within easy walking distance of the new rail service, while control households are not. Participants were instructed to log any walking trip of five minutes or more, including those whose purpose was to access transit.

At 18 months after the opening of the Expo Line, differences in VMT increase, with experimental households driving almost 10 fewer miles per day, significantly less than control households. The difference in the daily number of train trips remains significant. Experimental households took train trips at a rate three times that of control households. However, the differences in active travel decrease in the period from six to 18 months after opening. Though active trip rates remain slightly higher for experimental households, no statistically significant differences between groups exist in the final wave.

It should be noted that most of the difference in daily VMT between the two groups can be attributed to increases in the control households. The study took place during the recovery from the global recession that began in 2008. Available data indicate that driving increased in low and middle income neighbourhoods near our study area from 2011 to 2013 – a pattern that is typical of recovery from recessions. The Caltrans Highway Performance Monitoring System (HPMS) collects VMT data for incorporated cities, by year. While a comparison to Los Angeles (a city of over three million persons) will not inform driving in our control neighbourhoods, the nearby cities of Lynwood and Hawthorne have similar per capita incomes to our control group area. Caltrans HPMS data show increases in per capita VMT between 2011 and 2013 for Lynwood and Hawthorne of 14.20 percent and 12.80 percent, respectively, which is consistent with the idea that a counter-factual of increased driving is reasonable during the 2011–2013 time period. This reveals a benefit of having a control group. In a context where driving is generally increasing, as typically occurs during recovery from recessions, the effect of

Table 2. Before and after opening between groups differences, experimental versus control group.

		Before Opening					Six Months After Opening					18 Months After Opening				
Variable	Group	N	Mean	Mean Diff.	t	Sig.	N	Mean	Mean Diff.	t	Sig.	N	Mean	Mean Diff.	t	Sig.
VMT	Experimental	166	25.19	−3.47	−1.09		126	23.22	−6.89	−1.82	°	101	24.17	−9.75	−2.05	*
	Control	109	28.66				77	30.11				68	33.92			
Car driver trips	Experimental	171	3.12	−0.61	−1.74	°	127	3.22	−0.13	−0.33		100	3.41	−0.29	−0.57	
	Control	114	3.73				78	3.35				69	3.70			
Car passenger trips	Experimental	171	0.91	−0.26	−1.37		128	0.91	−0.12	−0.51		104	0.77	−0.39	−1.37	
	Control	114	1.17				79	1.03				69	1.16			
Bus trips	Experimental	171	0.62	0.13	0.83		128	0.55	−0.04	−0.21		103	0.44	−0.06	−0.35	
	Control	114	0.49				79	0.59				69	0.50			
Train trips	Experimental	171	0.07	0.01	0.47		128	0.29	0.25	3.35	***	104	0.30	0.21	2.49	*
	Control	114	0.06				79	0.04				69	0.09			
Total Transit Trips	Experimental	171	0.69	0.14	0.85		128	0.84	0.21	1.04		103	0.74	0.15	0.66	
	Control	114	0.55				79	0.63				69	0.59			
Walk trips	Experimental	171	1.58	0.29	1.25		127	1.75	0.56	2.10	*	103	1.58	0.24	0.73	
	Control	114	1.29				79	1.19				68	1.34			
Bicycle trips	Experimental	171	0.17	0.04	0.52		128	0.34	0.21	1.61		104	0.24	0.04	0.43	
	Control	114	0.13				79	0.13				69	0.20			
Total Trips	Experimental	171	6.58	−0.98	−1.31		126	7.16	0.77	1.02		98	6.86	−0.22	−0.25	
	Control	114	7.56				78	6.39				68	7.08			

Note: Significance codes: *** < 0.001, ** < 0.01, * < 0.05, ° < 0.10. All values are per household daily trip frequencies or VMT.

Table 3. Differences-in-differences estimation results.

