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The influence of infill development on travel behavior

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ABSTRACT

While the evidence that the built environment can influence travel behavior to date is fairly robust, the influence of specific, identifiable policy actions is limited. One policy action that can potentially change travel behavior is increasing infill development, particularly if that development is located near the center of a major metropolitan region. This study examines the influence of a large-scale, infill development, Atlantic Station, which opened in 2005 just west of Midtown Atlanta. The study uses propensity scores and differences-in-differences research designs to identify how travel patterns changed for new residents and for existing residents of the area around Atlantic Station, respectively. Atlantic Station reduced vehicle miles traveled and increased alternative mode share for its new residents, but it did not reduce the vehicle miles traveled or increase alternative mode share for the existing residents of the area around Atlantic Station.

1. Introduction

The goal of reducing vehicular dependence through a supportive built environment continues to be a primary objective of urban policy and planning. Continued greenhouse gas emissions, stressed transportation infrastructure, and the need to promote physically active travel are each important motivations for fostering reduced vehicular dependence and promoting alternative modes of travel.

Although planners now know that a built environment with more density, more diversity, better design, and higher destination accessibility can reduce vehicular dependence, the impact of specific planning actions – i.e. approving specific developments, increasing densities in particular locations, or increasing the mix of uses within particular activity centers – has rarely been studied. Before and after studies of such planning actions are informative because they are able to identify the impacts that specified land use changes have on travel behavior. Since the built environment of cities changes slowly and incrementally, understanding the impact of specific land use changes on travel behavior is of pivotal interest for urban planners.

In this study I examine the impact of the Atlantic Station infill development on the travel behavior of new residents to the area as well as for existing residents of the surrounding area. The Atlantic Station development is a large-scale, mixed-use, infill development that occurred on a former brownfield site close to the center of the Atlanta metropolitan region. The development was originally approved in 2001 and opened its doors in 2005. Although the Atlantic Station site was a former steel mill and surrounded by industrial uses to its west, it enjoys a prime location immediately west of the booming Midtown Atlanta area and just a short distance north of the Georgia Institute of Technology. Using travel survey data from 2001 to 2011, I examine how travel behavior in the area changed as a result of the Atlantic Station development. In addition, I compare the travel behavior of Atlantic Station area residents in 2011 with residents of similar demographic makeup from outside the area. Analyzing the impacts of Atlantic Station on travel behavior in this way yield insights into the transportation-related benefits of large-scale, mixed-use infill developments.

The results suggest that the Atlantic Station development did substantially reduce vehicular travel for its new residents by placing them in a high accessibility area close to the center of the metropolitan region. However, for those residents already living in this area, the new destinations introduced by the Atlantic Station development did not reduce their daily vehicular travel or increase their use of alternatives modes.

For planning practitioners, this study indicates that residential infill development in central parts of metropolitan areas can have a substantial influence on reducing vehicle dependence and on promoting alternative modes. The commercial portion of mixed-

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use infill development may reduce vehicle dependence through internal trip capture, but these effects appear to be small relative to the importance of locating additional residential units in central, high-accessibility areas well served by public transit. For planning scholars, this study is one of a few examples of before-and-after research designs of land use interventions, and the research designs presented here can be replicated to examine the transportation impact of other specific developments or area plans. By examining travel behavior before the area plan, and then again after the area plan is completed, planners can evaluate if the area plans shifted travel behavior in a meaningful way. In particular the difference-in-differences method is well suited to identifying causal effects of area plans on travel behavior.

1.1. Background on Atlantic Station

With 136 acres of redevelopment adjacent to Midtown Atlanta, Atlantic Station is one of the largest mixed-use, urban infill developments to be completed in the US in recent years (Chamberlin, 2006; Miller, 2006). As Fig. 1 indicates, the location of Atlantic Station is close to the center of the Atlanta metropolitan region, located about 3 miles to the north of Atlanta's historic downtown core. It is also located close to an existing MARTA Station (Atlanta's heavy rail system), the Arts Center Station, which is accessible by a lengthy walk or via the Atlantic Station shuttle. The development includes a shopping and entertainment district with a movie theatre, bars, and restaurants as well as a Target, a department store and other shopping; a multifamily residential district on its west side; an office tower district along the main east-west corridor of 17th Avenue; and townhomes serving as a transition from the denser core of Atlantic Station to the single family residential areas to its south. In addition, the Atlanta region's only Ikea store is located on the western edge of the Atlantic Station development. From the development program described above, it is apparent that the development contains a wide range of residential and commercial uses, mostly at medium to high intensities, typically with 3–4 stories of building height, but with much greater densities along the 17th Street spine.

According to the US Census Bureau as shown in Table 1, Atlantic Station had 2313 residents in 1784 households as of 2010. In comparison with the City of Atlanta, Atlantic Station had more racial diversity – an almost even balance between blacks, whites, and other races, smaller household sizes (1.30 vs. 2.11), a lower home ownership rate (35.7% vs. 44.9%), and a younger median age (28.7 vs. 32.9). All of these characteristics are consistent with newer and denser, and perhaps more gentrified, urban development brought about by Atlantic Station.

Table 2 lists 23 large-scale mixed-use redevelopment sites identified via a media article search, each with estimated total project value of over $1.0 billion dollars. Comparing project size between different redevelopment proposals is difficult because there is no uniform standard for reporting a project's size – some projects report total building square feet, while others report residential units and commercial square feet separately. Also since the proposed developments are massive in scale, often times only the size of the latest phase of development under construction are

Table 1
Demographics of Atlantic Station in 2010.

	Atlantic Station	City of Atlanta
Population	2313	420,003
Housing Units	2356	224,573
Households	1784	185,142
Avg. HH Size	1.30	2.11
Median Age	28.7	32.9
Home Ownership	35.7%	44.9%
% Black	37.7%	54.0%
% Other Non-White Race	23.3%	7.6%

(2010).
Source: U.S. Census Bureau, Census 2010 Summary File 1, Tables P5, P6, P8, P12, P13, P17, P19, P20, P25, P29, P31, P34, P37, P43, PCT5, PCT8, PCT11, PCT12, PCT19, PCT23, PCT24, H3, H4, H5, H11, H12, and H16.

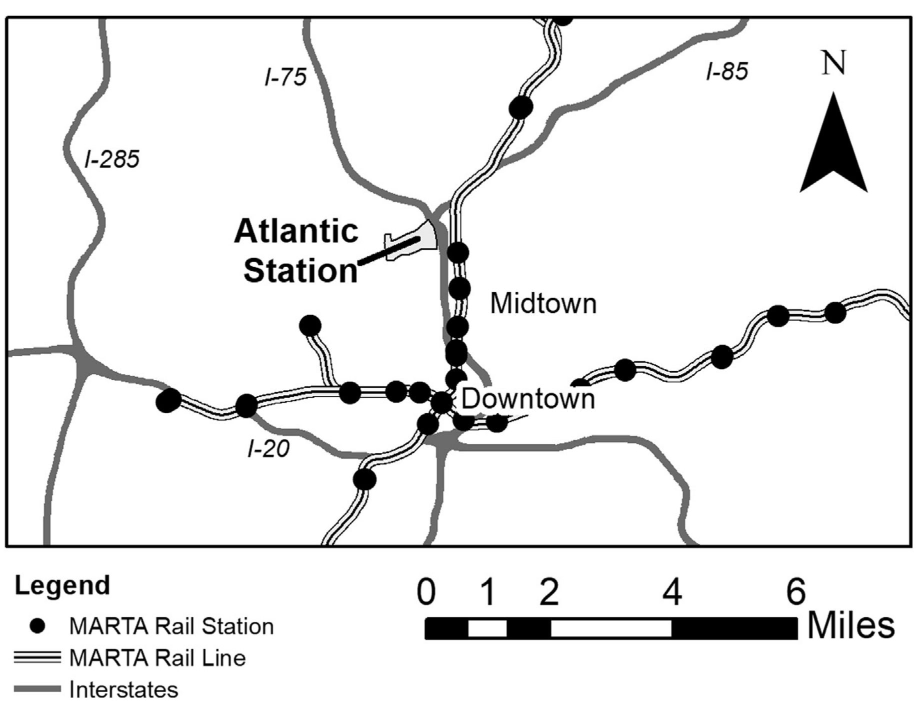

Fig. 1. Atlantic Station context map.
Map illustrates the location of Atlantic Station relative to Downtown and Midtown, as well as relative to major heavy rail stations and corridors.

Table 2
Largest mixed-use redevelopment sites in the US, 2005–2015: Largest mixed-use redevelopment sites in the US, 2005–2015.

Project Name	Status at Time of Latest Publication	Metro Area	Acres	Districts/Program	Estimated Costs (Millions)	Commercial Square Feet at Completion	Residential Units Proposed
San Francisco Shipyard	Under Construction	San Francisco	637	Mixed-use, primarily residential development with retail, professional sports facilities, and parks.	$8000	3.0 million	11600
Hudson Yards	Under Construction	New York	26	Dense, commercial and residential mixed-use development, including destination retail, hotel, public school, open space and a new subway station.	$6000	13 million (mixed-use)	5000
Atlantic Yards	Opened	New York	22	Basketball arena, office towers, residential.	$4000	8 million (mixed-use)	6000
Stapleton Airport	Opened	Denver	4700	11 mixed-use neighborhoods with over 1000 acres of new parks.	$4000	12.0 million (mixed-use)	12000
Harbor Point	Opened	New York	322	Post-industrial waterfront with mixed-use.	$3500	6.0 million (mixed-use)	2350
Seaport Square	Under Construction	Boston	23	Mixed-use waterfront development with retail, office, residential, and hospitality in an “innovation” district.	$3500	6.3 million (mixed-use)	800+
Yonkers Redevelopment	Proposed	New York	13	Ballpark, movie theatre, hotel, retail, office, and apartments.	$3100	1.0 million	950
Victory Park	Opened	Dallas	75	Basketball arena, residential, retail, indoor and outdoor recreation facilities, high-tech office space, and a hotel.	$3000	12.0 million (mixed-use)	4000
Willets Point	Proposed	New York	23	Housing, office, convention center.	$3000	5.0 million (mixed-use)	6800
Atlantic Station	Opened	Atlanta	138	Retail, residential, commercial, and public space.	$3000	13.0 million (mixed-use)	6400
Hempstead Village	Under Construction	New York	100	Four districts in a transit-oriented development: hospitality/entertainment, transit, commercial transition and downtown edge (largely residential).	$2500	2.0 million	3500
Navy Yard	Opened	Philadelphia	1200	Riverfront development with a commercial center, a research park, a marina district, and active port facilities.	$2000	15 million	
The Wharf	Under Construction	Washington DC	50	6000-seat concert hall, hotels and office buildings, apartments, condos, restaurants and shops, public plazas and parks, water access, marina.	$2000	3.2 million (mixed-use)	1369
New Eastside	Opened	Baltimore	88	Laboratory space for life science companies, townhouses, condominiums, apartments, retail, school, churches, parking and open space.	$1800	1.2 million	2200
New Quincy Center	Under Construction	Boston	20	Transit-oriented, mixed-use project, including business incubator, offices, retail, residences, parking garages, hotel, new streets, medical complex, daylighting a stream.	$1600	3.5 million (mixed-use)	1400
Navy Broadway Complex	Approved	San Diego	14	Office tower and park, hotel and museum, Navy headquarters building, boutique office and hotel.	$1200	3.0 million	
Treasury Island	Approved	San Francisco	403	Mixed-use neighborhood with open space on island in SF Bay.	$1200	0.5 million	8000
Old Capital Green	Scaled Back	Jackson, MI	50	“Green” mixed-use development with transit, offices, residential, retail, parking garage.	$1100		
Candlestick Point	Proposed	San Francisco	720	Shopping outlet, restaurant village, themed marketplace, performance venue, residences, hotel.	$1000	500,000	500
Garvies Point	Under Construction	New York	52	Residential, hotel, conference center, commercial, parks, marina, promenade.	$1000	75,000	860
Gates Rubber Plant	Delayed	Denver	50	Transit-oriented neighborhood with retail.	$1000	0.7 million (first phase)	1500
SoLA Village	Proposed	Los Angeles	7.5	Residential, hotel, retail, including shops, grocery, gym, restaurants.	$1000	1.7 million (mixed-use)	1449
Jordan Downs Redevelopment	Approved	Los Angeles	42	Mixed-use residential community with parks and some commercial space.	$1000	0.3 million	1800

Notes: All of these development sites were identified through media searches using the terms “mixed use” and “redevelopment” for publications issued over the time period 2005–2015. Only development sites under control of a single master developer are included; redevelopment areas with multiple ownership are omitted. The table reports information as available in the most recent media article with relevant information. Large-scale developments of this type typically have to undergo multiple approval processes and court challenges, and in addition require complex financing, so many projects are not fully implemented exactly as originally proposed. Even developments that are currently open are typically only partially completed and will be built out over a period of a decade or more.

reported. Acreages from these infill mixed-use projects vary massively from just 7.5 acres for the proposed SoLA village in Los Angeles to the massive 4000 + acres for Denver's Stapleton Airport redevelopment. Because the reporting on physical size of different development projects varies, expenditure comparisons may be the fairest way to compare project size; however even expenditure comparisons may be slightly biased, as expenditures tend to be higher in the more expensive real estate markets.

Measured in cost terms, Atlantic Station is the 10th largest mixed-use redevelopment project proposed or built in the US during the 2005–2015 period. With regard to commercial square feet, Atlantic Station is among the top three or four largest in the US, as large as Hudson Yards in New York and Victory Park in Dallas. The largest residential redevelopments include Denver's Stapleton Airport with 12,000 units and San Francisco's proposed Shipyard redevelopment with 11,600. In comparison to these Atlantic Station has about half as many units proposed at 5000 (Chamberlin, 2006) of which 2356 had been built as of 2010 (US Census Bureau, 2010). Clearly by any measure Atlantic Station is among the largest redevelopments in the country, but on the other hand it is by no means unique; many major metropolitan areas boast massive infill development projects currently underway.

For many, the Atlantic Station development is viewed as a major urban planning achievement (Environmental Protection Agency, 1999). The development occurred on the former brownfield site of Atlantic Steel, a steel manufacturer which had been in decline throughout the 1980s and ceased operation in 1998 (Sousa & Souza, 2013). Remediating the site involved removing 180,000 cubic yards of contaminated soil and creating a system to trap and treat groundwater coming from the site (Sousa & Souza, 2013). Environmental approvals were required from the Georgia Department of Environmental Projection for the brownfield remediation and from the US Environmental Protection Agency (EPA) for air quality impacts. The environmental clean-up and new infrastructure, which included a massive below-grade parking deck and the new 17th street bridge crossing I-75/I-85, required an intricate public-private finance structure (Atlanta Development Authority, 1998). The successful completion of the Atlantic Station development supported both local and national environmental, economic development, and livability goals.

On the other hand, Atlantic Station has also been criticized for its urban design shortcomings (Dagenhart, Leigh, & Skatch, 2006). It is interesting to note that the original site design was quite conventional and suburban in nature and that it took several iterations, including design suggestions from Duany Plater-Zyberk (DPZ), before the final design was settled upon (Dagenhart et al., 2006). Criticisms of the final urban design include lack of connectivity with surrounding sectins of the city, poor internal pedestrian circulation, and the over-separation of land uses within the site (Dagenhart et al., 2006). 17th Street, which does serve to connect Atlantic Station with Midtown to the east, also serves as a barrier between the north and south sides of Atlantic Station, due to its width and high traffic speeds. Generous provision of parking, located in a structure underneath Atlantic Station, encourages auto use. But despite these urban design shortcomings, Atlantic Station was nevertheless expected to bring transportation benefits due to its central regional location and mixed-use plan.

One twist in the history of the Atlantic Station development was its timing. Atlantic Station was approved during the years when the Atlanta's metropolitan planning organization, the Atlanta Regional Commission, was considered in violation of the Clean Air Act due to its non-complying regional transportation plan at the time (Environmental Protection Agency, 1999; US Environmental Protection Agency, 2000). Therefore, the transportation infrastructure of Atlantic Station required special approval from the EPA (Environmental Protection Agency, 1999). The EPA eventually approved the project under a provision called Project XL, which permitted the EPA to exercise discretionary authority with respect to existing regulations in order to achieve broader environmental goals.

The primary policy argument for approving the Atlantic Station development from the EPA's point of view was that the development would result in reduced air quality impacts at the regional level. New development in the Atlanta region has generally been widely scattered, and if Atlantic Station were not built, the same amount of development would likely occur elsewhere in the Atlanta region, resulting in higher VMT and worsened regional air quality (Schroeer & Anderson, 1999). The EPA commissioned several studies, including a scenario-based study of Atlantic Station's VMT impacts, in order to understand if the project would result in the VMT reductions and air quality improvements that were anticipated.

The air quality impacts of the Atlantic Station development were forecast by comparing its development proposal with the same amount of development occurring in three alternative locations (Schroeer & Anderson, 1999). Fig. 2: ***Alternative Sites***, shows the location of alternative sites used for comparison with Atlantic Station. All of these alternative sites are located well outside the center of the metropolitan region, as indicated by their location outside the circumferential highway known locally as "the Perimeter" or I-285. Schroeer and Anderson (1999) forecast the air quality impacts by employing the region's travel demand model and EPA's MOBILE 5 emissions model. Their study found that developing Atlantic Station would result in 14–52% less total VMT and 37–81% less total NOx than similar sized developments located elsewhere in the Atlanta metro region.