Travel Outcome	DID Est. Six Months After opening	S.E.	t	Sig.	DID Est. 18 Months After opening	S.E.	t	Sig.	Model Adj. R-sq.	N
VMT	−7.71	4.74	−1.63		−10.87	4.98	−2.18	*	0.32	524
Car Driver Trips	0.15	0.50	0.30		0.03	0.53	0.06		0.37	575
Car Passenger Trips	0.04	0.31	0.12		−0.05	0.32	−0.16		0.25	579
Bus Trips	−0.19	0.22	−0.87		−0.11	0.23	−0.49		0.25	579
Train Trips	0.23	0.10	2.39	*	0.20	0.10	2.00	*	0.09	579
Total Transit Trips	0.04	0.26	0.17		0.09	0.28	0.33		0.24	579
Walk Trips	−0.08	0.38	−0.22		−0.32	0.40	−0.78		0.14	577
Bicycle Trips	0.17	0.14	1.29		0.03	0.15	0.18		0.05	579
Total Trips	−0.36	0.90	0.24		−0.36	0.95	−0.37		0.37	573

Note: Significance codes: ** < 0.01, * < 0.05, $^\circ < 0.10$. Estimates are with an unbalanced panel of households that participated in at least two waves. Estimates are from the regression in equation (2), and the dependent variable for each row is the travel outcome variable in the left-hand column. Only the DID estimator is shown. Other regression coefficients are available upon request from the first author. The DID estimator is the effect of the Expo Line on experimental households, as a household daily average for trip frequencies or VMT.

light rail should be measured relative to a well specified counter-factual, which the control group provides.

Difference-in-differences analysis

DID regression analysis allows us to draw from our quasi-experimental panel data to evaluate the effect of the opening of the Expo Line over time. DID analysis assumes that the differences that arise in the groups are due only to the treatment, and allow us to control for potentially confounding factors, including changes in household size, income and car availability. For VMT, the 'treatment' effect on households within 1 km of the line six months after opening is –7.7 miles per day, though this change is not statistically significant. However, 18 months after opening, households close to Expo Line stations drive nearly 11 fewer miles per day. Among the other travel outcomes, the only significant change is in train use. At both six and 18 months after opening, households living within 1 km take an average of approximately 0.2 additional train trips per day.

Exploratory analysis: Travel changes are more than simple rail-for-car substitution

The results indicate significant changes in the driving behaviour of households located in close proximity to the newly opened Expo Line stations. However, even in the after opening period, train trips capture a small share of travel. It seems unlikely therefore that substitution of rail for car travel could completely account for the change in VMT. Our exploratory analysis draws on available data to consider an alternate hypothesis – that a combination of mode substitution and changes in car use are responsible for the VMT drop in experimental households.

First we examine changes in average car trip length for the two groups before and after opening (Table 4). Average trip length is calculated by dividing total household VMT for the seven-day study period by total car driver trips for each household. Households with no car trips are assigned an average trip length of zero. Table 4 shows the total number of households with valid observations in each wave of the study, along with the number and percentage of households that drove at least once during that wave. For control households, the percentage of households that drive is steady at 87 percent over the three survey periods. In contrast, the percentage of households in the experimental areas that drive declines slightly from 85.4 percent to 83 percent. The average trip length for control households is almost unchanged before and after the Expo Line opened. However, mean trip length decreases at each observation period for experimental households, and the difference in trip length between the experimental and control groups is statistically significant 18 months after the opening of the Expo Line. These results suggest that the opening of the Expo Line may have affected car use partly through shortened car trip lengths.

Somewhat counterintuitively, overall car trip rates did not decrease for the experimental group after the opening of the new line. One possible hypothesis for this result is that while light rail can serve as a substitute for longer distance travel, in the absence of mature transit oriented development it may not facilitate other trips that form part of a daily activity pattern. These include trips for daily shopping and personal needs as well as drop off trips for other household members. Our survey design does not allow us to examine changes in trip chaining patterns. However, Currie and Delbosc (2011) found that among travellers in Melbourne, Australia, 51 percent of car driver trips involved chains, compared to only five percent of train trips. This result lends support to this trip substitution mechanism as a

Table 4. Independent sample t-test comparison of average vehicle trip lengths.