In addition, the study found that trips starting from and arriving at Atlantic Station would be shorter and more likely to use transit than trips originating from or arriving at destinations elsewhere in the region. Table 3 displays the travel behavior forecasts from their analysis, including the average trip length for work and other trips with an origin in Atlantic Station, and for work and other trips with a destination in Atlantic Station. The table also shows forecast average trip lengths for the alternative development locations of Perimeter/Sandy Springs, Fulton/Cobb, and Henry. In almost every case, trips originating from or arriving at Atlantic Station would be significantly shorter on average than if the same amount of development were located in one of these alternative locations.

2. Calculation: innovations and benefits of new research designs

Traditionally research on the built environment and travel behavior has not focused on specific planning actions, but rather has examined the general correlation between built environments and travel behavior. Based upon this accumulated evidence and improved research designs, planners now have a substantial body of evidence suggesting that the built environment can have a moderating influence on vehicular travel demand. The four D's – destinations, density, diversity, and design – have all been associated with measurable reductions in vehicle miles traveled, decreased numbers of vehicular trips, and increased share of alternative modes (Cervero & Kockelman, 1997; Ewing & Cervero, 2010). A recent meta-analysis of travel and the built environment by Stevens (2016) suggests that the effect of the four D's are modest, but interestingly also finds that distance to downtown may have a larger effect than any of these traditional built environment variables – with an elasticity of VMT of up to −0.63 for this particular variable.

Since Ewing and Cervero's 2010 meta-analysis of the built

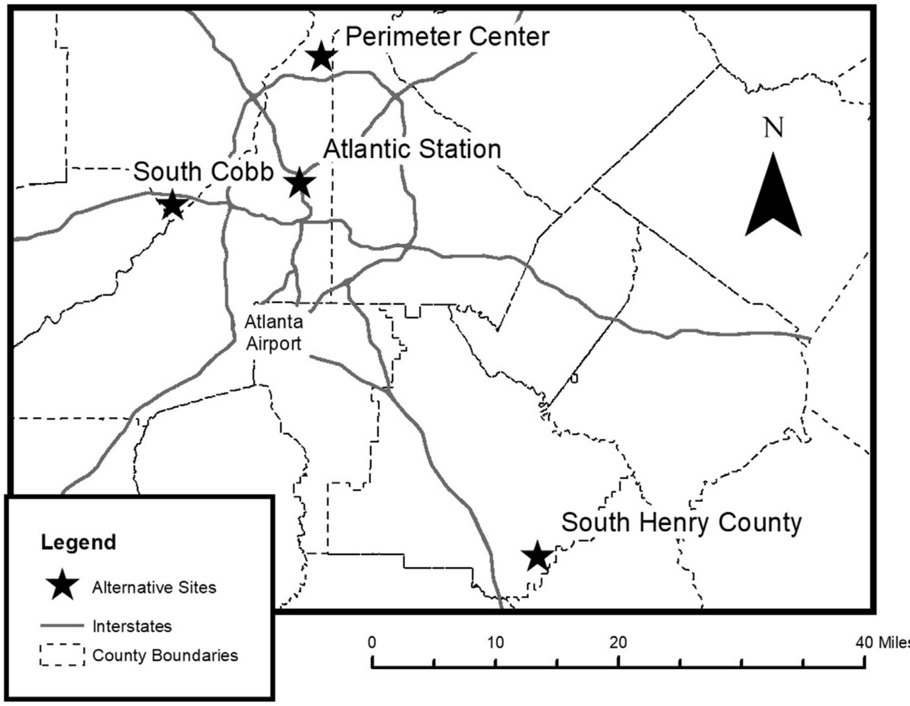

Fig. 2. Alternative sites to Atlantic Station.
Illustrates alternatives sites considered for the EPA's environmental impact analysis of Atlantic Station.
Source: Schroeer, W., & Anderson, G. (1999). Transportation and Environmental Analysis of the Atlantic Steel Development Proposal (p. 53).

Table 3
Prospective analysis of Atlantic Station's travel behavior impacts (Schroeer & Anderson, 1999).

	Regional Average	Atlantic Station	Perimeter/Sandy Springs	Fulton/Cobb	South Henry
Average Trip Length, Trip Origins	14.4 Work	5.3 Work	6.5 Work	11.0 Work	6.3 Work
	8.2 Other	3.4 Other	5.4 Other	6.3 Other	6.2 Other
Average Trip Length, Trip Destinations	14.4 Work	10.5 Work	14.4 Work	13.2 Work	26.7 Work
	8.2 Other	7.3 Other	9.4 Other	6.3 Other	11.7 Other
Transit Share of Trip Origins	7.7% Work	27.1% Work	12.5% Work	1.8% Work	0% Work
	1.9% Other	10.7% Other	6.0% Other	0.8% Other	0% Other
Transit Share of Trip Destinations	7.7% Work	27.1% Work	12.3% Work	1.7% Work	0% Work
	1.9% Other	10.7% Other	2.2% Other	0.6% Nonwork	0% Other

All trip lengths are reported in miles. Results are according to the Atlanta Regional Commission's travel demand model. The travel behavior impacts of Atlantic Station are here compared to similar amounts of development occurring in feasible alternative locations within the Atlanta region.
Source: Schroeer, W., & Anderson, G. (1999). Transportation and Environmental Analysis of the Atlantic Steel Development Proposal.

environment and travel behavior (Ewing & Cervero, 2010), the research on travel behavior has largely focused on methodological improvements over past studies. Broadly speaking, these methodological improvements have been focused on improved statistical methods, in particular simultaneous equation modeling (Cervero & Murakami, 2010; Liu, Shen, Chao, & Qing, 2011; Nasri & Zhang, 2012), and to a lesser extent on longitudinal studies (Ewing, Hamidi, Gallivan, Nelson, & Grace, 2013; Ewing, Hamidi, Goates, & Nelson, 2014; Guo, Agrawal, & Dill, 2011; Su, 2010). Almost all of these studies find a significant influence of the built environment in reducing vehicular use, and several of them find a larger effect than previous research has indicated (Cervero & Murakami, 2010; Heres-Del-Valle & Niemeier, 2011).

One tension in the research literature on built environment and vehicle use is that as research designs have become more statistically sophisticated, in some cases the measures of the built environment have also become more simplified and aggregated. A number of recent papers focus on the effects of residential density, based upon the argument that residential density serves as a proxy for many other types of built environment features (Bento, Cropper, Mobarak, & Vinha, 2005; Heres-Del-Valle & Niemeier, 2011). While it is true that residential density tends to be correlated with land use diversity, presence of destinations, and pedestrian-friendly urban design features, it is not clear that new dense developments will necessarily incorporate any or all of these relevant land use features. In particular, it is possible to have a dense and mixed-use development in an outlying location far from other regional destinations. Whether such a development would reduce vehicle use or not relative to more proximate conventional development is debatable. When research examines the density variable alone, it leaves obscured the question of whether local density and local mixed use or regional location and regional land use mix are more important for reducing vehicular use.

Other recent papers focus on built environment measures which aggregate data to the urban area scale (Cervero & Murakami, 2010; Su, 2010). The problem with this approach is that while it may credibly describe how current built environment features correlate with vehicle usage, such research may tell us little about what kinds of policy *actions* are likely to reduce vehicle use in the future. These articles suggest that population densities and roadway provision across the entire urban area have a statistically significant influence on vehicle miles traveled. However creating change at the scale of an entire urban area takes decades, and it is far from clear that increasing residential densities alone (where? In what configuration?) is the most helpful strategy. The aggregate nature of these studies provides us with only vague directional insights for meaningful policy intervention.

In contrast to these studies, a handful of policy-centered research papers have recently emerged. These new papers focus on the travel behavior impacts of discrete, identifiable policy actions. Such policy actions may include building new transportation infrastructure or approving new developments. The effect of these discrete policy actions is identifiable because they take place at a specific location and time.

One recent study by Ewing et al. (2014) illustrated the influence of a new light rail line on vehicle miles traveled in the Portland region, employing a before-and-after research design. Another recent study by Lovejoy and Handy (2013) examined how shopping locations varied before and after a new Target store was built in the Davis, California area. Both of these studies examine travel behavior in the wake of a specific policy action, and therefore isolate the effect of a clearly defined intervention and its impacts.

This paper is similar in that it focuses on specific, identifiable policy action, in this case the approval and subsidies necessary to abet a specific infill development, which may influence vehicle miles traveled and promote the use of alternative modes. Travel behavior is examined before and after the infill development with various research designs applied to isolate the influence of the development from the influence of extraneous factors.

3. Materials and methods

As new infill development is introduced, travel behavior may shift for two distinct reasons. One reason is that with the addition of residents close to the center of the region, these residents are likely to require less vehicle use than if they lived further away from the regional center. This affect clearly applies to new residents only.