Survey Period	Group	Total Households	Households with Car Trips	Percent with Car Trips	Mean Trip Length	S.D.	Mean Diff.	t	Sig.
Before Opening	Experimental	171	146	85.4	10.60	13.23	−1.37	−0.68	
	Control	114	99	86.8	11.97	17.56			
Six Months After Opening	Experimental	127	109	85.8	9.40	12.16	−2.21	−1.14	
	Control	78	68	87.2	11.61	12.62			
18 Months After Opening	Experimental	100	83	83.0	8.70	8.90	−3.97	−1.99	*
	Control	69	60	87.0	12.67	12.67			

Note: Significance codes: ** < 0.01, * < 0.05, ° < 0.10.

source for the lack of change in car trips in our study.

In order to gain more insight, we also examine differences in travel behaviour between households that used the train and those that did not (Table 5). Train user households are defined as those that use the train at least once during the survey wave of interest. The results show that average driving trip length declines over time for households that used the train while non-train household trip length remains relatively constant. Before the opening of the line, both sets of households drove an average of approximately nine miles per car trip. Six months after the opening of the new light rail line, average car trip length for rail users drops to less than seven miles. At the final observation period 18 months after the opening of the line, households that use the train averaged slightly more than four miles per car trip, compared to nine miles per trip for non-train users.

Table 5 also illustrates that disparities in income levels between train users and non-users decrease after the opening of the new service. Fisher's exact test of income distribution between train users and non-users based on survey categories (Table 5) shows that significant differences that exist in wave 1 disappear after the opening of the line. Train and non-train user average income was also calculated using mid-points of each category, with an assumed value of US$125,000 for the open-ended 'greater than $100,000' income category. Before opening, train user household average income was US$17,000 per year, compared to US$55,700 per year for non-train users, a gap of US$39,000. That gap closes to about US$7000 in the six months after opening survey, and while the gap is again statistically significant at 18 months, after opening train user household income is US$35,900 compared to US$53,400 for non-train users. Car availability across the two groups also narrows, from 0.72 cars per household for train users and 1.42 cars per household for non-train using households before opening to 1.09 cars per household (train users) and 1.39 cars per household (non-train users) 18 months after opening. The data indicate that the opening of the Expo Line is coincident with a shift in the train-riding population from 'non-choice' lower-income households before opening to more 'choice riders' after opening.

In Table 6 we provide a rough illustration of how the measured 'Expo Line' effect on household VMT can be decomposed into two effects, car-rail substitution and reduction in driving trip length. For rail substitution, we assume that all increases in rail trips (experimental versus control group) are one-for-one decreases in driving trips, which we acknowledge is an upper bound. Table 6 is illustrative, and we note that lacking a complete travel diary it is not possible to explain all travel behaviour change. The bottom row of Table 6 illustrates how changes in car trip lengths associated with shifts to train travel can lead to household VMT reduction. For that calculation, we assume that all train users (including those who used the train before the Expo Line opened) experience the car trip length reduction. This assumption is based on the fact that our measured change in car trip length is an average across the train user and non-train user groups.

Table 6 shows that in this exploratory analysis approximately 62 percent of the observed household VMT reduction from Table 3 can be accounted for by two effects, shifts of trips from cars to rail and shortening of car trips among rail users. The effect of shorter car trips is more than twice the size of the effect from car-to-rail trip substitution. This illustrates the complexity of travel behaviour and provides a cautionary example of how simple trip counts, by themselves, may not provide a sufficient measure of the impact of transportation projects.

Table 5. Comparison of train user and non-user household travel.