The second reason is that by supplying existing residents (i.e. people who lived in the area prior to the new development) with new destinations nearby, these residents may replace destinations that were further afield with these more proximate destinations. In particular, the Atlantic Station development offered a number of retail and entertainment activities to an area that was previously considered to be underserved, including a grocery store, a Target, movie theatres, and other entertainment venues. In addition, the Atlantic Station development is home to many office jobs to which nearby residents may commute. If the addition of these destinations made it easier for nearby residents to commute to jobs or to find services with less vehicular travel, their household VMT could reduce as a result.

In both cases, infill development may result in lower vehicle miles traveled and increased use of alternative modes. This paper examines each of these effects separately, with one analysis for those residents newly located within Atlantic Station and its surrounding area, and a distinct analysis for those residents living nearby Atlantic Station who may have been affected by the introduction of new proximate destinations.

The first analysis is for new residents. This analysis employs propensity score matching to determine the influence of moving into the Atlantic Station area on new residents. Propensity scores, or scores that predict the likelihood of choosing to live in the Atlantic Station Area, are created based on number of household characteristics, such as household size, income, composition, and life stage. Each household that moves into the Atlantic Station area is matched with a household who lives elsewhere in the region but has a similar likelihood of moving into the Atlantic Station area. Through the matching process, the population that lives within the Atlantic Station area and the matched population outside appear very similar across all of these measured characteristics. In short, the population living inside the Atlantic Station area is compared with a very similar population living outside the area, so that the effect of living in Atlantic Station itself is isolated from the effects of other characteristics. This allows us to determine how much moving to the Atlantic Station area influenced the travel behavior of new residents.

The second analysis involves understanding how the travel behavior of existing Atlanta Station area residents changed over time as a result of the development. This part of the analysis employs a difference-in-difference strategy. Travel behavior is tracked for residents of the area and for two control groups during two time periods, a before period (2001) and an after period (2011). The difference-in-difference analysis compares how much travel behavior changed for those living near Atlantic Station with those living further away over this period. Presumably those living near Atlantic Station will have their travel behavior influenced to a greater degree, so the results will show a greater reduction in VMT and a greater increase in alternative mode share in comparison with the control groups.

Both research strategies address the well-known problem of residential self-selection, at least in part. Propensity scores are designed to uncover the selection process itself by building a model that predicts what types of households will select into the Atlantic Station Area (Mokhtarian & Van Herick, 2016; Rubin, 2001). By understanding the factors that influence the selection of residential location, propensity scores can control for the self-selection process. The one limitation to the propensity scores used here is that the travel surveys do not include any questions about travel attitudes, and so the attitudinal portion of self-selection is not accounted for (van Wee & Mokhtarian, 2015). This is a limitation of this research approach.

The use of difference-in-differences also controls for the self-selection effects (van Wee & Mokhtarian, 2015). Difference-in-differences is a longitudinal method that effectively compares people who live in the Atlantic Station area in 2011 to a similar set of people living in the area in 2001. Therefore, the effects of self-selection should be controlled for by the difference-in-differences method, unless the people who chose to live in the area in 2011 changed significantly from the people who chose to live in the area in 2001. The difference-in-difference method also controls for major demographic variables, so in a sense the differences between the treatment and control groups are doubly controlled for via this method (Morgan & Winship, 2007).

In order to monitor changes in travel behavior over time, I analyzed two regional household travel surveys for the metro Atlanta region, one from year 2001, before the opening of Atlantic Station in 2005, and the other from the year 2011, after most of Atlantic Station had been built out (See aerial photo in Fig. 3). More precisely, as of 2011, Atlantic Station included 118 townhomes, 9 mid-rise residential apartment buildings, 2 high-rise residential buildings, 4 low-rise commercial buildings, 7 mid-rise commercial and mixed use buildings, and 4 high-rise office buildings, whereas two sites that could incorporate up to four towers remained vacant. The primary geographic area of analysis is a circle of three miles radius with its centroid in the middle of Atlantic Station, referred to hereafter as the “Atlantic Station Area” (see the Appendix for a discussion of why a three-mile radius was used). This is the area which is presumably most influenced by the construction of Atlantic Station because of the introduction of new, proximate

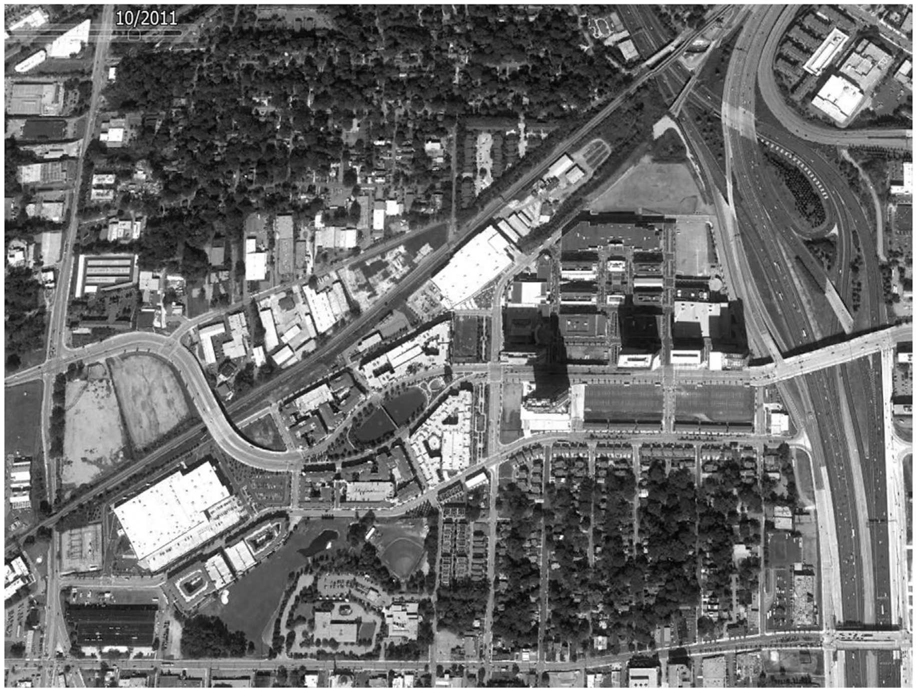

Fig. 3. Aerial of Atlantic Station from October 2011.
This aerial shows that most of the Atlantic Station site had been built as of 2011 except two sites which were planned for office towers. Source: Google Earth.

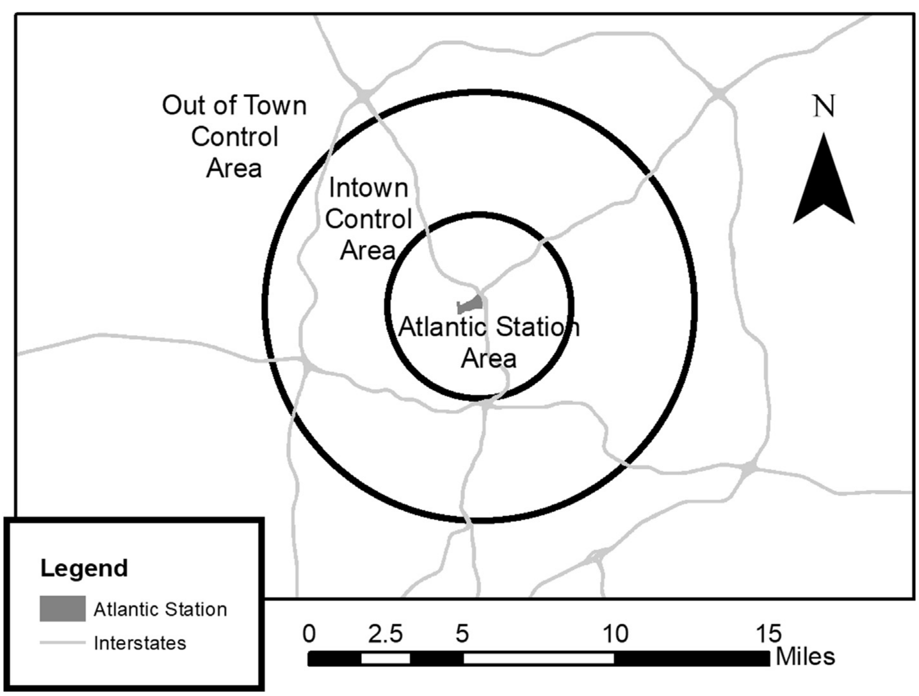

Fig. 4. Atlantic Station area and control areas.
This map illustrates the actual footprint of the Atlantic Station development in comparison with the surrounding Atlantic Station Area, the Intown Control Area, and the Out of Town Control Area.

destinations. Fig. 4 indicates the location of the Atlantic Station Area as well as the locations for the two control areas. One control area is located in a relatively intown area consisting of residents living between 3 and 7 miles from Atlantic Station, and is referred to as the "Intown Control" group. The other control area is located in a relatively suburban and exurban area consisting of residents living more than 7 miles away from Atlantic Station, and is referred to as the "Out of Town Control" group. The approach of the analysis is to examine how travel behavior changes between the before and after periods, i.e. between 2001 and 2011, with comparisons across these three geographic areas.

The 2001 and 2011 survey populations were not the same, so this is not a true longitudinal study. Rather this study uses repeated cross-sectional data to synthesize a difference-in-differences comparison of travel behavior over space and time. Some of the key differences in the Atlantic Station Area population between 2001 and 2011 are as follows: The percentage of the population that is of black race dropped from 33.2% to 19.5%. People with a college degree or higher education rose from 72.9% of the population to 78.7% of the population. Single-person households rose from 41.0% of the population to 51.8% of the population. And incomes in the top quintile rose from 21.8% of the population to 29.0% of the population. These demographic shifts are controlled for with the inclusion of appropriate covariates in the difference-in-differences analysis.

The key analytical challenge was to integrate the two travel surveys so that they could be compared within the same analysis framework. Key differences between the two surveys are described in Table 5. The 2001 travel survey included 8069 completed household surveys for a 13-county region with travel tracked over a 48-h period (NuStats, 2002). The 2001 survey was based on a stratified sample design with stratification across residential densities. The Nustats survey analysts constructed weights for the 2001 survey by taking into account residential density, county representation, household income, household size, household race, and household vehicle ownership. The 2011 travel survey included 10,278 completed household surveys from a 20-county region with travel tracked over a 24-h period (PTV NuStats, 2011). The surveyors stratified the sample by population and employment density in order to oversample denser parts of the region and further stratified by household size and employment status. The surveyors developed sampling weights for 2011 by weighting for the oversample of specific geographies or demographic groups, and then raking to align with a sample from the 2008–2010 American Community Survey.

Table 4 summarizes the changes in observed travel behavior between the two surveys. Comparing across the two surveys, trip purposes are largely stable. For both surveys, there are approximately 6.2 average trips outside the home per household per day (assuming that the number of trips for eating out stayed constant; eating out and eating in the home were not disaggregated for the 2001 survey). Work trips averaged 1.7 trips per household per day in 2001 and 1.8 in 2011. Mandatory trips averaged 1.7 in 2001 and 1.6 in 2011. Discretionary trips were recorded at 1.6 trips per household per day in 2001 and just 1.1 trips per household per day in 2011, but this may be a function of different trip purpose categories across the two surveys. The 2001 survey had a category for entertainment which recorded 0.7 trips per household per day, whereas there was no equivalent travel purpose in 2011.

Table 4
Trip purpose and mode comparison of 2001 and 2011 Atlanta household travel surveys.

Trip Purposes	2001	2011	Difference
Non-Home Trips	6.2	6.2	0.0
Work/School	1.7	1.8	0.1
Mandatory	1.7	1.6	−0.1
Discretionary[a]	1.6	1.1	−0.5
Travel-Related	0.9	1.3	0.4
Mode Shares	**2001**	**2011**	**Difference**
Walk	4.6%	6.1%	1.6%
Bike	0.14%	0.34%	0.2%
Auto Driver	64.4%	62.0%	−2.4%
Auto Passenger	22.8%	23.1%	0.3%
Public Bus	1.5%	1.2%	−0.2%
MARTA Train	0.9%	1.1%	0.2%
Paratransit	0.0%	0.1%	0.1%
Taxi	0.3%	0.1%	−0.1%
School Bus	5.5%	5.4%	0.0%
Motorcycle	0.0%	0.1%	0.1%
Other	0.0%	0.4%	0.4%

[a] Differences in discretionary travel may be related to differing trip purpose categories between 2001 and 2011.

Mode shares are also similar across the two surveys. The mode share of walking appears to have increased, from 4.6% to 6.1% from 2001 to 2011. Biking also increased rapidly, from 0.14% to 0.34% of trips, but remains a very small fraction of total trips in the region. These shifts to non-motorized modes appear to have come primarily at the expense of personal vehicle travel, which dropped from 64.4% mode share to 62.0% in 2011. So there is a slight regional trend towards non-motorized modes during this time frame.

I took the following measures to render the two travel surveys compatible with each other. First, the 2011 travel survey was limited to 13 counties. Then, for the 2001 survey, weekend travel was dropped. For both periods, households with no travel activity were dropped. In addition, households with trips well outside of the region, specifically trips over 164 miles in length (twice the width of the metropolitan region) were dropped.

I used the provided sampling weights from the 2001 and 2011 surveys, with one adjustment. I normalized the total sum of weights across each survey year to the same total so that data from the two survey years constituted equal total weight in the regressions. After the above data cleaning, it became clear that households in 2011 had lower vehicle miles traveled than those in 2001. This is consistent with national findings on peak travel which identify a decrease in travel in the late 2000's (Millard-Ball & Schipper, 2010).

All trip distances provided within the 2001 travel survey were respondent-reported distances. Therefore, for all 2001 trips where origin and destination were available, I calculated network distances with Network Analyst in ArcMap 10.1 using ESRI 2008 Streetsmap data. If either origin or destination location information was missing for these households, then these households were excluded from the VMT analysis (but not from the mode share analysis).

In addition, I calculated an alternative mode share for each household. The alternative mode share is defined as the percentage of all trips using a mode other than a private vehicle, including walking, bicycling, and any form of transit. Intercity modes are excluded from this calculation. For multimodal trips, I counted each part of the trip using a different mode as a separate trip.

Before and after measures of vehicle miles traveled and alternative mode share are taken for the treatment area, the Atlantic Station Area, and for the two control areas. Having two control areas allows for two comparison points for understanding the effect of the Atlantic Station development on travel behavior. However, the Intown Control area is more akin to the Atlantic Station Area and therefore is the preferred control for analysis purposes.

The Atlantic Station Area population has significantly different demographics than either the Intown Control area or the Out of Town Control area. Table 6 outlines some of the major differences between these areas during 2001 or the “before” period. The two-sided T-tests indicate that the Intown Control group has significantly larger household sizes, more full-time students, more children, and more single family housing on average than households in the Atlantic Station Area. Likewise, the Out of Town Control area also has larger households sizes, more workers, more full-time students, a higher presence of children, fewer unrelated adults, higher incomes, and more single family housing in comparison with residents of the Atlantic Station Area. These differences from the “before” period across areas are accounted for by including these covariates within the difference-in-differences regression analyses.

Table 5
Comparison of 2001 and 2011 Atlanta household travel surveys.

	2001 Travel Survey	2011 Travel Survey
Counties	13	20
Days of Week	Mon. – Sun.	Mon. – Fri.
Survey Hours	48	24
Unweighted Survey Counts		
Households with completed surveys	8069	10278
Households used for VMT analysis	6840	9017
Persons	21323	25810
Trips	126127	119480
Mean Survey Days	1.71	1.00
Mean Trips Per Household per Day	9.2	11.6
Weighted Summary Statistics, Cleaned Data[a]		
Average Household Size	2.7	2.7
Median Household Trips	7.0	8.0
Mean Household Trips	8.1	10.1
Median Household VMT	38.8	31.3
Mean Household VMT	49.8	41.2
Mean Alternative Mode Share	14.1%	12.8%

[a] Both survey samples were limited to weekday travel for residents of the 13-county Atlanta region. Households that had no trips, with trips outside the region, or with missing distance information were excluded to synchronize data across the two surveys.
Sources: NuStats, (2002). 2001 Atlanta Household Travel Survey. Atlanta, GA. PTV NuStats. (2011). Regional Travel Survey: Final Report. Atlanta, GA.

Table 6
Two sample difference of means T-Tests comparing Atlantic Station area and control area demographics for 2001.

Variable(s)	Intown Control	Atl. St. Area	Diff.	t stat	Pr (T > t)
Household Vehicle Miles Traveled	30.775	25.019	−5.755	4.12	0.0000***
Household Size	1.976	1.734	−0.242	5.01	0.0000***
# of Workers	1.07	1.08	0.01	0.31	0.7544
# of Full Time Students	0.303	0.201	−0.102	3.43	0.0006***
Presence of Children	0.197	0.142	−0.055	3.14	0.0017***
Presence of Unrelated Adults	0.057	0.055	−0.002	0.19	0.8505
Income Quintile	2.805	2.908	0.102	1.62	0.1063
Refused Income Question	0.073	0.084	0.011	0.94	0.3458
Multifamily/Attached Unit	0.378	0.566	0.188	8.41	0.0000***
Variable(s)	**Out of Town Control**	**Atl. St. Area**	**Diff.**	**t stat**	**Pr (T > t)**
Household Vehicle Miles Traveled	54.011	25.019	−28.992	16.35	0.0000***
Household Size	2.434	1.734	−0.7	14.75	0.0000***
# of Workers	1.163	1.08	−0.084	2.93	0.0035***
# of Full Time Students	0.472	0.201	−0.271	8.5	0.0000***
Presence of Children	0.326	0.142	−0.184	10.16	0.0000***
Presence of Unrelated Adults	0.029	0.055	0.026	3.63	0.0003***
Income Quintile	3.044	2.908	−0.137	2.6	0.0094***
Refused Income Question	0.074	0.084	0.01	0.98	0.3268
Multifamily/Dwelling Unit	0.177	0.566	0.389	24.47	0.0000***

$p < .05$ *; $p < .01$ **; $p < .001$ ***.
Differences between the Atlantic Station Area and the two control areas, Intown Control Area and Out of Town Control Area, on selected demographic variables.