	Six Months Before Opening					Six Months After Opening					18 Months After Opening				
	Train Users		Non-train Users			Train Users		Non-train Users			Train Users		Non-train Users		
	(n = 25, 8.8%)		(n = 260, 91.2%)			(n = 41, 19.8%)		(n = 166, 80.2%)			(n = 35, 20.3%)		(n = 138, 79.7%)		
	Mean	S.D.	Mean	S.D.	Sig	Mean	S.D.	Mean	S.D.	Sig	Mean	S.D.	Mean	S.D.	Sig
Household VMT	14.4	31.6	27.7	24.9	*	20.0	28.6	27.1	25.7		18.7	22.8	30.4	31.9	*
Driver Trips	1.36	2.85	3.55	2.87	***	2.35	3.36	3.50	2.65	*	2.39	2.79	3.81	3.41	*
Walk Trips	2.45	2.60	1.36	1.79	**	3.31	2.55	1.11	1.40	***	2.63	2.79	1.20	1.75	**
Bicycle Trips	0.24	0.72	0.14	0.52		0.51	1.15	0.20	0.84	°	0.16	0.33	0.24	0.62	
Total Trips	9.80	8.15	6.70	5.94	*	10.39	7.03	6.01	4.28	***	8.64	6.52	6.53	5.50	°
Car Trip Length	9.02	28.94	9.56	12.46		6.75	10.21	9.30	12.35		4.13	4.52	9.86	12.26	**
Cars Available	0.72	0.84	1.42	0.86	***	1.05	1.02	1.36	0.72	*	1.09	1.29	1.39	0.78	°
Household Size	2.08	1.08	2.11	1.23		2.12	1.29	1.83	1.14		2.20	1.41	2.01	1.19	
Household Income (x $1000)	17.0	27.3	55.7	36.5	***	46.9	42.1	54.7	35.8		35.9	39.3	53.4	34.9	*
	N	**percent**	**N**	**percent**	**Sig**	**N**	**percent**	**N**	**percent**	**Sig**	**N**	**percent**	**N**	**percent**	**Sig**
Household Income (categorical)					***					°					
less than $15k	11	45.8%	35	14.3%		12	30.8%	21	12.7%		11	32.4%	18	13.2%	
$15k to $35k	8	33.3%	51	20.9%		6	15.4%	36	21.8%		9	26.5%	32	23.5%	
$35k to $55k	3	12.5%	47	19.3%		6	15.4%	39	23.6%		4	11.8%	27	19.9%	
$55k to $75k	1	4.2%	42	17.2%		3	7.7%	27	16.4%		3	8.8%	27	19.9%	
$75k to $100k	0	0.0%	38	15.6%		6	15.4%	21	12.7%		3	8.8%	17	12.5%	
more than $100k	1	4.2%	31	12.7%		6	15.4%	21	12.7%		4	11.8%	15	11.0%	

Note: Significance codes: *** < 0.001, ** < 0.01, * < 0.05, ° < 0.10.

Table 6. Relative roles of rail–car trip substitution and shorter car trip lengths in VMT reduction after Expo Line opened.

Total Household VMT Reduction				−10.87 daily miles/ household
Rail Trips Displace Car Trips				
Effect Size	*Car Trip Length*	*Effect Calculation*	*Effect*	*Fraction of Total VMT Reduction*
−0.20 trips per day Note: Increase in rail trips, experimental vs. control, six months before to 18 months after opening, from Table 3; assumes new rail trips displace car trips one-for-one.	10.60 miles/trip Note: Experimental household car trip length, before opening, from Table 4.	= 10.60 miles/trip * 0.20 trips per day	−2.12 daily miles	20.0%
Car Trips Get Shorter				
Effect Size	*Penetration*	*Effect Calculation*	*Effect*	*Fraction of Total VMT Reduction*
−5.44 miles/trip Note: Experimental group change in car trip average length, train user households 18 months after opening minus non-train households, six months before opening. (3.83mi/trip – 9.27mi/ trip)	26.0% Fraction of 'any rail' households, experimental group, 18 months after opening (27/104).	Penetration (26.0%) * change in car trip length (–5.44 miles/ trip) * number of car trips *(3.12 car trips per day, experimental, before opening, from Table 2)	−4.41 daily miles	41.6%

Discussion and conclusions

The current study represents the first before-after evaluation of a major rail transit investment in California, and one of the few studies of the before and after effects of light rail on travel behaviour. The analysis adds to our understanding of two highly relevant policy questions: does light rail reduce car use, and does it increase the number of rail transit trips for households that live close to the line?