Table 7
Average treatment effect of moving to the Atlantic Station area on travel behavior, 2011

	Vehicle Miles Traveled	Mode Share
Avg. for Atlantic Station Area Residents	19.5	25.9%
Avg. for Matched Residents from Outside Atlantic Station Area	37.4	9.8%
Atlantic Station Area Difference	−17.9	+16.2%
Number of Matched Residents	4681	4681
T Statistic	−12.02	8.31
Point-Biserial Effect Size (r)	−0.173	0.121

This table shows the effect of living in the Atlantic Station Area as opposed to elsewhere in the Atlanta region on travel behavior for 2011 residents. The effect size is estimated through propensity score matching. Each household of the Atlantic Station Area is matched with one or more households from outside the area who has approximately equal probability of choosing to live within the Atlantic Station Area (Rubin, 2001). The propensity score match variables include household size, number of workers, number of license holders, number of full time students, presence of children, number of retired person, black race, middle income indicator, high income indicator, less than college indicator, college graduate indicator. The propensity score match results in a match between Atlantic Station Area households and outside households where both groups have approximately equivalent mean values across each of these variables for each propensity score band.
For more information on Point-Biserial Effect Size, please see (Rosenthal, Rosnow, & Rubin, 2000).

4. Results

4.1. Impact on new residents of the Atlantic Station area

First I present the influence of moving to the Atlantic Station Area for new residents using propensity score matching methods. Atlantic Station Area households have an average daily VMT of just 19.5 miles per day in comparison with matched residents living outside this area, who have an average VMT of 37.4 miles per day. Likewise, Atlantic Station Area households have an average alternative mode share of 25.9%, in comparison with an average of 9.8% for matched residents. Both of these effects are large from a practical perspective and highly statistically significant. For a further discussion of the details of the propensity score method applied, please see the Appendix on Analytical Methods.

Although there were only 9 households actually within the Atlantic Station development from the 2011 travel survey, we can compare the travel behavior of those within the Atlantic Station Area to the predictions made via the Schroeer and Anderson EPA study (1999). This comparison is illustrated in Table 8: Comparison of A-Priori Travel Behavior Forecasts with Atlantic Station Area Travel Behavior.

The EPA study predicted that work VMT would average 5.3 miles for work trips and 3.4 for non-work trips, whereas the Atlantic Station Area average was 4.3 miles for work trips and 3.1 miles for non-work trips. The EPA study predicted the transit mode share for work trips would be 27.1% for work trips and 10.7% for non-work trips, whereas the actual transit share in the Atlantic Station Area was just 2.1% for work trips and 2.8% for non-work trips. However, if you include non-motorized modes in transit share, then the total alternative mode share was 25.3% for work trips and 18.8% for non-work trips, which is similar to the transit mode shares predicted in the EPA study. Unfortunately it is unclear from the EPA report whether or not the analysts intended to include non-motorized share in their forecast for transit trips. Assuming that the EPA analysts intended to include non-motorized trips in their forecasts, the a-priori travel behavior forecasts of trip distance and mode share originating in Atlantic Station turned out to be reasonably accurate. If not, this is a very large overestimate of a key outcome – the predicted use of transit of Atlantic Station residents (although admittedly the Atlantic Station Area is larger than the Atlantic Station development itself, so there may be some variation between residents of the actual development and the larger area).

4.2. Impact on existing residents of the Atlantic Station area

This part of the analysis examines the effects of Atlantic Station on the residential population that lived nearby Atlantic Station before it was built. These are considered the "existing residents" in the terminology of this study. Table 9 displays the results of the difference-in-differences analysis for household daily vehicle miles traveled (VMT). Values for all the coefficient estimates of control covariates are included in the Appendix. Residents of the Atlantic Station Area had lower VMT than residents of the two control areas in both 2001 and in 2011, although the difference with the Intown Control group in 2001 was not statistically significant. However, the decrease in household VMT from 2001 to 2011 was the largest for the Out of Town Control group, followed by the Intown Control group, with the Atlantic Station Area group having the *smallest* decrease in VMT. In short, households living further from the Atlantic Station area decreased their VMT more between 2001 and 2011, contrary to expectations.

Table 9
Difference-in-differences results for impact of Atlantic Station on vehicle miles traveled of existing area residents.

	Average for 2001	Difference	Significance
Atlantic Station Area	40.8	na	na
Intown Control	45.1	4.4	**
Out of Town Control	61.9	21.2	***
	Average for 2011	**Difference**	**Significance**
Atlantic Station Area	32.3	Na	na
Intown Control	33.6	1.3	–
Out of Town Control	46.2	14.0	***
	Change from 2001 to 2011	**Difference**	**Significance**
Atlantic Station Area	−8.5	Na	na
Intown Control	−11.6	−3.1	–
Out of Town Control	−15.7	−7.2	***

$p < .05$ *; $p < .01$ **; $p < .001$ ***; - not significant at the 0.05 level.
Average column reflects values for a "typical" household with white race, two licensed, working adults and one child living in a multifamily unit, while the "Differences" column shows the difference of each of the two control groups with the Atlantic Station group. "Significance" column corresponds to the statistical significance of the "Differences" column. The "Difference" column in the third section shows the difference-in-differences average results. The full difference-in-difference regressions include household size, number of workers, number of license holders, number of full time students, presence of children, number of retired persons, presence of unrelated adults, income category, educational level, residence in a multifamily unit, and year as controls. For a full report of the difference-in-differences regressions, see the Appendix on Analytical Methods.

Table 10 illustrates the results for alternative mode shares for the three groups and how they change over time. As expected, residents of the Atlantic Station Area have the highest alternative mode share in both 2001 and 2011, although the difference with the Intown Control group is not quite statistically significant in 2011 ($p = .079$). The change in alternative mode share over time displays a very clear pattern – both in-town groups see a large boost in alternative mode shares between 2001 and 2011, whereas the Out of Town Control group stays basically the same on this variable. The growth in alternative mode share is about the same for the Atlantic Station Area group and the Intown Control group, and the differences in the growth of alternative modes is not statistically significant.

In short, the development of Atlantic Station did not appear to influence the travel behavior of those already living in the Atlantic

Table 8
Comparison of a-priori travel behavior forecasts with Atlantic Station area travel behavior.

	EPA Forecast[1]	Atlantic Station Area (2011)
Work Trip Average VMT	5.3	4.3
Non-Work Trip Average VMT	3.4	3.1
Work Trip Transit Mode Share	27.1%	2.1%
Non-Work Trip Transit Mode Share	10.7%	2.8%
Work Trip Alternative Mode Share	27.1%	25.3%
Non-Work Trip Alternative Mode Share	10.7%	18.8%

1 - Schroeer, W., & Anderson, G. (1999). Transportation and Environmental Analysis of the Atlantic Steel Development Proposal.
In the original EPA study it is unclear whether "transit mode share" included non-motorized modes within it. For that reason, the forecasts for transit mode share are compared here with both actual transit mode shares and with alternative mode shares, which include both transit and non-motorized modes.

Table 10
Difference-in-differences results for impact of Atlantic Station on mode share of existing area residents.

	Average for 2001	Difference	Significance
Atlantic Station Area	20.1%	na	na
Intown Control	16.1%	4.0%	*
Out of Town Control	11.0%	9.1%	***
	Average for 2011	Difference	Significance
Atlantic Station Area	27.2%	na	na
Intown Control	23.0%	4.2%	*
Out of Town Control	11.2%	16.0%	***
	Change from 2001 to 2011	Difference	Significance
Atlantic Station Area	+7.2%	na	na
Intown Control	+6.9%	−0.3%	–
Out of Town Control	+0.2%	−6.9%	**

p < .05 *; p < .01 **; p < .001 ***; - not statistically significant at the 0.05 level. Average column reflects values for a “typical” household with white race, two licensed, working adults and one child living in a multifamily unit, while the “Differences” column shows the difference of each of the two control groups with the Atlantic Station group. “Significance” column corresponds to the statistical significance of the “Differences” column. The “Difference” column in the third section shows the difference-in-differences average results. The full difference-in-difference regressions include household size, number of workers, number of license holders, number of full time students, presence of children, number of retired persons, presence of unrelated adults, income category, educational level, residence in a multifamily unit, and year as controls. For a full report of the difference-in-differences regressions, see the Appendix on Analytical Methods.

Station Area in any significant way. Although alternative mode shares did increase relative to the Out of Town Control group, they did not increase relative to the Intown Control group. Therefore, it does not appear that the development of Atlantic Station by itself caused a boost in alternative mode shares over the 2001–2011 time period.

5. Discussion: how infill development influences travel behavior

Residents of Atlantic Station and its surrounding areas have significantly less vehicle travel than similar residents living in other parts of the region, even after controlling for major travel demand factors (See Table 7). This is consistent with the EPA-supported prospective analysis of the VMT impacts of Atlantic Station. This EPA analysis suggested that VMT would reduce for trips originating from Atlantic Station (Table 3). Residents of Atlantic Station have a rich variety of destinations nearby, high regional accessibility, and better support for alternative modes than are typically present across the Atlanta metropolitan region as a whole. Therefore, channeling more residents into intown areas such as the Atlantic Station Area can have a significant effect in reducing total household VMT and in boosting the shares of alternative modes.

However, these results also suggest that Atlantic Station may not have had much influence as a *destination* in reducing the VMT for existing residents of nearby areas. If residents of the Atlantic Station Area had substituted destinations within Atlantic Station for those they had been traveling to which were further away, then their VMT would have reduced relative to residents living in other parts of the metropolitan region. On the contrary, this analysis finds that residents living *further* from Atlantic Station actually reduced their VMT more between 2001 and 2011. So there is no evidence here to support the claim that the new *destinations* provided within Atlantic Station helped to reduce total household VMT.

Likewise, residents of the Atlantic Station Area did not shift to alternative modes as a result of the Atlantic Station development itself. Rather, residents of the Atlantic Station Area participated in a broad shift towards alternative modes that swept the entire intown area (i.e. both the Atlantic Station Area and the Intown Control area) during the 2001–2011 time period. Relative to residents in the Out of Town Control area, all intown residents increased their share of alternative modes by about 7.4% over the 2001–2011 time period.

To explain these differing results, we must understand that regional location exerts a strong influence over demand for vehicular travel as well as the demand for alternative modes. This is consistent with the results of the recent Stevens (2016) meta-analysis on travel and the built environment, which finds that regional location is the most significant built environment variable influencing travel behavior. Because the Atlantic Station development is located close to the center of the Atlanta metropolitan region, the travel behavior of those who live in this area is shaped not just by the Atlantic Station development itself, but also by the legacy of more than a century of accumulated, dense, mixed-use built environment located within the intown area. Despite decades of suburbanization across the metropolitan region, the intown Atlanta area is nevertheless rife with work and non-work destinations proximate to its historic center. Households that live closer to the region's historic center therefore make significantly less use of vehicles and rely on alternative transportation modes significantly more than residents elsewhere in the region.

But since the Atlantic Station area already has a high regional destination accessibility, placing addition destinations in this area appears to have little additional effect. The availability of proximate opportunities for work, shopping, and social and recreational purposes is well established in this area, so even a development on the scale of Atlantic Station may not influence the amount of vehicular travel demand of existing city center residents much.

Interestingly the VMT decrease over the 2001–2011 period is larger in the Out-of-Town Area in comparison to the In-Town Area and the Atlantic Station Area. There are several feasible alternative explanations for this. One explanation is that Out-of-Town residents responded to the steep rise in gas prices between 2001 and 2011 by driving less (the average US gas price went from $1.91 per gallon in 2001 to $3.75 per gallon in 2011 (US Energy Information Administration, 2016)). Since Out-of-Town residents were previously driving more, they presumably were more sensitive to this increase in gas prices. Another explanation is that the decentralization of jobs and services enabled Out-of-Town residents to drive less while reaching the same activities. Indeed, it is well known that commuters to employment subcenters have shorter commute distances and times than those who commute to downtowns (Cervero & Wu, 1998; Giuliano & Small, 1993). Also, job decentralization has been linked to decreased commute times (Gordon & Lee, 2015). Moreover, the Atlanta metropolitan region is known for its trend towards job decentralization (Weitz & Crawford, 2012), which could in theory facilitate shorter commutes for suburban residents.

I conducted a secondary analysis to better understand the VMT decrease for Out-of-Town residents, by analyzing change in trips and change in VMT per trip for the three locational groups over the 2001–2011 period. There was no decrease in trip making for the Out-of-Town group relative to the other groups, however there was a statistically significant decrease in VMT per trip for the Out-of-Town group. This decrease in VMT per trip is consistent with either of the hypotheses above – that Out-of-Town residents economized by driving less per trip or that activity decentralization reduced the distances that Out-of-Town residents had to travel.

Repeated cross-sectional analyses of this type come with limitations and complexities. This analysis compares two different travel surveys which were not designed to be compared side by side. I had to make a number of adjustments to these surveys for their results to be comparable. Perhaps some differences between these surveys cannot be completely accounted for, such as the influence of internet technology in making survey completion easier and more accurate over time. In addition, the residents surveyed in 2001 and 2011 were not the same ones, so therefore the present analysis cannot be said to be truly longitudinal, but rather it makes use of repeated cross sections. However, the approach employed here with measures of travel behavior before and after a major built environment change is certainly an analytical improvement over traditional single point in time cross-sectional methods.

Self-selection is partially controlled for by the research designs employed here – propensity scores and difference-in-differences (Mokhtarian & Van Herick, 2016). However, these research designs still have their limitations. Propensity scores cannot account for attitudes about modal preferences unless attitudinal variables are included in the scoring method. Difference-in-differences cannot account for how self-selection behaviors may evolve over time. Nevertheless, both methods are an improvement over traditional cross-sectional multivariate regression as research designs.

In addition, although the Atlantic Station development is unusually large and prominent, many other changes to the built environment of metropolitan Atlanta occurred over this period. During 2001–2011 the intown area in general experienced high rates of infill development. So the influence of the Atlantic Station development cannot be extricated from the influence of other nearby intown developments by the analysis methods employed here. Development was occurring throughout the region during this time; other land use changes in outlying areas may also have influenced vehicular use and alternative mode shares in meaningful ways.

6. Conclusion

This study analyzes the influence of the large-scale, mixed-use, intown Atlantic Station development on the travel behavior of new residents of the Atlantic Station development and on the travel behavior of existing residents who lived in the area nearby the development. I examine the influence of the development on new residents by using propensity score matching methods, and I examine the influence of the development on existing residents using difference-in-difference analysis, which compares the changes in the travel behavior of Atlantic Station Area residents over time with that of two control groups.

This research finds that the Atlantic Station development did reduce households' VMT by placing new residents in an area with high regional accessibility and strong support for alternative travel modes. Residents of the Atlantic Station Area have significantly lower VMT and higher alternative mode shares than comparable households located elsewhere in the metropolitan region. As a result planners can shift travel patterns by increasing the amount of infill residential development in intown areas with high destination accessibility.

However, the results also suggest that previously existing residents of the Atlantic Station Area did not reduce their total daily VMT by shifting their destinations towards the new opportunities available within Atlantic Station. This finding is contrary to the prospective analysis conducted on Atlantic Station at the behest of EPA, which found that VMT would be reduced for Atlantic Station both as an origin and as a destination for trips. Therefore, adding new destinations to intown, high accessibility areas is not likely to influence vehicular travel behavior much.

The before and after analysis using difference-in-differences employed here may be applicable to other studies of the influence of the built environment on travel behavior. Ideally such studies would focus on the influence of large-scale changes to the built environment on travel behavior, so that the changes are large enough in magnitude to have a discernible influence. However, if the results obtained here hold generally, the addition of new destinations within high accessibility areas may not have much influence. Therefore, the addition of new destinations may have the greatest effect in more outlying locations, such as within emerging edge cities. There is some evidence from previous research that edge cities may reduce travel demand by increasing the jobs-housing balance of suburban locations (Giuliano & Small, 1993). This is a promising area of study for extensions of the research methods presented in this paper.

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A. Appendix on analytical methods

A.1. Defining the Atlantic Station area

A likely question is why was a 3-mile radius included around the centroid of Atlantic Station to determine the Atlantic Station Area? A tighter radius might have represented the travel behavior impacts of the development more accurately.

The answer is simply that a 3-mile radius was necessary to have a large enough sample size from both the 2001 and 2011 travel surveys for analysis. There are 398 households within a 2-mile radius in and 726 within a 3-mile radius in 2001, while there are 219 household within a 2-mile radius and 378 households within a 3-mile radius in 2011. Propensity score methods then further subdivide that sample size up into 8 or more blocks. An analysis with household within a 2-mile radius is possible but fewer variables could be accounted for within the propensity score matching process.