Based on our analysis, households within 1 km of the new stations drove significantly fewer miles compared to those further away. At 18 months after opening, daily mileage for households close to the line was approximately 30 percent lower than that of control households. This change appears to have resulted primarily from changes in car trip lengths. Average car trip length declined in each wave for the households within 1 km of new light rail stations, resulting in a difference of nearly four miles per trip at 18 months after the opening of the Expo Line. Our results also indicate that train user households, who predominantly reside within 1 km of stations, had average car trip lengths that were only 40 percent of that for households that did not make any rail trips. Though these direct rail-related effects do not explain the entire VMT reduction exhibited by the experimental households, at least one study (Bailey et al., 2008) estimated that transit availability has an indirect impact on VMT that is larger than, and independent of, transit use. These indirect impacts may play a role in this case as well.

We note that our results are unlikely to be due to classic Hawthorne effects, in which survey respondents answer questions in ways that they believe that the researcher desires to hear (e.g. Jones, 1992). Our primary result relates to VMT, while if households were to guess that our study related to the Expo Line they might have been tempted to alter their rail ridership information but they would be less likely to infer our interest in VMT. The VMT data are from odometer readings, which are objective although self-reported. As Table 2 indicates, the change in household VMT is due in larger part to an increase in VMT among control group households, which is plausible given that the Los Angeles region was recovering from a deep recession during our study period. Purposeful VMT over-reporting in the after opening periods among control group households seems exceptionally strategic and highly unlikely.

It is also important to note that this study was designed to measure the response of households that resided in neighbourhoods close to the new line prior to its opening. Approximately two thirds of participating households had lived at their current address for five years or more at the beginning of the study, and only five percent of participants had been at their address for less than one year at that point. By the final wave of the study, nearly 75 percent of households had been at their address for five years or more. The current results give insight into how transportation investments affect neighbourhood travel in the near term, among households living in the area prior to the investment and before changes in neighbourhood composition caused by new households moving into the rail station areas. The impact of new light rail service on those who choose to move into an area in response to transportation infrastructure improvements requires further research.

Our results provide important insights into the effect of light rail investment on vehicle miles travelled and, by proxy, transportation-related pollution and greenhouse gas emissions. Understanding and quantifying these impacts is crucial if cities are to move forward effectively and efficiently towards a sustainable future. The research methods and evaluation techniques described here provide a prototype that can be adapted and improved to answer important questions about the impact of any number of neighbourhood-based interventions designed to improve quality of life and decrease the environmental impact of urban development.

In the context of California's SB375 legislation, and other policies designed to promote sustainability goals through coordinated land use and transportation planning, the limited geographic extent of the impact of the new service is noteworthy. In our study households, train use declines rapidly beyond half a mile from a new station, and our control households located 1 to 5 km from stations did not exhibit any impact from the new service. This result underlines the importance of dense transit-oriented development in conjunction with transit infrastructure investment. The neighbourhoods in the vicinity of the Expo Line stations studied here are generally built out at a medium density, limiting the potential for transit-oriented transformation. Our results appear to indicate that this type of environment can lead to a reduction in VMT without a corresponding reduction in number of automobile trips. This implies that while the new light rail service may substitute for longer car trips, it has little effect on shorter trips for local shopping and personal services. Our results suggest a need for more evaluation studies in areas where more transit-oriented land use mixes and densities exist at the time of opening.

Beyond questions of impact measurement, Los Angeles' rail transit investment has the potential to transform neighbourhoods – positively or negatively. The Expo Line Phase I corridor passes through lower income, predominantly minority communities, and is seen by residents along the corridor as both a possible catalyst for economic development and a potential threat. Will the Expo Line trigger new business activity that will provide jobs and retail opportunities in the corridor? Or will the Expo Line cause property price appreciation that may price out renters and displace some current corridor residents? Or possibly (even likely) might there be a combination of both effects, with complicated net effects? Those questions are beyond the scope of this travel behaviour study, but a large body of theory argues convincingly that changes in land use, economic development and quality of life are longer-term downstream effects that flow from (and are caused by) more short-term changes in patterns of accessibility and travel behaviour (e.g. Handy, 2005). This study's focus on travel behaviour change is an important first step in broader efforts to understand the longer-term impacts of investments in transit and in transportation more generally.

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