A.2. Propensity score matching

Propensity score matching works by identifying a control population that is as similar to the treatment group as possible. More specifically, each member of the treatment group is matched with one or more members of the control group that have similar covariate values across a wide number of covariates. This approach is based on the work of Rubin, who found that an average treatment effect can be estimated by matching every member of the treatment group with a member of the control group whom has equal probability of being assigned to treatment (Rosenbaum, 1987; Rubin, 2001). In other words, households are selected that do not live in Atlantic Station but look as if they would choose to do so, with equal probability of those who actually do live in Atlantic Station.

The specific commands used in Stata 13.1 are **pscore** and **attnd** (Becker & Inchino, 2002). The **pscore** command calculates the probability of being assigned to the treatment group (i.e. the probability that a household will choose to live in the Atlantic Station Area) with a probit or logistic regression. Then the area of common support is determined – if there are members of the treatment group with higher probability of being assigned to treatment than any member of the control group, these are dropped from the analysis. Based on the probability of being assigned to treatment, the treatment and control groups are then placed into smaller and smaller blocks until the average probability of being assigned to treatment is the same for the treatment and control groups within each block. At this point the treatment and control groups within each block should be "balanced", because they have approximately equal probability of being assigned to treatment. Then the procedure examines the mean value of each covariate within each block, to ensure that the treatment and control groups are roughly equivalent within each block. Only if there are no significant differences between the treatment and control groups within each block (determined by a differences of means test with a 1% significance level) is the propensity score match considered successful.

Once a successful match is completed, then every member of the treatment group is matched with one or more members of the control group with the closest possible propensity score. New weights are created so that the matched controls equal the weight of their treated partner. The difference of the outcome variable between each treated household and their matches are calculated and a weighted sum is taken to achieve an average treatment effect on the treated.

The variables I selected for developing the propensity score were household size, number of workers, number of license holders, number of full time students, presence of children, black race, middle income indicator, high income indicator, less than college education indicator, and college graduate education indicator. Note that the college graduate indicator excludes advanced degrees. I intentionally did not include any household variables that could likely be effected by household location choice, namely, the number of vehicles in the household and the housing unit type. While these variables may effect residential location choice, they are just as likely to be effected *by* residential location choice, and therefore including them in the propensity score might bias the analysis. Also, not every variable I wanted to include could be included in a successful propensity score match. Originally I tried to include Hispanic ethnicity and other nonwhite race but the propensity score failed to find balanced blocks. Since these variables appeared to relate to a small percentage of the population and have little influence on travel behavior, I excluded them from the final propensity score.

Table 11
Propensity score model for households choosing to live in Atlantic Station area

Variable	Coefficient	Std. Err.	Z Score	P Score
Household Size	−0.2068777	0.0802852	−2.58	0.01
# of Workers	0.0876617	0.0653941	1.34	0.18
# of License Holders	−0.3374332	0.0787757	−4.28	0
# of Full Time Students	0.0805186	0.0958267	0.84	0.401
Presence of Children	−0.161008	0.1154037	−1.4	0.163
# of Retired Persons	−0.0982998	0.0862964	−1.14	0.255
Black	−0.2285504	0.0720134	−3.17	0.002
Middle Income	−0.0503746	0.0824172	−0.61	0.541
High Income	0.2414273	0.096579	2.5	0.012
No College	−0.4410695	0.1120014	−3.94	0
College Graduate	−0.1040285	0.0587976	−1.77	0.077

Probit model predicting likelihood of living in the Atlantic Station area used for propensity score matching.

This regression had a pseudo-R Squared of 0.0915 and a common support of [0.001%,25.782%]. It should be noted that no mode preference variables were available from the two travel surveys, and therefore these type of variables were not included in the propensity score match, even though if such variables were available they might explain both residential location choice and travel behavior well. This is certainly a limitation of the current analysis. However, the above analysis provides the best propensity score match that is possible with the available variables.

A.3. Difference-in-differences

Difference-in-differences is implemented via a normal regression analysis, but with a series of special dummy variables to control for differences between the treatment and control groups and for differences over time within the treatment and control groups. The outcome of interest is changes to the treatment group over time *relative to* changes in the control group. Additional covariates which are expected to influence the outcome of interest can be included as well.

As an alternative analysis pathway, I also examined two separate regressions for the 2001 and 2011 periods and compared their results. The results from these two regressions are included in Tables 12 and 13 below. The reason I preferred the difference-in-differences regression is that this requires the influence of all of the covariates to be equivalent across the two time periods. Separate regressions allow for differential effects of the same variable between the two time periods. For example, being from a Spanish-speaking household increases VMT in 2001 but decreases VMT in 2011, with no clear reason for this differential effect. Or to take another example, the highest income group travels 22 miles more than the lowest income group in 2001, while only traveling 12 miles more than the lowest income group in 2011. Since these are control variables and not the primary variables on interest, I am concerned about "overfit" to noise if two separate regressions are fit for each year. Requiring the effect of control demographic and economic variables to be the same between 2001 and 2011 results in a more robust and credible set of controls in my estimation. Both difference-in-difference regressions as well as all four individual period regressions are included in tables below.

Table 12
Difference-in-differences regression for household VMT

	Coefficient	Std. Err.	T-Statistic	P Score
Intown Control	4.39	1.51	2.9	0.004
DinD Intown Control	−3.06	2.36	−1.3	0.194
Out of Town Control	21.18	1.39	15.25	0
DinD Out of Town Control	−7.20	2.09	−3.45	0.001
Household Size	−2.58	0.67	−3.86	0
# of Workers	5.90	0.85	6.96	0
# of Licensed Drivers	16.10	0.90	17.85	0
# of Full Time Students	2.93	0.72	4.1	0
Children Present	2.50	1.45	1.72	0.086
# of Retired Persons	−4.14	0.98	−4.22	0
Unrelated Adult Present	−3.58	1.95	−1.83	0.067
Black Householder	1.84	1.09	1.69	0.091
Income Quintile				
2nd	6.14	1.15	5.33	0
3rd	10.94	1.19	9.18	0
4th	15.17	1.51	10.05	0
5th	16.98	1.60	10.62	0
Refused to Report Income	−5.39	1.45	−3.72	0
Educational Attainment				
Not Reported	7.37	6.26	1.18	0.239
High School	1.21	1.93	0.63	0.53
Some College	4.86	1.99	2.44	0.015
Associate/Technical	8.53	2.31	3.69	0
College	6.14	1.96	3.13	0.002
Graduate/Professional	2.94	2.03	1.45	0.148
Multifamily Residence	−5.80	0.87	−6.68	0
Year 2011	−8.50	1.87	−4.54	0
Constant	−9.28	2.55	−3.65	0
N	16,300			
R Squared	0.2624			

N·B.: DinD Intown Control is the interaction of the year dummy variable (year 2011 = 1) with living in the Intown Control area. DinD Out of Town Control is the interaction of the year dummy variable (year 2011 = 1) with living in the Intown Control area. The omitted category for Income Quintile is 1st quintile. The omitted category for Educational Attainment is less than high school education.

Table 13
Difference-in-differences regression for alternative mode share

	Coefficient	Std. Err.	T-Statistic	P Score
Intown Control	−0.04	0.02	−2.27	0.023
DinD Intown Control	0.00	0.03	−0.07	0.944
Out of Town Control	−0.09	0.01	−6.81	0
DinD Out of Town Control	−0.07	0.03	−2.74	0.006
Household Size	0.05	0.01	9.04	0
# of Workers	0.02	0.00	3.68	0
# of Licensed Drivers	−0.10	0.01	−17.83	0
# of Full Time Students	0.03	0.00	6.53	0
Children Present	0.01	0.01	1.57	0.116
# of Retired Persons	0.00	0.00	0.82	0.41
Unrelated Adult Present	0.02	0.01	1.35	0.178
Black Householder	0.07	0.01	10.67	0
Income Quintile				
2nd	−0.07	0.01	−7.27	0
3rd	−0.06	0.01	−6.68	0
4th	−0.05	0.01	−5.8	0
5th	−0.05	0.01	−5.81	0
Refused to Report Income	0.01	0.01	1.12	0.264
Educational Attainment				
Not Reported	−0.08	0.05	−1.54	0.123
High School	−0.02	0.03	−0.79	0.427
Some College	−0.07	0.03	−2.61	0.009
Associate/Technical	−0.06	0.03	−2.04	0.042
College	−0.08	0.03	−3.08	0.002
Graduate/Professional	−0.09	0.03	−3.25	0.001
Multifamily Residence	0.06	0.01	8.02	0
Year 2011	0.07	0.02	2.88	0.004
Constant	0.30	0.03	10.33	0
N	17005			
R Squared	0.2834			

N·B.: DinD Intown Control is the interaction of the year dummy variable (year 2011 = 1) with living in the Intown Control area. DinD Out of Town Control is the interaction of the year dummy variable (year 2011 = 1) with living in the Intown Control area. The omitted category for Income Quintile is 1st quintile. The omitted category for Educational Attainment is less than high school education.

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